



William R. Gideon
Vice President
Brunswick Nuclear Plant
P.O. Box 10429
Southport, NC 28461

o: 910.832.3698

**Letter Enclosure Attachments 5a, 6a, 7a, 8a, 9a, 10a, 11a, 12a, 13a, 14a, 15a, 16a, and 17a
Contain Proprietary Information Withhold in Accordance with 10 CFR 2.390**

October 11, 2018

Serial: RA-18-0100

10 CFR 50.90

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Brunswick Steam Electric Plant, Unit Nos. 1 and 2
Renewed Facility Operating License Nos. DPR-71 and DPR-62
Docket Nos. 50-325 and 50-324
Request for License Amendment Regarding Application of Advanced Framatome Methodologies

Ladies and Gentlemen:

Pursuant to 10 CFR 50.90, Duke Energy Progress, LLC (Duke Energy), hereby requests a revision to the Technical Specifications (TSs) for the Brunswick Steam Electric Plant (BSEP), Unit Nos. 1 and 2. The proposed license amendments revise TS 5.6.5.b to allow application of Advanced Framatome Methodologies for determining core operating limits in support of loading Framatome fuel type ATRIUM 11. The Enclosure to this letter provides a description and assessment of the proposed change. Enclosure Attachment 4 provides a list of regulatory commitments associated with the proposed license amendments.

Duke Energy has evaluated the proposed change in accordance with 10 CFR 50.91(a)(1), using the criteria in 10 CFR 50.92(c), and determined that this change involves no significant hazards consideration.

Approval of the proposed amendments is requested by February 20, 2020 to support reactor startup following the Unit 1 refueling outage. Once approved, the Unit 1 amendment shall be implemented prior to start-up from the 2020 Unit 1 refueling outage, and the Unit 2 amendment shall be implemented prior to startup from the 2021 Unit 2 refueling outage.

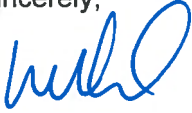
The Enclosure to this letter contains Attachments considered proprietary to Framatome (i.e., Enclosure Attachments 5a, 6a, 7a, 8a, 9a, 10a, 11a, 12a, 13a, 14a, 15a, 16a, and 17a). Within these Attachments, proprietary information has been denoted by brackets. As owner of the proprietary information, Framatome has executed affidavits for each proprietary document, which identify the information as proprietary, is customarily held in confidence, and should be withheld from public disclosure in accordance with 10 CFR 2.390. Enclosure Attachments 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b, 13b, 14b, 15b, 16b, and 17b provide non-proprietary versions of each proprietary Framatome document. Corresponding affidavits are provided in Enclosure Attachments 5c, 6c, 7c, 8c, 9c, 10c, 11c, 12c, 13c, 14c, 15c, 16c, and 17c.

In accordance with 10 CFR 50.91, Duke Energy is providing a copy of the proposed license amendments to the designated representative for the State of North Carolina.

Please refer any questions regarding this submittal to Mr. Lee Grzeck, Manager - Regulatory Affairs, at (910) 832-2487.

I declare, under penalty of perjury, that the foregoing is true and correct. Executed on October 11, 2018.

Sincerely,



William R. Gideon

SBY/sby

Enclosure:

Description and Assessment of the Proposed Change

Attachments:

- 1: Technical Specification Mark-Ups – Unit 1
- 2: Technical Specification Mark-Ups – Unit 2
- 3: Technical Specification Bases Mark-Ups – Unit 1 (For Information Only)
- 4: List of Regulatory Commitments
- 5a: ANP-3705P, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 5b: ANP-3705NP, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel
- 5c: Affidavit for ANP-3705P, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel
- 6a: ANP-3686P, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 6b: ANP-3686NP, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies
- 6c: Affidavit for ANP-3686P, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies
- 7a: ANP-3643P, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 7b: ANP-3643NP, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 7c: Affidavit for ANP-3643P, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 8a: ANP-3644P, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 8b: ANP-3644NP, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies

- 8c: Affidavit for ANP-3644P, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 9a: ANP-3668P, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 9b: ANP-3668NP, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR
- 9c: Affidavit for ANP-3668P, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR
- 10a: ANP-3661P, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 10b: ANP-3661NP, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design
- 10c: Affidavit for ANP-3661P, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design
- 11a: ANP-3667P, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 11b: ANP-3667NP, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report
- 11c: Affidavit for ANP-3667P, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report
- 12a: ANP-3702P, Brunswick ATRIUM 11 Transient Demonstration **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 12b: ANP-3702NP, Brunswick ATRIUM 11 Transient Demonstration
- 12c: Affidavit for ANP-3702P, Brunswick ATRIUM 11 Transient Demonstration
- 13a: ANP-3674P, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 13b: ANP-3674NP, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel
- 13c: Affidavit for ANP-3674P, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel
- 14a: ANP-3694P, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 14b: ANP-3694NP, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA
- 14c: Affidavit for ANP-3694P, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA
- 15a: ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 15b: ANP-3703NP, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA
- 15c: Affidavit for ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA
- 16a: DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**

- 16b: DPC-NE-1009, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III
- 16c: Affidavit for DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III
- 17a: ANP-3714P, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 17b: ANP-3714NP, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology
- 17c: Affidavit for ANP-3714P, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology

cc (with Enclosure and all Enclosure Attachments):

U. S. Nuclear Regulatory Commission, Region II
ATTN: Ms. Catherine Haney, Regional Administrator
245 Peachtree Center Ave, NE, Suite 1200
Atlanta, GA 30303-1257

U. S. Nuclear Regulatory Commission
ATTN: Mr. Gale Smith, NRC Senior Resident Inspector
8470 River Road
Southport, NC 28461-8869

U. S. Nuclear Regulatory Commission
ATTN: Mr. Andrew Hon (Mail Stop OWFN 8G9A)
11555 Rockville Pike
Rockville, MD 20852-2738

cc (with Enclosure and Non-Proprietary Enclosure Attachments):

Chair - North Carolina Utilities Commission **(Electronic Copy Only)**
4325 Mail Service Center
Raleigh, NC 27699-4300
swatson@ncuc.net

Mr. W. Lee Cox, III, Section Chief **(Electronic Copy Only)**
Radiation Protection Section
North Carolina Department of Health and Human Services
1645 Mail Service Center
Raleigh, NC 27699-1645
lee.cox@dhhs.nc.gov

Description and Assessment of the Proposed Change

Subject: Request for License Amendment Regarding Application of Advanced Framatome Methodologies

1. SUMMARY DESCRIPTION
2. DETAILED DESCRIPTION
 - 2.1 System Design and Operation
 - 2.2 Current Technical Specification Requirements
 - 2.3 Reason for the Proposed Change
 - 2.4 Description of Proposed Change
3. TECHNICAL EVALUATION
4. REGULATORY EVALUATION
 - 4.1 Applicable Regulatory Requirements/Criteria
 - 4.2 No Significant Hazards Consideration Determination Analysis
 - 4.3 Conclusions
5. ENVIRONMENTAL CONSIDERATION
6. REFERENCES

ATTACHMENTS:

- 1: Technical Specification Mark-Ups – Unit 1
- 2: Technical Specification Mark-Ups – Unit 2
- 3: Technical Specification Bases Mark-Ups – Unit 1 (For Information Only)
- 4: List of Regulatory Commitments
- 5a: ANP-3705P, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 5b: ANP-3705NP, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel
- 5c: Affidavit for ANP-3705P, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel
- 6a: ANP-3686P, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 6b: ANP-3686NP, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies
- 6c: Affidavit for ANP-3686P, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies
- 7a: ANP-3643P, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 7b: ANP-3643NP, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies

- 7c: Affidavit for ANP-3643P, Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 8a: ANP-3644P, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 8b: ANP-3644NP, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 8c: Affidavit for ANP-3644P, Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies
- 9a: ANP-3668P, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 9b: ANP-3668NP, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR
- 9c: Affidavit for ANP-3668P, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR
- 10a: ANP-3661P, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 10b: ANP-3661NP, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design
- 10c: Affidavit for ANP-3661P, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design
- 11a: ANP-3667P, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 11b: ANP-3667NP, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report
- 11c: Affidavit for ANP-3667P, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report
- 12a: ANP-3702P, Brunswick ATRIUM 11 Transient Demonstration **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 12b: ANP-3702NP, Brunswick ATRIUM 11 Transient Demonstration
- 12c: Affidavit for ANP-3702P, Brunswick ATRIUM 11 Transient Demonstration
- 13a: ANP-3674P, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 13b: ANP-3674NP, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel
- 13c: Affidavit for ANP-3674P, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel
- 14a: ANP-3694P, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 14b: ANP-3694NP, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA
- 14c: Affidavit for ANP-3694P, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA

- 15a: ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA
[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]
- 15b: ANP-3703NP, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA
- 15c: Affidavit for ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA
- 16a: DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 16b: DPC-NE-1009, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III
- 16c: Affidavit for DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III
- 17a: ANP-3714P, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology **[Proprietary Information – Withhold from Public Disclosure in Accordance with 10 CFR 2.390]**
- 17b: ANP-3714NP, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology
- 17c: Affidavit for ANP-3714P, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology

1. SUMMARY DESCRIPTION

Duke Energy Progress, LLC (Duke Energy), is requesting a revision to the Technical Specifications (TSs) for the Brunswick Steam Electric Plant (BSEP), Unit Nos. 1 and 2. The proposed license amendments revise TS 5.6.5.b to allow application of Advanced Framatome Methodologies for determining core operating limits in support of loading Framatome fuel type ATRIUM 11.

2. DETAILED DESCRIPTION

2.1 System Design and Operation

Core operating limits are established each operating cycle. These operating limits ensure that the fuel design limits are not exceeded during any conditions of normal operation and in the event of any Anticipated Operational Occurrence (AOO).

2.2 Current Technical Specification Requirements

The Core Operating Limits Report (COLR) is the unit specific document that provides cycle specific parameter limits for the current reload cycle. These cycle specific limits are determined for each reload cycle in accordance with TS 5.6.5.

TS 5.6.5.a lists the core operating limits required to be established for each cycle. The methods used to determine the operating limits are those previously found acceptable by the U.S. Nuclear Regulatory Commission (NRC) and listed in TS 5.6.5.b.

2.3 Reason for the Proposed Change

BSEP plans to transition to the Framatome fuel type ATRIUM 11. These proposed license amendments to allow application of Advanced Framatome Methodologies are necessary for this fuel transition. Duke Energy is pursuing the ATRIUM 11 fuel type due to the improved fuel cycle economics and safety margins.

The ATRIUM 11 fuel type consists of an array of 11 by 11 fuel rods; whereas the current fuel design (i.e., ATRIUM 10XM) consists of an array of 10 by 10 fuel rods. This increase in the number of fuel rods significantly reduces Linear Heat Generation Rate (LHGR) and fuel duty, thereby improving safety margin.

The ATRIUM 11 fuel type incorporates enhanced debris protection features which make the fuel design less susceptible to debris related fuel failures. In addition, the channel design changes incorporated with ATRIUM 11 make the fuel design less susceptible to channel bow and bulge.

2.4 Description of the Proposed Change

The following Methodologies will be removed from TS 5.6.5.b:

- XN-NF-84-105(P)(A) Volume 1, XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis (i.e., Reference 6.24)
- ANF-913(P)(A) Volume 1, COTRANSA2: A Computer Program for Boiling Water Reactor Transient Analyses (i.e., Reference 6.10)
- NEDC-33075P-A, GE Hitachi Boiling Water Reactor, Detect and Suppress Solution - Confirmation Density, Revision 8, November 2013 (i.e., Reference 6.11)

The above methodologies are no longer applicable with addition of the Advanced Methodologies described below.

The Advanced Methodologies that will be added to TS 5.6.5.b are listed below:

- ANP-10333P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA), Revision 0, March 2018 (i.e., Reference 6.7)
- ANP-10300P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Revision 1, January 2018 (i.e., Reference 6.1)
- ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA, Revision 0, August 2018 (i.e., Reference 6.2)
- DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018 (i.e., Reference 6.3)
- BAW-10247P-A, Supplement 2P-A, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods, Revision 0, August 2018 (i.e., Reference 6.4)
- ANP-10340P-A, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods, Revision 0, May 2018 (i.e., Reference 6.5)
- ANP-10335P-A, ACE/ATRIUM 11 Critical Power Correlation, Revision 0, May 2018 (i.e., Reference 6.6)
- ANP-10332P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, Revision 0, [DATE]

The Final Safety Evaluation (SE) for Topical Report (TR) ANP-10332P, AURORA-B LOCA (i.e., Reference 6.8) has not been issued. As a result, the Draft SE (i.e., Reference 6.9) along with ANP-10332P are being referenced for this LAR submittal and the date for ANP-10332P-A is being left blank above and in the TS markups (i.e., Attachments 1 and 2). All the limitations and conditions presented in Reference 6.9 are addressed in this LAR. Following issuance of the final SE for ANP-10332P, this LAR will be supplemented with reference to the approved AURORA-B LOCA TR (i.e., ANP-10332P-A) and any changes in limitations and conditions will be addressed. Reference 6.14 documents NRC concurrence with this approach and Attachment 4 of this Enclosure documents the commitment to supplement this LAR.

With the addition of the methodologies listed above, BSEP is transitioning from the Detect and Suppress Solution – Confirmation Density (DSS-CD) stability methodology to the Best Estimate Enhanced Option-III with Confirmation Density Algorithm (BEO-III w/CDA) stability methodology (i.e., Reference 6.2 and 6.3). As with DSS-CD, the CDA will remain the licensing basis trip, and identical Oscillation Power Range Monitor (OPRM) setpoints will be used for BEO-III w/CDA thereby minimizing the impact to BSEP. As a result of the transition from DSS-CD to BEO-III w/CDA, TS Table 3.3.1.1-1 Note f will be removed from TS. This is a conditional note regarding arming DSS-CD that was only applicable during the first reactor startup and shutdown following DSS-CD Implementation; therefore, this note is no longer applicable and is being removed.

In addition to the methodology changes outlined above, with the transition from ATRIUM 10XM fuel to ATRIUM 11 fuel, BSEP will transition to RAMONA5-FA for the licensing basis Anticipated Transient Without Scram with Instability (ATWS-I) analysis. The current ATWS-I licensing basis analysis is the TRACG ATWS-I evaluation performed with ATRIUM 10XM fuel for Maximum

Extended Load Line Limit Analysis Plus (MELLLA+) which was approved for BSEP September 18, 2018 (i.e., Reference 6.13).

Unit 1 and Unit 2 TS Mark-Ups are provided in Attachments 1 and 2 respectively. The Mark-Ups demonstrate how BSEP plans to incorporate the proposed change into TSs. In addition, Unit 1 TS Bases Mark-Ups directly related to the proposed change are provided in Attachment 3 for information.

3. TECHNICAL EVALUATION

Attachments 5a through 17a provide the detailed Technical Evaluation for the proposed change outlined in Section 2.4. The information presented in these Attachments demonstrates acceptable safety margin for the proposed change supporting operation of the new ATRIUM 11 fuel type in the currently approved operating domain. The currently approved operating domain includes Extended Power Uprate (EPU) conditions, approved for BSEP in 2002 (i.e., Reference 6.12), as well as MELLLA+, approved for BSEP in 2018 (i.e., Reference 6.13). It should be noted that within this LAR, MELLLA+ and Extended Power/Flow Operating Domain (EPFOD) represent the identical operating domain for BSEP, and therefore may be used interchangeably.

The sections below provide a brief summary of what is included in the Attachments. The table below is provided to correlate the Advanced Methodologies that will be added to TS 5.6.5.b with the Attachments in which the methodology is applied. Note that the Attachments with the 'a' designation provide the full report, while the Attachments with the 'b' designation provide the non-proprietary version of the full report (i.e., proprietary information is redacted). For ease of reference throughout this LAR, only the Attachments with the 'a' designation are referenced in the discussions.

Methodology	Application
ANP-10333P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA), Revision 0, March 2018 (i.e., Reference 6.7)	Attachment 17a
ANP-10300P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Revision 1, January 2018 (i.e., Reference 6.1)	Attachment 12a
ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA, Revision 0, August 2018 (i.e., Reference 6.2)	Attachment 15a
DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018 (i.e., Reference 6.3)	Attachment 16a
BAW-10247P-A, Supplement 2P-A, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods, Revision 0, August 2018 (i.e., Reference 6.4)	Attachment 6a
ANP-10340P-A, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods, Revision 0, May 2018 (i.e., Reference 6.5)	Attachment 9a
ANP-10335P-A, ACE/ATRIUM 11 Critical Power Correlation, Revision 0, May 2018 (i.e., Reference 6.6)	Attachment 7a, 8a, 10a, and 12a
ANP-10332P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, Revision 0, [DATE]	Attachment 13a

Attachment 5a: ANP-3705P, Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel

ANP-2637P, "Boiling Water Reactor Licensing Methodology Compendium" is a compendium of Framatome methodologies and design criteria, which are described in TRs that the NRC has found acceptable for referencing in Boiling Water Reactor (BWR) licensing applications. Framatome provided this document to the NRC for information by letter dated September 18, 2018 (i.e., Reference 6.27). This compendium provides a concise, organized source for BWR TRs. It presents information about the application of each TR, the associated Safety Evaluation Report (SER) and its conclusions and restrictions/limitations for each TR, the relationships among the TRs, and, for certain methodologies, descriptions of their unique characteristics or applications. Compliance with the SER restrictions/limitations is assured by implementing them within the engineering guidelines or by incorporating them into the computer codes.

ANP-3705P demonstrates that the Framatome licensing methodologies presented in ANP-2637P are applicable to the ATRIUM 11 fuel type and operation of BSEP in the currently approved operating domain.

Attachment 6a: ANP-3686P, Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies

ANP-3686P documents the successful completion of all licensing analyses and related testing necessary to verify that the mechanical design criteria are met for the ATRIUM 11 Fuel Assemblies supplied by Framatome for insertion into BSEP reactors. This report also provides a description of the mechanical design and licensing methods for ATRIUM 11. The scope of this report is limited to an evaluation of the mechanical design of the fuel assembly and fuel channel. The fuel assembly design was evaluated according to the Framatome BWR generic mechanical design criteria (i.e., Reference 6.16). The fuel channel design was evaluated to the criteria given in the fuel channel TRs (i.e., References 6.17 and 6.18). The generic design criteria have been approved by the NRC and the criteria are applicable to the subject fuel assembly and channel design. Mechanical analyses for ATRIUM 11 have been performed using NRC-approved design analysis methodology (i.e., References 6.4, 6.16, 6.17, and 6.18).

Attachment 7a and 8a: ANP-3643P/ANP-3644P, Brunswick Unit 1/2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies

ANP-3643P and ANP-3644P present the results of BSEP Unit 1 and Unit 2 thermal-hydraulic analyses which demonstrate that Framatome ATRIUM 11 fuel is hydraulically compatible with the previously loaded ATRIUM 10XM fuel design. These reports also provide the hydraulic characterization of the ATRIUM 11 and the coresident ATRIUM 10XM design for both Units. The generic thermal-hydraulic design criteria applicable to the design have been reviewed and approved by the NRC in Reference 6.16. In addition, thermal-hydraulic criteria applicable to the design have also been reviewed and approved by the NRC in Reference 6.19.

Attachment 9a: ANP-3668P, ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR

ANP-3668P reports the results of thermal-mechanical analyses for the performance of ATRIUM 11 fuel assemblies inserted into to an equilibrium cycle for the BSEP units and

demonstrates that the design criteria relevant to the Thermal-Mechanical limits are satisfied. These analyses assume the use of chromia additive in the fuel and assume operation in the currently approved operating domain. Both the design criteria and the analysis methodology used in this report have been approved by the NRC. The analysis results are evaluated according to the generic fuel rod thermal and mechanical design criteria contained Reference 6.16 along with design criteria provided in Reference 6.28. In addition, the approved methodology for the inclusion of chromia additive in the fuel pellets (i.e., Reference 6.5) is also used.

Attachment 10a: ANP-3661P, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design

In ANP-3661P, Framatome has performed an equilibrium fuel cycle design for BSEP Unit 1. This design uses the ATRIUM 11 fuel assembly and the currently approved operating domain. This analysis has been performed with the approved Framatome neutronic modeling methodology (i.e., Reference 6.20). This analysis has also used the Reference 6.6 critical power methodology. The CASMO-4 lattice depletion code was used to generate nuclear data including cross sections and local power peaking factors. The MICROBURN-B2 three dimensional core simulator code, combined with the ACE critical power correlation, was used to model the core. The MICROBURN-B2 pin power reconstruction (PPR) model was used to determine the thermal margins presented in the report. Design results including projected control rod patterns and evaluations of thermal and reactivity margins are presented.

Attachment 11a: ANP-3667P, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report

ANP-3667P provides results of the neutronic design analyses performed by Framatome for BSEP Unit 1 ATRIUM 11 equilibrium cycle fuel assemblies (i.e., used in Attachment 10a). NRC-approved neutronic design criteria are provided in Reference 6.16, and the NRC-approved neutronic design analysis methodology (i.e., Reference 6.20) was used to determine conformance to design criteria. Pertinent fuel design information is given in Section 2.0 and in Appendices A through D of Attachment 11a.

Attachment 12a: ANP-3702P, Brunswick ATRIUM 11 Transient Demonstration

ANP-3702P summarizes the results of a subset of limiting transient analyses performed to show example BSEP results utilizing the Reference 6.1 and Reference 6.6 methodologies based upon an equilibrium cycle of ATRIUM 11 fuel. The AURORA-B AOO methodology (i.e., Reference 6.1) is used to calculate the change in the minimum critical power ratio (Δ MCPR) during the AOO. The Δ MCPR is combined with the safety limit MCPR (SLMCPR) to establish or confirm the plant operating limits for MCPR. The AURORA-B AOO methodology is also used to calculate the maximum reactor vessel pressure and the maximum dome pressure during the ASME and ATWS events. The ACE/ATRIUM 11 critical power correlation (i.e., Reference 6.6) is used to evaluate the thermal margin of the ATRIUM 11 fuel.

Attachment 13a: ANP-3674P, Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel

ANP-3674P presents the results of a loss-of-coolant accident (LOCA) break spectrum and emergency core cooling system (ECCS) analyses for BSEP Units 1 and 2. The analyses documented in this report are performed with Framatome LOCA Evaluation Models for reactor licensing analyses pending approval by the NRC (i.e., Reference 6.14). The models and computer codes used by Framatome for LOCA analyses are collectively referred to as the

AURORA-B LOCA Evaluation Model (i.e., References 6.8, 6.9, 6.21, and 6.28). The purpose of the break spectrum analysis is to identify the break characteristics that result in the highest calculated peak cladding temperature (PCT) during a postulated LOCA. The results provide the maximum average planar linear heat generation rate (MAPLHGR) limit for ATRIUM 11 fuel as a function of exposure. The calculations described in this report are performed in conformance with 10 CFR 50 Appendix K requirements and satisfy the event acceptance criteria identified in 10 CFR 50.46.

Attachment 14a: ANP-3694P, ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA

ANP-3694P documents Anticipated Transient Without Scram with Instability (ATWS-I) analyses for Brunswick with ATRIUM 11 fuel and the currently approved operating domain. Attachment 14a presents a description of BWR instability transients that are not terminated by scram, and thus power and flow oscillations grow to large amplitudes. This class of transients is referred to as ATWS-I. This report documents a plant-specific, RAMONA5-FA based method for evaluating the fuel-related aspects of these events. The method is applicable to the limiting BSEP ATWS-I events covering the event from the initiation through inception of oscillations and final suppression through operator action.

Attachment 15a: ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA

ANP-3703P presents a plant-specific, best-estimate methodology for the evaluation of the Long-Term Stability Solution Enhanced Option-III (i.e., BEO-III). This report documents a RAMONA5-FA based method for determining the core operating limit MCPR based on the Option-III Period-Based Detection Algorithm (PBDA). The methodology defines how the two manual Backup Stability Protection (BSP) Regions are generated. The methodology shows compliance with 10 CFR Part 50, Appendix A, General Design Criteria (GDC) 10 and 12.

Included in the report is the application of this BEO-III methodology to the BSEP Unit 1 reactor. The primary difference between Unit 1 and 2 that directly affects stability is the inlet pressure drop. Since BSEP Unit 1 has a much lower inlet pressure drop due to larger inlet orifices, the fuel assemblies will be hydraulically less stable and therefore bound the results for Unit 2.

Attachment 16a: DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III

DPC-NE-1009-P provides the Duke Energy methodology that will be used to implement the CDA stability algorithm within the plant specific BEO-III analysis framework (i.e., BEO-III w/CDA). BSEP is not seeking generic approval of the BEO-III w/CDA stability methodology; application of the BEO-III w/CDA methodology will be specific to BSEP. This report, in conjunction with Attachment 15a, replaces Reference 6.11 as the Long-Term Stability Solution for BSEP Units 1 and 2.

The CDA was installed as the licensing basis algorithm with the implementation of MELLLA+ at BSEP (i.e., Reference 6.13), and was incorporated in TS, TS Bases, plant procedures, and training programs. The CDA is contained in the OPRM function of the Nuclear Measurement Analysis and Control, Average Power Range Monitor hardware which is part of the Power Range Neutron Monitoring System. The CDA is able to detect oscillations at the onset of instability before there is a significant reduction in margin to the SLMCPR. For these reasons, it

was decided to maintain the CDA trip function as the primary stability protection mechanism for BSEP instead of the Period Based Detection Algorithm that serves as the licensing basis for BEO-III as described in Attachment 15a. The PBDA, along with the other Option III algorithms (i.e., Growth Rate and Amplitude Based) will be maintained for defense-in-depth functions and will not be credited in the SLMCPR margin determination.

DPC-NE-1009-P shows the implementation of BEO-III with CDA with sample Brunswick ATRIUM 11 results from the currently approved operating domain. In addition, DPC-NE-1009-P describes the methodology for the Automated BSP and BSP Boundary which are defined in the COLR and are utilized when the OPRM Upscale trip function is inoperable.

Attachment 17a: ANP-3714P, Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology

ANP-10333P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident Scenarios (i.e., Reference 6.7) is the Framatome methodology to analyze the BWR control rod drop accident (CRDA). The methodology includes the use of a nodal three-dimensional kinetics solution with both thermal-hydraulic and fuel temperature feedback. These models provide more precise localized neutronic and thermal conditions than previous methods.

The Framatome methodology for the CRDA evaluation includes both generic evaluations and cycle-specific analysis. Generic studies are used to address at power conditions and system pressurization. The cycle specific analysis includes the determination of candidate control rods that could challenge fuel failure criteria and the subsequent evaluation of these candidate rods with a three-dimensional neutron kinetics and thermal-hydraulics code system.

This methodology has been developed to support recent changes in the CRDA acceptance criteria and evaluation process as reflected in the Interim Acceptance Criteria and Guidance of Appendix B of NUREG-0800 Section 4.2 (i.e., Reference 6.15).

ANP-3714P provides the initial application demonstration of the new CRDA methodology (i.e., Reference 6.7). This CRDA analysis is performed using the ATRIUM-11 Equilibrium Cycle Design (i.e., Attachment 10a). Though not part of the BSEP licensing basis, the criteria used for the Brunswick initial application demonstration are based upon Draft Regulatory Guide DG-1327 (i.e., Reference 6.22) which was also used in the Reference 6.23 responses to NRC request for additional information.

ATRIUM 11 Fuel Design and Cycle Specific Reports

The NRC approved the use of Framatome fuel and core design methodologies to determine BSEP core operating limits with the issuance of License Amendments 246 and 274 for BSEP Units 1 and 2, respectively. Framatome licensing TR ANF-89-98(P)(A) Revision 1 and Supplement 1 is one of these NRC-approved methodologies. ANF-89-98(P)(A) Revision 1 and Supplement 1, as clarified by a Siemens Power Corporation letter dated October 12, 1999, (i.e., Reference 6.25) and an NRC letter dated May 31, 2000, (i.e., Reference 6.26) requires that a summary of the evaluation of the ATRIUM 11 design against the NRC-approved generic design criteria be provided to the NRC for information. Framatome provided this evaluation to the NRC for information by letter dated September 18, 2018, which transmitted Framatome document ANP-3653P Revision 0, "Fuel Design Evaluation for ATRIUM 11 BWR Reload Fuel" (i.e., Reference 6.27). In accordance with the process described in ANF-89-98(P)(A) Revision 1

and Supplement 1, new fuel designs or fuel design changes satisfying the ANF-89-98(P)(A) design criteria do not require explicit NRC review and approval (i.e., satisfaction of the design criteria is sufficient for approval by reference to the criteria).

ANP-3653P identifies fuel design criteria, specified in ANF-89-98(P)(A) Revision 1 and Supplement 1, which are evaluated on a cycle specific basis. Reports summarizing the results of analyses performed to demonstrate BSEP compliance with the cycle specific criteria are provided by Framatome to Duke Energy as part of the normal reload licensing document package. This type of information is not available until later in the reload licensing process. Consistent with the process described in ANF-89-98(P)(A) Revision 1 and Supplement 1 (i.e., as clarified by References 6.25 and 6.26), Duke Energy will provide the BSEP Unit 1 Cycle 23 reload reports outlined in the table below to the NRC for information. The reports will be provided in supplemental letters as documented in Attachment 4. The anticipated schedule is presented in the table below.

Report	Estimated Transmittal Date
Fuel Cycle Design Report	March 2019
Nuclear Fuel Bundle Design Report	March 2019
Safety Limit MCPR Report	May 2019
Fuel Rod Design Report	October 2019
Reload Safety Analysis Report	October 2019

ANP-3653P also identifies fuel design criteria, specified in ANF-89-98(P)(A) Revision 1 and Supplement 1, that are evaluated on a plant-specific basis. The key differences in system configuration between BSEP Unit 1 and Unit 2 are in the core inlet region and the Turbine Bypass System. The central orifice diameter in Unit 2 is smaller than Unit 1; 2.09 inches compared to 2.43 inches, and the Turbine Bypass System for Unit 2 has 10 valves whereas Unit 1 has 4 valves. Differences in neutronic design and operation are minimal since both units operate on 24 month fuel cycles.

Based on the minimal differences between Units 1 and 2, the information that is included in this LAR, and the information in the table above which will be provided for Unit 1 Cycle 23, limited information needs to be provided for Unit 2. Therefore, Duke Energy will include, for information, the Unit 2 Cycle 25 Reload Safety Analysis Report with transmittal of the COLR prior to startup from the Unit 2 Cycle 25 refueling outage (i.e., March 2020 timeframe) which will load the first reload batch of ATRIUM 11 fuel into the Unit 2 reactor core. Attachment 4 of this Enclosure documents this commitment to provide this report.

4. REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

10 CFR 50.36(c)(5) states that the TSs will include administrative controls that address the provisions relating to organization and management, procedures, record keeping, review and audit, and reporting necessary to assure operation of the facility in a safe manner. The COLR is required as a part of the reporting requirements specified in the BSEP TSs Administrative Controls section. The TSs require the core operating limits to be established prior to each reload cycle, or prior to any remaining portion of a reload cycle, and to be documented in the COLR. In addition, it requires the analytical methods used to determine the core operating limits to be

those that have been previously reviewed and approved by the NRC, and specifically to be those described in TS 5.6.5.b. The proposed amendments ensure that these requirements are met.

10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water power reactors," establishes the acceptance criteria for the design basis LOCA. Paragraph (b)(1) requires the calculated maximum fuel element cladding temperature (i.e., PCT) to not exceed 2200°F. 10 CFR Part 50, Appendix K, establishes required and acceptable features of evaluation models for heat removal by the ECCS after the blowdown phase of a LOCA. The use of the proposed analytical methods to determine core operating limits will continue to ensure that fuel performance during normal, transient, and accident conditions complies with these requirements. Specific Average Planar Linear Heat Generation Rate (APLHGR) limits will be determined in conformance with 10 CFR 50 Appendix K requirements and documented in the COLR to ensure compliance with 10 CFR 50.46(b)(1).

The BSEP design was reviewed for construction under the *General Design Criteria for Nuclear Power Plant Construction*, issued for comment by the AEC in July 1967, and is committed to meet the intent of the GDC, published in the Federal Register on May 21, 1971, as Appendix A to 10 CFR Part 50. GDC 10, 12, and 28 are applicable to this review.

GDC 10 requires that the reactor core and associated coolant, control, and protection systems be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of AOOs. Duke Energy will use the proposed analytical methods to perform plant-specific analyses for APLHGR, MCPR, and LHGR. The limits on the APLHGR are specified to ensure that the PCT during the postulated design basis LOCA does not exceed the limits specified in 10 CFR 50.46. The SLMCPR ensures that sufficient conservatism exists in the operating limit MCPR such that, in the event of an AOO, there is a reasonable expectation that at least 99.9 percent of the fuel rods in the core will avoid boiling transition for the power distribution within the core including all uncertainties. Limits on the LHGR are specified to ensure that fuel thermal-mechanical design limits are not exceeded anywhere in the core during normal operation, including AOOs. Therefore, compliance with GDC 10 of 10 CFR 50, Appendix A is maintained.

GDC 12 requires that the reactor core and associated coolant, control, and protection systems be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed. As part of the methodology changes outlined above, Duke Energy will transition from DSS-CD to BEO-III w/CDA stability methodology. With BEO-III w/CDA the CDA will continue to provide the licensing basis trip function, and the Automated and Manual BSP functions will be maintained. The CDA provides reliable, automatic detection and suppression of stability related power oscillations. The Automated and Manual BSP functions assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible. Therefore, compliance with GDC 12 of 10 CFR 50, Appendix A is maintained.

GDC 28 requires the reactivity control systems be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor pressure vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents include consideration of rod ejection (i.e., unless prevented by

positive means), rod dropout, steam line rupture, changes in reactor coolant temperature and pressure, and cold water addition. The use of the proposed analytical methods for the CRDA calculations will continue to demonstrate compliance with GDC 28.

10 CFR 50.62, "Requirements for reduction of risk from anticipated transients without scram (ATWS) events for light-water-cooled nuclear power plants," defines an ATWS as an AOO followed by the failure of the reactor trip portion of the protection system specified in GDC 20. During an ATWS the potential exists for thermal-hydraulic instability to develop. The analyses presented in this LAR demonstrate ATWS regulatory criteria are satisfied for BSEP, including those specifically applicable to ATWS-I (i.e., demonstrating core coolability is maintained).

Duke Energy has determined that the proposed change does not require any exemptions or relief from regulatory requirements, other than the TSs, and does not affect conformance with the intent of any GDC differently than described in the Updated Final Safety Analysis Report.

4.2 No Significant Hazards Consideration Determination Analysis

Duke Energy Progress, LLC (Duke Energy), is requesting a revision to the Technical Specifications (TSs) for the Brunswick Steam Electric Plant (BSEP), Unit Nos. 1 and 2. The proposed license amendments revise TSs to allow application of Advanced Framatome Methodologies for determining core operating limits in support of loading Framatome fuel type ATRIUM 11.

Duke Energy has evaluated whether a significant hazards consideration is involved with the proposed amendment(s) by focusing on the three standards set forth in 10 CFR 50.92, *Issuance of amendment*, as discussed below:

1. Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?

Response: No

The probability of an evaluated accident is derived from the probabilities of the individual precursors to that accident. The proposed amendments revise the list of NRC-approved analytical methods used to establish core operating limits. The change does not require any physical plant modifications, physically affect any plant components, or entail changes in plant operation. Since no individual precursors of an accident are affected, the proposed amendments do not increase the probability of a previously analyzed event.

The consequences of an evaluated accident are determined by the operability of plant systems designed to mitigate those consequences. The proposed amendments revise the list of NRC-approved analytical methods used to establish core operating limits. The changes in methodology do not alter the assumptions of accident analyses. Based on the above, the proposed amendments do not increase the consequences of a previously analyzed accident.

Therefore, the proposed amendments do not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?

Response: No

Creation of the possibility of a new or different kind of accident requires creating one or more new accident precursors. New accident precursors may be created by modifications of plant configuration, including changes in allowable modes of operation. The proposed amendments revise the list of NRC-approved analytical methods used to establish core operating limits. The proposed amendments do not involve any plant configuration modifications or changes to allowable modes of operation thereby ensuring no new accident precursors are created.

Therefore, the proposed amendments do not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. Does the proposed change involve a significant reduction in a margin of safety?

Response: No

The proposed amendments revise the list of NRC-approved analytical methods used to establish core operating limits. The proposed change will ensure that the current level of fuel protection is maintained by continuing to ensure that the fuel design safety criteria are met.

Therefore, the proposed amendments do not result in a significant reduction in the margin of safety.

Based on the above, Duke Energy concludes that the proposed amendments present no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

4.3 Conclusion

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5. ENVIRONMENTAL CONSIDERATION

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or a significant increase in the amounts of any effluents that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

6. REFERENCES

1. ANP-10300P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Revision 1, January 2018.
2. ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA, Revision 0, August 2018.
3. DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018.
4. BAW-10247P-A, Supplement 2P-A, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods, Revision 0, August 2018.
5. ANP-10340P-A, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods, Revision 0, May 2018.
6. ANP-10335P-A, ACE/ATRIUM 11 Critical Power Correlation, Revision 0, May 2018.
7. ANP-10333P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA), Revision 0, March 2018.
8. ANP-10332P, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, Revision 0, February 2014.
9. Project No. 728 / Docket No. 99902041, Draft Safety Evaluation for Framatome Inc. Topical Report ANP-10332P, Revision 0, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, (CAC No. MF3829 / EPID: L-2014-TOP-0004) US NRC, August 2018.
10. ANF-913(P)(A) Volume 1, COTRANSA2: A Computer Program for Boiling Water Reactor Transient Analyses.
11. NEDC-33075P-A, GE Hitachi Boiling Water Reactor, Detect and Suppress Solution - Confirmation Density, Revision 8, November 2013.
12. Letter from the U.S. Nuclear Regulatory Commission to Mr. John S. Keenan, Issuance of Amendment Re: Extended Power Uprate, dated May 31, 2002, ADAMS Accession Number ML021430551.
13. Letter from the U.S. Nuclear Regulatory Commission to Mr. William R. Gideon, Brunswick Steam Electric Plant, Units 1 and 2 – Issuance of Amendment Regarding Core Flow Operating Range Expansion (MELLLA+), dated September 18, 2018, ADAMS Accession Number ML18172A258.
14. Letter from the U.S. Nuclear Regulatory Commission to Mr. Bryan B. Wooten, Brunswick Steam Electric Plant, Units 1 and 2 – Request for One-Time Exception to Nuclear Reactor Regulation Office Instructions LIC-109, LIC-101, and LIC-500 Acceptance Review Criteria, dated September 21, 2018, ADAMS Accession Number ML18239A309.
15. NUREG-0800, Section 4.2, Revision 3, FUEL SYSTEM DESIGN, Standard Review Plan: LWR Edition, US NRC: Washington, DC, March 2007.
16. ANF-89-98(P)(A) Revision 1 and Supplement 1, Generic Mechanical Design Criteria for BWR Fuel Designs, Advanced Nuclear Fuels Corporation, May 1995.
17. EMF-93-177(P)(A) Revision 1, Mechanical Design for BWR Fuel Channels, Framatome ANP Inc., August 2005.

18. EMF-93-177P-A Revision 1, Supplement 1P-A, Revision 0, Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs, AREVA NP Inc., September 2013.
19. XN-NF-80-19(P)(A) Volume 4 Revision 1, Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads, Exxon Nuclear Company, June 1986.
20. EMF-2158(P)(A) Revision 0, Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2, Siemens Power Corporation, October 1999.
21. XN-NF-82-07(P)(A) Revision 1, Exxon Nuclear Company ECCS Cladding Swelling and Rupture Model, Exxon Nuclear Company, November 1982.
22. US NRC Draft Regulatory Guide DG-1327, Pressurized Water Reactor Control Rod Ejection and Boiling Water Reactor Control Rod Drop Accidents, November 2016, ADAMS Accession Number ML16124A200.
23. ANP-10333Q1P Revision 0, AURORA-B: An Evaluation Model for Boiling Water Reactors: Application to Control Rod Drop Accident (CRDA) – Responses to NRC Request for Additional Information, AREVA Inc., April 2017.
24. XN-NF-84-105(P)(A) Volume 1, XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis.
25. Letter from Siemens Power Corporation to the NRC Document Control Desk, Revisions to Attachment 1 of Letter NRC:99:030, Request for Concurrence on SER Clarifications, dated October 12, 1999.
26. Letter from the U.S. Nuclear Regulatory Commission to Siemens Power Corporation, Siemens Power Corporation Re: Request for Concurrence on Safety Evaluation Report Clarifications (TAC No. MA6160), dated May 31, 2000, ADAMS Accession Number ML003719373.
27. Letter from Framatome Inc. to the NRC Document Control Desk, Informational Transmittal of ANP-3653P Revision 0, "Fuel Design Evaluation for ATRIUM 11 BWR Reload Fuel" and ANP-2637P Revision 7, "Boiling Water Reactor Licensing Methodology Compendium", dated September 18, 2018.
28. BAW-10247PA Revision 0, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, AREVA NP Inc., February 2008.

Technical Specification Mark-Ups – Unit 1

Table 3.3.1.1-1 (page 2 of 3)
Reactor Protection System Instrumentation

FUNCTION	APPLICABLE MODES OR OTHER SPECIFIED CONDITIONS	REQUIRED CHANNELS PER TRIP SYSTEM	CONDITIONS REFERENCED FROM REQUIRED ACTION D.1	SURVEILLANCE REQUIREMENTS	ALLOWABLE VALUE
2. Average Power Range Monitors (continued)					
c. Neutron Flux—High	1	3 ^(c)	F	SR 3.3.1.1.2 SR 3.3.1.1.3 SR 3.3.1.1.5 SR 3.3.1.1.8 SR 3.3.1.1.11 SR 3.3.1.1.13	≤ 118.7% RTP
d. Inop	1,2	3 ^(c)	G	SR 3.3.1.1.5 SR 3.3.1.1.11	NA
e. 2-Out-Of-4 Voter	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.11 SR 3.3.1.1.15 SR 3.3.1.1.17	NA
f. OPRM Upscale	≥ 18% RTP ^(f)	3 ^(c)	I	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.8 SR 3.3.1.1.11 SR 3.3.1.1.13 SR 3.3.1.1.18	(d)
3. Reactor Vessel Steam Dome Pressure— High	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≤ 1077 psig
4. Reactor Vessel Water Level—Low Level 1	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≥ 153 inches
5. Main Steam Isolation Valve—Closure	1	8	F	SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≤ 10% closed
6. Drywell Pressure—High	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15	≤ 1.8 psig

(continued)

(c) Each APRM channel provides inputs to both trip systems.

(d) See COLR for OPRM Confirmation Density Algorithm (CDA) setpoints.

(f) ~~Following DSS-CD implementation, DSS-CD is not required to be armed while in the DSS-CD Armed Region during the first reactor startup and during the first controlled shutdown that passes completely through the DSS-CD Armed Region. However, DSS-CD is considered OPERABLE and shall be maintained OPERABLE and capable of automatically arming for operation at recirculation drive flow rates above the DSS-CD Armed Region.~~

5.6 Reporting Requirements (continued)

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

6. XN-NF-80-19(P)(A) Volume 1, Exxon Nuclear Methodology for Boiling Water Reactors – Neutronic Methods for Design and Analysis.
7. XN-NF-80-19(P)(A) Volume 4, Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads.
8. EMF-2158(P)(A), Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2.
9. XN-NF-80-19(P)(A) Volume 3, Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description.
10. ~~XN-NF-84-105(P)(A) Volume 1, XCOBRA-T: A Computer Code for BWR Transient Thermal Hydraulic Core Analysis.~~
11. ANP-10307PA, AREVA MCPR Safety Limit Methodology for Boiling Water Reactors, Revision 0, June 2011.
12. ~~ANF-913(P)(A) Volume 1, COTRANSA2: A Computer Program for Boiling Water Reactor Transient Analyses.~~
13. ANF-1358(P)(A), The Loss of Feedwater Heating Transient in Boiling Water Reactors.
14. EMF-2209(P)(A), SPCB Critical Power Correlation.
15. EMF-2245(P)(A), Application of Siemens Power Corporation's Critical Power Correlations to Co-Resident Fuel.
16. EMF-2361(P)(A), EXEM BWR-2000 ECCS Evaluation Model.
17. EMF-2292(P)(A), ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients.
18. EMF-CC-074(P)(A) Volume 4, BWR Stability Analysis – Assessment of STAIF with Input from MICROBURN-B2.
19. ~~NEDC-33075P-A, GE Hitachi Boiling Water Reactor, Detect and Suppress Solution – Confirmation Density, Revision 8, November 2013.~~

(continued)

ANP-10300P-A,
AURORA-B: An
Evaluation Model for
Boiling Water Reactors;
Application to Transient
and Accident
Scenarios, Revision 1,
January 2018.

5.6 Reporting Requirements (continued)

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

Insert A

- 
20. BAW-10247PA, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Revision 0, April 2008.
 21. ANP-10298P-A, ACE/ATRIUM 10XM Critical Power Correlation, Revision 1, March 2014.
- c. The core operating limits shall be determined such that all applicable limits (e.g., fuel thermal mechanical limits, core thermal hydraulic limits, Emergency Core Cooling Systems (ECCS) limits, nuclear limits such as SDM, transient analysis limits, and accident analysis limits) of the safety analysis are met.
 - d. The COLR, including any midcycle revisions or supplements, shall be provided upon issuance for each reload cycle to the NRC.

5.6.6 Post Accident Monitoring (PAM) Instrumentation Report

When a report is required by Condition B or F of LCO 3.3.3.1, "Post Accident Monitoring (PAM) Instrumentation," a report shall be submitted within the following 14 days. The report shall outline the preplanned alternate method of monitoring, the cause of the inoperability, and the plans and schedule for restoring the instrumentation channels of the Function to OPERABLE status.

5.6.7 Oscillation Power Range Monitor (OPRM) Report

When a report is required by Condition I of LCO 3.3.1.1, "RPS Instrumentation," a report shall be submitted within the following 90 days. The report shall outline the preplanned means to provide backup stability protection, the cause of the inoperability, and the plans and schedule for restoring the required instrumentation channels to OPERABLE status.

Insert A

22. DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018
23. BAW-10247P-A, Supplement 2P-A, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods, Revision 0, August 2018
24. ANP-10340P-A, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods, Revision 0, May 2018
25. ANP-10335P-A, ACE/ATRIUM 11 Critical Power Correlation, Revision 0, May 2018
26. ANP-10332P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, Revision 0, [DATE]

Technical Specification Mark-Ups – Unit 2

Table 3.3.1.1-1 (page 2 of 3)
Reactor Protection System Instrumentation

FUNCTION	APPLICABLE MODES OR OTHER SPECIFIED CONDITIONS	REQUIRED CHANNELS PER TRIP SYSTEM	CONDITIONS REFERENCED FROM REQUIRED ACTION D.1	SURVEILLANCE REQUIREMENTS	ALLOWABLE VALUE
2. Average Power Range Monitors (continued)					
c. Neutron Flux—High	1	3 ^(c)	F	SR 3.3.1.1.2 SR 3.3.1.1.3 SR 3.3.1.1.5 SR 3.3.1.1.8 SR 3.3.1.1.11 SR 3.3.1.1.13	≤ 118.7% RTP
d. Inop	1,2	3 ^(c)	G	SR 3.3.1.1.5 SR 3.3.1.1.11	NA
e. 2-Out-Of-4 Voter	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.11 SR 3.3.1.1.15 SR 3.3.1.1.17	NA
f. OPRM Upscale	≥ 18% RTP ^(f)	3 ^(c)	I	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.8 SR 3.3.1.1.11 SR 3.3.1.1.13 SR 3.3.1.1.18	(d)
3. Reactor Vessel Steam Dome Pressure— High	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≤ 1077 psig
4. Reactor Vessel Water Level—Low Level 1	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≥ 153 inches
5. Main Steam Isolation Valve—Closure	1	8	F	SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.13 SR 3.3.1.1.15 SR 3.3.1.1.17	≤ 10% closed
6. Drywell Pressure—High	1,2	2	G	SR 3.3.1.1.2 SR 3.3.1.1.5 SR 3.3.1.1.9 SR 3.3.1.1.10 SR 3.3.1.1.13 SR 3.3.1.1.15	≤ 1.8 psig

(continued)

(c) Each APRM channel provides inputs to both trip systems.

(d) See COLR for OPRM Confirmation Density Algorithm (CDA) setpoints.

(f) ~~Following DSS-CD implementation, DSS-CD is not required to be armed while in the DSS-CD Armed Region during the first reactor startup and during the first controlled shutdown that passes completely through the DSS-CD Armed Region. However, DSS-CD is considered OPERABLE and shall be maintained OPERABLE and capable of automatically arming for operation at recirculation drive flow rates above the DSS-CD Armed Region.~~

5.6 Reporting Requirements (continued)

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

6. XN-NF-80-19(P)(A) Volume 1, Exxon Nuclear Methodology for Boiling Water Reactors – Neutronic Methods for Design and Analysis.
7. XN-NF-80-19(P)(A) Volume 4, Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads.
8. EMF-2158(P)(A), Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2.
9. XN-NF-80-19(P)(A) Volume 3, Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description.
10. ~~XN-NF-84-105(P)(A) Volume 1, XCOBRA-T: A Computer Code for BWR Transient Thermal Hydraulic Core Analysis.~~
11. ANP-10307PA, AREVA MCPR Safety Limit Methodology for Boiling Water Reactors, Revision 0, June 2011.
12. ~~ANF-913(P)(A) Volume 1, COTRANSA2: A Computer Program for Boiling Water Reactor Transient Analyses.~~
13. ANF-1358(P)(A), The Loss of Feedwater Heating Transient in Boiling Water Reactors.
14. EMF-2209(P)(A), SPCB Critical Power Correlation.
15. EMF-2245(P)(A), Application of Siemens Power Corporation's Critical Power Correlations to Co-Resident Fuel.
16. EMF-2361(P)(A), EXEM BWR-2000 ECCS Evaluation Model.
17. EMF-2292(P)(A), ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients.
18. EMF-CC-074(P)(A) Volume 4, BWR Stability Analysis – Assessment of STAIF with Input from MICROBURN-B2.
19. ~~NEDC-33075P-A, GE Hitachi Boiling Water Reactor, Detect and Suppress Solution – Confirmation Density, Revision 8, November 2013.~~

(continued)

ANP-10300P-A,
AURORA-B: An
Evaluation Model for
Boiling Water Reactors;
Application to Transient
and Accident
Scenarios, Revision 1,
January 2018.

5.6 Reporting Requirements (continued)

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

Insert A



- 20. BAW-10247PA, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Revision 0, April 2008.
- 21. ANP-10298P-A, ACE/ATRIUM 10XM Critical Power Correlation, Revision 1, March 2014.

- c. The core operating limits shall be determined such that all applicable limits (e.g., fuel thermal mechanical limits, core thermal hydraulic limits, Emergency Core Cooling Systems (ECCS) limits, nuclear limits such as SDM, transient analysis limits, and accident analysis limits) of the safety analysis are met.
- d. The COLR, including any midcycle revisions or supplements, shall be provided upon issuance for each reload cycle to the NRC.

5.6.6 Post Accident Monitoring (PAM) Instrumentation Report

When a report is required by Condition B or F of LCO 3.3.3.1, "Post Accident Monitoring (PAM) Instrumentation," a report shall be submitted within the following 14 days. The report shall outline the preplanned alternate method of monitoring, the cause of the inoperability, and the plans and schedule for restoring the instrumentation channels of the Function to OPERABLE status.

5.6.7 Oscillation Power Range Monitor (OPRM) Report

When a report is required by Condition I of LCO 3.3.1.1, "RPS Instrumentation," a report shall be submitted within the following 90 days. The report shall outline the preplanned means to provide backup stability protection, the cause of the inoperability, and the plans and schedule for restoring the required instrumentation channels to OPERABLE status.

Insert A

22. DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018
23. BAW-10247P-A, Supplement 2P-A, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods, Revision 0, August 2018
24. ANP-10340P-A, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods, Revision 0, May 2018
25. ANP-10335P-A, ACE/ATRIUM 11 Critical Power Correlation, Revision 0, May 2018
26. ANP-10332P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, Revision 0, [DATE]

Technical Specification Bases Mark-Ups – Unit 1
(For Information Only)

BASES

BACKGROUND (continued)

Operation above the boundary of the nucleate boiling regime could result in excessive cladding temperature because of the onset of transition boiling and the resultant sharp reduction in heat transfer coefficient. Inside the steam film, high cladding temperatures are reached, and a cladding water (zirconium water) reaction may take place. This chemical reaction results in oxidation of the fuel cladding to a structurally weaker form. This weaker form may lose its integrity, resulting in an uncontrolled release of activity to the reactor coolant.

The reactor vessel water level SL ensures that adequate core cooling capability is maintained during all MODES of reactor operation. Establishment of Emergency Core Cooling System initiation setpoints higher than this safety limit provides margin to ensure the safety limit will not be reached or exceeded such that fuel damage would occur.

APPLICABLE SAFETY ANALYSES

The fuel cladding must not sustain damage as a result of normal operation and AOOs. The reactor core SLs are established to preclude violation of the fuel design criterion that an MCPR limit is to be established, such that at least 99.9% of the fuel rods in the core would not be expected to experience the onset of transition boiling.

The Reactor Protection System setpoints (LCO 3.3.1.1, "Reactor Protection System (RPS) Instrumentation"), in combination with the other LCOs, are designed to prevent any anticipated combination of transient conditions for Reactor Coolant System water level, pressure, and THERMAL POWER level that would result in reaching the MCPR limit.

2.1.1.1 Fuel Cladding Integrity

The critical power correlations are valid for critical power calculations at pressures ≥ 600 psia and bundle mass fluxes $\geq 0.09\text{E}+6$ lbm/hr-ft² (References ~~1 and 4~~). For operation at low pressures or low flows, another basis is used, as follows:

1, 4, and 6

Since the pressure drop in the bypass region is essentially all elevation head, the core pressure drop at low power and flows will always be > 4.5 psi. Analyses show that with a bundle flow of 28×10^3 lb/hr, bundle pressure drop is nearly independent of bundle power and has a value of 3.5 psi. Thus, the bundle flow with a 4.5 psi driving head will be $> 28 \times 10^3$ lb/hr. Full scale ATLAS test data taken at pressures from 14.7 psia (0 psig) to 800 psia (785 psig) indicate that the fuel assembly critical power at this flow is approximately 3.35 MWt. With the design peaking factors, this corresponds to a THERMAL POWER $> 46\%$ RTP. Thus, a THERMAL POWER limit of 23% RTP for reactor pressure < 785 psig is conservative.

(continued)

BASES

APPLICABLE 2.1.1.2 _____ MCPR SAFETY ANALYSES (continued)

The fuel cladding integrity SL is set such that no fuel damage is calculated to occur if the limit is not violated. Since the parameters that result in fuel damage are not directly observable during reactor operation, the thermal and hydraulic conditions that result in the onset of transition boiling have been used to mark the beginning of the region in which fuel damage could occur. Although it is recognized that the onset of transition boiling would not result in damage to BWR fuel rods, the critical power at which boiling transition is calculated to occur has been adopted as a convenient limit. However, the uncertainties in monitoring the core operating state and in the procedures used to calculate the critical power result in an uncertainty in the value of the critical power. Therefore, the fuel cladding integrity SL is defined as the critical power ratio in the limiting fuel assembly for which more than 99.9% of the fuel rods in the core are expected to avoid boiling transition, considering the power distribution within the core and all uncertainties.

4, and 6



The MCPR SL is determined using a statistical model that combines all the uncertainties in operating parameters and the procedures used to calculate critical power. The probability of the occurrence of boiling transition is determined using the approved AREVA critical power correlations. One specific uncertainty included in the SL is the uncertainty inherent in the critical power correlation. References 1, 2, 3, and 4 describe the uncertainties and methodology used to determine the MCPR SL.

2.1.1.3 Reactor Vessel Water Level

During MODES 1 and 2 the reactor vessel water level is required to be above the top of the active irradiated fuel to provide core cooling capability. In conjunction with LCOs, the limiting safety system settings, defined in LCO 3.3.1.1 as the Allowable Values, establish the threshold for protective system action to prevent exceeding acceptable limits, including this reactor vessel water level SL, during Design Basis Accidents. With fuel in the reactor vessel during periods when the reactor is shut down, consideration must be given to water level requirements due to the effect of decay heat. If the water level should drop below the top of the active irradiated fuel during this period, the ability to remove decay heat is reduced. This reduction in cooling capability could lead to elevated cladding temperatures and clad perforation in the event that the water level becomes $< 2/3$ of the core height. The reactor vessel water level SL has been established at the top of the active irradiated fuel to provide a point that can be monitored and to also provide adequate margin for effective action.

(continued)

BASES

SAFETY LIMITS	The reactor core SLs are established to protect the integrity of the fuel clad barrier to prevent the release of radioactive materials to the environs. SL 2.1.1.1 and SL 2.1.1.2 ensure that the core operates within the fuel design criteria. SL 2.1.1.3 ensures that the reactor vessel water level is greater than the top of the active irradiated fuel in order to prevent elevated clad temperatures and resultant clad perforations.

APPLICABILITY	SLs 2.1.1.1, 2.1.1.2, and 2.1.1.3 are applicable in all MODES.

SAFETY LIMIT VIOLATIONS	Exceeding an SL may cause fuel damage and create a potential for radioactive releases in excess of 10 CFR 50.67, "Accident Source Term," limits (Ref. 5). Therefore, it is required to insert all insertable control rods and restore compliance with the SLs within 2 hours. The 2 hour Completion Time ensures that the operators take prompt remedial action and also ensures that the probability of an accident occurring during this period is minimal.

REFERENCES	1. EMF-2209(P)(A), "SPCB Critical Power Correlation," (as identified in the COLR). 2. EMF-2245(P)(A), "Application of Siemens Power Corporation's Critical Power Correlations to Co-Resident Fuel," (as identified in the COLR). 3. ~~ANF 524(P)(A), "ANF Critical Power Methodology for Boiling Water Reactors,"~~ (as identified in the COLR). 4. ANP-10298PA, "ACE/ATRIUM 10XM Critical Power Correlation," (as identified in the COLR). 5. 10 CFR 50.67.

ANP-10307PA, "AREVA MCPR Safety Limit Methodology for Boiling Water Reactors,"

6. ANP-10335P-A, "ACE/ATRIUM 11 Critical Power Correlation," (as identified in the COLR).

BASES

ACTIONS

B.1 and B.2 (continued)

When nine or more OPERABLE control rods are not in compliance with BPWS, the reactor must be manually scrammed within 1 hour. This ensures the reactor is shut down and, as such, does not meet the applicability requirements of this LCO. The allowed Completion Time of 1 hour is reasonable to allow insertion of control rods to restore compliance, and is appropriate relative to the low probability of a CRDA occurring with the control rods out of sequence.

SURVEILLANCE REQUIREMENTS

SR 3.1.6.1

The control rod pattern is periodically verified to be in compliance with the BPWS to ensure the assumptions of the CRDA analyses are met. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program. The RWM provides control rod blocks to enforce the required sequence and is required to be OPERABLE when operating at $\leq 8.75\%$ RTP.

REFERENCES

1. UFSAR, Section 15.4.
2. ~~XM-NF-80-19(P)(A), Volume 1, "Exxon Nuclear Methodology for Boiling Water Reactors: Neutronic Methods for Design and Analysis," (as identified in the COLR).~~
3. EMF-2158(P)(A), "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO/MICROBURN-B2," (as identified in the COLR).
4. NEDE-24011-P-A-11-US, General Electric Standard Application for Reactor Fuel, Supplement for United States, Section 2.2.3.1, November 1995.
5. NRC Safety Evaluation Report, Acceptance for Referencing of Licensing Topical Report NEDE-24011-P-A, General Electric Standard Application for Reactor Fuel, Revision 8, Amendment 17; December 27, 1987.
6. UFSAR, Section 4.3.2.5.
7. NUREG-0800, Section 15.4.9, Revision 2, July 1981.
8. NEDO-21778-A, Transient Pressure Rises Affected Fracture Toughness Requirements for Boiling Water Reactors, December 1978.

ANP-10333P-A, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA),"

(continued)

B 3.2 POWER DISTRIBUTION LIMITS

B 3.2.1 AVERAGE PLANAR LINEAR HEAT GENERATION RATE (APLHGR)

BASES

BACKGROUND	The APLHGR is a measure of the average LHGR of all the fuel rods in a fuel assembly at any axial location. Limits on the APLHGR are specified to ensure that the peak cladding temperature (PCT) during the postulated design basis loss of coolant accident (LOCA) does not exceed the limits specified in 10 CFR 50.46.
APPLICABLE SAFETY ANALYSES	The analytical methods and assumptions used in evaluating the fuel design limits are presented in References 1, 2, ~~and 6~~. The analytical methods and assumptions used in evaluating Design Basis Accidents (DBAs), anticipated operational transients, and normal operation that determine the APLHGR limits are presented in References 1, 2, 3, 4, 6, ~~and 7~~. , and 8 The analytical methods and assumptions used in evaluating the DBA that determine the APLHGR limit are presented in Reference 6. APLHGR limits are developed as a function of planar exposure. and 8 LOCA analyses are performed to ensure that the APLHGR limits are adequate to meet the PCT and maximum oxidation limits of 10 CFR 50.46. The analysis is performed using analysis models that are consistent with the requirements of 10 CFR 50, Appendix K. The analysis models and methodology are described in Reference 6. and 8 The APLHGR limits are presented in the COLR. For single recirculation loop operation, a multiplier is applied to the two recirculation loop operation exposure dependent APLHGR limits. This multiplier is due to an earlier departure from nucleate boiling with one recirculation loop available, resulting in a more severe cladding heatup during a LOCA. The APLHGR satisfies Criterion 2 of 10 CFR 50.36(c)(2)(ii) (Ref. 5).
LCO	The APLHGR limits specified in the COLR are the result of the DBA analyses. For two recirculation loops operating, the limit is dependent on exposure. With only one recirculation loop in operation, in conformance with LCO 3.4.1, "Recirculation Loops Operating," the limit is determined by multiplying the exposure dependent APLHGR limit by a multiplier determined by a specific single recirculation loop analysis. Additional APLHGR operating limits adjustments may be provided in the COLR to support analyzed equipment out-of-service operation.

(continued)

BASES (continued)

REFERENCES

1. NEDO-24011-P-A "General Electric Standard Application for Reactor Fuel" (latest approved version).
2. UFSAR, Chapter 4.
3. UFSAR, Chapter 6.
4. UFSAR, Chapter 15.
5. 10 CFR 50.36(c)(2)(ii).
6. EMF-2361(P)(A), "EXEM BWR-2000 ECCS Evaluation Model," (as identified in the COLR).
7. EMF-2292(P)(A), ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients," (as identified in the COLR).



8. ANP-10332P-A, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios," (as identified in the COLR).

B 3.2 POWER DISTRIBUTION LIMITS

B 3.2.2 MINIMUM CRITICAL POWER RATIO (MCPR)

BASES

BACKGROUND

MCPR is a ratio of the fuel assembly power that would result in the onset of boiling transition to the actual fuel assembly power. The MCPR Safety Limit (SL) is set such that 99.9% of the fuel rods avoid boiling transition if the limit is not violated (refer to the Bases for SL 2.1.1.2). The operating limit MCPR is established to ensure that no fuel damage results during anticipated operational occurrences (AOOs). Although fuel damage does not necessarily occur if a fuel rod actually experienced boiling transition (Ref.1), the critical power at which boiling transition is calculated to occur has been adopted as a fuel design criterion.

The onset of transition boiling is a phenomenon that is readily detected during the testing of various fuel bundle designs. Based on these experimental data, correlations have been developed to predict critical bundle power (i.e., the bundle power level at the onset of transition boiling) for a given set of plant parameters (e.g., reactor vessel pressure, flow, and subcooling). Because plant operating conditions and bundle power levels are monitored and determined relatively easily, monitoring the MCPR is a convenient way of ensuring that fuel failures due to inadequate cooling do not occur.

and

APPLICABLE SAFETY ANALYSES

The analytical methods and assumptions used in evaluating the AOOs to establish the operating limit MCPR are presented in References 2, 3, 4, 5, 7, 8, 9, and 10. To ensure that 99.9% of the fuel rods avoid boiling transition during any transient that occurs with moderate frequency, limiting transients are analyzed to determine the largest reduction in critical power ratio (CPR). The types of transients evaluated are loss of flow, increase in pressure and power, positive reactivity insertion, and coolant temperature decrease. The limiting transient yields the largest change in CPR (Δ CPR). When the largest Δ CPR is added to the MCPR SL, the required operating limit MCPR (OLMCPR) is obtained.

The MCPR operating limits derived from the transient analysis are dependent on the operating core flow and power state ($MCPR_f$ and $MCPR_p$ respectively) to ensure adherence to fuel design limits during the worst transient that occurs with moderate frequency as identified in the UFSAR Chapter 15 (Reference 5).

Flow dependent MCPR limits are determined using steady state thermal hydraulic methods (Reference 7) to analyze slow flow runout transients. The $MCPR_f$ limits are dependent on the maximum core flow runout capability of the Recirculation System.

(continued)

8 and 9

BASES

APPLICABLE SAFETY ANALYSES (continued)	Power dependent MCPR limits ($MCPR_p$) are determined on a cycle-specific basis using the methodologies presented in References ~~8, 9, and 10~~. The $MCPR_p$ limits are established for a set of exposure intervals. Due to the sensitivity of the transient response to initial core flow levels at power levels below those at which turbine stop valve and/or turbine control valve fast closure and the associated scrams occur, high and low flow $MCPR_p$ operating limits may be provided for the following core power level ranges: 23 to 26% RTP and 26 to 50% RTP. The 26% RTP is the previously mentioned bypass power level and 50% RTP is the power level below which the power load unbalance unit (PLU) may not generate a turbine control valve fast closure on a generator loss of load event. The MCPR satisfies Criterion 2 of 10 CFR 50.36(c)(2)(ii) (Ref. 11).

LCO	The MCPR operating limits, as a function of core flow, core power, and cycle exposure, specified in the COLR are the result of the Design Basis Accident (DBA) and transient analysis. The operating limit MCPR is determined by the larger of the $MCPR_f$ and $MCPR_p$ limits.

APPLICABILITY	The MCPR operating limits are primarily derived from transient analyses that are assumed to occur at high power levels. Below 23% RTP, the reactor is operating at a minimum recirculation pump speed and the moderator void ratio is small. Surveillance of thermal limits below 23% RTP is unnecessary due to the large inherent margin that ensures that the MCPRSL is not exceeded even if a limiting transient occurs. Statistical analyses indicate that the nominal value of the initial MCPR expected at 23% RTP is > 3.5. Studies of the variation of limiting transient behavior have been performed over the range of power and flow conditions. These studies encompass the range of key actual plant parameter values important to typically limiting transients. The results of these studies demonstrate that a margin is expected between performance and the MCPR requirements, and that margins increase as power is reduced to 23% RTP. This trend is expected to continue to the 5% to 15% power range when entry into MODE 2 occurs. When in MODE 2, the intermediate range monitor provides rapid scram initiation for any significant power increase transient, which effectively eliminates any MCPR compliance concern. Therefore, at THERMAL POWER levels $< 23\%$ RTP, the reactor is operating with substantial margin to the MCPR limits and this LCO is not required.

(continued)

BASES

ANP-10307PA, "AREVA MCPR Safety Limit Methodology for Boiling Water Reactors," (as identified in the COLR).

REFERENCES

1. UFSAR Section 4.4.2.1.
2. ~~ANF 524(P)(A), "ANF Critical Power Methodology for Boiling Water Reactors."~~
3. UFSAR, Chapter 4.
4. UFSAR, Chapter 6.
5. UFSAR, Chapter 15.
6. (Deleted.)
7. X N-NF-80-19(P)(A) Volume 3, "Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description," (as identified in the COLR).
8. EMF-2158(P)(A), "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2," (as identified in the COLR).
9. ~~ANF 913(P)(A) Volume 1, "COTRANSA2: A Computer Program for Boiling Water Reactor Transient Analyses," (as identified in the COLR).~~
10. ~~XN NF 84 105(P)(A), XCOBRA T: A Computer Code for BWR Transient Thermal Hydraulic Core Analysis," (as identified in the COLR).~~
11. 10 CFR 50.36(c)(2)(ii).

(Deleted.)

ANP-10300P-A, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios," (as identified in the COLR).

Revision No. 99

BASES

APPLICABLE SAFETY ANALYSES, LCO, and APPLICABILITY	<u>2.f. Oscillation Power Range Monitor (OPRM) Upscale</u> (continued) The OPRM Upscale Function is required to be OPERABLE when THERMAL POWER is $\geq 18\%$ RTP, which is established as a power level that is $\geq 5\%$ below the lower boundary of the Enabled Region. This requirement is designed to encompass the region of power-flow operation where anticipated events could lead to thermal-hydraulic instability and related neutron flux oscillations. The OPRM Upscale Function is automatically trip-enabled when THERMAL POWER, as indicated by the APRM Simulated Thermal Power, is $\geq 23\%$ RTP (i.e., corresponding to the MCPR monitoring threshold) and reactor recirculation drive flow is $\leq 75\%$ of rated drive flow. This region is the OPRM Enabled Region. ~~Note (f) allows for entry into the DSS-CD Enabled Region without automatic arming of DSS-CD prior to completely passing through the DSS-CD Enabled Region during both the first startup and the first shutdown following DSS-CD implementation.~~ ~~Note (f) reflects the need for plant data collection in order to test the DSS-CD equipment. Testing the DSS-CD equipment ensures its proper operation and prevents spurious reactor trips. Entry into the DSS-CD Enabled Region (also called the Armed Region) without automatic arming of DSS-CD during this initial testing phase also allows for changes in plant operations to address maintenance or other operational needs. However, during this initial testing period, the OPRM Upscale Function is OPERABLE and DSS-CD operability and capability to automatically arm shall be maintained at recirculation drive flow rates above the DSS-CD Enabled Region flow boundary.~~ (continued)

Revision No. 99

BASES

ACTIONS

I.2 and I.3 (continued)

~~Section 7.4 of Reference 17, the Automated BSP Scram Region is designed to avoid reactor instability by automatically preventing entry into the region of the power and flow-operating map that is susceptible to reactor instability. The reactor trip would be initiated by the modified APRM Simulated Thermal Power High scram setpoints for flow reduction events that would have terminated in the Manual BSP Region I. The Automated BSP Scram Region ensures an early scram and SLMCPR protection.~~

The Completion Time of 12 hours to complete Action I.2 is reasonable, based on operational experience, and based on the importance of restoring an automatic reactor trip for thermal-hydraulic instability events.

BSP is intended as a temporary means to protect against thermal-hydraulic instability events. Action I.3 should be initiated immediately to document the situation and prepare the report. The reporting requirements of Specification 5.6.7 document the corrective actions and schedule to restore the required channels to an OPERABLE status. The 90 day Completion Time shown in Specification 5.6.7 is adequate to allow time to evaluate the cause of the inoperability and to determine the appropriate corrective actions and schedule to restore the required channels to OPERABLE status.

J.1

If the Required Actions I are not completed within the associated Completion Times, then Action J is required. The Bases for the Manual BSP Regions and associated Completion Time is addressed in the Bases for I.1. The Manual BSP Regions are required in conjunction with the BSP Boundary.

J.2

~~The BSP Boundary, as described in Section 7.3 of Reference 17, defines an operating domain where potential instability events can be effectively addressed by the specified BSP manual operator actions. The BSP Boundary is constructed such that a flow reduction event initiated from this boundary and terminated at the core natural circulation line (NCL) would not exceed the Manual BSP Region I stability criterion. Potential instabilities would develop slowly as a result of the feedwater temperature transient (Ref. 17).~~

The Completion Time of 12 hours to complete the specified action is reasonable, based on operational experience, to reach the specific

(continued)

The BSP Boundary is defined in Reference 17 as the MELLLA boundary. Potential instabilities following flow reduction events from below the MELLLA boundary develop more slowly and can be effectively addressed by the specific BSP manual operator actions.

BASES

DPC-NE-1009-P, Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III, Revision 0, September 2018.

REFERENCES
(continued)

- 17. ~~NEDC 33075P A, Revision 8, "GE Hitachi Boiling Water Reactor Detect and Suppress Solution Confirmation Density," November 2013.~~
- 18. ~~J. Harrison (GEH) letter to NRC, "NEDC 33075P A, Detect and Suppress Solution Confirmation Density (DSS CD) Analytical Limit," October 29, 2008 (ADAMS Accession No. ML083040052).~~

ANP-3703P, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA, Revision 0, August 2018.

BASES

12 and 13

APPLICABLE
SAFETY ANALYSES,
LCO, and
APPLICABILITY
(continued)

2. Rod Worth Minimizer

The RWM enforces the banked position withdrawal sequence (BPWS) to ensure that the initial conditions of the CRDA analysis are not violated. The analytical methods and assumptions used in evaluating the CRDA are summarized in References ~~11 and 12~~. The BPWS requires that control rods be moved in groups, with all control rods assigned to a specific group required to be within specified banked positions. Requirements that the control rod sequence is in compliance with the BPWS are specified in LCO 3.1.6, "Rod Pattern Control."

The RWM Function satisfies Criterion 3 of 10 CFR 50.36(c)(2)(ii) (Ref. 3).

The RWM is a microprocessor-based system with the principle task to reinforce procedural control to limit the reactivity worth of control rods under lower power conditions. Only one channel of the RWM is available and required to be OPERABLE. Special circumstances provided for in the Required Action of LCO 3.1.3, "Control Rod OPERABILITY," and LCO 3.1.6 may necessitate bypassing the RWM to allow continued operation with inoperable control rods, or to allow correction of a control rod pattern not in compliance with the BPWS. As required by these conditions, one or more control rods may be bypassed in the RWM or the RWM may be bypassed. However, the RWM must be considered inoperable and the Required Actions of this LCO followed since the RWM can no longer enforce compliance with the BPWS.

Compliance with the BPWS, and therefore OPERABILITY of the RWM, is required in MODES 1 and 2 when THERMAL POWER is $\leq 8.75\%$ RTP. When THERMAL POWER is $> 8.75\%$ RTP, there is no possible control rod configuration that results in a control rod worth that could exceed the 280 cal/gm fuel damage limit during a CRDA (Refs. 5 and 6). In MODES 3 and 4, all control rods are required to be inserted into the core;

(continued)

BASES (continued)

REFERENCES	1.	UFSAR, Section 7.6.1.1.5.
	2.	NEDC-31654P, Maximum Extended Operating Domain Analysis For Brunswick Steam Electric Plant, February 1989.
	3.	10 CFR 50.36(c)(2)(ii).
	4.	NEDC-32466P, Power Uprate Safety Analysis Report for Brunswick Steam Electric Plant Unit 1 and 2, September 1995.
	5.	UFSAR Section 15.4.
	6.	NRC SER, Acceptance for Referencing of Licensing Topical Report NEDE-24011-P-A; General Electric Standard Application for Reactor Fuel, Revision 8, Amendment 17, December 27, 1987.
	7.	GENE-770-06-1-A, Bases for Changes to Surveillance Test Intervals and Allowed Out-of-Service Times for Selected Instrumentation Technical Specifications, December 1992.
	8.	NEDC-30851P-A, Supplement 1, Technical Specification Improvement Analysis for BWR Control Rod Block Instrumentation, October 1988.
	9.	NEDC-32410P-A, Nuclear Measurement Analysis and Control Power Range Neutron Monitor (NUMAC PRNM) Retrofit Plus Option III Stability Trip Function, October 1995.
	10.	NEDC-32410P-A Supplement 1, Nuclear Measurement Analysis and Control Power Range Neutron Monitor (NUMAC PRNM) Retrofit Plus Option III Stability Trip Function, November 1997.
	11.	XN-NF-80-19(P)(A) Volume 1, "Exxon Nuclear Methodology for Boiling Water Reactors - Neutronic Methods for Design and Analysis," (as identified in the COLR).
	12.	EMF-2158(P)(A), "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2," (as identified in the COLR).

13. ANP-10333P-A, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA)," (as identified in the COLR).

List of Regulatory Commitments

List of Regulatory Commitments

Commitment Description	One-Time Action	Continuing Compliance	Scheduled Completion Date (If Required)
Following issuance of the Final Safety Evaluation for ANP-10332P, Duke Energy will supplement this License Amendment Request with reference to the approved AURORA-B LOCA Topical Report (i.e., ANP-10332P-A) and any changes in limitations and conditions will be addressed.	☒	☐	45 days following issuance of ANP-10332P-A
Duke Energy will provide the BSEP Unit 1 Cycle 23 Fuel Cycle Design Report to the NRC for information.	☒	☐	15 days following approval of the report
Duke Energy will provide the BSEP Unit 1 Cycle 23 Nuclear Fuel Bundle Design Report to the NRC for information.	☒	☐	15 days following approval of the report
Duke Energy will provide the BSEP Unit 1 Cycle 23 Safety Limit MCPR Report to the NRC for information.	☒	☐	15 days following approval of the report
Duke Energy will provide the BSEP Unit 1 Cycle 23 Fuel Rod Design Report to the NRC for information.	☒	☐	15 days following approval of the report
Duke Energy will provide the BSEP Unit 1 Cycle 23 Reload Safety Analysis Report to the NRC for information.	☒	☐	15 days following approval of the report
Duke Energy will provide the BSEP Unit 2 Cycle 25 Reload Safety Analysis Report to the NRC for information.	☒	☐	Upon issuance of the BSEP Unit 2 Cycle 25 COLR

ANP-3705NP, Applicability of Framatome BWR Methods to
Brunswick with ATRIUM 11 Fuel



Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel

ANP-3705NP
Revision 0

September 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

ATRIUM, ULTRAFLOW, FUELGUARD, Z4B, and S-RELAP5 are trademarks or registered trademarks of Framatome (formerly known as AREVA Inc.) or its affiliates, in the USA or other countries.

Framatome Inc.

ANP-3705NP
Revision 0Applicability of Framatome BWR Methods to
Brunswick with ATRIUM 11 Fuel

Page i

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 OVERVIEW	2-1
3.0 ATRIUM 11 FUEL ASSEMBLY DESIGN	3-1
4.0 MECHANICAL LIMITS METHODOLOGY	4-1
5.0 THERMAL HYDRAULICS	5-1
5.1 ATRIUM 11 Void Fraction	5-1
5.2 ACE/ATRIUM 11 Critical Power Ratio Correlation	5-1
5.3 Loss Coefficients	5-3
6.0 TRANSIENTS AND ACCIDENTS	6-1
6.1 Void Quality Correlation Uncertainties	6-1
6.2 Assessment of the Void-Quality Correlation	6-2
7.0 ATWS	7-1
7.1 ATWS General	7-1
7.2 Void Quality Correlation Bias	7-1
7.3 ATWS Containment Heatup	7-2
8.0 NEUTRONICS	8-1
8.1 Shutdown Margin	8-1
8.2 Monitoring	8-1
8.3 Power Distribution Uncertainty	8-1
8.4 Bypass modeling	8-2
9.0 REFERENCES	9-1

List of Tables

Table 2-1	Framatome Licensing Topical Reports	2-2
Table 3-1	Fuel Assembly and Component Description.....	3-3
Table 3-2	Fuel Channel and Fastener Description	3-4
Table 5-1	ACE/ATRIUM 10XM Bounds Checking	5-2
Table 5-2	Comparison of the Range of Applicability for the ATRIUM 11 and ATRIUM 10XM Correlations	5-2
Table 5-3	Hydraulic Characteristics of ATRIUM 11 Fuel Assemblies	5-5
Table 7-1	[.....].....	7-3

List of Figures

Figure 1-1	Brunswick Power Flow Operating Map with the MELLLA+ EPFOD	1-2
Figure 5-1	Measured versus Predicted (MICROBURN-B2) Bundle Pressure Drop.....	5-6

Nomenclature

(If applicable)

Acronym	Definition
ACE	Framatome's advanced critical power correlation []
ASME	American Society of Mechanical Engineers
ATWS	anticipated transient without scram
BWR	boiling water reactor
CHF	critical heat flux
CPR	critical power ratio
DIVOM	delta-over-Initial CPR versus oscillation magnitude
EPFOD	Extended Power Flow Operating Domain
EPU	extended power uprate
KATHY	Karlstein thermal hydraulic test facility
LHGR	linear heat generation rate
LOCA	loss of coolant accident
MELLLA+ MCPR	Maximum Extended Load Line Limit Analysis Plus minimum critical power ratio
NRC	Nuclear Regulatory Commission, U. S.
OLMCPR	operating limit minimum critical power ratio
PLFR	part length fuel rod
SLMCPR	safety limit minimum critical power ratio
SER	safety evaluation report
TIP	traversing incore probe

1.0 INTRODUCTION

This document reviews the Framatome approved licensing methodologies to demonstrate that they are applicable to licensing and operation of the Brunswick Nuclear Plant with ATRIUM™ 11 in the extended power uprate (EPU) operating domain with a representative power/flow operating map in Figure 1-1 (Extended Flow Domain). General applicability of Framatome licensing methods to the Brunswick units in the EPU operating domain was discussed in ANP-3108P Revision 1. Application of the new methods added for ATRIUM 11 (ACE ATRIUM 11, RODEX-4 for Chromia doped fuel, AURORA-B AOO, CRDA* and LOCA) for EPU applications are addressed in this document or in plant specific applications of the new methodologies.

This document applies to both Brunswick units since both Brunswick BWR/4s have only minor differences. The most significant difference between the units is the core loadings and corresponding core designs. The impact of the differences in core designs between units and cycles is addressed in the cycle specific reload report for each unit. Minor differences between the plants and units, such as orifice diameters and bypass valve capacities do not impact the application of Framatome's methodology as presented in this document.

For the introduction of ATRIUM 11 at EPU conditions with extended flow operating domain a review of the RAI's received from previous license applications was used to identify anything that needed to be addressed.

* For the Brunswick ATRIUM 11 plant-specific application of CRDA, [

] has

been applied for the startup range evaluations.



Figure 1-1
Brunswick Power Flow Operating Map with the MELLLA+ EPFOD

2.0 OVERVIEW

ANP-3108P Revision 1 (Reference 1) demonstrated the applicability of Framatome methods for analyses for ATRIUM 10XM at EPU power levels and extended flow domains. The introduction of ATRIUM 11 fuel coincides with the application of a new modern suite of methodologies (References 2 through 9) that also address a number of industry concerns. This is the first application of the entire suite of new and upgraded methodologies. The design characteristics of the ATRIUM 10XM and ATRIUM 11 are explicitly accounted for in all of the models for operation with EPU and extended flow domains. The differences in fuel design characteristics between the ATRIUM 10XM and ATRIUM 11 are discussed in Section 3.0.

The first step in determining the applicability of current licensing methods to Brunswick operating conditions was a review of Framatome BWR topical reports listed in Table 2-1 to identify SER restrictions. This review identified that there are no SER restrictions on core power level or core flow for the Framatome topical reports. The review also indicated that the [

]. This is discussed in the Thermal Hydraulics section.

Based on the fundamental characteristics of the fuel designs, each of the major analysis domains thermal-mechanics, thermal-hydraulics, mechanics (Reference 10), core neutronics, transient analysis, LOCA (Reference 11) and stability (Reference 12) are assessed to determine any challenges to application.

Table 2-1 Framatome Licensing Topical Reports

Document Number	Document Title
XN-NF-79-56(P)(A) Revision 1 and Supplement 1	"Gadolinia Fuel Properties for LWR Fuel Safety Evaluation," Exxon Nuclear Company, November 1981
XN-NF-85-67(P)(A) Revision 1	"Generic Mechanical Design for Exxon Nuclear Jet Pump BWR Reload Fuel," Exxon Nuclear Company, September 1986
XN-NF-85-92(P)(A)	"Exxon Nuclear Uranium Dioxide/Gadolinia Irradiation Examination and Thermal Conductivity Results," Exxon Nuclear Company, November 1986
ANF-89-98(P)(A) Revision 1 and Supplement 1	"Generic Mechanical Design Criteria for BWR Fuel Designs," Advanced Nuclear Fuels Corporation, May 1995
ANF-90-82(P)(A) Revision 1	"Application of ANF Design Methodology for Fuel Assembly Reconstitution," Advanced Nuclear Fuels Corporation, May 1995
EMF-93-177(P)(A) Revision 1	"Mechanical Design for BWR Fuel Channels," Framatome ANP, August 2005
EMF-93-177P-A Revision 1 Supplement 1P-A Revision 0	"Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs," AREVA Inc., September 2013
BAW-10247PA Revision 0	"Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors," AREVA NP, April 2008
XN-NF-80-19(P)(A) Volume 1 and Supplements 1 and 2	"Exxon Nuclear Methodology for Boiling Water Reactors - Neutronic Methods for Design and Analysis," Exxon Nuclear Company, March 1983
XN-NF-80-19(P)(A) Volume 4 Revision 1	"Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads," Exxon Nuclear Company, June 1986
EMF-CC-074(P)(A) Volume 1	"STAIF - A Computer Program for BWR Stability Analysis in the Frequency Domain," and Volume 2 "STAIF - A Computer Program for BWR Stability Analysis in the Frequency Domain - Code Qualification Report," Siemens Power Corporation, July 1994
EMF-2158(P)(A) Revision 0	"Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2," Siemens Power Corporation, October 1999
EMF-CC-074(P)(A) Volume 4, Revision 0	"BWR Stability Analysis Assessment of STAIF with Input from MICROBURN-B2," Siemens Power Corporation, August 2000

Table 2-1 Framatome Licensing Topical Reports *(Continued)*

Document Number	Document Title
BAW-10255PA Revision 2	"Cycle-Specific DIVOM Methodology Using the RAMONA5-FA Code," AREVA NP, May 2008
EMF-3028P-A Volume 2 Revision 4	"RAMONA5-FA: A Computer Program for BWR Transient Analysis in the Time Domain Volume 2: Theory Manual," AREVA NP, March, 2013
XN-NF-79-59(P)(A)	"Methodology for Calculation of Pressure Drop in BWR Fuel Assemblies," Exxon Nuclear Company, November 1983
XN-NF-80-19(P)(A) Volume 3 Revision 2	"Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description," Exxon Nuclear Company, January 1987
ANP-10298PA Revision 1	"ACE/ATRIUM 10XM Critical Power Correlation," AREVA, March 2014
ANP-10307PA Revision 0	"AREVA MCPR Safety Limit Methodology for Boiling Water Reactors," AREVA NP, June 2011
XN-NF-84-105(P)(A) Volume 1 and Volume 1 Supplements 1 and 2	"X-COBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis," Exxon Nuclear Company, February 1987
EMF-2292(P)(A) Revision 0	"ATRIUM™-10: Appendix K Spray Heat Transfer Coefficients," Siemens Power Corporation, September 2000
ANF-1358(P)(A) Revision 3	"The Loss of Feedwater Heating Transient in Boiling Water Reactors," Framatome ANP, September 2005
BAW-10247PA, Supplement 1P-A, Revision 0	"Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 1: Qualification of RODEX4 for Recrystallized Zircaloy-2 Cladding"
BAW-10247P-A, Supplement 2P-A, Revision 0	Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods
ANP-10340PA Revision 0	Incorporation of Chromium-Doped Fuel in AREVA Approved Methods
ANP-10335P-A Revision 0	ACE/ATRIUM 11 Critical Power Correlation

Framatome Inc.

ANP-3705NP
Revision 0Applicability of Framatome BWR Methods to
Brunswick with ATRIUM 11 Fuel

Page 2-4

Table 2-1 Framatome Licensing Topical Reports *(Continued)*

Document Number	Document Title
ANP-10300P-A Revision 0	AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios
ANP-10332P Revision 0 and Draft Safety Evaluation	AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios
ANP-10333P-A Revision 0	AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident Scenarios

3.0 ATRIUM 11 FUEL ASSEMBLY DESIGN

The ATRIUM 11 fuel assembly design consists of a lower tie plate (LTP) and upper tie plate (UTP), 112 fuel rods, 9 spacer grids, a central water channel, and miscellaneous assembly hardware.

The fuel design utilizes a square internal water channel which occupies nine (3x3) lattice positions. The upper and lower ends of the water channel are attached to connecting hardware which provides a load chain between the upper and lower tie plates.

The 11x11 rod array is comprised of 92 full length fuel rods, 8 long part length fuel rods (PLFR) and 12 short PLFRs. The PLFRs are captured in the LTP grid to prevent axial movement.

The fuel rod pitch is slightly larger in the upper section of the assembly relative to the fuel rod pitch in the lower section of the assembly. The array of fuel rods remain orthogonal throughout the assembly.

The nine ULTRAFLOW™ spacers are fabricated from Alloy 718 material and utilize integrated spring and dimple elements. Eight spacers are axially distributed over the heated length, while a ninth spacer is located just above the LTP to restrain the lower ends of the fuel rods.

The fuel assembly design reflects improvements to keep debris out of the fuel assembly. The LTP and UTP designs are now modular to take advantage of optimized components within those major component assemblies. The UTP has a spacer-like grid construction that provides a lower pressure drop and closed openings where larger debris could enter the top of the fuel assembly. The LTP utilizes the 3rd Generation FUELGUARD™ (3GFG) filter insert that is captured within a two piece assembly of frame and transition piece. The inlet region of the transition piece can be configured to provide similar pressure drop characteristics of co-resident fuel designs.

The new fuel channel uses the Advanced Fuel Channel (AFC) design configuration.

This design has exterior machining between the corners and for ATRIUM 11, introduces additional interior milling of the []. This provides additional []. To address channel bow, the desired and default material is []

]

Table 3-1 Fuel Assembly and Component Description

Table 3-2 Fuel Channel and Fastener Description

4.0 MECHANICAL LIMITS METHODOLOGY

The LHGR limit is established to support plant operation while satisfying the fuel mechanical design criteria. The methodology for performing the fuel rod evaluation is described in References 4 through 6. The extension of these methods to fuel incorporating chromia is described in Reference 7. Fuel rod design criteria evaluated by the methodology are contained in References 4 and 13.

Fuel rod power histories are generated as part of the methodology for equilibrium cycle conditions as well as cycle-specific operation. These power histories include the impact of channel bow as described in Reference 4. A comprehensive number of uncertainties are taken into account in the categories of operating power uncertainties, code model parameter uncertainties, and fuel manufacturing tolerances. In addition, adjustments are made to the power history inputs for possible differences in planned versus actual operation. Upper limits on the analysis results are obtained for comparison to the design limits for fuel melt, cladding strain, rod internal pressure and other topics as described by the design criteria.

Since the power history inputs, which include LHGR, fast neutron flux, reactor coolant pressure and reactor coolant temperature, are used as input to the analysis, the results explicitly account for conditions representative of the ATRIUM 11 operation. The resulting LHGR limit is used to monitor the fuel so it is maintained within the same maximum allowable steady-state power envelope as analyzed.

5.0 THERMAL HYDRAULICS

5.1 ATRIUM 11 Void Fraction

The [] void-quality correlation has been qualified by Framatome against both the FRIGG void measurements, ATRIUM-10 and ATRIUM 10XM measurements. A discussion can be found in Appendix B of Reference 1 on the applicability of the [] correlation.

The ATRIUM 11 [] void fraction measurements. The [] correlation was assessed against previous measurements based upon fundamental hydraulic characteristics. The Marviken assembly of FRIGG had a 2-sigma error of [] in void prediction. The ATRIUM-10 has a 2-sigma error of [] for void. []; therefore, the use of a 2-sigma error of [] is justified for the ATRIUM 11.

5.2 ACE/ATRIUM 11 Critical Power Ratio Correlation

The critical power ratio (CPR) correlation used in MICROBURN-B2, SAFLIM3D, S-RELAP5, RAMONA5-FA, X-COBRA, and X-COBRA-T is based on the ACE/ATRIUM 11 critical power correlation described in Reference 8. As with all Framatome correlations, the range of applicability is enforced in Framatome methods through automated bounds checking and corrective actions. The ATRIUM 11 bounds checking process is the same as the ATRIUM 10XM as provided in Table 5-1. The ACE CPR correlation uses K-factor values to account for rod local peaking, rod location and bundle geometry effects.

The K-factor parameter is described in detail in Section 6.10 of Reference 8.

The ranges of applicability of the ACE/ATRIUM 11 and ACE/ATRIUM 10XM are compared in Table 5-2

Table 5-1 ACE/ATRIUM 10XM Bounds Checking

**Table 5-2 Comparison of the Range of Applicability for the ATRIUM 11 and
ATRIUM 10XM Correlations**

* The information on the ACE/ATRIUM 10XM correlation is provided in this document for the purpose of comparison to the ACE/ATRIUM 11 correlation only. Reference 8 should not be used for any licensed application of the ACE/ATRIUM 10XM correlation. For Information Only

5.3 *Loss Coefficients*

Wall friction and component loss coefficients were determined for Brunswick based on single-phase testing of a prototypic ATRIUM 11 fuel assembly in the Portable Hydraulic Test Facility (PHTF). Prototypical fuel rods, spacer grids, flow channel, upper tie plate and lower tie plate were used in the testing. A description of the PHTF facility and an overview of the process for determining the component loss coefficients are described in Reference 14.

The ATRIUM 11 PHTF tests form the basis for the single phase loss coefficients currently used for design and licensing analyses supporting U.S. BWRs. The PHTF is used by Framatome to obtain single phase loss coefficients for the spacers. The friction factor correlation is a Reynolds dependent function based on the Moody friction model and the measured surface roughness. The pressure drops across the spacers are measured in the PHTF for each new design. [

]

The wall friction and component loss coefficients determined from the PHTF and utilized in Brunswick for the ATRIUM 11 fuel design are provided in Table 5-3.

PHTF data was reduced to determine single phase losses for the spacers in the [

] of the bundle. The values have been selected because they are representative of the hydraulic characteristics of actual ATRIUM 11 fuel assemblies loaded into the reactor.

The modeling of the two-phase spacer pressure drop multiplier for the ATRIUM 11 fuel design has been confirmed with two-phase pressure drop measurements taken in the KATHY facility.

Figure 5-1 shows measured versus the MICROBURN-B2 predicted two phase pressure drop for a range of conditions. This figure confirms the applicability of the thermal-hydraulic models to predict pressure drop for the ATRIUM 11 design.

**Table 5-3 Hydraulic Characteristics
of ATRIUM 11 Fuel Assemblies**

* Loss coefficients are referenced to the adjacent assembly bare rod flow area.

† [

]

Framatome Inc.

ANP-3705NP
Revision 0
ERRATA 1NP-000

Applicability of Framatome BWR Methods to
Brunswick with ATRIUM 11 Fuel

Page 5-6



**Figure 5-1 Measured versus Predicted (MICROBURN-B2) Bundle
Pressure Drop**

6.0 TRANSIENTS AND ACCIDENTS

6.1 *Void Quality Correlation Uncertainties*

The Framatome analyses methods and the correlations used are applicable for all Framatome designs in EPU conditions. The approach for addressing the void-quality correlation bias and uncertainties remains unchanged and is applicable for Brunswick operation with the ATRIUM 11 fuel design.

The OLMCPR is determined based on the safety limit MCPR (SLMCPR) methodology and the transient analysis (Δ CPR) methodology. Void-quality correlation uncertainty is not a direct input to either of these methodologies; however, the impact of void-correlation uncertainty is inherently incorporated in both methodologies as discussed below.

The SLMCPR methodology explicitly considers important uncertainties in the Monte Carlo calculation performed to determine the number of rods in boiling transition. One of the uncertainties considered in the SLMCPR methodology is the bundle power uncertainty. This uncertainty is determined through comparison of calculated to measured core power distributions. Any miscalculation of void conditions will increase the error between the calculated and measured power distributions and be reflected in the bundle power uncertainty. Therefore, void-quality correlation uncertainty is an inherent component of the bundle power uncertainty used in the SLMCPR methodology.

The transient analyses methodology is a combination of deterministic, bounding analyses and a statistical evaluation of the impact of model uncertainties that contains conservatism in addition to uncertainties in individual phenomena. Conservatism is incorporated in the methodology in two ways: (1) computer code models are developed to produce conservative results on an integral basis relative to benchmark tests, and (2) important input parameters are biased in a conservative direction in licensing calculations.

The transient analyses methodology results in predicted power increases that are bounding relative to benchmark tests. In addition, for licensing calculations a multiplier is applied to the calculated integral power to provide additional conservatism to account for uncertainties in individual phenomena as defined in the transient analyses methodology. Therefore, uncertainty in the void-quality correlation is inherently incorporated in the transient analysis methodology.

In addition to the impact of void-quality correlation uncertainty being inherently incorporated in the analytical methods used to determine the OLMCPR, biasing of important input parameters in licensing calculations provides additional conservatism in establishing the OLMCPR. No additional adjustments to the OLMCPR are required to address void-quality correlation uncertainty.

6.2 *Assessment of the Void-Quality Correlation*

As discussed in Section 5.1, the [] is equally applicable to the ATRIUM 11 applications at Brunswick.

7.0 ATWS

7.1 ATWS General

The AURORA-B methodology is used for the ATWS overpressurization analysis. The ACE/ATRIUM 11 critical power correlation pressure limit is not a factor in the analysis.

Dryout might occur in the limiting (high power) channels of the core during the ATWS event. For the ATWS overpressurization analysis, ignoring dryout for the hot channels is conservative in that it maximizes the heat transferred to the coolant and results in a higher calculated pressure.

The ATWS event is not limiting relative to acceptance criteria identified in 10 CFR 50.46. The core remains covered and adequately cooled during the event. Following the initial power increase during the pressurization phase, the core returns to natural circulation conditions after the recirculation pumps trip and fuel cladding temperatures are maintained at acceptable low levels. The ATWS event is significantly less limiting than the loss of coolant accident relative to 10 CFR 50.46 acceptance criteria.

7.2 Void Quality Correlation Bias

Framatome performs cycle-specific ATWS analyses of the short-term reactor vessel peak pressure using the AURORA-B methodology. The ATWS peak pressure calculation is a core-wide pressurization event that is sensitive to similar phenomenon as other pressurization transients. Bundle design is included in the development of input for the coupled neutronic and thermal-hydraulic S-RELAP5 core model. Important inputs to the S-RELAP5 system model are biased in a conservative direction.

The Framatome transient analysis methodology is a deterministic, bounding approach that contains sufficient conservatism and evaluates uncertainties in individual phenomena. As demonstrated in Section 5.1 the void-quality correlation is robust for past and present designs including the ATRIUM 11.

The reference ATWS analysis evaluation presented in the topical report (Reference 2) of the core active density response, which is closely related to the void quality correlation, showed minimal changes in the peak vessel pressure. A study was also performed for the ASME overpressure event (FWCF) with similar results.

7.3 *ATWS Containment Heatup*

Fuel design differences may impact the power and pressure excursion experienced during the ATWS event. This in turn may impact the amount of steam discharged to the suppression pool and containment.

[

]

[
]

Table 7-1 [
]

* Boron worth is quoted as a positive value since it refers to the boron defect. The ppm boron used is 720 at 68 F. The calculation uses the equivalent boron at 360.8 F, used in BRK SLCS calculations.

8.0 NEUTRONICS

From the neutronics perspective, the ATRIUM 11 fuel design differs from the ATRIUM-10XM fuel design primarily in the fuel rod pitch and position and number of the part length rods. The CASMO-4 code is designed to model a wide range of fuel rod pitches. The neutronic models have already been demonstrated to accurately model the vacant positions and this continues to be true for the ATRIUM 11 fuel design.

8.1 *Shutdown Margin*

The part length rod in the corner of the assembly improves the shutdown margin performance of the fuel design because of the flux trap that is created in the cold condition with the vacant rod position of all four assemblies in a control cell being in close proximity. The heterogeneous solution of CASMO-4 accurately models the vacant rod position and the associated reactivity. No change in predicted hot operating or cold critical eigenvalue is anticipated with the ATRIUM 11 fuel design.

8.2 *Monitoring*

The part length rod in the corner of the assembly has an impact on the corner flux that influences the detector response. The heterogeneous solution of CASMO-4 accurately calculates this corner flux depression. This characterization is used directly in the MICROBURN-B2 determination of the predicted detector response. For the Brunswick analyses the plena have been explicitly modeled with the heterogeneous CASMO-4 model, thus providing the most accurate model available.

8.3 *Power Distribution Uncertainty*

No significant change in the uncertainty of the predicted detector response relative to the measurements is anticipated.

8.4 *Bypass modeling*

The bypass behavior of the ATRIUM 11 fuel design is identical to the ATRIUM-10XM fuel design, thus there is no difference in the modeling. Any differences in bypass heat deposition are treated explicitly.

9.0 REFERENCES

1. ANP-3108P Revision 1, "Applicability of AREVA BWR Methods to Brunswick Extended Power Flow Operating Domain," AREVA Inc., July 2015.
2. ANP-10300P-A Revision 1, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios," Framatome Inc., January 2018.
3. ANP-10333P-A Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA) ," Framatome Inc., March 2018
4. BAW-10247PA Revision 0, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, " AREVA NP Inc., February 2008.
5. BAW-10247PA Revision 0 Supplement 1P-A, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 1: Qualification of RODEX4 for Recrystallized Zircaloy-2 Cladding," AREVA Inc., April 2017.
6. BAW-10247 Supplement 2P-A, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors Supplement 2: Mechanical Methods," Framatome Inc., August 2018.
7. ANP-10340PA Revision 0, "Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods," Framatome Inc., May 2018.
8. ANP-10335P-A Revision 0, "ACE/ATRIUM 11 Critical Power Correlation," Framatome Inc., May 2018.
9. EMF-93-177P-A Revision 1 Supplement 1P-A Revision 0 "Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs," AREVA Inc., September 2013.
10. ANP-3686P Revision 0, "Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies," Framatome Inc., August 2018.
11. ANP-3674P&NP Revision 0, "Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel," Framatome Inc., August 2018.
12. ANP-3703P Revision 0, "Best Estimate Option-III Analysis Methodology for Brunswick Using RAMONA5-FA," Framatome Inc., August 2018.
13. ANF-89-98(P)(A) Revision 1 and Supplement 1, "Generic Mechanical Design Criteria for BWR Fuel Designs," Advanced Nuclear Fuels Corporation, May 1995.
14. I.K. Madni, et al., "Development of Correlations for Pressure Loss/Drop Coefficients Obtained From Flow Testing of Fuel Assemblies In Framatome ANP'S PHTF," Paper Number 22428, Proceedings of ICONE10, Arlington, VA, April 14-18,2002.

**Affidavit for ANP-3705P, Applicability of Framatome BWR
Methods to Brunswick with ATRIUM 11 Fuel**

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3705P, Revision 0 "Applicability of Framatome BWR Methods to Brunswick with ATRIUM 11 Fuel," dated September 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(a), 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

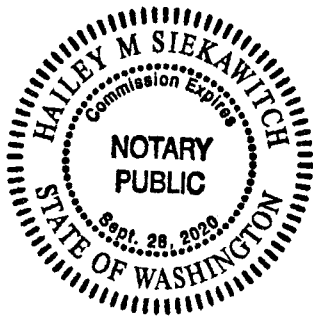
9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Ala G. May

SUBSCRIBED before me this 10th
day of September, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3686NP, Mechanical Design Report for Brunswick
ATRIUM 11 Fuel Assemblies



Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies

ANP-3686NP
Revision 0

Licensing Report

September 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

ATRIUM, FUELGUARD, ULTRAFLOW, and Z4B are trademarks or registered trademarks of Framatome or its affiliates, in the USA or other countries.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION.....	1
2.0 DESIGN DESCRIPTION.....	2
2.1 Overview	2
2.1.1 Fuel Assembly	3
2.1.2 Spacer Grid.....	4
2.1.3 Water Channel.....	4
2.1.4 Lower Tie Plate.....	5
2.1.5 Upper Tie Plate and Connecting Hardware	6
2.1.6 Fuel Rods	7
2.2 Fuel Channel and Components.....	7
3.0 FUEL DESIGN EVALUATION	11
3.1 Objectives.....	11
3.2 Fuel Rod Evaluation	12
3.3 Fuel System Evaluation.....	12
3.3.1 Stress, Strain, or Loading Limits on Assembly Components.....	13
3.3.2 Fatigue.....	13
3.3.3 Fretting Wear	14
3.3.4 Oxidation, Hydriding, and Crud Buildup.....	14
3.3.5 Rod Bow	15
3.3.6 Axial Irradiation Growth	15
3.3.7 Rod Internal Pressure.....	16
3.3.8 Assembly Lift-off	16
3.3.9 Fuel Assembly Handling	17
3.3.10 Miscellaneous Component Criteria.....	18
3.4 Fuel Coolability.....	19
3.4.1 Cladding Embrittlement	19
3.4.2 Violent Expulsion of Fuel	19
3.4.3 Fuel Ballooning	19
3.4.4 Structural Deformations	19
3.5 Fuel Channel and Components.....	23
3.5.1 Design Criteria for Normal Operation	24
3.5.2 Design Criteria for Accident Conditions	25
4.0 REFERENCES.....	31

Appendices

Appendix A: Illustrations	32

Tables

Table 2-1 Fuel Assembly and Component Description.....	8
Table 2-2 Fuel Channel and Channel Spacer Assembly Description	10
Table 3-1 Results for ATRIUM 11 Fuel Assembly	27
Table 3-2 Results for ATRIUM 11 Advanced Fuel Channel	29

Figures

Figure A-1 ATRIUM 11 Fuel Assembly	33
Figure A-2 UTP with Locking Hardware.....	34
Figure A-3 3 rd Generation FUELGUARD LTP.....	35
Figure A-4 ATRIUM 11 ULTRAFLOW Spacer Grid	36
Figure A-5 Full and Part-Length Fuel Rods	37
Figure A-6 ATRIUM 11 Advanced Fuel Channel and Channel Spacer	38

Nomenclature

Acronym	Definition
AFC	Advanced fuel channel
AOO	Anticipated operational occurrences
ASME	American Society of Mechanical Engineers
B&PV	Boiler and pressure vessel
BQ	Beta-quench
BWR	Boiling water reactor
EOL	End of life
HALC	Harmonized advanced load chain
LTA	Lead test assembly
LOCA	Loss-of-coolant accident
LTP	Lower tie plate
MWd/kgU	Megawatt-days per kilogram of Uranium
NRC	U. S. Nuclear Regulatory Commission
PLFR	Part-length fuel rods
SRP	Standard review plan
UTP	Upper tie plate
Z4B	Proprietary Zircaloy BWR material similar to Zircaloy-4
Zry-4	Zircaloy-4
Zry-2	Zircaloy-2
3GFG	3 rd Generation FUELGUARD

1.0 INTRODUCTION

This report documents the successful completion of all licensing analyses and related testing necessary to verify that the mechanical design criteria are met for the ATRIUM™ 11 Fuel Assemblies supplied by Framatome Inc. (Framatome) for insertion into Brunswick Unit 1 Cycle 23 (BRK1-23). This report also provides a description of the mechanical design and licensing methods. The scope of this report is limited to an evaluation of the mechanical design of the fuel assembly and fuel channel.

The ATRIUM 11 design is a Framatome advanced BWR fuel design that builds on the history of proven ATRIUM family of fuel designs. The design uses an 11x11 fuel array, a [] fuel rod, a central water channel that displaces a 3x3 array of rods and is made from an advanced Zirconium alloy Z4B™ material, a modular lower tie plate with a 3rd generation FUELGUARD™ and nine ULTRAFLOW™ spacer grids [] .

The fuel assembly design was evaluated according to the Framatome boiling water reactor (BWR) generic mechanical design criteria (Reference 1). The fuel channel design was evaluated to the criteria given in the fuel channel topical reports (References 2 and 3). The generic design criteria have been approved by the U.S. Nuclear Regulatory Commission (NRC) and the criteria are applicable to the subject fuel assembly and channel design. Mechanical analyses have been performed using NRC-approved design analysis methodology (References 1, 2, 3 and 4). The methodology permits maximum licensed assembly and fuel channel exposures of [] (Reference 4, Section 1.0).

The fuel assembly and fuel channel meet all mechanical compatibility requirements for use in Brunswick Unit 1. This includes compatibility with both co-resident fuel and the reactor core internals.

2.0 DESIGN DESCRIPTION

This section provides a design description of the ATRIUM 11 fuel assembly and fuel channel. Reload-specific design information is available in the design package provided by Framatome for each reload delivery.

2.1 *Overview*

Brunswick has successfully operated for several cycles with reload quantities of ATRIUM-10 and ATRIUM 10XM fuel designs and ATRIUM 11 Lead Test Assemblies. Brunswick will operate with ATRIUM 11 Fuel Assemblies in reload quantities starting with Brunswick Unit 1 Cycle 23. The ATRIUM 11 bundle consists of an 11x11 fuel lattice with a square internal water channel that displaces a 3x3 array of rods.

The ATRIUM 11 incorporates the following key design features relative to the ATRIUM 10XM:



As compared to the 8 ATRIUM 11 Lead assemblies being reloaded into a Brunswick core, the ATRIUM 11 fuel assemblies delivered in reload quantities have a modified Harmonized Advanced Load Chain (HALC). [

].

Table 2-1 lists the key design parameters of the ATRIUM 11 fuel assembly.

2.1.1 Fuel Assembly

[

].

The fuel assembly is accompanied by a fuel channel, as described later in this section.

Table 2-1 lists the main fuel assembly attributes, and an illustration of the fuel bundle is provided in Appendix A, Figure A-1.

2.1.2 Spacer Grid

[

].

Table 2-1 lists the main spacer grid attributes, and an illustration of the spacer grid is provided in Appendix A, Figure A-4.

2.1.3 Water Channel

[

].

[

].

Table 2-1 lists the main water channel attributes, and an illustration of the water channel is provided in Appendix A.

2.1.4 Lower Tie Plate

[

].

Appendix A, Figure A-3 provides an illustration of the LTP.

2.1.5 Upper Tie Plate and Connecting Hardware

[

].

Appendix A, Figure A-2 provides an illustration of the UTP and locking components.

2.1.6 Fuel Rods

This mechanical design report documents the fuel structural analyses. The Brunswick fuel rod thermal-mechanical report provides fuel rod design description detail. Appendix A, Figure A-5, provides an illustration of the full-length and the two part-length fuel rods.

2.2 *Fuel Channel and Components*

[

].

Table 2-2 lists the fuel channel component attributes. The fuel channel and fuel channel spacer assembly are depicted in Appendix A, Figure A-6.

Table 2-1 Fuel Assembly and Component Description

Table 2-1 Fuel Assembly and Component Description
(Continued)

Table 2-2 Fuel Channel and Channel Spacer Assembly Description

3.0 FUEL DESIGN EVALUATION

A summary of the mechanical methodology and results from the structural design evaluations are provided in this section. Results from the mechanical design evaluation demonstrate that the design satisfies the mechanical criteria to the analyzed exposure limit. The following sections correspond to the criteria sections within Reference 1, Section 3.0 and Table 3-1.

3.1 Objectives

The objectives of designing fuel assemblies (systems) to specific criteria are to provide assurance that:

- The fuel assembly (system) shall not fail as a result of normal operation and anticipated operational occurrences (AOOs). The fuel assembly (system) dimensions shall be designed to remain within operational tolerances, and the functional capabilities of the fuel shall be established to either meet or exceed those assumed in the safety analysis.
- Fuel assembly (system) damage shall never prevent control rod insertion when it is required.
- The number of fuel rod failures shall be conservatively estimated for postulated accidents.
- Fuel coolability shall always be maintained.
- The mechanical design of fuel assemblies shall be compatible with co-resident fuel and the reactor core internals.
- Fuel assemblies shall be designed to withstand the loads from handling and shipping.

The first four objectives are those cited in the Standard Review Plan (SRP). The latter two objectives are to assure the structural integrity of the fuel and the compatibility with the existing reload fuel. To satisfy these objectives, the criteria are applied to the fuel rod and the fuel assembly (system) designs. Specific component criteria are also necessary to assure compliance. The criteria established to meet these objectives include those given in Chapter 4.2 of the SRP.

3.2 *Fuel Rod Evaluation*

The mechanical design report documents the fuel structural analyses only. The fuel rod evaluation will be documented in the Brunswick fuel rod thermal-mechanical report. However, the fuel rod mechanical fracturing (Reference 1, Section 3.2.7) is evaluated in Section 3.4.4 *Structural Deformations*.

3.3 *Fuel System Evaluation*

The detailed fuel system design evaluation is performed to ensure the structural integrity of the design under normal operation, AOO, faulted conditions, handling operations, and shipping. The analysis methods are based on fundamental mechanical engineering techniques, often employing finite element analysis, prototype testing, and correlations based on in-reactor performance data. Summaries of the major assessment topics and associated testing are described in the sections that follow.

Prototype testing is an essential element of Framatome's methodology for demonstrating compliance with structural design requirements. Results from design verification testing may directly demonstrate compliance with criteria or may be used as input to design analyses.

Testing performed to qualify the mechanical design or evaluate assembly characteristics includes:

- Fuel assembly axial load structural strength test
- Fuel assembly fretting test
- Fuel assembly static lateral deflection test
- Fuel assembly lateral vibration tests
- Fuel assembly impact tests
- Spacer grid lateral impact strength test
- Tie plate lateral load strength tests

3.3.1 Stress, Strain, or Loading Limits on Assembly Components

The structural integrity of the fuel assemblies is assured by setting design limits on stresses and deformations due to various handling, operational, and accident or faulted loads. Framatome uses Section III of the ASME B&PV Code as a guide to establish acceptable stress, deformation, and load limits for standard assembly components. These limits are applied to the design and evaluation of the UTP, LTP, spacer grids, springs, and load chain components, as applicable.

All significant loads experienced during normal operation, AOOs, and under faulted conditions are evaluated to confirm the structural integrity of the fuel assembly components. Outside of faulted conditions, most structural components are under the most limiting loading conditions during fuel handling. See Section 3.3.9 for a discussion of fuel handling loads and Section 3.4.4 for the structural evaluation of faulted conditions. Although normal operation and AOO loads are often not limiting for structural components, a stress evaluation may be performed to confirm the design margin and to establish a baseline for adding accident loads. The stress calculations use conventional, open-literature equations. A general-purpose, finite element stress analysis code, such as ANSYS, may be used to calculate component stresses.

See Table 3-1 for results from the component strength evaluations.

3.3.2 Fatigue

Section addressed in the fuel rod thermal-mechanical report.

3.3.3 Fretting Wear

Fuel rod failures due to grid-to-rod fretting shall not occur. [] .

Fretting wear is evaluated by testing, as described in Section 3.3.3.1. The testing is conducted by []

[] . The inspection measurements for wear are documented. The lack of significant wear demonstrates adequate rod restraint geometry at the contact locations. Also, the lack of significant wear at the spacer cell locations [] provides further assurance that no significant fretting will occur at higher exposure levels.

3.3.3.1 Fuel Assembly Fretting Test

A fretting test was conducted on a full-size test assembly to evaluate the ATRIUM 11 fuel rod support design. []

[] . After the test, the assembly was inspected for signs of fretting wear. No significant wear was found on fuel rods in contact with spacer springs []

[] . The results agree with past test results on BWR designs where no noticeable wear was found on the fuel rods or other interfacing components following exposure to coolant flow conditions.

3.3.4 Oxidation, Hydriding, and Crud Buildup

Section addressed in the fuel rod thermal-mechanical report.

3.3.5 Rod Bow

The predicted rod-to-rod gap closure due to bow is assessed by thermal hydraulics group for impact on thermal margins.

Differential expansion between the fuel rods and cage structure, and lateral thermal and flux gradients can lead to lateral creep bow of the rods in the spans between spacer grids. This lateral creep bow alters the pitch between the rods and may affect the peaking and local heat transfer. The Framatome design criterion for fuel rod bowing is [

].

Visual exams on ATRIUM 11 have not revealed any unusual fuel rod bow behavior for exposures up to 35 MWd/kgU based on the latest experience from Lead Test Assembly post-irradiation exams. This exposure is beyond the threshold where increasing rod bow had been observed on other designs. Therefore, ATRIUM 11 has been shown to have minimal rod bow which can be conservatively bound with the new rod-to-rod gap closure correlation given in Reference 4.

3.3.6 Axial Irradiation Growth

Reference 4 requires [

].

[

].

The fuel rod growth correlation was established from [

]

[
].

Assembly growth was established from ATRIUM-10x10 and 11x11 arrayed fuel assemblies with water channels made of Zry-4 and Z4B. It is based on the ATRIUM type fuel assembly growth data only and excludes designs with load bearing tie rods as well as the European bundle-in-basket designs. [

]. The assembly and fuel rod growth approved correlations are described within Reference 4 along with the respective tolerance limits.

3.3.7 Rod Internal Pressure

Section addressed in the fuel rod thermal-mechanical report.

3.3.8 Assembly Lift-off

Fuel assembly lift-off is evaluated under both normal operating conditions (including AOOs) and under faulted conditions. The fuel shall not levitate under normal operating or AOO conditions. Under postulated accident conditions, the fuel shall not become disengaged from the fuel support. These criteria assure control blade insertion is not impaired. Additionally, Brunswick meets a more stringent requirement of no liftoff under applicable plant licensing basis accident conditions.

For normal operating conditions, the net axial force acting on the fuel assembly is calculated by adding the loads from gravity, hydraulic resistance from coolant flow, difference in fluid flow entrance and exit momentum, and buoyancy. The calculated net force is confirmed to be in the downward direction, indicating no assembly lift-off. [

].

Mixed core conditions for assembly lift-off are considered on a cycle-specific basis, as determined by the plant and other fuel types. Analyses to date indicate a large margin to assembly lift-off under normal operating conditions. Therefore, fuel lift-off in BWRs under normal operating conditions is considered to be a small concern.

For faulted conditions, [

] . The fuel will not lift and it will not become disengaged from the fuel support nor block insertion of the control blade in all operating conditions.

3.3.9 Fuel Assembly Handling

The fuel assembly shall withstand, without permanent deformation, all normal axial loads from shipping and fuel handling operations. Analysis or testing shall show that the fuel is capable of

[

].

The fuel assembly structural components are assessed for axial fuel handling loads by analysis and testing. To demonstrate compliance with the criteria, the test or analysis are performed by loading a test assembly or the individual components of the load chain to an axial tensile force greater than [] (Reference 1, Section 3.3.9). An acceptable test or analysis shows no yielding after loading.

There are also handling requirements for the fuel rod plenum spring which are addressed in the Brunswick fuel rod thermal-mechanical report.

3.3.9.1 Fuel Assembly Axial Load Tests

Each test is used in support of analytical or Finite Element Analysis to demonstrate that no significant permanent deformation occurs for loads [

].

Descriptions of tests:

3.3.10 Miscellaneous Component Criteria

3.3.10.1 Compression Spring Forces

The ATRIUM 11 has a single large compression spring mounted on the central water channel. The compression spring serves the same function as previous designs by providing support for the UTP and fuel channel. The spring force is calculated based on the deflection and specified spring force requirements. Irradiation-induced relaxation is taken into account for EOL conditions. The minimum compression spring force at EOL is shown to be greater than the combined weight of the UTP assembly and fuel channel assembly and screws. Since the compression spring does not interact with the fuel rods, no consideration is required for fuel rod buckling loads.

3.3.10.2 LTP Seal Spring

The LTP seal spring shall limit the bypass coolant leakage rate between the LTP and fuel channel. The seal spring shall accommodate expected channel deformation while remaining in contact with the fuel channel. Also, the seal spring shall have adequate corrosion resistance and be able to withstand the operating stresses without yielding.

Flow testing is used to confirm acceptable bypass flow characteristics. The seal spring is designed with adequate deflection to accommodate the maximum expected channel bulge while maintaining acceptable bypass flow. [] is selected as the material because of its high strength at elevated temperature and its excellent corrosion resistance. Seal spring stresses are analyzed using a finite element method.

3.4 Fuel Coolability

For accidents in which severe fuel damage might occur, core coolability and the capability to insert control blades are essential. Chapter 4.2 of the SRP provides several specific areas important to fuel coolability, as discussed below.

3.4.1 Cladding Embrittlement

This evaluation is not part of the mechanical design analysis.

3.4.2 Violent Expulsion of Fuel

This evaluation is not part of the mechanical design analysis.

3.4.3 Fuel Ballooning

This evaluation is not part of the mechanical design analysis.

3.4.4 Structural Deformations

Deformations or stresses from postulated accidents are limited according to requirements contained in the ASME B&PV Code, Section III, Division 1, Appendix F, and SRP Section 4.2, Appendix A. The limits for each ATRIUM 11 structural component are derived from analyses and/or component load tests.

The methodology for analyzing the fuel under the influence of accident loads is described in the Mechanical Designs for BWR Fuel channels Topical Report Reference 2. Evaluations performed for the fuel under accident conditions include [

]. Assembly liftoff under accident conditions is described in Section 3.3.8.

Fuel assemblies are tested with and without a fuel channel as described in Reference 2, Appendix C. Testing is performed to obtain the dynamic characteristics of the fuel assembly and spacer grids. The stiffness, natural frequencies and damping values derived from the tests are used as inputs for analytical models of the fuel assembly and fuel channel. In general, the testing and analyses have shown the dynamic response of ATRIUM 11 to be similar to ATRIUM 10XM.

[

].

Therefore, the introduction of ATRIUM 11 fuel does not impact RPV and internals margin evaluations previously performed for introduction of ATRIUM-10.

3.4.4.1 Fuel Assembly Static Lateral Deflection Test

A lateral deflection test was performed to determine the fuel assembly stiffness, both with and without the fuel channel. The stiffness is obtained by supporting the fuel assembly at the two ends in a vertical position, applying a side displacement at the central spacer location, and measuring the corresponding force.

3.4.4.2 Fuel Assembly Lateral Vibration Tests

The lateral vibration testing consists of both a free vibration test and a forced vibration test

[] .

The test setup for the free vibration test [

] .

The forced vibration testing [

] .

3.4.4.3 Fuel Assembly Impact Tests

Impact testing was performed in a similar manner to the lateral deflection tests. The unchanneled assembly is supported in a vertical position with both ends fixed. The assembly is displaced a specified amount and then released. [

].

3.4.4.4 Spacer Grid Lateral Impact Strength Test

Spacer grid impact strength was determined by a [

].

The maximum force prior to the onset of buckling was determined from the testing. The results were adjusted to reactor operating temperature conditions to establish an allowable lateral load per Reference 1, Section 3.3.1.

3.4.4.5 Tie Plate Strength Tests

In addition to the axial tensile tests described in Section 3.3.9.1, a lateral load test is performed on the UTP and LTP.

The UTP lateral load test was conducted on a test machine which applied [] . This provides a limiting lateral load for accident conditions.

To determine a limiting lateral load for accident conditions for the 3GFG LTP, a lateral load test was conducted by attaching the grid of the tie plate to a rigid vertical plate [] .

The results were adjusted to reactor operating temperature conditions to establish an allowable lateral load per Reference 1, Section 3.3.1.

3.4.4.6 Fuel Storage Seismic Qualification

The High Density Spent Fuel Storage Racks (HDSFSR), New Fuel Storage (NFS), and the Fuel Preparation Machine (FPM) analyses account for the fuel as added mass in calculating the structural integrity under postulated seismic loads. The existing analyses take into account fuel designs with weights encompassing the weight of the ATRIUM 11 fuel design. Therefore, the HDSFSR, NFS, and FPM remain qualified with the introduction of the ATRIUM 11 fuel design.

3.5 Fuel Channel and Components

The fuel channel and channel spacer assembly design criteria are summarized below, and evaluation results are summarized in Table 3-2. The analysis methods are described in detail in Reference 2.

3.5.1 Design Criteria for Normal Operation

Steady-State Stress Limits. The stress limits during normal operation are obtained from the ASME B&PV Code, Section III, Division 1, Subsection NG for Service Level A. The calculated stress intensities are due to the differential pressure across the channel wall. The pressure loading includes the normal operating pressure plus the increase during AOO. The unirradiated properties of the fuel channel material are used since the yield and ultimate tensile strength increase during irradiation (Reference 6).

As an alternative to the elastic analysis stress intensity limits, a plastic analysis may be performed as permitted by paragraph NB-3228.3 of the ASME B&PV Code.

In the case of AOOs, the amount of bulging is limited to that value which will permit control blade movement. During normal operation, any significant permanent deformation due to yielding is precluded by restricting the maximum stresses at the inner and outer faces of the channel to be less than the yield strength.

Fuel Channel Fatigue. Cyclic changes in power and flow during operation impose a duty loading on the fuel channel. The cyclic duty from pressure fluctuations is limited to less than the fatigue lifetime of the fuel channel. The fatigue life is based on the O'Donnell and Langer curve (Reference 5), which includes a factor of 2 on stress amplitude or a factor of 20 on the number of cycles, whichever is more conservative.

Oxidation and Hydrogen Concentration. Oxidation reduces the material thickness and results in less load-carrying capacity. The fuel channels have thicker walls than other components (e.g., fuel rods), and the normal amounts of oxidation and hydrogen pickup are not limiting provided: the alloy composition and impurity limits are carefully selected; the heat treatments are also carefully chosen; and the water chemistry is controlled. [

].

Long-Term Creep Deformation. Changes to the geometry of the fuel channel occur due to creep deformation during the long term exposure in the reactor core environment. Overall deformation of the fuel channel occurs from a combination of bulging and bowing. Bulging of the side walls occurs because of the differential pressure across the wall. Lateral bowing of the channel is caused primarily from the neutron flux and thermal gradients. Too much deflection may prevent normal control blade maneuvers and it may increase control blade insertion time above the Technical Specification limits. The total channel deformation must not stop free movement of the control blade. [

].

3.5.2 Design Criteria for Accident Conditions

Fuel Channel Stresses and Limit Load. The criteria are based on the ASME B&PV Code, Section III, Appendix F, for faulted conditions (Service Level D). Component support criteria for elastic system analysis are used as defined in paragraphs F-1332.1 and F-1332.2. The unirradiated properties of the fuel channel material are used since the yield and ultimate tensile strength increase during irradiation (Reference 6).

[

].

The amount of bulging remains limited to that value which will permit control blade insertion.

Channel Bending from Combined Horizontal Excitations. []

Framatome Inc.

ANP-3686NP

Revision 0

Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies

Licensing Report

Page 26

[

].

Fuel Channel Gusset Load Rating. [

].

Table 3-1 Results for ATRIUM 11 Fuel Assembly

Criteria Section	Description	Criteria	Results
ANF-89-98(P)(A) (Reference 1) Associated Mechanical Design Criteria Sections			
3.3	Fuel System Criteria		
3.3.1	Stress, strain and loading limits on assembly components	The ASME B&PV Code Section III is used to establish acceptable stress levels or load limits for assembly structural components. The design limits for accident conditions are derived from Appendix F of Section III.	[] .
3.3.3	Fretting wear	[]	[] .
3.3.5	Rod bow	Protect thermal limits	[]
3.3.6	Axial irradiation growth Upper end cap clearance	Clearance always exists	[]
3.3.8	Assembly liftoff Normal operation (including AOOs) Postulated accident	No liftoff from fuel support No disengagement from fuel support	[] [] .

Table 3-1 Results for ATRIUM 11 Fuel Assembly (Continued)

Criteria Section	Description	Criteria	Results
3.3	Fuel System Criteria (Continued)		
3.3.9	Fuel assembly handling	[]	Verified by testing and Analyses to meet requirement
3.3.10	Miscellaneous components		
3.3.10.1	Compression spring forces		The design criteria are met
3.3.10.2	LTP seal spring		The design criteria are met
3.4	Fuel Coolability		
3.4.4	Structural deformations	Maintain coolable geometry and ability to insert control blades. SRP 4.2, App. A, and ASME Section III, App. F.	[]

Table 3-2 Results for ATRIUM 11 Advanced Fuel Channel

Criteria Section	Description	Criteria	Results
<i>EMF-93-177(P)(A) (Reference 2) Associated Fuel Channel (FC) Criteria Sections</i>			
FC 3.2	ATRIUM 11 Advanced Fuel Channel – Normal Operation		
FC 3.2.1	Stress due to pressure differential	The pressure load including AOO is limited to [] according to ASME B&PV Code, Section III. The pressure load is also limited such that [] .	The deformation during AOO remains within functional limits for normal control blade operation and the [] is met. There is no significant plastic deformation.
FC 3.2.2	Fatigue	Cumulative cyclic loading to be less than the design cyclic fatigue life for Zircaloy.	Expected number of cycles is less than allowable
FC 3.2.3	Oxidation and hydriding	Oxidation shall be accounted for in the stress and fatigue analyses	The maximum expected oxidation is low in relation to the wall thickness. Oxidation was accounted for in the stress and fatigue analyses.
FC 7.0	Long-term deformation (bulge creep and bow)	Bulge and bow shall not interfere with free movement of the control blade	Margin to a stuck control blade remains positive

Table 3-2 Results for ATRIUM 11 Advanced Fuel Channel (Continued)

Criteria Section	Description	Criteria	Results
FC 3.3	ATRIUM 11 Advanced Fuel Channel – Accident Conditions		
FC 3.3.1	Fuel channel stresses and load limit and vertical accelerations	The pressure load is limited to []. The pressure load is also limited such that [].	The deformation during blowdown does not interfere with control blade insertion. This also satisfies the less restrictive [].
FC 3.3.1 (continued)	Channel bending from combined horizontal excitations	Allowable bending moment based on ASME Code, Section III, Appendix F [].	[]
FC 3.3.2	Fuel channel gusset strength	Vertical load must be less than ASME allowable load rating based on testing.	[]

4.0 REFERENCES

1. ANF-89-98(P)(A) Revision 1 and Supplement 1, "Generic Mechanical Design Criteria for BWR Fuel Designs," Advanced Nuclear Fuels Corporation, May 1995.
2. EMF-93-177(P)(A) Revision 1, "Mechanical Design for BWR Fuel Channels," Framatome ANP Inc., August 2005.
3. EMF-93-177P-A Revision 1, Supplement 1P-A, Revision 0, "Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs," AREVA NP Inc., September 2013.
4. BAW-10247P-A Supplement 2P-A Revision 0, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Supplement 2: Mechanical Methods," Framatome Inc., August 2018.
5. W. J. O'Donnell and B. F. Langer, "Fatigue Design Basis for Zircaloy Components," Nuclear Science and Engineering, Volume 20, January 1964.
6. Huan, P. Y., Mahmood, S. T., and Adamson, R. B. "Effects of Thermomechanical Processing on In-Reactor Corrosion and Post-Irradiation Properties of Zircaloy-2," *Zirconium in the Nuclear Industry: Eleventh International Symposium*, ASTM STP 1295, E. R. Bradley and G. P. Sabol, Eds., American Society for Testing and Materials, 1996, pp. 726-757.
7. ANF-10336P-A Revision 0, "Z4B™ Fuel Channel Irradiation Program," AREVA Inc., July 2017.

Appendix A: Illustrations

The following table lists the fuel assembly and fuel channel component illustrations in this section:

Description	Page
ATRIUM 11 Fuel Assembly	33
UTP with Locking Hardware	34
3 rd Generation FUELGUARD LTP	35
ATRIUM 11 ULTRAFLOW Spacer Grid	36
Full and Part-Length Fuel Rods	37
ATRIUM 11 Advanced Fuel Channel and Channel Spacer	38

These illustrations are for descriptive purpose only. Please refer to the current reload design package for product dimensions and specifications.

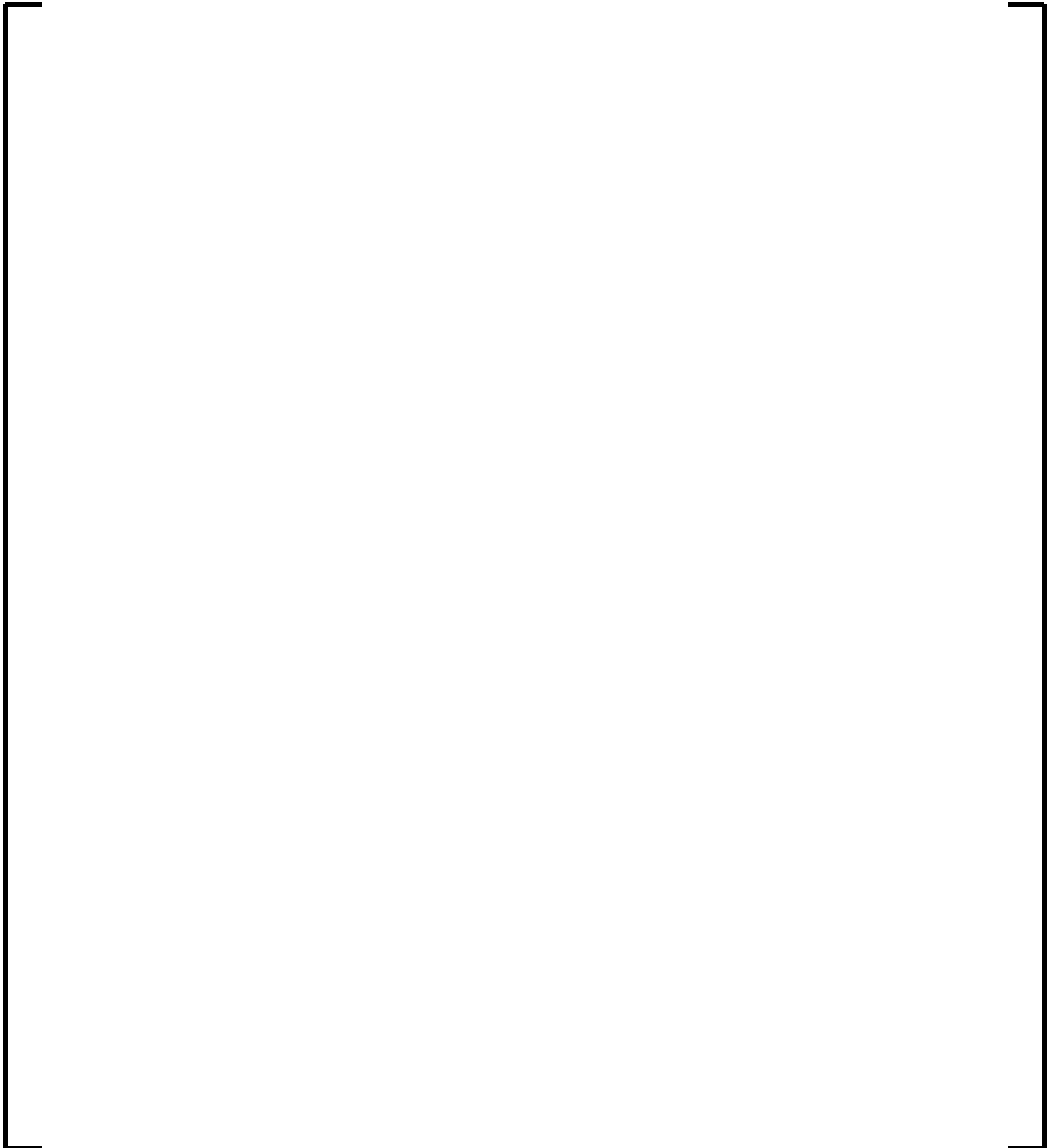


Figure A-1 ATRIUM 11 Fuel Assembly
(not to scale)

Figure A-2 UTP with Locking Hardware
(not to scale)

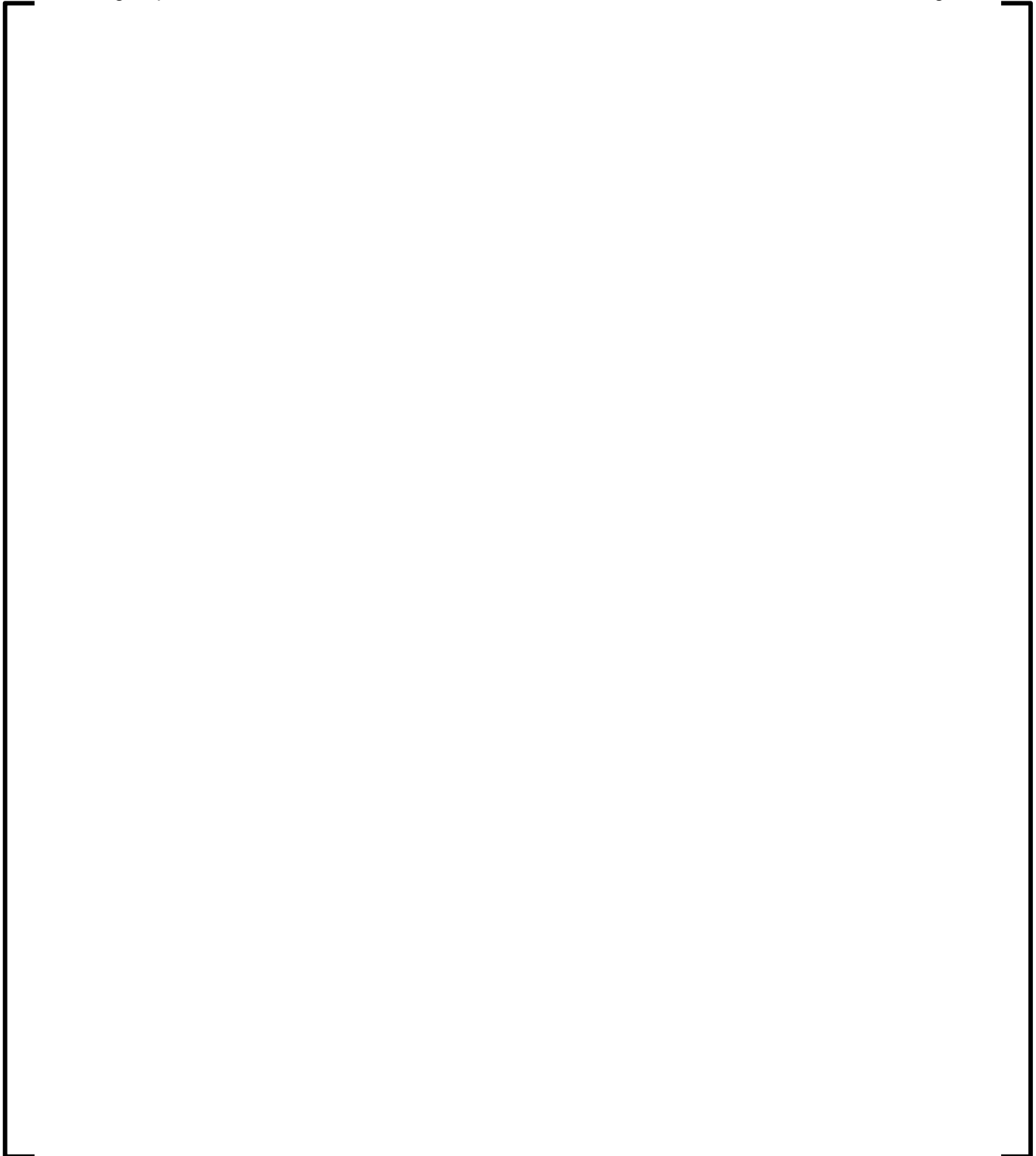


Figure A-3 3rd Generation FUELGUARD LTP
(not to scale)

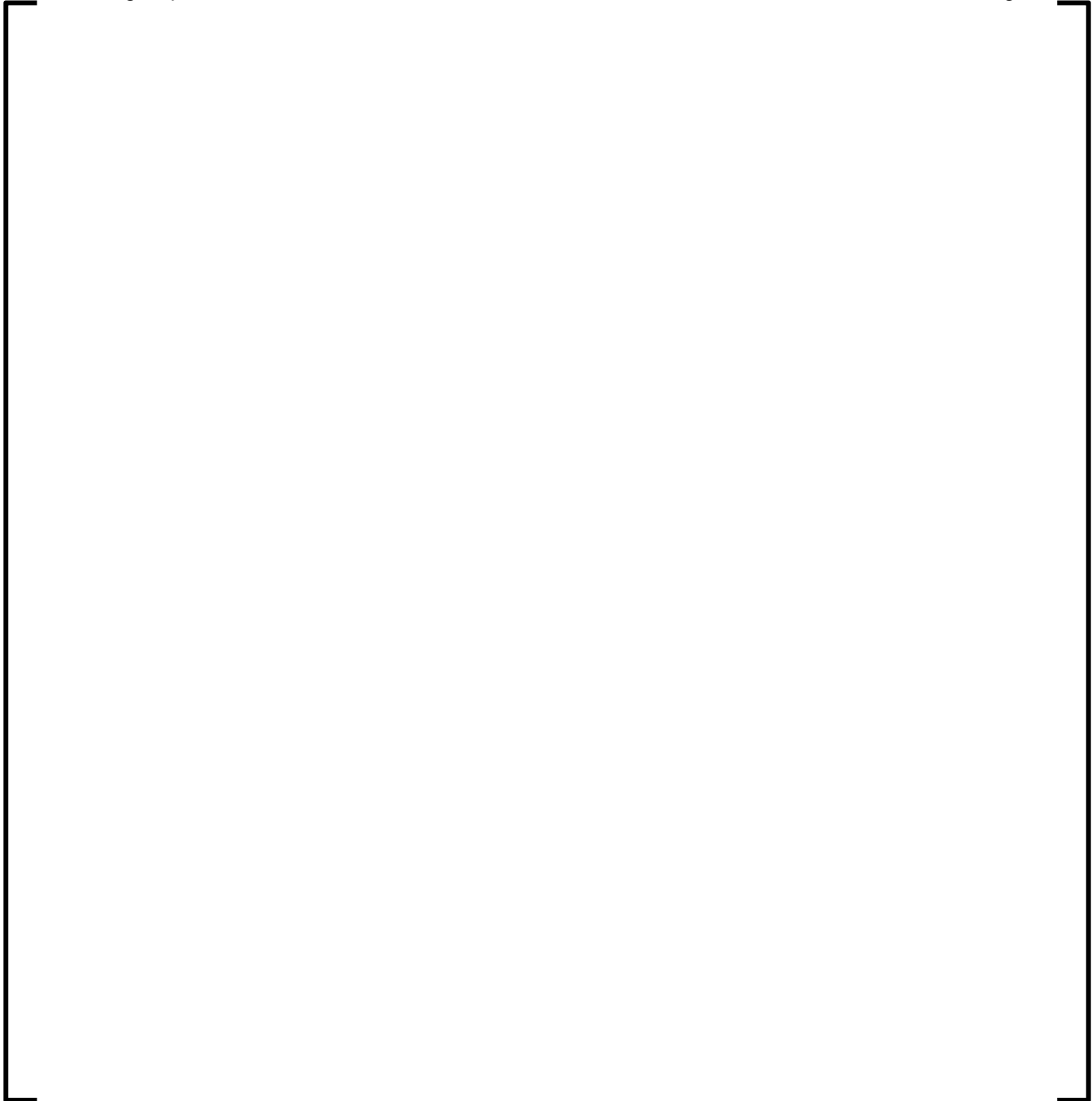


Figure A-4 ATRIUM 11 ULTRAFLOW Spacer Grid
(not to scale)

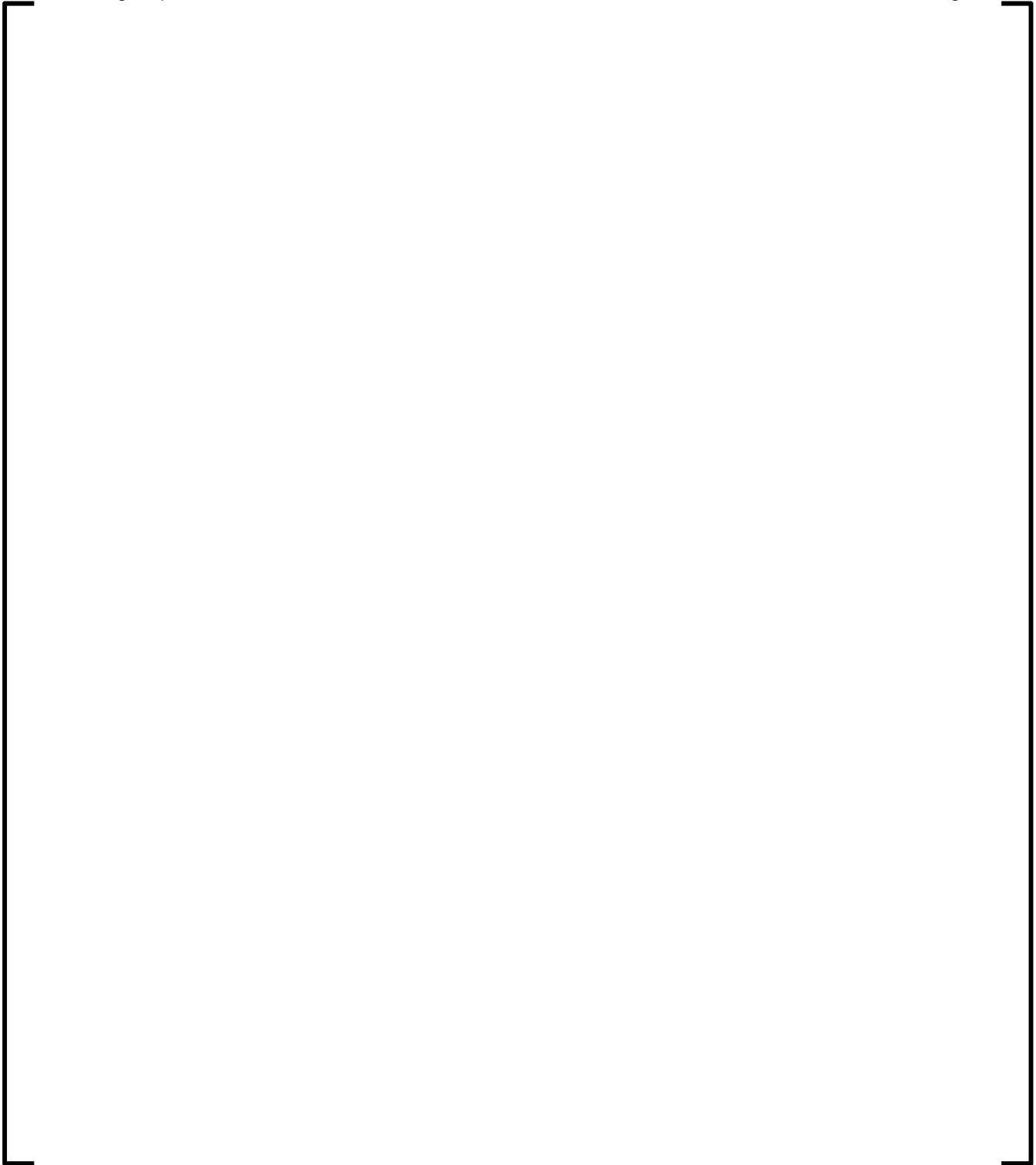


Figure A-5 Full and Part-Length Fuel Rods
(not to scale)

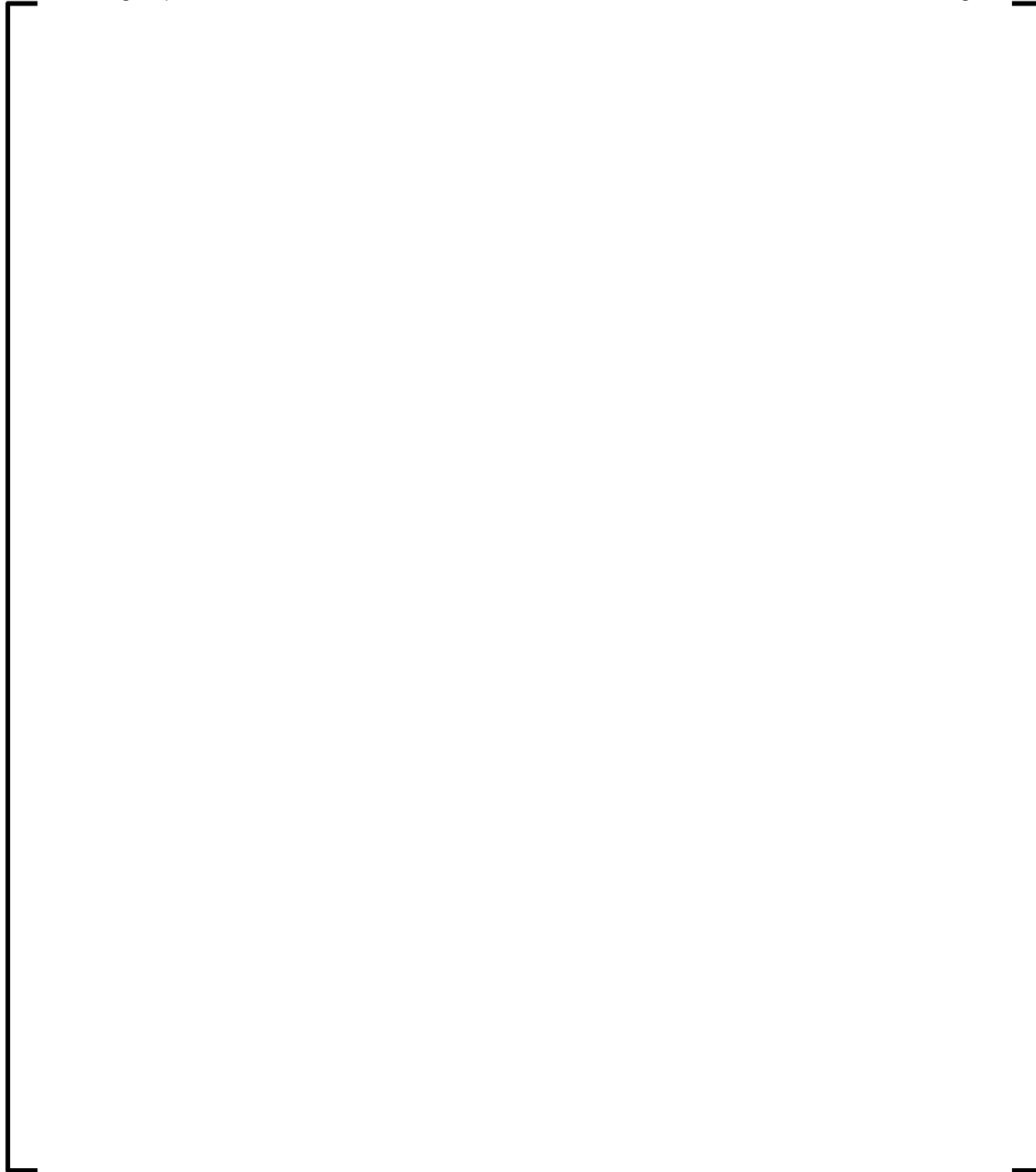


Figure A-6 ATRIUM 11 Advanced Fuel Channel and Channel Spacer
(not to scale)

Affidavit for ANP-3686P, Mechanical Design Report for
Brunswick ATRIUM 11 Fuel Assemblies

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3686P, Revision 0, "Mechanical Design Report for Brunswick ATRIUM 11 Fuel Assemblies," dated September 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

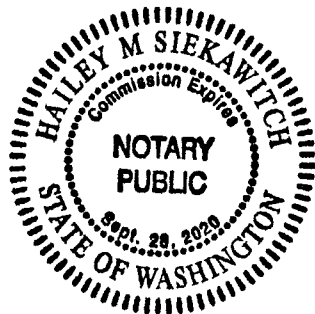
Ala E. Mag

SUBSCRIBED before me this 5th

day of September, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3643NP, Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies



Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0

August 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP

Revision 0

Page i

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

1.0	INTRODUCTION	1-1
2.0	SUMMARY AND CONCLUSIONS	2-1
3.0	THERMAL-HYDRAULIC DESIGN EVALUATION	3-1
3.1	Hydraulic Characterization.....	3-2
3.2	Hydraulic Compatibility	3-3
3.3	Thermal Margin Performance	3-4
3.4	Rod Bow	3-5
3.5	Bypass Flow	3-5
3.6	Stability	3-5
4.0	REFERENCES	4-1

Tables

Table 3.1	Design Evaluation of Thermal and Hydraulic Criteria for the ATRIUM 11 Fuel Assembly.....	3-7
Table 3.2	Comparative Description of Brunswick Unit 1 ATRIUM 11 and ATRIUM 10XM Fuel Types	3-9
Table 3.3	Hydraulic Characterization Comparison Between Brunswick Unit 1 ATRIUM 10XM and ATRIUM 11 Fuel	3-10
Table 3.4	Brunswick Unit 1 Thermal-Hydraulic Design Conditions	3-11
Table 3.5	Brunswick Unit 1 First Transition Core Thermal-Hydraulic Results at Rated Conditions (100%P / 100°F)	3-12
Table 3.6	Brunswick Unit 1 First Transition Core Thermal-Hydraulic Results at Off-Rated Conditions (60%P / 45°F)	3-13
Table 3.7	Brunswick Unit 1 Thermal-Hydraulic Results at Rated Conditions (100%P / 100°F) for Transition to ATRIUM 11 Fuel	3-14
Table 3.8	Brunswick Unit 1 Thermal-Hydraulic Results at Off-Rated Conditions (60%P / 45°F) for Transition to ATRIUM 11 Fuel	3-15

Figures

Figure 3.1 Axial Power Shapes	3-16
Figure 3.2 First Transition Core: Hydraulic Demand Curves 100%P/100%F	3-17
Figure 3.3 First Transition Core: Hydraulic Demand Curves 60%P/45%F	3-18

Nomenclature

AOO	anticipated operational occurrence
ASME	American Society of Mechanical Engineers
BWR	boiling water reactor
CHF	critical heat flux
CPR	critical power ratio
CRDA	control rod drop accident
LOCA	loss-of-coolant accident
LTP	lower tie plate
MAPLHGR	maximum average planar linear heat generation rate
MCPR	minimum critical power ratio
NRC	Nuclear Regulatory Commission, U.S.
PLFR	part-length fuel rod
RPF	radial peaking factor
UTP	upper tie plate

1.0 Introduction

The results of Brunswick Unit 1 thermal-hydraulic analyses are presented to demonstrate that Framatome* ATRIUM™ 11[†] fuel is hydraulically compatible with the previously loaded ATRIUM 10XM fuel design. This report also provides the hydraulic characterization of the ATRIUM 11 and the coresident ATRIUM 10XM design for Brunswick Unit 1.

The generic thermal-hydraulic design criteria applicable to the design have been reviewed and approved by the U.S. Nuclear Regulatory Commission (NRC) in the topical report ANF-89-98(P)(A) Revision 1 and Supplement 1 (Reference 1). In addition, thermal-hydraulic criteria applicable to the design have also been reviewed and approved by the NRC in the topical report XN-NF-80-19(P)(A) Volume 4 Revision 1 (Reference 2).

* Framatome Inc. formerly known as AREVA Inc.

† ATRIUM is a trademark of Framatome Inc.

2.0 Summary and Conclusions

ATRIUM 11 fuel assemblies have been determined to be hydraulically compatible with the coresident ATRIUM 10XM fuel design in the Brunswick Unit 1 reactor for the entire range of the licensed power-to-flow operating map. Detailed calculation results supporting this conclusion are provided in Section 3.2 and Tables 3.4–3.8.

The ATRIUM 11 fuel design is geometrically different from the coresident ATRIUM 10XM design, but the designs are hydraulically compatible. [

]

Core bypass flow (defined as leakage flow through the LTP flow holes, channel seal, core support plate, and LTP-fuel support interface) is not adversely affected by the introduction of the ATRIUM 11 fuel design. Analyses at rated conditions show a core bypass flow of [] of rated core flow for transition core configurations from a full core of ATRIUM 10XM fuel to a full core of ATRIUM 11 fuel.

Analyses demonstrate the thermal-hydraulic design and compatibility criteria discussed in Section 3.0 are satisfied for the Brunswick Unit 1 core consisting of ATRIUM 10XM fuel with ATRIUM 11 fuel for the expected core power distributions and core power/flow conditions encountered during operation.

3.0 Thermal-Hydraulic Design Evaluation

Thermal-hydraulic analyses are performed to verify that design criteria are satisfied and to help establish thermal operating limits with acceptable margins of safety during normal reactor operation and anticipated operational occurrences (AOOs). The design criteria that are applicable to the ATRIUM 11 fuel design is described in Reference 1. To the extent possible, these analyses are performed on a generic fuel design basis. However, due to reactor and cycle operating differences, many of the analyses supporting these thermal-hydraulic operating limits are performed on a plant- and cycle-specific basis and are documented in plant- and cycle-specific reports.

The thermal-hydraulic design criteria are summarized below:

- **Hydraulic compatibility.** The hydraulic flow resistance of the reload fuel assemblies shall be sufficiently similar to the existing fuel in the reactor such that there is no significant impact on total core flow or the flow distribution among assemblies in the core. This criterion evaluation is addressed in Sections 3.1 and 3.2.
- **Thermal margin performance.** Fuel assembly geometry, including spacer design and rod-to-rod local power peaking, should minimize the likelihood of boiling transition during normal reactor operation as well as during AOOs. The fuel design should fall within the bounds of the applicable empirically based boiling transition correlation approved for Framatome reload fuel. Within other applicable mechanical, nuclear, and fuel performance constraints, the fuel design should achieve good thermal margin performance. The thermal-hydraulic design impact on steady-state thermal margin performance is addressed in Section 3.3. Additional thermal margin performance evaluations dependent on the cycle-specific design are addressed in the reload licensing report.
- **Fuel centerline temperature.** Fuel design and operation shall be such that fuel centerline melting is not projected for normal operation and AOOs. This criterion evaluation is addressed in the fuel rod thermal and mechanical design report.
- **Rod bow.** The anticipated magnitude of fuel rod bowing under irradiation shall be accounted for in establishing thermal margin requirements. This criterion evaluation is addressed in Section 3.4.
- **Bypass flow.** The bypass flow characteristics of the reload fuel assemblies shall not differ significantly from the existing fuel in order to provide adequate flow in the bypass region. This criterion evaluation is addressed in Section 3.5.
- **Stability.** Reactors fueled with new fuel designs must be stable in the power and flow operating region. The stability performance of new fuel designs will be equivalent to, or better than, existing (approved) Framatome fuel designs. This criterion evaluation is addressed in Section 3.6. Additional core stability evaluations dependent on the cycle-specific design are addressed in the reload licensing report.

- **Loss-of-coolant accident (LOCA) analysis.** LOCAs are analyzed in accordance with Appendix K modeling requirements using NRC-approved models. The criteria are defined in 10 CFR 50.46. LOCA analysis results are presented in the break spectrum and MAPLHGR report.
- **Control rod drop accident (CRDA) analysis.** The deposited enthalpy must be less than the applicable criteria. This criterion evaluation is addressed in the reload licensing report.
- **ASME overpressurization analysis.** ASME pressure vessel code requirements must be satisfied. This criterion evaluation is addressed in the reload licensing report.
- **Seismic/LOCA liftoff.** Under accident conditions, the assembly must remain engaged in the fuel support. This criterion evaluation is addressed in the mechanical design report.

A summary of the thermal-hydraulic design evaluations is given in Table 3.1.

3.1 **Hydraulic Characterization**

Basic geometric parameters for the ATRIUM 11 and ATRIUM 10 XM fuel designs are summarized in Table 3.2. Component loss coefficients for the fuels mentioned are based on tests and are presented in Table 3.3. These loss coefficients include modifications to the test data reduction process [

]. The bare rod friction, ULTRAFLOW™* spacer, UTP and LTP losses for ATRIUM 11 and ATRIUM 10XM are based on tests performed at Framatome's Portable Hydraulic Test Facility. [

]

The primary resistance for the leakage flow through the LTP flow holes is [

]. The resistances for the leakage paths are shown in Table 3.3.

* ULTRAFLOW is a trademark of Framatome Inc.

3.2 ***Hydraulic Compatibility***

The thermal-hydraulic analyses were performed in accordance with the Framatome thermal-hydraulic methodology for BWRs. The methodology and constitutive relationships used by Framatome for the calculation of pressure drop in BWR fuel assemblies are presented in Reference 3 and are implemented in the XCOBRA code. The XCOBRA code predicts steady-state thermal-hydraulic performance of the fuel assemblies of BWR cores at various operating conditions and power distributions. XCOBRA received NRC approval in Reference 4. The NRC reviewed the information provided in Reference 5 regarding inclusion of water rod models in XCOBRA and accepted the inclusion in Reference 6.

Hydraulic compatibility, as it relates to the relative performance of the ATRIUM 11 and coresident ATRIUM 10XM fuel designs, has been evaluated. Detailed analyses were performed for full cores of each fuel design present herein. Analyses for mixed cores with ATRIUM 11 and ATRIUM 10XM fuel were also performed to demonstrate that the thermal-hydraulic design criteria are satisfied for transition core configurations.

The hydraulic compatibility analysis is based on [

]

Table 3.4 summarizes the input conditions for the analyses. These conditions reflect two of the state points considered in the analyses: 100% power/100% flow and 60% power/45% flow. Table 3.4 also defines the core loading for the transition core configurations. Input for other core configurations is similar in that core operating conditions remain the same and the same axial power distribution is used. Evaluations were made with the bottom-, middle-, and top-peaked axial power distributions presented in Figure 3.1. Results presented in this report are for the middle-peaked power distribution. Results for bottom- and top-peaked axial power distributions show similar trends.

Table 3.5 and Table 3.6 provide a summary of calculated thermal-hydraulic results using the first transition core configuration. Table 3.7 and Table 3.8 provide a summary of results for all

core configurations evaluated. Core average results and the differences between the ATRIUM 11 and ATRIUM 10XM results at rated power are within the range which is considered compatible. Similar agreement occurs at lower power levels. As shown in Table 3.5, [

]. Table 3.6 shows that [

]. Differences in assembly flow between the ATRIUM 11 and ATRIUM 10XM fuel designs as a function of assembly power level are shown in Figure 3.2 and Figure 3.3.

Core pressure drop and core bypass flow fraction are also provided for the configurations evaluated. Based on the reported changes in pressure drop and assembly flow caused by the introduction of ATRIUM 11, the ATRIUM 11 design is considered hydraulically compatible with the coresident fuel designs since the thermal-hydraulic design criteria are satisfied.

3.3 ***Thermal Margin Performance***

Relative thermal margin analyses were performed in accordance with the thermal-hydraulic methodology for Framatome's XCOBRA code. The calculation of the fuel assembly critical power ratio (CPR) (thermal margin performance) is established by means of an empirical correlation based on results of boiling transition test programs. The CPR methodology is the approach used by Framatome to determine the margin to thermal limits for BWRs.

CPR values for ATRIUM 11 are calculated with the ACE/ATRIUM 11 critical power correlation (Reference 7) while the CPR values for the ATRIUM 10XM are calculated with the ACE/ATRIUM 10XM critical power correlation (Reference 9). Assembly design features are incorporated in the CPR calculation through the K-factor term in the ACE correlations. The K-factors are based on the local power peaking for the nuclear design and on additive constants determined in accordance with approved procedures. The local peaking factors are a function of assembly void fraction and exposure.

For the compatibility evaluation, steady-state analyses evaluated ATRIUM 11 and ATRIUM 10XM assemblies with radial peaking factors (RPFs) between [

]. Table 3.5 and Table 3.6 show CPR results of the ATRIUM 11 and ATRIUM 10XM fuel. Table 3.7 and Table 3.8 show similar comparisons of CPR and assembly

flow for the various core configurations evaluated. Analysis results indicate ATRIUM 11 fuel will not cause thermal margin problems for the coresident ATRIUM 10XM fuel design.

3.4 ***Rod Bow***

The bases for rod bow are discussed in the mechanical design report. Rod bow magnitude is determined during the fuel-specific mechanical design analyses and confirmed on a cycle-specific basis.

[

]

3.5 ***Bypass Flow***

Total core bypass flow is defined as leakage flow through the LTP flow holes, channel seal, core support plate, and LTP-fuel support interface. Table 3.7 shows that total core bypass flow (excluding water rod flow) fraction at rated conditions is [] of rated core flow for the core configurations presented (middle-peaked power shape). In summary, adequate bypass flow will be available with the introduction of the ATRIUM 11 fuel design and applicable design criteria are met.

3.6 ***Stability***

Each new fuel design is analyzed to demonstrate that the stability performance is equivalent to or better than an existing Framatome fuel design. The stability performance is a function of the core power, core flow, core power distribution, and to a lesser extent, the fuel design.

[

] A comparative stability

analysis was performed with the NRC-approved STAIF code (Reference 8). The study shows that the ATRIUM 11 fuel design has decay ratios equivalent to or better than other Framatome fuel designs.

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-6

As stated above, the stability performance of a core is strongly dependent on the core power, core flow, and power distribution in the core. Therefore, core stability is evaluated on a cycle-specific basis and addressed in the reload licensing report.

**Table 3.1 Design Evaluation of Thermal and Hydraulic Criteria
for the ATRIUM 11 Fuel Assembly**

Report Section	Description	Criteria	Results or Disposition
Thermal and Hydraulic Criteria			
3.1 / 3.2	Hydraulic compatibility	Hydraulic flow resistance shall be sufficiently similar to existing fuel such that there is no significant impact on total core flow or flow distribution among assemblies.	Verified on a plant-specific basis. ATRIUM 11 demonstrated to be compatible with ATRIUM 10XM fuel. []
3.3	Thermal margin performance	Fuel design shall be within the limits of applicability of an approved CHF correlation.	ACE/ATRIUM 11 critical power correlation is applied to the ATRIUM 11 fuel. ACE/ATRIUM 10XM critical power correlation is applied to the ATRIUM 10 XM fuel.
		< 0.1% of rods in boiling transition.	Verified on cycle-specific basis for Chapter 15 analyses.
	Fuel centerline temperature	No centerline melting.	Plant- and fuel-specific analyses are performed.
3.4	Rod bow	Rod bow must be accounted for in establishing thermal margins.	The lateral displacement of the fuel rods due to fuel rod bowing is not of sufficient magnitude to impact thermal margins. Verified on a cycle-specific basis.
3.5	Bypass flow	Bypass flow characteristics shall be similar among assemblies to provide adequate bypass flow.	Verified on a plant-specific basis. Analysis results demonstrate that adequate bypass flow is provided.

**Table 3.1 Design Evaluation of Thermal and Hydraulic Criteria
for the ATRIUM 11 Fuel Assembly (Continued)**

Report Section	Description	Criteria	Results or Disposition
Thermal and Hydraulic Criteria (Continued)			
3.6	Stability	New fuel designs are stable in the approved power and flow operating region, and stability performance will be equivalent to (or better than) existing (approved) Framatome fuel designs.	ATRIUM 11 channel and core decay ratios have been demonstrated to be equivalent to or better than other approved Framatome fuel designs. Core stability behavior is evaluated on a cycle-specific basis.
	LOCA analysis	LOCA analyzed in accordance with Appendix K modeling requirements. Criteria defined in 10 CFR 50.46.	Plant- and fuel-specific analysis is performed with Appendix K LOCA models and verified with cycle specific calculations.
	CRDA analysis	Applicable criteria	Cycle-specific analysis is performed.
	ASME over-pressurization analysis	ASME pressure vessel core requirements shall be satisfied.	Cycle-specific analysis is performed.
	Seismic/LOCA liftoff	Assembly remains engaged in fuel support.	Plant- and fuel-specific analyses are performed.

**Table 3.2 Comparative Description of Brunswick Unit 1
ATRIUM 11 and ATRIUM 10XM Fuel Types**

Fuel Parameter	ATRIUM 10XM	ATRIUM 11
Number of fuel rods		
Full-length fuel rods	79	92
PLFRs	12	
Short PLFRs		12
Long PLFRs		8
Fuel clad OD, in	0.4047	0.3701
Number of spacers	9	9
Active fuel length, ft		
Full-length fuel rods	12.500	12.500
PLFRs	6.25	
Short PLFRs		4.66
Long PLFRs		7.34
Hydraulic resistance characteristics	Table 3.3	Table 3.3
Number of water rods	1	1
Water rod OD, in	1.378*	1.299*

* Square water channel outer width.

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-10

**Table 3.3 Hydraulic Characterization Comparison Between
Brunswick Unit 1 ATRIUM 10XM and ATRIUM 11 Fuel**

[

]

[

]

**Table 3.4 Brunswick Unit 1
Thermal-Hydraulic Design Conditions**

Reactor Conditions	100%P / 100°F	60%P / 45°F
Core power level, MWt	2923.0	1753.8
Core exit pressure, psia	1058.3	988.2
Core inlet enthalpy, Btu/lbm	528.3	504.6
Total core coolant flow, Mlbm/hr	77.0	34.65
Axial power shape	Middle-peaked (Figure 3.1)	Middle-peaked (Figure 3.1)

Number of Assemblies	
Central Region	Peripheral Region
First Transition Core Loading	
[	]
[	]
Second Transition Core Loading	
[	]
[	]

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-12

**Table 3.5 Brunswick Unit 1
First Transition Core Thermal-Hydraulic Results at
Rated Conditions (100%P / 100°F)**

[

]

[

]

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-13

**Table 3.6 Brunswick Unit 1
First Transition Core Thermal-Hydraulic Results at
Off-Rated Conditions (60%P / 45°F)**

[

]

[

]

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-14

**Table 3.7 Brunswick Unit 1 Thermal-Hydraulic Results at
Rated Conditions (100%P / 100°F) for
Transition to ATRIUM 11 Fuel**

[

]

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-15

**Table 3.8 Brunswick Unit 1 Thermal-Hydraulic Results at
Off-Rated Conditions (60%P / 45%F) for
Transition to ATRIUM 11 Fuel**

[

]

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP

Revision 0

Page 3-16

[

]

Figure 3.1 Axial Power Shapes

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-17

[

]

**Figure 3.2 First Transition Core:
Hydraulic Demand Curves 100%P/100%F**

Framatome Inc.

Brunswick Unit 1 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3643NP
Revision 0
Page 3-18

[

]

**Figure 3.3 First Transition Core:
Hydraulic Demand Curves 60%P/45%F**

4.0 References

1. ANF-89-98(P)(A) Revision 1 and Supplement 1, *Generic Mechanical Design Criteria for BWR Fuel Designs*, Advanced Nuclear Fuels Corporation, May 1995.
2. XN-NF-80-19(P)(A) Volume 4 Revision 1, *Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads*, Exxon Nuclear Company, June 1986.
3. XN-NF-79-59(P)(A), *Methodology for Calculation of Pressure Drop in BWR Fuel Assemblies*, Exxon Nuclear Company, November 1983.
4. XN-NF-80-19(P)(A) Volume 3 Revision 2, *Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description*, Exxon Nuclear Company, January 1987.
5. Letter, R.A. Copeland (ANF) to R.C. Jones (USNRC), "Explicit Modeling of BWR Water Rod in XCOBRA," RAC:002:90, January 9, 1990.
6. Letter, R.C. Jones (USNRC) to R.A. Copeland (ANF), no subject (regarding XCOBRA water rod model), February 1, 1990.
7. ANP-10335P-A Revision 0, *ACE/ATRIUM 11 Critical Power Correlation*, Framatome, May 2018.
8. EMF-CC-074(P)(A) Volume 1, *STAIF – A Computer Program for BWR Stability Analysis in the Frequency Domain*; and Volume 2, *STAIF – A Computer Program for BWR Stability Analysis in the Frequency Domain – Code Qualification Report*, Siemens Power Corporation, July 1994.
9. ANP-10298PA Revision 1, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2014.

**Affidavit for ANP-3643P, Brunswick Unit 1 Thermal-
Hydraulic Design Report for ATRIUM 11 Fuel Assemblies**

A F F I D A V I T

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3643P, Revision 0 "Brunswick Unit 1 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies," dated August 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

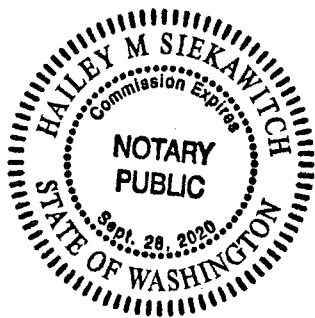
9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Al B. Meyer

SUBSCRIBED before me this 7th
day of August, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3644NP, Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies



Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0

August 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP

Revision 0

Page i

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

1.0	INTRODUCTION	1-1
2.0	SUMMARY AND CONCLUSIONS	2-1
3.0	THERMAL-HYDRAULIC DESIGN EVALUATION	3-1
3.1	Hydraulic Characterization.....	3-2
3.2	Hydraulic Compatibility	3-3
3.3	Thermal Margin Performance	3-4
3.4	Rod Bow	3-5
3.5	Bypass Flow	3-5
3.6	Stability	3-5
4.0	REFERENCES	4-1

Tables

Table 3.1	Design Evaluation of Thermal and Hydraulic Criteria for the ATRIUM 11 Fuel Assembly.....	3-7
Table 3.2	Comparative Description of Brunswick Unit 2 ATRIUM 11 and ATRIUM 10XM Fuel Types	3-9
Table 3.3	Hydraulic Characterization Comparison Between Brunswick Unit 2 ATRIUM 10XM and ATRIUM 11 Fuel	3-10
Table 3.4	Brunswick Unit 2 Thermal-Hydraulic Design Conditions	3-11
Table 3.5	Brunswick Unit 2 First Transition Core Thermal-Hydraulic Results at Rated Conditions (100%P / 100°F)	3-12
Table 3.6	Brunswick Unit 2 First Transition Core Thermal-Hydraulic Results at Off-Rated Conditions (60%P / 45°F)	3-13
Table 3.7	Brunswick Unit 2 Thermal-Hydraulic Results at Rated Conditions (100%P / 100°F) for Transition to ATRIUM 11 Fuel	3-14
Table 3.8	Brunswick Unit 2 Thermal-Hydraulic Results at Off-Rated Conditions (60%P / 45°F) for Transition to ATRIUM 11 Fuel	3-15

Figures

Figure 3.1	Axial Power Shapes.....	3-16
Figure 3.2	First Transition Core: Hydraulic Demand Curves 100%P/100%F	3-17
Figure 3.3	First Transition Core: Hydraulic Demand Curves 60%P/45%F	3-18

Nomenclature

AOO	anticipated operational occurrence
ASME	American Society of Mechanical Engineers
BWR	boiling water reactor
CHF	critical heat flux
CPR	critical power ratio
CRDA	control rod drop accident
LOCA	loss-of-coolant accident
LTP	lower tie plate
LTA	Leads Test Assembly
MAPLHGR	maximum average planar linear heat generation rate
MCPR	minimum critical power ratio
NRC	Nuclear Regulatory Commission, U.S.
PLFR	part-length fuel rod
RPF	radial peaking factor
UTP	upper tie plate

1.0 Introduction

The results of Brunswick Unit 2 thermal-hydraulic analyses are presented to demonstrate that Framatome* ATRIUM™ 11[†] fuel is hydraulically compatible with the previously loaded ATRIUM 10XM fuel design. This report also provides the hydraulic characterization of the ATRIUM 11 and the coresident ATRIUM 10XM design for Brunswick Unit 2.

The generic thermal-hydraulic design criteria applicable to the design have been reviewed and approved by the U.S. Nuclear Regulatory Commission (NRC) in the topical report ANF-89-98(P)(A) Revision 1 and Supplement 1 (Reference 1). In addition, thermal-hydraulic criteria applicable to the design have also been reviewed and approved by the NRC in the topical report XN-NF-80-19(P)(A) Volume 4 Revision 1 (Reference 2).

* Framatome Inc. formerly known as AREVA Inc.

† ATRIUM is a trademark of Framatome Inc.

2.0 Summary and Conclusions

ATRIUM 11 fuel assemblies have been determined to be hydraulically compatible with the coresident ATRIUM 10XM fuel design in the Brunswick Unit 2 reactor for the entire range of the licensed power-to-flow operating map. Detailed calculation results supporting this conclusion are provided in Section 3.2 and Tables 3.4–3.8.

The ATRIUM 11 fuel design is geometrically different from the coresident ATRIUM 10XM design, but the designs are hydraulically compatible. [

]

Core bypass flow (defined as leakage flow through the LTP flow holes, channel seal, core support plate, and LTP-fuel support interface) is not adversely affected by the introduction of the ATRIUM 11 fuel design. Analyses at rated conditions show a core bypass flow of [] of rated core flow for transition core configurations from a full core of ATRIUM 10XM fuel to a full core of ATRIUM 11 fuel.

Analyses demonstrate the thermal-hydraulic design and compatibility criteria discussed in Section 3.0 are satisfied for the Brunswick Unit 2 core consisting of ATRIUM 10XM fuel with ATRIUM 11 fuel for the expected core power distributions and core power/flow conditions encountered during operation.

3.0 Thermal-Hydraulic Design Evaluation

Thermal-hydraulic analyses are performed to verify that design criteria are satisfied and to help establish thermal operating limits with acceptable margins of safety during normal reactor operation and anticipated operational occurrences (AOOs). The design criteria that are applicable to the ATRIUM 11 fuel design is described in Reference 1. To the extent possible, these analyses are performed on a generic fuel design basis. However, due to reactor and cycle operating differences, many of the analyses supporting these thermal-hydraulic operating limits are performed on a plant- and cycle-specific basis and are documented in plant- and cycle-specific reports.

The thermal-hydraulic design criteria are summarized below:

- **Hydraulic compatibility.** The hydraulic flow resistance of the reload fuel assemblies shall be sufficiently similar to the existing fuel in the reactor such that there is no significant impact on total core flow or the flow distribution among assemblies in the core. This criterion evaluation is addressed in Sections 3.1 and 3.2.
- **Thermal margin performance.** Fuel assembly geometry, including spacer design and rod-to-rod local power peaking, should minimize the likelihood of boiling transition during normal reactor operation as well as during AOOs. The fuel design should fall within the bounds of the applicable empirically based boiling transition correlation approved for Framatome reload fuel. Within other applicable mechanical, nuclear, and fuel performance constraints, the fuel design should achieve good thermal margin performance. The thermal-hydraulic design impact on steady-state thermal margin performance is addressed in Section 3.3. Additional thermal margin performance evaluations dependent on the cycle-specific design are addressed in the reload licensing report.
- **Fuel centerline temperature.** Fuel design and operation shall be such that fuel centerline melting is not projected for normal operation and AOOs. This criterion evaluation is addressed in the fuel rod thermal and mechanical design report.
- **Rod bow.** The anticipated magnitude of fuel rod bowing under irradiation shall be accounted for in establishing thermal margin requirements. This criterion evaluation is addressed in Section 3.4.
- **Bypass flow.** The bypass flow characteristics of the reload fuel assemblies shall not differ significantly from the existing fuel in order to provide adequate flow in the bypass region. This criterion evaluation is addressed in Section 3.5.
- **Stability.** Reactors fueled with new fuel designs must be stable in the power and flow operating region. The stability performance of new fuel designs will be equivalent to, or better than, existing (approved) Framatome fuel designs. This criterion evaluation is addressed in Section 3.6. Additional core stability evaluations dependent on the cycle-specific design are addressed in the reload licensing report.

- **Loss-of-coolant accident (LOCA) analysis.** LOCAs are analyzed in accordance with Appendix K modeling requirements using NRC-approved models. The criteria are defined in 10 CFR 50.46. LOCA analysis results are presented in the break spectrum and MAPLHGR report.
- **Control rod drop accident (CRDA) analysis.** The deposited enthalpy must be less than the applicable criteria. This criterion evaluation is addressed in the reload licensing report.
- **ASME overpressurization analysis.** ASME pressure vessel code requirements must be satisfied. This criterion evaluation is addressed in the reload licensing report.
- **Seismic/LOCA liftoff.** Under accident conditions, the assembly must remain engaged in the fuel support. This criterion evaluation is addressed in the mechanical design report.

A summary of the thermal-hydraulic design evaluations is given in Table 3.1.

3.1 *Hydraulic Characterization*

Basic geometric parameters for the ATRIUM 11 and ATRIUM 10 XM fuel designs are summarized in Table 3.2. Component loss coefficients for the fuels mentioned are based on tests and are presented in Table 3.3. These loss coefficients include modifications to the test data reduction process [

]. The bare rod friction, ULTRAFLOW™* spacer, UTP and LTP losses for ATRIUM 11 and ATRIUM 10XM are based on tests performed at Framatome's Portable Hydraulic Test Facility. [

]

The primary resistance for the leakage flow through the LTP flow holes is [

]. The resistances for the leakage paths are shown in Table 3.3.

* ULTRAFLOW is a trademark of Framatome Inc.

3.2 ***Hydraulic Compatibility***

The thermal-hydraulic analyses were performed in accordance with the Framatome thermal-hydraulic methodology for BWRs. The methodology and constitutive relationships used by Framatome for the calculation of pressure drop in BWR fuel assemblies are presented in Reference 3 and are implemented in the XCOBRA code. The XCOBRA code predicts steady-state thermal-hydraulic performance of the fuel assemblies of BWR cores at various operating conditions and power distributions. XCOBRA received NRC approval in Reference 4. The NRC reviewed the information provided in Reference 5 regarding inclusion of water rod models in XCOBRA and accepted the inclusion in Reference 6.

Hydraulic compatibility, as it relates to the relative performance of the ATRIUM 11 and coresident ATRIUM 10XM fuel designs, has been evaluated. Detailed analyses were performed for full cores of each fuel design present herein. Analyses for mixed cores with ATRIUM 11 and ATRIUM 10XM fuel were also performed to demonstrate that the thermal-hydraulic design criteria are satisfied for transition core configurations.

The hydraulic compatibility analysis is based on [

]

Table 3.4 summarizes the input conditions for the analyses. These conditions reflect two of the state points considered in the analyses: 100% power/100% flow and 60% power/45% flow. Table 3.4 also defines the core loading for the transition core configurations. Input for other core configurations is similar in that core operating conditions remain the same and the same axial power distribution is used. Evaluations were made with the bottom-, middle-, and top-peaked axial power distributions presented in Figure 3.1. Results presented in this report are for the middle-peaked power distribution. Results for bottom- and top-peaked axial power distributions show similar trends.

Table 3.5 and Table 3.6 provide a summary of calculated thermal-hydraulic results using the first transition core configuration. Table 3.7 and Table 3.8 provide a summary of results for all

core configurations evaluated. Core average results and the differences between the ATRIUM 11 and ATRIUM 10XM results at rated power are within the range which is considered compatible. Similar agreement occurs at lower power levels. As shown in Table 3.5, [

]. Table 3.6 shows that [

]. Differences in assembly flow between the ATRIUM 11 and ATRIUM 10XM fuel designs as a function of assembly power level are shown in Figure 3.2 and Figure 3.3.

Core pressure drop and core bypass flow fraction are also provided for the configurations evaluated. Based on the reported changes in pressure drop and assembly flow caused by the introduction of ATRIUM 11, the ATRIUM 11 design is considered hydraulically compatible with the coresident fuel designs since the thermal-hydraulic design criteria are satisfied.

3.3 ***Thermal Margin Performance***

Relative thermal margin analyses were performed in accordance with the thermal-hydraulic methodology for Framatome's XCOBRA code. The calculation of the fuel assembly critical power ratio (CPR) (thermal margin performance) is established by means of an empirical correlation based on results of boiling transition test programs. The CPR methodology is the approach used by Framatome to determine the margin to thermal limits for BWRs.

CPR values for ATRIUM 11 are calculated with the ACE/ATRIUM 11 critical power correlation (Reference 7) while the CPR values for the ATRIUM 10XM are calculated with the ACE/ATRIUM 10XM critical power correlation (Reference 9). Assembly design features are incorporated in the CPR calculation through the K-factor term in the ACE correlations. The K-factors are based on the local power peaking for the nuclear design and on additive constants determined in accordance with approved procedures. The local peaking factors are a function of assembly void fraction and exposure.

For the compatibility evaluation, steady-state analyses evaluated ATRIUM 11 and ATRIUM 10XM assemblies with radial peaking factors (RPFs) between [

]. Table 3.5 and Table 3.6 show CPR results of the ATRIUM 11 and ATRIUM 10XM fuel. Table 3.7 and Table 3.8 show similar comparisons of CPR and assembly

flow for the various core configurations evaluated. Analysis results indicate ATRIUM 11 fuel will not cause thermal margin problems for the coresident ATRIUM 10XM fuel design.

3.4 ***Rod Bow***

The bases for rod bow are discussed in the mechanical design report. Rod bow magnitude is determined during the fuel-specific mechanical design analyses and confirmed on a cycle-specific basis.

[

]

3.5 ***Bypass Flow***

Total core bypass flow is defined as leakage flow through the LTP flow holes, channel seal, core support plate, and LTP-fuel support interface. Table 3.7 shows that total core bypass flow (excluding water rod flow) fraction at rated conditions is [] of rated core flow for the core configurations presented (middle-peaked power shape). In summary, adequate bypass flow will be available with the introduction of the ATRIUM 11 and applicable design criteria are met.

3.6 ***Stability***

Each new fuel design is analyzed to demonstrate that the stability performance is equivalent to or better than an existing Framatome fuel design. The stability performance is a function of the core power, core flow, core power distribution, and to a lesser extent, the fuel design.

[

] A comparative stability

analysis was performed with the NRC-approved STAIF code (Reference 8). The study shows that the ATRIUM 11 fuel design has decay ratios equivalent to or better than other Framatome fuel designs.

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-6

As stated above, the stability performance of a core is strongly dependent on the core power, core flow, and power distribution in the core. Therefore, core stability is evaluated on a cycle-specific basis and addressed in the reload licensing report.

**Table 3.1 Design Evaluation of Thermal and Hydraulic Criteria
for the ATRIUM 11 Fuel Assembly**

Report Section	Description	Criteria	Results or Disposition
Thermal and Hydraulic Criteria			
3.1 / 3.2	Hydraulic compatibility	Hydraulic flow resistance shall be sufficiently similar to existing fuel such that there is no significant impact on total core flow or flow distribution among assemblies.	Verified on a plant-specific basis. ATRIUM 11 demonstrated to be compatible with ATRIUM 10XM fuel. []
3.3	Thermal margin performance	Fuel design shall be within the limits of applicability of an approved CHF correlation.	ACE/ATRIUM 11 critical power correlation is applied to the ATRIUM 11 fuel. ACE/ATRIUM 10XM critical power correlation is applied to the ATRIUM 10 XM fuel.
		< 0.1% of rods in boiling transition.	Verified on cycle-specific basis for Chapter 15 analyses.
	Fuel centerline temperature	No centerline melting.	Plant- and fuel-specific analyses are performed.
3.4	Rod bow	Rod bow must be accounted for in establishing thermal margins.	The lateral displacement of the fuel rods due to fuel rod bowing is not of sufficient magnitude to impact thermal margins. Verified on a cycle-specific basis.
3.5	Bypass flow	Bypass flow characteristics shall be similar among assemblies to provide adequate bypass flow.	Verified on a plant-specific basis. Analysis results demonstrate that adequate bypass flow is provided.

**Table 3.1 Design Evaluation of Thermal and Hydraulic Criteria
for the ATRIUM 11 Fuel Assembly (Continued)**

Report Section	Description	Criteria	Results or Disposition
Thermal and Hydraulic Criteria (Continued)			
3.6	Stability	New fuel designs are stable in the approved power and flow operating region, and stability performance will be equivalent to (or better than) existing (approved) Framatome fuel designs.	ATRIUM 11 channel and core decay ratios have been demonstrated to be equivalent to or better than other approved Framatome fuel designs. Core stability behavior is evaluated on a cycle-specific basis.
	LOCA analysis	LOCA analyzed in accordance with Appendix K modeling requirements. Criteria defined in 10 CFR 50.46.	Plant- and fuel-specific analysis is performed with Appendix K LOCA models and verified with cycle specific calculations.
	CRDA analysis	Applicable criteria	Cycle-specific analysis is performed.
	ASME over-pressurization analysis	ASME pressure vessel core requirements shall be satisfied.	Cycle-specific analysis is performed.
	Seismic/LOCA liftoff	Assembly remains engaged in fuel support.	Plant- and fuel-specific analyses are performed.

**Table 3.2 Comparative Description of Brunswick Unit 2
ATRIUM 11 and ATRIUM 10XM Fuel Types**

Fuel Parameter	ATRIUM 10XM	ATRIUM 11
Number of fuel rods		
Full-length fuel rods	79	92
PLFRs	12	
Short PLFRs		12
Long PLFRs		8
Fuel clad OD, in	0.4047	0.3701
Number of spacers	9	9
Active fuel length, ft		
Full-length fuel rods	12.500	12.500
PLFRs	6.25	
Short PLFRs		4.66
Long PLFRs		7.34
Hydraulic resistance characteristics	Table 3.3	Table 3.3
Number of water rods	1	1
Water rod OD, in	1.378*	1.299*

* Square water channel outer width.

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-10

**Table 3.3 Hydraulic Characterization Comparison Between
Brunswick Unit 2 ATRIUM 10XM and ATRIUM 11 Fuel**

[

]

[

]

**Table 3.4 Brunswick Unit 2
Thermal-Hydraulic Design Conditions**

Reactor Conditions	100%P / 100°F	60%P / 45°F
Core power level, MWt	2923.0	1753.8
Core exit pressure, psia	1058.3	988.2
Core inlet enthalpy, Btu/lbm	528.3	504.6
Total core coolant flow, Mlbm/hr	77.0	34.65
Axial power shape	Middle-peaked (Figure 3.1)	Middle-peaked (Figure 3.1)

	Number of Assemblies	
	Central Region	Peripheral Region
First Transition Core Loading		
[		]
[		]
Second Transition Core Loading		
[		]
[		]

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-12

**Table 3.5 Brunswick Unit 2
First Transition Core Thermal-Hydraulic Results at
Rated Conditions (100%P / 100°F)**

[

]

[

]

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-13

**Table 3.6 Brunswick Unit 2
First Transition Core Thermal-Hydraulic Results at
Off-Rated Conditions (60%P / 45°F)**

[

]

[

]

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-14

**Table 3.7 Brunswick Unit 2 Thermal-Hydraulic Results at
Rated Conditions (100%P / 100°F) for
Transition to ATRIUM 11 Fuel**

[

]

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-15

**Table 3.8 Brunswick Unit 2 Thermal-Hydraulic Results at
Off-Rated Conditions (60%P / 45%F) for
Transition to ATRIUM 11 Fuel**

[

]

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-16

[

]

Figure 3.1 Axial Power Shapes

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-17

[

]

**Figure 3.2 First Transition Core:
Hydraulic Demand Curves 100%P/100%F**

Framatome Inc.

Brunswick Unit 2 Thermal-Hydraulic Design
Report for ATRIUM 11 Fuel Assemblies

ANP-3644NP
Revision 0
Page 3-18

[

]

**Figure 3.3 First Transition Core:
Hydraulic Demand Curves 60%P/45%F**

4.0 References

1. ANF-89-98(P)(A) Revision 1 and Supplement 1, *Generic Mechanical Design Criteria for BWR Fuel Designs*, Advanced Nuclear Fuels Corporation, May 1995.
2. XN-NF-80-19(P)(A) Volume 4 Revision 1, *Exxon Nuclear Methodology for Boiling Water Reactors: Application of the ENC Methodology to BWR Reloads*, Exxon Nuclear Company, June 1986.
3. XN-NF-79-59(P)(A), *Methodology for Calculation of Pressure Drop in BWR Fuel Assemblies*, Exxon Nuclear Company, November 1983.
4. XN-NF-80-19(P)(A) Volume 3 Revision 2, *Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description*, Exxon Nuclear Company, January 1987.
5. Letter, R.A. Copeland (ANF) to R.C. Jones (USNRC), "Explicit Modeling of BWR Water Rod in XCOBRA," RAC:002:90, January 9, 1990.
6. Letter, R.C. Jones (USNRC) to R.A. Copeland (ANF), no subject (regarding XCOBRA water rod model), February 1, 1990.
7. ANP-10335P-A Revision 0, *ACE/ATRIUM 11 Critical Power Correlation*, Framatome, May 2018.
8. EMF-CC-074(P)(A) Volume 1, *STAIF – A Computer Program for BWR Stability Analysis in the Frequency Domain*; and Volume 2, *STAIF – A Computer Program for BWR Stability Analysis in the Frequency Domain – Code Qualification Report*, Siemens Power Corporation, July 1994.
9. ANP-10298PA Revision 1, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2014.

**Affidavit for ANP-3644P, Brunswick Unit 2 Thermal-
Hydraulic Design Report for ATRIUM 11 Fuel Assemblies**

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3644P, Revision 0 "Brunswick Unit 2 Thermal-Hydraulic Design Report for ATRIUM 11 Fuel Assemblies," dated August 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Alan E. Meyer

SUBSCRIBED before me this 7th
day of August, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3668NP, ATRIUM 11 Fuel Rod Thermal-Mechanical
Evaluation for Brunswick LAR



ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Brunswick LAR

ANP-3668NP
Revision 0

Licensing Report

August 2018

Framatome Inc.

(c) 2018 Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

**FUELGUARD and ATRIUM are trademarks or registered trademarks of
Framatome or its affiliates, in the USA or other countries.**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 SUMMARY AND CONCLUSIONS	2-1
3.0 FUEL ROD DESIGN EVALUATION	3-1
3.1 Fuel Rod Design	3-1
3.2 RODEX4 and Statistical Methodology Summary	3-2
3.3 Summary of Fuel Rod Design Evaluation	3-4
3.3.1 Internal Hydriding	3-6
3.3.2 Cladding Collapse	3-6
3.3.3 Overheating of Fuel Pellets	3-6
3.3.4 Stress and Strain Limits	3-7
3.3.5 Fuel Densification and Swelling	3-8
3.3.6 Fatigue	3-8
3.3.7 Oxidation, Hydriding, and Crud Buildup	3-8
3.3.8 Rod Internal Pressure	3-10
3.3.9 Plenum Spring Design (Fuel Assembly Handling).....	3-10
4.0 REFERENCES	4-1

List of Tables

Table 2-1 Summary of Fuel Rod Design Evaluation Results (MELLLA+)	2-2
Table 3-1 Key Fuel Rod Design Parameters, ATRIUM 11 for Brunswick LAR.....	3-11
Table 3-2 RODEX4 Fuel Rod Results Equilibrium Cycle—MELLLA+	3-13
Table 3-3 Cladding and Cladding-End Cap Steady-State Stresses	3-14

List of Figures

Figure 2-1 LHGR Limit (Normal Operation).....	2-3

Nomenclature

Acronym	Definition
3GFG	3 rd generation FUELGUARD
AOO	anticipated operational occurrences
ASME	American Society of Mechanical Engineers
B&PV	Boiler and Pressure Vessel
BOL	beginning of life
BWR	boiling water reactor
CRWE	control rod withdrawal error
CUF	cumulative usage factor
EOL	end of life
FDL	fuel design limit
ID	inside diameter
LAR	License Amendment Request
LHGR	linear heat generation rate
LTP	lower tie plate
MWd/kgU	megawatt days per kilogram of initial uranium
MELLLA+	maximum extended load line limit analysis plus
NRC	Nuclear Regulatory Commission, U. S.
OD	outside diameter
PCI	pellet-to-cladding-interaction
PLFR	part length fuel rod
ppm	parts per million
SRA	stress relieved annealed
S-N	stress amplitude versus number of cycles
UTL	upper tolerance limit

1.0 INTRODUCTION

This document reports the results of thermal-mechanical analyses for the performance of ATRIUM 11 fuel assemblies inserted into to an equilibrium cycle for the Brunswick units and demonstrates that the design criteria relevant to these limits are satisfied. This report is intended to support a License Amendment Request (LAR) for the approval to use the Framatome advanced analysis methods that will be deployed coincident with the implementation of the ATRIUM 11 fuel assembly design. These analyses assume the use of chromia additive in the enriched urania portions of the fuel and assume operation in the Maximum Extended Load Line Limit Plus (MELLLA+) operation domain. Both the design criteria and the analysis methodology have been approved by the U. S. NRC (NRC).

The analysis results are evaluated according to the generic fuel rod thermal and mechanical design criteria contained in ANF-89-98(P)(A) Revision 1 and Supplement 1 (Reference 1) along with design criteria provided in the RODEX4 fuel rod thermal-mechanical topical report (Reference 2)*. Approved methodology for the inclusion of chromia additive in the fuel pellets is also used (Reference 3).

The RODEX4 fuel rod thermal-mechanical analysis code is used to analyze the fuel rod for fuel centerline temperature, cladding strain, rod internal pressure, cladding collapse, cladding fatigue and external oxidation. The code and application methodology are described in the RODEX4 topical report (Reference 2). The cladding steady-state stress and plenum spring design methodology are summarized in Reference 1.

The following sections describe the fuel rod design, design criteria and methodology with reference to the source topical reports. Results from the analyses are summarized for comparison to the design criteria.

* (N.B., the cladding external oxidation limit from that topical report of [] was reduced to [] when the RODEX4 methodology was approved for application to the Brunswick units (Reference 5)).

2.0 SUMMARY AND CONCLUSIONS

Key results are compared against each design criterion in:

- Table 3-2 for MELLLA+ operating domain

Results are presented for the limiting cases. Additional RODEX4 results are given in Section 3.0.

The analyses support a maximum fuel rod discharge exposure of 62 MWd/kgU. However, the licensed rod average exposure is limited at the Brunswick units to 60 MWd/kgU (Reference 4).

Fuel rod criteria applicable to the design are summarized in Section 3.0. Analyses show the criteria are satisfied when the fuel is operated at or below the LHGR (linear heat generation rate) limit (Fuel Design Limit – FDL) presented in Figure 2-1.

Table 2-1 Summary of Fuel Rod Design Evaluation Results (MELLLA+)

Criteria Section*	Description	Criteria	Result, Margin [†] or Comment
3.2	Fuel Rod Criteria		
3.2.1	Internal hydriding	[	]
(3.1.1)	Cladding collapse	[	]
(3.1.2)	Overheating of fuel pellets	No fuel melting margin to fuel melt > 0. °C	[]
3.2.5	Stress and strain limits		
(3.1.1) (3.1.2)	Pellet-cladding interaction	[	]
3.2.5.2	Cladding steady-state stresses	[	]
3.3	Fuel System Criteria		
(3.1.1)	Fatigue	[	]
(3.1.1) [‡]	Oxidation, hydriding, and crud buildup	[	]
(3.1.1) (3.1.2)	Rod internal pressure	[	]
3.3.9	Fuel rod plenum spring (fuel handling)	Plenum spring to [	]

* Numbers in the column refer to paragraph sections in the generic design criteria document, ANF-89-98(P)(A) Revision 1 and Supplement 1 (Reference 1). A number in parentheses is the paragraph section in the RODEX4 fuel rod topical report (Reference 2).

[†] Margin is defined as (limit – result).

[‡] The cladding external oxidation limit is restricted to [] by Reference 5.

[

Figure 2-1 LHGR Limit (Normal Operation)

]

1.

[

]

As on previous ATRIUM fuel designs that incorporated the 3rd generation FUELGUARD (3GFG) Lower Tie Plate (LTP), the PLFR's have a [

]

Table 3-1 lists the main parameters for the fuel rod and components.

3.2 *RODEX4 and Statistical Methodology Summary*

RODEX4 evaluates the thermal-mechanical response of the fuel rod surrounded by coolant. The fuel rod model considers the fuel column, gap region, cladding, gas plena and the fill gas and released fission gases. The fuel rod is divided into axial and radial regions with conditions computed for each region. The operational conditions are controlled by the [

].

The heat conduction in the fuel and clad is [

].

Mechanical processes include [

].

As part of the methodology, fuel rod power histories are generated [

].

Since RODEX4 is a best-estimate code, uncertainties are taken into account by a [

]. Uncertainties taken

into account in the analysis are summarized as:

- Power measurement and operational uncertainties – [

].

- Manufacturing uncertainties – [

].

- Model uncertainties – [

].

[

].

3.3 Summary of Fuel Rod Design Evaluation

Results from the analyses are listed in Table 3-2. Summaries of the methods and codes used in the evaluation are provided in the following paragraphs. The design criteria also are listed along with references to the sections of the design criteria topical reports (References 1 and 2).

The fuel rod thermal and mechanical design criteria are summarized as follows.

- **Internal Hydriding.** The fabrication limit [] to preclude cladding failure caused by internal sources of hydrogen (Section 3.2.1 of Reference 1).
- **Cladding Collapse.** Clad creep collapse shall be prevented. [] (Section 3.1.1 of Reference 2).
- **Overheating of Fuel Pellets.** The fuel pellet centerline temperature during anticipated transients shall remain below the melting temperature (Section 3.1.2 of Reference 2).
- **Stress and Strain Limits.** [] during normal operation and during anticipated transients (Sections 3.1.1 and 3.1.2 of Reference 2).

Fuel rod cladding steady-state stresses are restricted to satisfy limits derived from the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code (Section 3.2.5.2 of Reference 1).
- **Cladding Fatigue.** The fatigue cumulative usage factor for clad stresses during normal operation and design cyclic maneuvers shall be below [] (Section 3.1.1 of Reference 2).
- **Cladding Oxidation, Hydriding and Crud Buildup.** Section 3.1.1 of Reference 2 limits the maximum cladding oxidation to less than [] to prevent clad corrosion failure. The oxidation limit is further reduced to [] (Reference 5).
- **Rod Internal Pressure.** The rod internal pressure is limited [] to ensure that significant outward clad creep does not occur and unfavorable hydride reorientation on cooldown does not occur (Section 3.1.1 of Reference 2).
- **Plenum Spring Design (Fuel Handling).** The rod plenum spring must maintain a force against the fuel column stack [] (Section 3.3.9 of Reference 1).

Cladding collapse, overheating of fuel, cladding transient strain, cladding cyclic fatigue, cladding oxidation, and rod pressure are evaluated []. Cladding stress and the plenum spring are evaluated [].

3.3.1 Internal Hydriding

The absorption of hydrogen by the cladding can result in cladding failure due to reduced ductility and formation of hydride platelets. Careful moisture control during fuel fabrication reduces the potential for hydrogen absorption on the inside of the cladding. The fabrication limit [] is verified by quality control inspection during fuel manufacturing.

3.3.2 Cladding Collapse

Creep collapse of the cladding and the subsequent potential for fuel failure is avoided in the design by limiting the gap formation due to fuel densification subsequent to pellet-clad contact. The size of the axial gaps which may form due to densification following first pellet-clad contact shall be less than [].

The evaluation is performed using the RODEX4 code and methodology. RODEX4 takes into account the []

].

Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.3 Overheating of Fuel Pellets

Fuel failure from the overheating of the fuel pellets is not allowed. The centerline temperature of the fuel pellets must remain below melting during normal operation and AOOs. The melting point of the fuel includes adjustments for []. Framatome establishes an LHGR limit to protect against fuel centerline melting during steady-state operation and during AOOs.

Fuel centerline temperature is evaluated using the RODEX4 code and methodology for both normal operating conditions and AOOs.

Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.4 Stress and Strain Limits

3.3.4.1 Pellet/Cladding Interaction

Cladding strain caused by transient-induced deformations of the cladding is calculated using the RODEX4 and methodology. [

]. The strain limit is 1%.

Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.4.2 Cladding Stress

Cladding stresses are calculated using solid mechanics elasticity solutions and finite element methods. The stresses are conservatively calculated for the individual loadings and are categorized as follows:

Category	Membrane	Bending
Primary	[	]
Secondary	[	]

Stresses are calculated at the cladding outer and inner diameter in the three principal directions for both beginning of life (BOL) and end of life (EOL) conditions. At EOL, the stresses due to mechanical bow and contact stress are decreased due to irradiation relaxation. The separate stress components are then combined, and the stress intensities for each category are compared to their respective limits.

The cladding-to-end cap weld stresses are evaluated for loadings from differential pressure, differential thermal expansion, rod weight, and plenum spring force.

The design limits are derived from the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel (B&PV) Code Section III (Reference 6) and the minimum specified material properties.

Table 3-3 lists the results in comparison to the limits for Beginning-of-Life (BOL) Hot conditions and End-of-Life (EOL) at both Hot and Cold conditions.

3.3.5 Fuel Densification and Swelling

Fuel densification and swelling are limited by the design criteria for fuel temperature, cladding strain, cladding collapse, and rod internal pressure criteria. Although there are no explicit criteria for fuel densification and swelling, the effect of these phenomena are included in the RODEX4 code and methodology.

3.3.6 Fatigue

Fuel rod cladding fatigue is calculated using the RODEX4 code and methodology. [

]. The CUF (cumulative usage factor) is summed for each of the axial regions of the fuel rod using Miner's rule. The axial region with the highest CUF is used in the subsequent [

]. The maximum CUF for the cladding must remain below [] to satisfy the design criterion. Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.7 Oxidation, Hydriding, and Crud Buildup

Cladding external oxidation is calculated using the RODEX4 code and methodology. The corrosion model includes an enhancement factor that is derived from poolside measurement data to obtain a fit of the expected oxide thickness. An uncertainty value for the model enhancement factor also is determined from the data. The model uncertainty is included as part of the [].

[

]

[].

In the event abnormal crud is observed at a plant, a specific analysis is required to address the higher crud level. An abnormal level of crud is defined by a formation that increases the calculated fuel average temperature by 25°C above the design basis calculation. The formation of crud is not calculated within RODEX4. Instead, an upper bound of expected crud based on plant observations is input by the use of the crud heat transfer coefficient. The corrosion model also takes into consideration the effect of the higher thermal resistance from the crud on the corrosion rate. A higher corrosion rate is therefore included as part of the abnormal crud evaluation. A similar specific analysis is required if an abnormal corrosion layer is observed instead of crud.

In the case of the Brunswick units, no additional crud is taken into account in the calculations because an abnormal crud or corrosion layer (beyond the design basis) has not been observed at the Brunswick units.

[].

Currently, [

].

The oxide limit is evaluated such that greater than [].

Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.8 Rod Internal Pressure

Fuel rod internal pressure is calculated using the RODEX4 code and methodology. The maximum rod pressure is calculated under steady-state conditions and also takes into account slow transients. Rod internal pressure is limited to [

]. The expected upper bound of rod pressure [] is calculated for comparison to the limit.

Table 3-2 lists the results for an equilibrium cycle operating in the MELLLA+ operating domain.

3.3.9 Plenum Spring Design (Fuel Assembly Handling)

The plenum spring must maintain a force against the fuel column to prevent [

]. This is accomplished by designing and verifying the spring force in relation to the fuel column weight. The plenum spring is designed such that the [

].

Table 3-1 Key Fuel Rod Design Parameters, ATRIUM 11 for Brunswick LAR

[

]

* The theoretical density of enriched $\text{UO}_2\text{-Cr}$ is 10.94 g/cm^3 while that for $\text{UO}_2\text{-Gd}_2\text{O}_3$ and naturally enriched UO_2 is 10.96 g/cm^3 .

Table 3-1 Key Fuel Rod Design Parameters, ATRIUM 11 for Brunswick LAR (cont'd)

[

]

Table 3-2 RODEX4 Fuel Rod Results Equilibrium Cycle—MELLLA+*

[

]

* Note that the results are provided up to fuel assembly discharge.

† Margin is defined as (limit – result).

Table 3-3 Cladding and Cladding-End Cap Steady-State Stresses

Description, Stress Category	Criteria	Result		
		BOL Cold	BOL Hot	EOL Hot
Cladding stress				
P _m (primary membrane stress)	[	]		
P _m + P _b (primary membrane + bending)	[	]		
P + Q (primary + secondary)	[	]		
Cladding-End Cap stress				
P _m + P _b	[	]		

4.0 REFERENCES

1. ANF-89-98(P)(A) Revision 1 and Supplement 1, *Generic Mechanical Design Criteria for BWR Fuel Designs*, Advanced Nuclear Fuels Corporation, May 1995.
2. BAW-10247PA Revision 0, *Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors*, AREVA NP Inc., February 2008.
3. ANP-10340P-A Revision 0. *Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods*, Framatome Inc., May 2018.
4. 38-9061815-000, Letter, U.S. Nuclear Regulatory Commission to CP&L, "Issuance of Amendment No. 153 to Facility Operating License No. DPR-62, Brunswick Steam Electric Plant, Unit 2, Regarding Fuel Cycle No. 8 – Reload Extended Burnup Fuel (TAC No. 66155)," September 20, 1988.
5. Letter from Farideh E. Saba (NRC) to Michael J. Annacone (CP&L), "BRUNSWICK STEAM ELECTRIC PLANT, UNITS 1 AND 2 – ISSUANCE OF AMENDMENTS REGARDING ADDITION OF ANALYTICAL METHODOLOGY TOPICAL REPORT TO TECHNICAL SPECIFICATION 5.6.5 (TAC NOS. ME3858 AND ME3859), ML11101A043, NRC 1109968, dated April 8, 2011.
6. *ASME Boiler and Pressure Vessel Code*, Section III, "Rules for Construction of Nuclear Power Plant Components," 1977.
7. O'Donnell, W.J., and B. F. Langer, "Fatigue Design Basis for Zircaloy Components," *Nuclear Science and Engineering*, Vol. 20, 1964.

**Affidavit for ANP-3668P, ATRIUM 11 Fuel Rod Thermal-
Mechanical Evaluation for Brunswick LAR**

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3668P, Revision 0 "ATRIUM 11 Fuel Rod Thermal-Mechanical Evaluation for Burnswick LAR," dated August 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

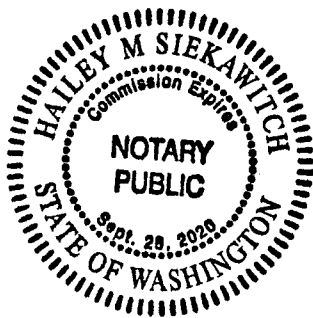
Alan S. May

SUBSCRIBED before me this 1st

day of August, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3661NP, Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design



Brunswick ATRIUM 11

Equilibrium Cycle

Fuel Cycle Design

ANP-3661NP
Revision 0

July 2018

Framatome Inc.

(c) 2018 Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 SUMMARY	2-1
3.0 FUEL CYCLE DESIGN.....	3-1
3.1 General Description	3-1
3.2 Control Rod Patterns and Thermal Limits	3-1
3.3 Hot Excess Reactivity and Cold Shutdown Margin	3-1
4.0 VOIDING IN THE CHANNEL BYPASS REGION	4-1
5.0 REFERENCES	5-1
Appendix A Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Step-through Depletion Summary, Control Rod Patterns and Core Average Axial Power and Exposure Distributions	A-1
Appendix B Elevation Views of the Brunswick Unit 1 ATRIUM 11 Equilibrium Design Fresh Reload Batch Fuel Assemblies.....	B-1
Appendix C Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Radial Exposure and Power Distributions	C-1

This document contains a total of 100 pages.

List of Tables

Table 2.1	Brunswick ATRIUM 11 Equilibrium Cycle Energy and Key Results Summary	2-2
Table 2.2	Brunswick ATRIUM 11 Equilibrium Cycle Design Assembly ID Range by Nuclear Fuel Type.....	2-3
Table 2.3	Brunswick ATRIUM 11 Equilibrium Cycle - Assumed MCPR Operating Limit	2-3
Table 2.4	Brunswick ATRIUM 11 Equilibrium Cycle - Assumed LHGR Limit	2-3
Table 2.5	Brunswick ATRIUM 11 Equilibrium Cycle - Assumed APLHGR Limit	2-4
Table 3.1	Cycle 28 Core Composition and Design Parameters	3-3
Table 3.2	Brunswick ATRIUM 11 Equilibrium Cycle Hot Operating Target k-eff Versus Cycle Exposure.....	3-4
Table 3.3	Brunswick ATRIUM 11 Equilibrium Cycle Cold Critical Target k-eff Versus Cycle Exposure.....	3-4
Table 3.4	Brunswick ATRIUM 11 Equilibrium Cycle Reactivity Margin Summary	3-5
Table 4.1	Maximum Bypass Voiding at LPRM Level D	4-1

List of Figures

Figure 2.1	Brunswick Unit 1 ATRIUM 11 Equilibrium Design Step-through k-eff versus Cycle Exposure Plot.....	2-5
Figure 2.2	Brunswick Unit 1 ATRIUM 11 Equilibrium Design Step-through Margin to Thermal versus Cycle Exposure Plot.....	2-5
Figure 3.1	Brunswick Unit 1 Equilibrium Design Reference Loading Pattern	3-6
Figure 3.2	Brunswick Unit 1 Equilibrium Design Upper Left Quarter Core Layout by Fuel Type.....	3-7

Nomenclature

Acronym	Definition
ACE	Framatome critical power correlation []
BOC	beginning of cycle
BOL	beginning of life
BWR	boiling water reactor
CSDM	cold shutdown margin
EOC	end of cycle
EOFP	end of full power capability
FFTR	final feedwater temperature reduction
GWd/MTU	gigawatt days per metric ton of initial uranium
HEXR	hot excess reactivity
LHGR	linear heat generation rate
MCPR	minimum critical power ratio
MICROBURN-B2	Framatome advanced BWR core simulator methodology with PPR capability
MWd/MTU	megawatt days per metric ton of initial uranium
NEOC	near end of cycle (MCPR limit exposure breakpoint)
NRC	(United States) Nuclear Regulatory Commission
PPR	Pin Power Reconstruction. The PPR methodology accounts for variation in local rod power distributions due to neighboring assemblies and control state. The local rod power distributions are reconstructed based on the actual flux solution for each statepoint.
R Value	the larger of zero or the shutdown margin at BOC minus the minimum calculated shutdown margin in the cycle
SLC	standby liquid control

1.0 INTRODUCTION

Framatome Inc. has performed an equilibrium fuel cycle design for the Brunswick Unit 1 reactor. This design uses the ATRIUM 11 fuel assembly and the MELLLA+ operating domain. This analysis has been performed with the approved Framatome neutronic modeling methodology (Reference 1). This analysis has also used the Reference 2 critical power methodology. The CASMO-4 lattice depletion code was used to generate nuclear data including cross sections and local power peaking factors. The MICROBURN-B2 three dimensional core simulator code, combined with the ACE critical power correlation, was used to model the core. The MICROBURN-B2 pin power reconstruction (PPR) model was used to determine the thermal margins presented in this report. Design results including projected control rod patterns and evaluations of thermal and reactivity margins are presented in this report. The following MICROBURN-B2 version 2 modeling features were also used in the analyses supporting this document:

- Control Blade Boron (^{10}B) Depletion
- Explicit neutronic treatment of spacer grids
- Explicit modeling of PLFR plenums
- Explicit modeling of the water rod flow

2.0 SUMMARY

The fresh batch size [] and batch average enrichment [] were determined to meet the energy requirements provided by Duke Energy in Reference 3. The loading of the fuel as described in this report results in a projected full power energy capability (including FFTR) of $1,961 \pm 30$ GWd ($19,349 \pm 300$ MWd/MTU). Beyond the nominal full power capability, the cycle has been designed to achieve an additional 40.9 GWd of additional energy via constant pressure power coastdown operation.

In order to obtain optimum operating flexibility, the projected control rod patterns were developed with acceptable margin to thermal limits. The cycle design calculations also demonstrate adequate hot excess reactivity and cold shutdown margin throughout the cycle. Key results from the design analysis are summarized in Table 2.1. Table 2.2 summarizes the assembly identification range by nuclear fuel type batch. Table 2.3, Table 2.4 and Table 2.5 contain the assumed thermal limits for this design. Figures 2.1 and 2.2 provide a summary of the cycle design step-through projection.

Table 2.1 Brunswick ATRIUM 11 Equilibrium Cycle Energy and Key Results Summary

Cycle Energy, GWd (Cycle Exposure, MWd/MTU)	
Previous Cycle (Cycle 27)	
• Nominal window EOC	2,002 (19,753)
• Short window EOC	1,958 (19,320)
Results Cycle (Cycle 28)	
• EOFP Energy (including FFTR)	1,961±30 (19,349±300)
• Power Coastdown Energy	41 (404)
• EOC Energy	2,002±30 (19,753±300)
Key Results	
BOC CSDM, %Δk/k (based on short EOC 27)	1.03
Minimum CSDM, %Δk/k (based on short EOC 27)	1.03
Cycle Exposure of Minimum CSDM, MWd/MTU (short basis)	0.0
Cycle Temperature of Minimum CSDM, °F (short basis)	68.0
Cycle R Value, %Δk/k (short basis)	0.00
Minimum SLC SDM, %Δk/k (based on short EOC 27)	1.16
Cycle Exposure of Minimum SLC SDM, MWd/MTU (short basis)	0.0
BOC HEXR, %Δk/k (based on nominal EOC 27)	2.00
Maximum HEXR, %Δk/k (based on nominal EOC 27)	2.04
Cycle Exposure of Maximum HEXR, MWd/MTU (nominal basis)	9,000.0
Minimum MAPLHGR Margin, %	14.4
Exposure of Minimum MAPLHGR Margin, MWd/MTU	8,000.0
Minimum LHGR Margin, %	9.5
Exposure of Minimum LHGR Margin, MWd/MTU	3,000.0
Minimum CPR Margin, %	5.7
Exposure of Minimum CPR Margin, MWd/MTU	2,500.0

Table 2.2 Brunswick ATRIUM 11 Equilibrium Cycle Design Assembly ID Range by Nuclear Fuel Type

Nuclear Fuel Type	Number of Assemblies	Assembly ID Range
1	[]	[]
2	[]	[]
3	[]	[]
4	[]	[]
5	[]	[]
6	[]	[]
7	[]	[]
8	[]	[]
9	[]	[]

Table 2.3 Brunswick ATRIUM 11 Equilibrium Cycle - Assumed MCPR Operating Limit

Table 2.4 Brunswick ATRIUM 11 Equilibrium Cycle - Assumed LHGR Limit

Table 2.5 Brunswick ATRIUM 11 Equilibrium Cycle - Assumed APLHGR Limit

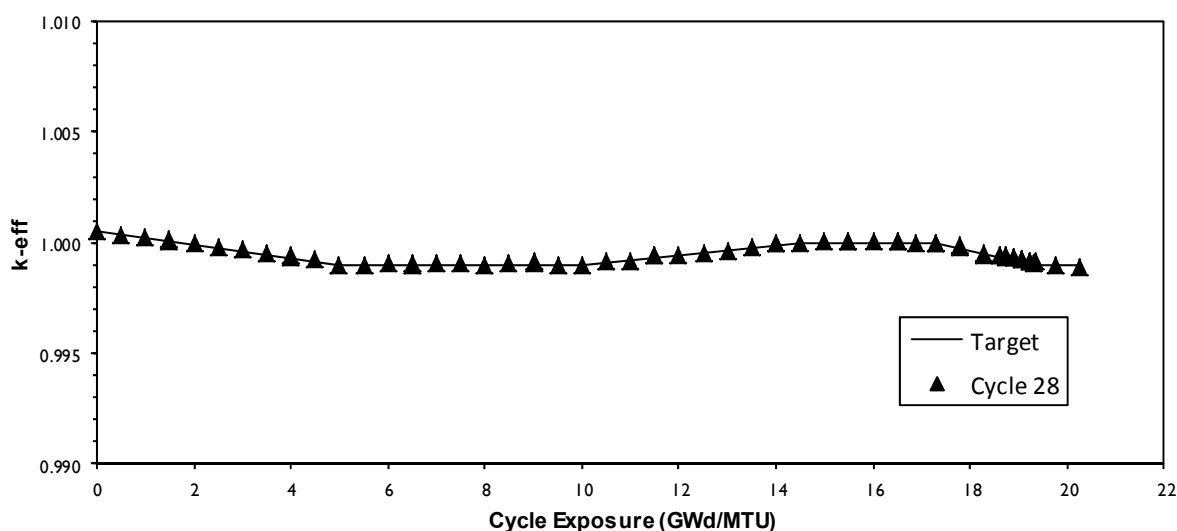


Figure 2.1 Brunswick Unit 1 ATRIUM 11 Equilibrium Design Step-through k_{eff} versus Cycle Exposure Plot

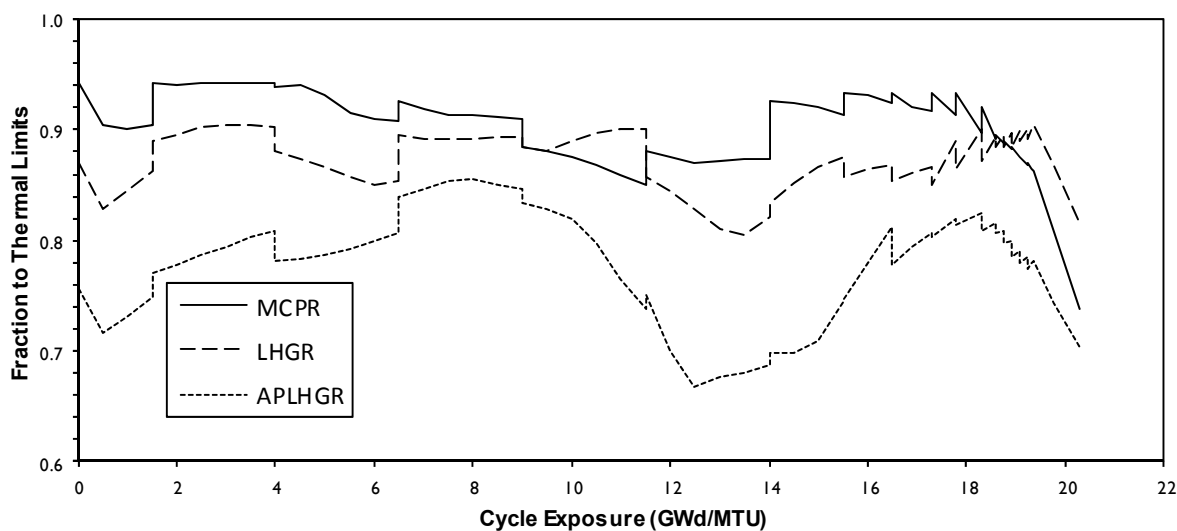


Figure 2.2 Brunswick Unit 1 ATRIUM 11 Equilibrium Design Step-through Margin to Thermal versus Cycle Exposure Plot

3.0 FUEL CYCLE DESIGN

3.1 *General Description*

Elevation views of the fresh reload fuel design axial enrichment and gadolinia distributions are shown in Appendix B, Figures B.1, B.2, and B.3. The loading pattern maintains quarter core symmetry within a scatter load fuel management scheme. This loading in conjunction with the control rod patterns presented in Appendix A shows acceptable power peaking and associated margins to limits. The analyses supporting this fuel cycle design were based on the core parameters shown in Table 3.1. Figures 3.1 and 3.2 along with Table 3.1 define the reference loading pattern used in the fuel cycle design. Key results for the cycle are summarized in Table 2.1. Exposure limits have been checked using the long cycle N-1 and long cycle N energy window of 703 EFPD. It has been confirmed that no rod-averaged exposure exceeds 60 GWd/MTU.

3.2 *Control Rod Patterns and Thermal Limits*

Projected control rod patterns and resultant key operating parameters including thermal margins are shown in Appendix A. The thermal margins presented in this report were determined using the MICROBURN-B2 3D core simulator PPR model to provide adequate margin to thermal limits. A detailed summary of the core parameters resulting from the step-through projection analysis is provided in Tables A.1 and A.2. Limiting results from the step-through are summarized in Table 2.1 and in Figure 2.2. The hot operating target k-eff versus cycle exposure which was determined to be appropriate for this evaluation is shown in Table 3.2. The k-eff and margin to limits results from the design cycle depletion are presented graphically in Figures 2.1 and 2.2. The k-eff values presented in Figure 2.1 and in Appendix A are not bias corrected. Selected exposure and radial power distributions from the design step-through are presented in Appendix C. The maximum core exit void fraction for the design step-through was determined to be 88.8%. The radial peaking factor does not exceed 1.60.

3.3 *Hot Excess Reactivity and Cold Shutdown Margin*

The cycle design calculations demonstrate adequate hot excess reactivity, SLC shutdown margin, and cold shutdown margin throughout the cycle. Key shutdown margin and R-Value results are presented in Table 2.1. The shutdown margin is in conformance with the Technical

Specification limit of $R + 0.38 \% \Delta k/k$ at BOC. The cold target k_{eff} versus exposure determined to be appropriate for calculation of cold shutdown margin is shown in Table 3.3. The core hot excess reactivity was calculated at full power with all rods out, 77.0 Mlb/hr core flow, with equilibrium xenon. Table 3.4 summarizes the reactivity margins versus cycle exposure, including the SLC shutdown margin for the cycle. Cold shutdown margin calculations have also been performed at temperatures above 68 °F to determine the shutdown margin at the most reactive temperature.

Table 3.1 Cycle 28 Core Composition and Design Parameters

Fuel Description	Cycle Loaded	Nuclear Fuel Type	Number of Assemblies
ATRIUM 11 []	26	1	[]
ATRIUM 11 []	26	2	[]
ATRIUM 11 []	26	3	[]
ATRIUM 11 []	27	4	[]
ATRIUM 11 []	27	5	[]
ATRIUM 11 []	27	6	[]
ATRIUM 11 []	28	7	[]
ATRIUM 11 []	28	8	[]
ATRIUM 11 []	28	9	[]
Number of Fuel Assemblies in Core			560
Total Number of Fresh Assemblies			[]
Total Core Mass, MTU			101.36
Rated Thermal Power Level, MW _t			2,923
Rated Core Flow, Mlb/hr			77.0
Reference Pressure, psia			1,045*
Reference Inlet Subcooling, Btu/lbm			21.3 [†]

* Value is representative of MICROBURN-B2 input for dome pressure at rated conditions and varies depending on core state point.

[†] Value is typically determined by MICROBURN-B2 using a heat balance method based on nominal feedwater temperature and other parameters identified in the cycle specific plant parameters document.

Table 3.2 Brunswick ATRIUM 11 Equilibrium Cycle Hot Operating Target k-eff Versus Cycle Exposure

Cycle Exposure (MWd/MTU)	Hot Operating k-eff*
0.0	1.0005
5,000.0	0.9990
10,000.0	0.9990
14,500.0	1.0000
17,300.0	1.0000
19,300.0	0.9990
20,300.0	0.9990

Table 3.3 Brunswick ATRIUM 11 Equilibrium Cycle Cold Critical Target k-eff Versus Cycle Exposure

Cycle Exposure (MWd/MTU)	Cold Critical k-eff*
0.0	0.9925
6,000.0	0.9895
20,300.0	0.9895

* Values are linearly interpolated between cycle exposure points.

Table 3.4 Brunswick ATRIUM 11 Equilibrium Cycle Reactivity Margin Summary

Cycle Exposure (MWd/MTU)	Cold Shutdown Margin*, † (% Δk/k)	SLC Cold Shutdown Margin‡ (%Δk/k)	Hot Excess Reactivity§ (%Δk/k)
0	1.03**	1.16	2.00
1,500	1.85	1.69	1.82
4,000	1.95	1.42	1.99
6,500	2.18	1.38	2.00
9,000	1.83	1.32	2.04
10,000	1.48	1.41	2.02
11,000	1.29	1.58	1.94
12,000	1.34	1.94	1.83
13,000	1.50	2.40	1.72
14,000	1.77	2.96	1.59
16,500	2.21	4.14	1.07
17,300	2.08	4.34	0.72
18,300	1.90	4.74	0.15
18,900	1.80	5.01	--
19,349	1.70	5.23	--
19,753	1.67	5.46	--

NOTE: Values for cold shutdown margin are shown in **bold font** if the most reactive temperature is greater than 68 °F.

* Based on short window EOC 27.

† This includes the center control cell using the EOC cold keff target in accordance with Reference 3 item 7d.

‡ Based on short window EOC 27, calculated at 360.8 °F ARO conditions.

§ Based on nominal EOC 27.

** This is the center control cell with the lowest cold keff target. (The shutdown margin without this conservative approach is 1.18 %Δk/k at BOC).

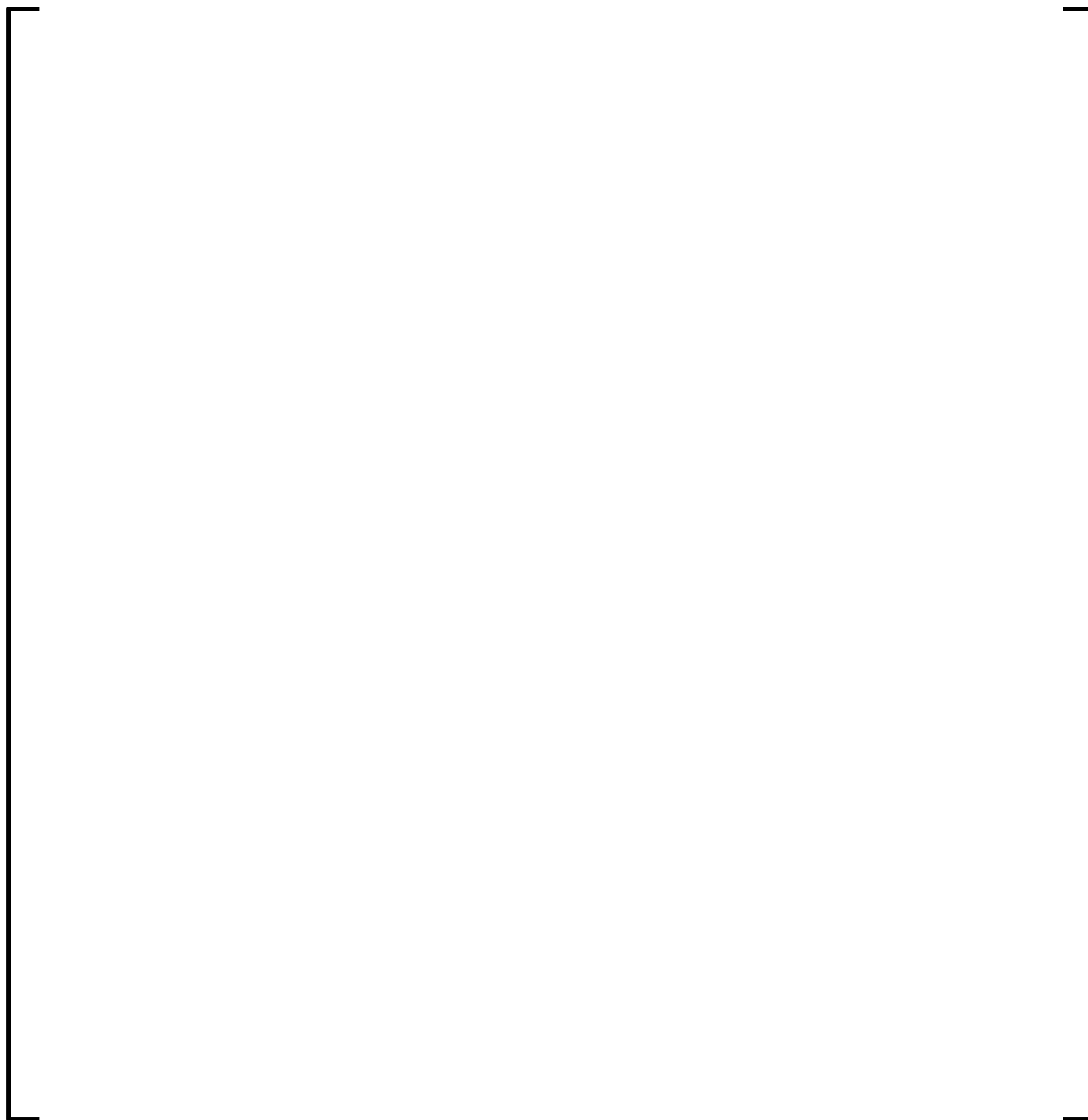


**Figure 3.1 Brunswick Unit 1 Equilibrium Design Reference Loading
Pattern**

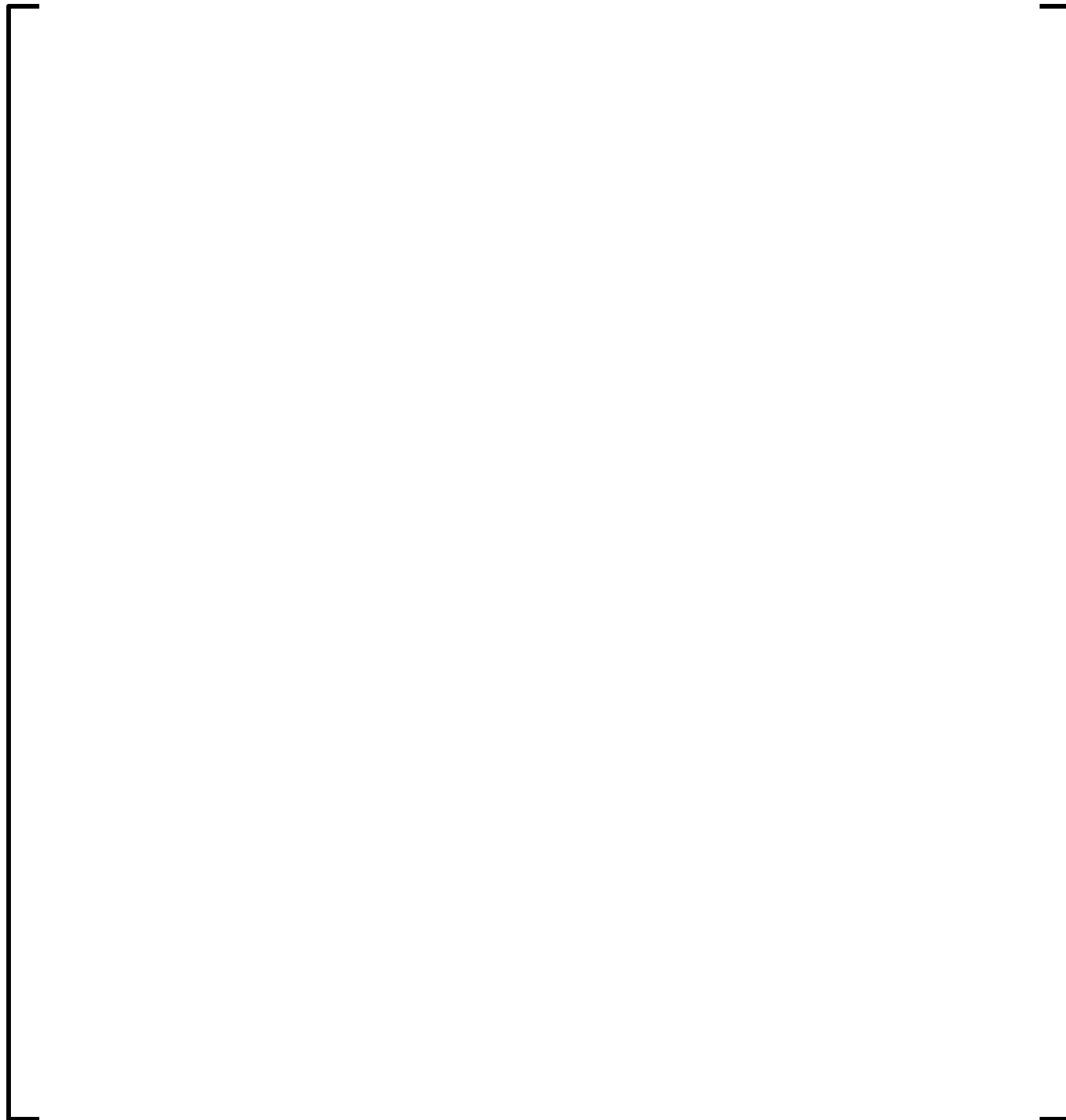


**Figure 3.2 Brunswick Unit 1 Equilibrium Design Upper Left Quarter Core
Layout by Fuel Type**

4.0 VOIDING IN THE CHANNEL BYPASS REGION

To demonstrate compliance with the NRC's requirement that there be less than 5% bypass voiding around the LPRMs (see Section 5.1.1.5.1 of Reference 5), the bypass void level has been evaluated throughout the equilibrium cycle. The maximum bypass void value applicable to the equilibrium cycle design [

]

Table 4.1 Maximum Bypass Voiding at LPRM Level D

Power (%), Flow (%) Condition	Cycle Exposure (GWd/MTU)	Bypass Void (%)
[		]

Note: There is no bypass voiding at LPRM levels A, B, or C.

* [

† [

]

]

5.0 REFERENCES

1. EMF-2158(P)(A) Revision 0, Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2, Siemens Power Corporation, October, 1999.
2. ANP-10335P-A, Revision 0, ACE/ATRIUM 11 Critical Power Correlation, Framatome Inc., May 2018.
3. FS1-0033768, Revision 1.0, BRUNSWICK ATRIUM-11 EQUILIBRIUM CYCLE RELOAD SCOPE DOCUMENT, AREVA Inc., September 2017.
4. FS1-0033607, Revision 1.0, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Target K-Effective and Operating Limit Selection, Framatome Inc., January 2018.
5. Safety Evaluation By The Office Of Nuclear Reactor Regulation Licensing Topical Report NEDC-33006P, "General Electric Boiling Water Reactor Maximum Extended Load Line Limit Analysis Plus", General Electric Hitachi Nuclear Energy America, LLC, October 2008 (ADAMS Accession Number ML 081130008).
6. ANP-3667P Revision 0, Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report, Framatome Inc., March 2018.

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page A-1

**Appendix A Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Step-through Depletion
Summary, Control Rod Patterns and Core Average Axial Power and Exposure
Distributions**

Table A.1 Brunswick ATRIUM 11 Equilibrium Cycle Design Depletion Summary

Cycle Exposure (GWD/MT)	Calculated K-eff	Control Rod Density	Total Core Power MWt	Total Core Flow (Mlb/hr)	Ref. Pressure (psia)	Inlet Sub- Cooling (Btu/lb)	Void Fraction	Core Minimum CPR	Core Maximum LHGR (kW/ft)	Core Maximum APLHGR (kW/ft)
0.000	1.00052	5.96	2923.0	67.76	1044.69	24.62	0.523	1.422	12.18	8.69
0.500	1.00037	5.96	2923.0	73.92	1044.74	22.34	0.502	1.482	11.51	8.25
1.000	1.00022	5.96	2923.0	74.31	1044.75	22.20	0.502	1.488	11.67	8.47
1.500	1.00013	5.96	2923.0	73.15	1044.74	22.60	0.505	1.483	11.81	8.74
1.501	1.00009	5.35	2923.0	70.07	1044.71	23.72	0.518	1.422	12.26	8.98
2.000	0.99994	5.35	2923.0	68.92	1044.70	24.17	0.522	1.423	12.26	9.11
2.500	0.99978	5.35	2923.0	67.76	1044.69	24.63	0.526	1.421	12.28	9.25
3.000	0.99967	5.35	2923.0	66.84	1044.68	25.01	0.530	1.421	12.31	9.40
3.500	0.99953	5.35	2923.0	66.22	1044.67	25.27	0.532	1.422	12.31	9.53
4.000	0.99931	5.35	2923.0	65.45	1044.67	25.60	0.535	1.422	12.28	9.62
4.001	0.99939	5.69	2923.0	67.76	1044.69	24.63	0.520	1.427	11.99	9.33
4.500	0.99923	5.69	2923.0	67.38	1044.68	24.78	0.522	1.425	11.88	9.38
5.000	0.99897	5.69	2923.0	66.99	1044.68	24.94	0.523	1.438	11.78	9.44
5.500	0.99899	5.69	2923.0	67.38	1044.68	24.79	0.523	1.463	11.67	9.51
6.000	0.99905	5.69	2923.0	67.76	1044.69	24.63	0.522	1.472	11.57	9.59
6.500	0.99899	5.69	2923.0	67.76	1044.69	24.63	0.522	1.476	11.60	9.69
6.501	0.99903	6.33	2923.0	67.76	1044.69	24.63	0.526	1.447	12.18	10.07
7.000	0.99904	6.33	2923.0	68.14	1044.69	24.47	0.526	1.460	12.13	10.15
7.500	0.99908	6.33	2923.0	68.14	1044.69	24.47	0.527	1.466	12.12	10.24
8.000	0.99902	6.33	2923.0	67.76	1044.69	24.63	0.528	1.465	12.10	10.27
8.500	0.99905	6.33	2923.0	67.76	1044.69	24.63	0.528	1.470	12.10	10.17
9.000	0.99905	6.33	2923.0	67.76	1044.69	24.63	0.527	1.474	12.03	10.14
9.001	0.99912	6.02	2923.0	67.76	1044.69	24.63	0.533	1.516	11.91	9.97
9.500	0.99900	6.02	2923.0	67.76	1044.69	24.63	0.530	1.522	11.68	9.86
10.000	0.99897	6.02	2923.0	68.14	1044.69	24.47	0.526	1.531	11.35	9.69
10.500	0.99913	6.02	2923.0	69.30	1044.70	24.02	0.518	1.544	10.94	9.38
11.000	0.99920	6.02	2923.0	70.46	1044.71	23.58	0.508	1.559	10.66	8.93
11.500	0.99939	6.02	2923.0	72.00	1044.72	23.01	0.497	1.574	10.34	8.60
11.501	0.99940	5.23	2923.0	68.14	1044.69	24.47	0.509	1.521	10.34	8.75
12.000	0.99944	5.23	2923.0	69.68	1044.70	23.87	0.496	1.531	9.59	8.16
12.500	0.99956	5.23	2923.0	71.22	1044.72	23.29	0.483	1.539	9.34	7.84
13.000	0.99966	5.23	2923.0	72.76	1044.73	22.74	0.469	1.538	9.42	7.88
13.500	0.99977	5.23	2923.0	74.31	1044.75	22.21	0.455	1.535	9.45	7.95
14.000	0.99996	5.23	2923.0	76.23	1044.76	21.57	0.441	1.533	9.43	7.98
14.001	1.00002	5.05	2923.0	73.15	1044.74	22.60	0.442	1.446	9.57	8.09
14.500	1.00002	5.05	2923.0	74.84	1044.75	22.02	0.428	1.451	9.66	8.08
15.000	1.00008	5.05	2923.0	76.61	1044.77	21.45	0.413	1.457	9.87	8.46
15.500	1.00006	5.05	2923.0	78.54	1044.78	20.85	0.399	1.466	10.11	8.81
15.501	1.00005	4.84	2923.0	73.92	1044.74	22.33	0.405	1.435	9.99	8.85
16.000	1.00008	4.84	2923.0	76.23	1044.76	21.57	0.389	1.438	10.36	9.15
16.500	1.00005	4.84	2923.0	79.31	1044.79	20.62	0.373	1.449	10.76	9.63
16.501	1.00006	2.74	2923.0	70.46	1044.71	23.56	0.407	1.434	10.15	9.10
16.900	1.00002	2.74	2923.0	74.31	1044.75	22.21	0.390	1.457	10.27	9.26
17.300	0.99998	2.74	2923.0	78.54	1044.78	20.86	0.374	1.473	10.34	9.37
17.301	1.00001	2.46	2923.0	73.77	1044.74	22.38	0.380	1.446	10.37	9.40
17.800	0.99987	2.46	2923.0	80.46	1044.80	20.29	0.358	1.476	10.64	9.54
17.801	0.99983	1.22	2923.0	72.38	1044.73	22.86	0.377	1.446	10.54	9.52
18.300	0.99952	1.22	2923.0	80.46	1044.80	20.29	0.354	1.503	10.57	9.57
18.301	0.99947	0.00	2923.0	73.15	1044.74	22.59	0.373	1.468	10.48	9.42
18.600	0.99945	0.00	2923.0	79.31	1044.79	20.63	0.357	1.515	10.46	9.45
18.601	0.99947	0.00	2923.0	76.61	1044.70	22.91	0.357	1.506	10.37	9.36
18.750	0.99940	0.00	2923.0	79.69	1044.70	21.91	0.349	1.521	10.38	9.37
18.751	0.99935	0.00	2923.0	76.61	1044.70	25.01	0.348	1.517	10.22	9.22
18.900	0.99930	0.00	2923.0	79.69	1044.70	23.93	0.340	1.531	10.25	9.26
18.901	0.99938	0.00	2923.0	76.23	1044.70	27.81	0.339	1.528	10.05	9.08
19.080	0.99925	0.00	2923.0	79.69	1044.70	26.48	0.330	1.543	10.10	9.14
19.081	0.99921	0.00	2923.0	77.00	1044.70	29.37	0.329	1.541	9.95	9.00
19.220	0.99916	0.00	2923.0	80.08	1044.70	28.13	0.321	1.555	10.00	9.04
19.221	0.99912	0.00	2923.0	77.39	1044.70	30.99	0.321	1.551	9.86	8.92
19.320	0.99910	0.00	2923.0	79.69	1044.70	30.01	0.315	1.562	9.95	8.95
19.349	0.99916	0.00	2923.0	80.46	1044.70	29.69	0.314	1.565	9.98	8.97
19.753	0.99900	0.00	2708.4	80.46	1044.70	27.35	0.295	1.670	9.55	8.53
20.272	0.99886	0.00	2434.3	80.46	1044.70	24.36	0.271	1.829	8.98	8.02

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page A-3

Table A.2 Brunswick Unit 1 Cycle 28 Design Depletion Thermal Margin Summary

Cycle Exposure (Gwd/MT)	Calculated K-eff	Control Rod Density	Core Limiting CPR	of Limiting CPR	Limiting LHGR (kW/ft)	of Limiting LHGR	Limiting APLHGR (kW/ft)	of Limiting APLHGR
0.000	1.00052	5.961	1.422	0.942	12.18	0.870	8.69	0.756
0.500	1.00037	5.961	1.482	0.904	11.51	0.828	7.83	0.717
1.000	1.00022	5.961	1.488	0.900	11.67	0.845	7.93	0.731
1.500	1.00013	5.961	1.483	0.904	11.81	0.862	8.74	0.749
1.501	1.00009	5.353	1.422	0.942	12.26	0.889	8.98	0.771
2.000	0.99994	5.353	1.423	0.941	12.26	0.895	9.11	0.778
2.500	0.99978	5.353	1.421	0.943	12.28	0.903	9.25	0.787
3.000	0.99967	5.353	1.421	0.943	12.31	0.905	9.40	0.795
3.500	0.99953	5.353	1.422	0.942	12.31	0.905	9.53	0.803
4.000	0.99931	5.353	1.422	0.942	12.28	0.903	8.43	0.808
4.001	0.99939	5.687	1.427	0.939	11.99	0.881	9.33	0.782
4.500	0.99923	5.687	1.425	0.940	11.88	0.873	9.38	0.783
5.000	0.99897	5.687	1.438	0.932	11.78	0.866	9.44	0.787
5.500	0.99899	5.687	1.463	0.916	11.67	0.858	9.51	0.792
6.000	0.99905	5.687	1.472	0.910	11.57	0.851	9.59	0.799
6.500	0.99899	5.687	1.476	0.908	11.60	0.853	9.69	0.807
6.501	0.99903	6.326	1.447	0.926	12.18	0.896	10.07	0.839
7.000	0.99904	6.326	1.460	0.918	12.13	0.892	10.15	0.846
7.500	0.99908	6.326	1.466	0.914	12.12	0.891	10.24	0.854
8.000	0.99902	6.326	1.465	0.914	12.10	0.892	10.27	0.856
8.500	0.99905	6.326	1.470	0.912	11.98	0.894	10.17	0.851
9.000	0.99905	6.326	1.474	0.909	12.03	0.894	10.14	0.846
9.001	0.99912	6.022	1.516	0.884	11.81	0.885	9.97	0.833
9.500	0.99900	6.022	1.522	0.880	7.90	0.881	9.83	0.829
10.000	0.99897	6.022	1.531	0.875	7.67	0.889	9.69	0.819
10.500	0.99913	6.022	1.544	0.868	7.53	0.897	9.38	0.798
11.000	0.99920	6.022	1.559	0.859	7.36	0.901	8.93	0.766
11.500	0.99939	6.022	1.574	0.851	7.16	0.901	6.92	0.739
11.501	0.99940	5.231	1.521	0.881	6.72	0.858	8.67	0.750
12.000	0.99944	5.231	1.531	0.875	6.44	0.845	8.06	0.701
12.500	0.99956	5.231	1.539	0.870	6.16	0.829	6.33	0.668
13.000	0.99966	5.231	1.538	0.871	6.07	0.811	6.37	0.677
13.500	0.99977	5.231	1.535	0.873	6.41	0.805	7.94	0.681
14.000	0.99996	5.231	1.533	0.874	6.38	0.821	6.46	0.688
14.001	1.00002	5.049	1.446	0.926	6.61	0.834	8.09	0.698
14.500	1.00002	5.049	1.451	0.924	6.58	0.852	8.04	0.698
15.000	1.00008	5.049	1.457	0.920	6.52	0.866	8.46	0.710
15.500	1.00006	5.049	1.466	0.914	6.42	0.876	8.81	0.745
15.501	1.00005	4.836	1.435	0.934	6.28	0.857	8.85	0.748
16.000	1.00008	4.836	1.438	0.932	6.17	0.865	9.15	0.779
16.500	1.00005	4.836	1.449	0.925	6.04	0.868	8.31	0.813
16.501	1.00006	2.737	1.434	0.934	6.07	0.853	9.07	0.778
16.900	1.00002	2.737	1.457	0.920	5.98	0.861	9.21	0.794
17.300	0.99998	2.737	1.473	0.917	5.91	0.867	9.29	0.806
17.301	1.00001	2.464	1.446	0.933	7.41	0.851	9.32	0.803
17.800	0.99987	2.464	1.476	0.914	8.33	0.890	9.45	0.820
17.801	0.99983	1.217	1.446	0.934	8.09	0.864	9.52	0.814
18.300	0.99952	1.217	1.503	0.898	8.21	0.901	9.54	0.825
18.301	0.99947	0.000	1.468	0.920	7.07	0.871	9.42	0.809
18.600	0.99945	0.000	1.515	0.891	7.98	0.893	9.45	0.815
18.601	0.99947	0.000	1.506	0.896	7.91	0.885	9.36	0.807
18.750	0.99940	0.000	1.521	0.888	7.94	0.896	9.36	0.809
18.751	0.99935	0.000	1.517	0.890	7.84	0.885	9.22	0.797
18.900	0.99930	0.000	1.531	0.882	7.88	0.897	9.23	0.800
18.901	0.99938	0.000	1.528	0.884	7.77	0.884	9.06	0.785
19.080	0.99925	0.000	1.543	0.875	7.82	0.899	9.11	0.791
19.081	0.99921	0.000	1.541	0.876	7.73	0.889	8.97	0.779
19.220	0.99916	0.000	1.555	0.868	7.78	0.901	9.02	0.785
19.221	0.99912	0.000	1.551	0.870	7.70	0.892	8.90	0.774
19.320	0.99910	0.000	1.562	0.864	7.74	0.901	8.91	0.779
19.349	0.99916	0.000	1.565	0.863	7.75	0.904	8.93	0.781
19.753	0.99900	0.000	1.670	0.809	7.27	0.868	7.28	0.744
20.272	0.99886	0.000	1.829	0.738	6.63	0.816	6.82	0.703

Cycle:	28	Core Average Exposure: MWd/MTU	17552.9
Exposure: MWd/MTU (GWd)	0.0 (0.00)		
Delta E: MWd/MTU, (GWd)	0.0 (0.00)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.62		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.130 3.186 1 0.299 0.300 17 52
		24	0.318 7.610 2 0.475 0.691 47 16
		23	0.483 11.562 3 0.447 0.561 47 14
		22	0.578 13.718 4 1.225 1.363 31 26
		21	0.641 15.224 5 0.996 1.298 39 18
		20	0.703 16.421 6 0.844 0.959 25 48
		19	0.755 17.253 7 1.269 1.384 23 32
		18	0.810 18.075 8 1.087 1.294 39 16
		17	0.865 18.820 9 1.070 1.097 45 22
		16	0.931 19.128
		15	1.032 19.268
		14	1.104 20.193
		13	1.165 20.890
		12	1.230 21.660
		11	1.276 22.018
		10	1.380 21.032
		9	1.400 21.420
		8	1.398 21.783
		7	1.431 22.246
		6	1.482 22.517*
		5	1.539 22.227
		4	1.594* 21.542
		3	1.526 19.705
		2	0.959 11.996
		Bottom 1	0.271 3.831
Control Rod Density: %	5.96		
k-effective:	1.00052		
Void Fraction:	0.523		
Core Delta-P: psia	19.619	% AXIAL TILT	-29.932 -12.506
Core Plate Delta-P: psia	15.067	AVG BOT 8ft/12ft	1.1892 1.0781
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.95	Active Channel Flow: Mlb/hr	56.75
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00034		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.384	7	23	32	1.422	0.942	7	23	8.69	0.756	0.0	7	19	12.18	0.870	0.0
1.382	7	21	30	1.422	0.942	7	31	8.64	0.751	0.0	7	25	12.10	0.864	0.0
1.368	7	25	34	1.432	0.936	7	25	8.63	0.750	0.0	7	21	12.04	0.860	0.0
1.365	7	33	26	1.437	0.933	7	33	8.61	0.749	0.0	7	29	12.00	0.857	0.0
1.363	4	31	26	1.439	0.931	7	25	8.50	0.740	0.0	7	17	11.96	0.854	0.0
1.354	4	25	32	1.444	0.928	7	29	8.50	0.739	0.0	7	23	11.88	0.848	0.0
1.349	7	23	36	1.446	0.927	7	29	8.45	0.734	0.0	7	13	11.78	0.841	0.0
1.348	7	23	28	1.450	0.924	7	35	8.04	0.731	30.8	4	17	11.70	0.836	0.0
1.347	7	25	30	1.467	0.914	8	11	8.06	0.731	30.2	4	27	11.62	0.830	0.0
1.345	7	35	24	1.468	0.913	7	27	8.40	0.730	0.0	7	15	11.61	0.829	0.0

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.1 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 0.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-5

Cycle:	28	Core Average Exposure: MWd/MTU	18052.5
Exposure: MWd/MTU (GWd)	500.0 (50.68)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.34		
Flow: Mlb/hr	73.92 (96.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.139 3.259 1 0.298 0.299 17 52
		24	0.341 7.790 2 0.475 0.691 47 16
		23	0.518 11.837 3 0.446 0.559 47 14
		22	0.618 14.048 4 1.227 1.366 31 26
		21	0.682 15.589 5 0.999 1.301 39 18
		20	0.743 16.821 6 0.848 0.964 25 48
		19	0.792 17.680 7 1.266 1.380 23 32
		18	0.843 18.532 8 1.085 1.290 39 16
		17	0.895 19.306 9 1.068 1.095 45 22
		16	0.955 19.637
		15	1.053 19.797
		14	1.119 20.756
		13	1.176 21.483
		12	1.237 22.284
		11	1.280 22.665
		10	1.382 21.662
		9	1.402 22.053
		8	1.397 22.415
		7	1.423 22.890
		6	1.459 23.181*
		5	1.490 22.913
		4	1.508* 22.243
		3	1.415 20.368
		2	0.883 12.410
		Bottom 1	0.250 3.961
			% AXIAL TILT -26.987 -12.746
			AVG BOT 8ft/12ft 1.1723 1.0795
Control Rod Density: %	5.96		
k-effective:	1.00037		
Void Fraction:	0.502		
Core Delta-P: psia	22.087		
Core Plate Delta-P: psia	17.530		
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	64.48	Active Channel Flow: Mlb/hr	62.14
Total Bypass Flow (%):	12.8	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00043		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.380	7	23	32	1.482	0.904	7	23	32	7.83	0.717	31.8	4	17	28	5	11.51	0.828	1.5	7	19	28	5
1.378	7	31	24	1.483	0.904	7	31	24	7.85	0.716	31.2	4	27	18	5	11.46	0.824	1.5	8	11	36	4
1.366	7	25	34	1.489	0.900	7	25	34	8.25	0.715	1.1	7	19	28	4	11.43	0.822	1.5	7	27	20	5
1.366	4	31	26	1.494	0.897	7	33	26	8.25	0.714	1.1	7	21	30	4	11.38	0.818	1.5	8	13	38	4
1.364	7	33	26	1.495	0.897	7	25	30	8.23	0.712	1.0	7	29	22	4	11.33	0.815	1.5	8	37	14	4
1.358	4	25	32	1.502	0.892	7	29	26	8.20	0.710	1.1	7	25	34	4	11.28	0.812	1.5	8	35	12	4
1.345	7	23	28	1.509	0.888	7	29	36	8.11	0.702	1.0	7	17	30	4	11.18	0.804	1.5	7	35	30	5
1.345	7	23	36	1.516	0.884	7	35	30	8.10	0.701	1.0	7	23	36	4	11.18	0.804	1.5	7	29	36	5
1.344	7	25	30	1.531	0.876	8	11	36	8.04	0.696	1.0	7	13	34	4	11.15	0.802	1.5	7	21	30	4
1.341	7	35	24	1.532	0.875	7	27	38	7.66	0.693	29.9	4	21	28	4	11.08	0.797	1.4	7	29	22	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.2 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-6

Cycle:	28	Core Average Exposure: MWd/MTU	18552.4
Exposure: MWd/MTU (GWd)	1000.0 (101.36)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.20		
Flow: Mlb/hr	74.31 (96.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.140 3.335 1 0.294 0.295 17 52
		24	0.343 7.977 2 0.470 0.687 47 16
		23	0.519 12.122 3 0.441 0.554 47 14
		22	0.617 14.389 4 1.226 1.364 31 26
		21	0.679 15.965 5 0.996 1.299 39 18
		20	0.738 17.229 6 0.843 0.959 25 48
		19	0.784 18.115 7 1.273 1.389 23 32
		18	0.833 18.994 8 1.087 1.296 39 16
		17	0.882 19.796 9 1.071 1.099 45 22
		16	0.941 20.148
		15	1.037 20.326
		14	1.104 21.318
		13	1.161 22.074
		12	1.224 22.908
		11	1.270 23.310
		10	1.377 22.290
		9	1.407 22.687
		8	1.412 23.049
		7	1.445 23.538
		6	1.484 23.846*
		5	1.512 23.592
		4	1.522* 22.929
		3	1.423 21.008
		2	0.892 12.809
		Bottom 1	0.255 4.087
Control Rod Density: %	5.96		
k-effective:	1.00022		
Void Fraction:	0.502		
Core Delta-P: psia	22.283	% AXIAL TILT	-27.713 -12.942
Core Plate Delta-P: psia	17.725	AVG BOT 8ft/12ft	1.1745 1.0806
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	64.82	Active Channel Flow: Mlb/hr	62.46
Total Bypass Flow (%):	12.8	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.389	7	23	32	1.488	0.900	7	23	32	7.93	0.731	32.8	4	17	28	5	11.67	0.845	3.0	7	19	28	5
1.387	7	31	24	1.488	0.900	7	31	24	8.47	0.730	2.1	7	19	28	5	11.59	0.839	2.9	7	27	20	5
1.375	7	25	34	1.496	0.896	7	25	34	7.95	0.730	32.2	4	27	18	5	11.49	0.832	3.0	8	11	36	4
1.372	7	33	26	1.502	0.892	7	25	30	8.44	0.727	2.1	7	25	34	5	11.41	0.827	3.0	8	13	38	4
1.364	4	31	26	1.502	0.892	7	33	26	8.40	0.724	2.1	7	21	30	4	11.36	0.823	2.9	8	37	14	4
1.356	4	25	32	1.509	0.888	7	29	26	8.38	0.722	2.1	7	29	22	4	11.34	0.821	2.9	7	35	30	5
1.354	7	29	26	1.513	0.886	7	29	36	8.25	0.711	2.1	7	17	30	4	11.33	0.820	2.9	7	29	36	5
1.353	7	23	36	1.520	0.882	7	35	30	8.24	0.710	2.1	7	23	36	4	11.32	0.820	2.9	8	35	12	4
1.352	7	25	30	1.538	0.872	7	27	38	7.73	0.704	30.9	4	21	28	4	11.26	0.815	2.9	7	21	30	4
1.349	7	35	24	1.539	0.871	8	11	36	8.15	0.702	2.0	7	13	34	4	11.18	0.810	2.8	7	37	28	5

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.3 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 1,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	19052.3
Exposure: MWd/MTU (GWd)	1500.0 (152.05)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.60		
Flow: Mlb/hr	73.15 (95.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.141 3.411 1 0.291 0.292 17 52
		24	0.343 8.164 2 0.466 0.683 47 16
		23	0.517 12.406 3 0.437 0.550 47 14
		22	0.614 14.729 4 1.223 1.360 31 26
		21	0.673 16.338 5 0.993 1.296 39 18
		20	0.730 17.634 6 0.837 0.954 25 48
		19	0.774 18.545 7 1.280 1.397 23 32
		18	0.821 19.451 8 1.092 1.302 39 16
		17	0.869 20.280 9 1.076 1.104 45 22
		16	0.927 20.652
		15	1.021 20.848
		14	1.087 21.873
		13	1.146 22.659
		12	1.211 23.524
		11	1.259 23.950
		10	1.371 22.917
		9	1.410 23.323
		8	1.428 23.691
		7	1.469 24.196
		6	1.512 24.523*
		5	1.537 24.282
		4	1.540* 23.621
		3	1.437 21.654
		2	0.903 13.213
		Bottom 1	0.260 4.215
Control Rod Density: %	5.96		
k-effective:	1.00013		
Void Fraction:	0.505		
Core Delta-P: psia	21.820	% AXIAL TILT	-28.582 -13.149
Core Plate Delta-P: psia	17.264	AVG BOT 8ft/12ft	1.1777 1.0817
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	63.77	Active Channel Flow: Mlb/hr	61.44
Total Bypass Flow (%):	12.8	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00050		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.397	7	23	32	1.483	0.904	7	23	32	8.74	0.749	3.2	7	19	28	5	11.81	0.862	4.5	7	19	28	5
1.395	7	31	24	1.483	0.904	7	31	24	8.70	0.746	3.1	7	25	34	5	11.73	0.856	4.4	7	27	20	5
1.382	7	25	34	1.493	0.897	7	25	34	8.02	0.745	33.8	4	17	28	5	11.52	0.841	4.4	8	11	36	4
1.380	7	33	26	1.499	0.894	7	33	26	8.05	0.744	33.2	4	27	18	5	11.48	0.837	4.3	7	35	30	5
1.361	7	23	36	1.499	0.894	7	25	30	8.55	0.733	3.1	7	21	30	4	11.47	0.836	4.3	7	29	36	5
1.361	7	29	26	1.507	0.889	7	29	26	8.53	0.731	3.1	7	29	22	4	11.44	0.835	4.4	8	13	38	4
1.360	4	31	26	1.508	0.889	7	29	36	8.39	0.720	3.1	7	17	30	4	11.39	0.831	4.4	8	37	14	4
1.360	7	25	30	1.514	0.885	7	35	30	8.38	0.719	3.1	7	23	36	4	11.36	0.829	4.4	8	35	12	4
1.356	7	35	24	1.533	0.874	7	27	38	7.75	0.717	33.1	4	21	26	5	11.35	0.828	4.3	7	21	30	4
1.352	4	25	32	1.537	0.872	8	11	36	8.27	0.710	3.1	7	15	28	4	11.31	0.825	4.3	7	37	28	5

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.4 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 1,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-8

Cycle:	28	Core Average Exposure: MWd/MTU	19053.3
Exposure: MWd/MTU (GWd)	1501.0 (152.15)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.72		
Flow: Mlb/hr	70.07 (91.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.132 3.411 1 0.303 0.304 17 52
		24	0.321 8.165 2 0.469 0.676 15 48
		23	0.484 12.406 3 0.447 0.526 47 14
		22	0.575 14.730 4 1.181 1.366 25 28
		21	0.633 16.338 5 1.018 1.267 23 42
		20	0.690 17.635 6 0.888 1.075 25 48
		19	0.737 18.546 7 1.210 1.402 33 26
		18	0.790 19.452 8 1.135 1.352 41 26
		17	0.845 20.281 9 1.175 1.199 23 46
		16	0.913 20.653
		15	1.015 20.849
		14	1.089 21.874
		13	1.152 22.660
		12	1.220 23.525
		11	1.271 23.951
		10	1.384 22.918
		9	1.424 23.324
		8	1.443 23.692
		7	1.484 24.197
		6	1.530 24.524*
		5	1.558 24.283
		4	1.570* 23.623
		3	1.500 21.655
		2	0.960 13.213
		Bottom 1	0.279 4.216
			% AXIAL TILT -31.019 -13.150
			AVG BOT 8ft/12ft 1.1938 1.0817
Control Rod Density: %	5.35		
k-effective:	1.00009		
Void Fraction:	0.518		
Core Delta-P: psia	20.606		
Core Plate Delta-P: psia	16.055		
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	60.99	Active Channel Flow: Mlb/hr	58.72
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00041		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.402	7	33	26	1.422	0.942	8	11	8.98	0.771	3.1	7	37	26	4	12.26
1.388	7	37	26	1.432	0.936	7	19	8.15	0.751	32.6	4	21	28	6	12.02
1.374	7	25	30	1.451	0.923	7	37	8.70	0.747	3.1	7	35	24	4	11.89
1.366	4	25	28	1.452	0.923	8	27	8.64	0.743	2.7	7	23	28	6	11.79
1.363	7	29	26	1.452	0.923	7	27	8.04	0.742	32.8	4	35	26	4	11.73
1.361	7	35	24	1.462	0.916	7	21	8.61	0.738	3.2	7	33	26	4	11.74
1.358	7	31	24	1.464	0.916	7	29	8.53	0.733	2.9	7	39	24	4	11.71
1.352	8	41	26	1.468	0.913	7	35	7.95	0.732	32.6	4	39	26	4	11.55
1.347	4	35	26	1.488	0.901	8	21	7.89	0.724	32.0	4	27	26	5	11.46
1.345	8	25	42	1.491	0.899	8	29	7.86	0.721	32.1	4	37	24	4	11.50

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.5 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 1,501.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-9

Cycle:	28	Core Average Exposure: MWd/MTU	19552.4
Exposure: MWd/MTU (GWd)	2000.0 (202.73)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.17		
Flow: Mlb/hr	68.92 (89.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.133 3.483 1 0.300 0.301 17 52
		24	0.321 8.340 2 0.465 0.673 15 48
		23	0.482 12.671 3 0.443 0.522 47 14
		22	0.572 15.046 4 1.178 1.360 25 28
		21	0.628 16.686 5 1.014 1.262 23 42
		20	0.683 18.013 6 0.881 1.067 25 48
		19	0.729 18.949 7 1.217 1.409 33 26
		18	0.779 19.884 8 1.140 1.355 41 26
		17	0.833 20.743 9 1.180 1.204 23 46
		16	0.899 21.141
		15	0.999 21.359
		14	1.072 22.420
		13	1.136 23.238
		12	1.205 24.138
		11	1.259 24.590
		10	1.377 23.546
		9	1.427 23.966
		8	1.458 24.346
		7	1.509 24.872
		6	1.559 25.220*
		5	1.584 24.993
		4	1.589* 24.336
		3	1.514 22.334
		2	0.970 13.646
		Bottom 1	0.283 4.356
			% AXIAL TILT -31.874 -13.433
			AVG BOT 8ft/12ft 1.1968 1.0832
Control Rod Density: %	5.35		
k-effective:	0.99994		
Void Fraction:	0.522		
Core Delta-P: psia	20.159		
Core Plate Delta-P: psia	15.609		
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	59.95	Active Channel Flow: Mlb/hr	57.71
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.409	7	33	26	1.423	0.941	8	11	9.11	0.778	4.2	7	37	12.26	0.895	4.7
1.394	7	37	26	1.426	0.940	7	19	8.23	0.766	34.0	4	21	12.05	0.885	5.7
1.381	7	25	30	1.446	0.926	7	27	8.90	0.761	3.7	7	23	11.92	0.874	5.4
1.370	7	29	26	1.447	0.926	7	37	8.84	0.755	4.2	7	35	11.90	0.869	4.6
1.367	7	35	24	1.452	0.923	8	27	8.09	0.752	33.8	4	35	11.78	0.865	5.7
1.366	7	31	24	1.456	0.920	7	21	8.76	0.748	4.2	7	33	11.76	0.863	5.5
1.360	4	25	28	1.460	0.918	7	29	7.97	0.740	33.6	4	39	11.73	0.861	5.7
1.355	8	41	26	1.462	0.917	7	35	8.65	0.739	4.0	7	39	11.58	0.850	5.6
1.348	8	25	42	1.484	0.903	8	21	7.97	0.736	33.0	4	27	11.50	0.845	5.8
1.342	4	35	26	1.489	0.900	8	29	7.90	0.730	33.1	4	37	11.52	0.841	4.6

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.6 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 2,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	20052.4
Exposure: MWd/MTU (GWd)	2500.0 (253.41)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.133 3.555 1 0.296 0.298 17 52
		24	0.319 8.515 2 0.461 0.670 37 6
		23	0.479 12.934 3 0.439 0.519 47 14
		22	0.567 15.361 4 1.175 1.352 25 28
		21	0.622 17.031 5 1.010 1.258 23 42
		20	0.674 18.388 6 0.876 1.062 25 48
		19	0.718 19.349 7 1.223 1.415 33 26
		18	0.767 20.310 8 1.144 1.360 41 26
		17	0.819 21.199 9 1.186 1.210 23 46
		16	0.883 21.621
		15	0.981 21.861
		14	1.054 22.958
		13	1.119 23.809
		12	1.190 24.745
		11	1.248 25.224
		10	1.371 24.173
		9	1.432 24.612
		8	1.475 25.008
		7	1.535 25.559
		6	1.590 25.932*
		5	1.612* 25.716
		4	1.611 25.060
		3	1.530 23.020
		2	0.982 14.085
		Bottom 1	0.288 4.498
Control Rod Density: %	5.35		
k-effective:	0.99978		
Void Fraction:	0.526		
Core Delta-P: psia	19.720	% AXIAL TILT	-32.865 -13.727
Core Plate Delta-P: psia	15.171	AVG BOT 8ft/12ft	1.2005 1.0847
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.91	Active Channel Flow: Mlb/hr	56.69
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00050		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.415	7	33	26	1.421	0.943	8	11	28	9.25	0.787	5.3	7	37	26	4	12.28	0.903	6.2	8	11	28	4
1.400	7	37	26	1.422	0.942	7	19	28	8.33	0.781	35.1	4	21	26	6	12.10	0.889	7.3	7	37	28	4
1.386	7	27	30	1.443	0.929	7	37	28	9.15	0.779	4.9	7	23	28	6	12.01	0.883	6.5	7	29	28	6
1.375	7	29	26	1.444	0.928	7	27	30	8.99	0.764	5.3	7	35	24	4	11.94	0.878	6.1	8	27	12	4
1.374	7	35	24	1.449	0.925	8	27	12	8.14	0.762	34.9	4	35	26	4	11.84	0.871	7.2	7	35	30	4
1.372	7	31	24	1.453	0.923	7	21	30	8.92	0.758	5.3	7	33	26	4	11.81	0.868	7.0	7	13	30	4
1.360	8	41	26	1.458	0.919	7	35	30	8.02	0.750	34.6	4	39	26	4	11.79	0.867	7.2	8	21	12	4
1.353	8	25	42	1.459	0.918	7	29	28	8.04	0.748	34.0	4	27	26	5	11.67	0.858	7.1	7	33	26	4
1.352	4	25	28	1.480	0.905	8	21	12	8.79	0.747	5.1	7	39	24	4	11.58	0.851	6.1	8	29	44	4
1.339	7	39	24	1.484	0.903	8	29	44	7.96	0.741	34.1	4	37	24	4	11.55	0.849	7.3	8	35	12	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.7 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 2,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-11

Cycle:	28	Core Average Exposure: MWd/MTU	20552.3
Exposure: MWd/MTU (GWd)	3000.0 (304.09)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-25.01		
Flow: Mlb/hr	66.84 (86.80 %)		
2 6 10 14 18 22 26 30 34 38 42 46 50		Axial Profile	Edit Radial Power
51	-- -- -- -- --	N(PRA) Power Exposure	Zone Avg. Max. IR JR
47	-- -- -- -- --	Top 25 0.133 3.628	1 0.293 0.294 17 52
43	-- -- -- -- --	24 0.318 8.689	2 0.457 0.667 37 6
39	-- -- -- -- --	23 0.476 13.196	3 0.435 0.515 47 14
35	-- -- -- 6 -- 6 -- 6 -- 6 -- -- --	22 0.563 15.673	4 1.172 1.344 25 28
31	-- -- -- -- --	21 0.615 17.372	5 1.006 1.254 23 42
27	-- -- -- -- -- 40 -- 40 -- -- --	20 0.666 18.758	6 0.870 1.056 25 48
23	-- -- -- -- --	19 0.708 19.742	7 1.228 1.421 33 26
19	-- -- -- 6 -- 6 -- 6 -- 6 -- -- --	18 0.755 20.730	8 1.149 1.365 41 26
15	-- -- -- -- --	17 0.805 21.646	9 1.192 1.216 23 46
11	-- -- -- -- --	16 0.868 22.094	
7	-- -- -- -- --	15 0.964 22.354	
3	-- -- -- -- --	14 1.036 23.488	
2 6 10 14 18 22 26 30 34 38 42 46 50		13 1.102 24.372	
		12 1.175 25.344	
		11 1.237 25.853	
		10 1.365 24.797	
		9 1.436 25.259	
		8 1.492 25.678	
		7 1.561 26.258	
		6 1.621 26.657*	
		5 1.640* 26.452	
		4 1.632 25.793	
		3 1.547 23.715	
		2 0.993 14.529	
		Bottom 1 0.293 4.643	
Control Rod Density: %	5.35		
k-effective:	0.99967		
Void Fraction:	0.530		
Core Delta-P: psia	19.378	% AXIAL TILT	-33.835 -14.031
Core Plate Delta-P: psia	14.830	AVG BOT 8ft/12ft	1.2041 1.0863
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.07	Active Channel Flow: Mlb/hr	55.88
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00050		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.421	7	33	26	1.421	0.943	7	19	28	9.40	0.795	6.5	7	37	26	4	12.31	0.905	7.8	8	11	28	4
1.406	7	37	26	1.421	0.943	8	11	28	9.37	0.794	6.0	7	23	28	6	12.13	0.892	8.8	7	37	28	4
1.391	7	27	30	1.441	0.930	7	37	28	8.40	0.794	36.1	4	21	26	6	12.08	0.888	8.0	7	29	28	6
1.380	7	29	26	1.443	0.928	7	27	30	8.20	0.773	35.9	4	35	26	4	11.97	0.880	7.6	8	27	12	4
1.380	7	35	24	1.448	0.925	8	27	12	9.14	0.773	6.4	7	35	24	4	11.88	0.874	8.7	7	35	30	4
1.378	7	31	24	1.451	0.923	7	21	30	9.11	0.771	6.4	7	33	26	5	11.85	0.871	8.5	7	13	30	4
1.365	8	41	26	1.456	0.921	7	35	30	8.07	0.759	35.6	4	39	26	4	11.83	0.870	8.7	8	21	12	4
1.358	8	25	42	1.462	0.916	7	29	28	8.10	0.759	35.0	4	27	26	5	11.74	0.863	8.5	7	33	26	4
1.345	7	39	24	1.478	0.906	8	21	12	8.93	0.756	6.2	7	39	24	4	11.64	0.856	7.6	8	29	44	4
1.344	4	25	28	1.482	0.904	8	29	44	8.01	0.751	35.1	4	37	24	4	11.61	0.854	8.0	7	27	30	5

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.8 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 3,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-12

Cycle:	28	Core Average Exposure: MWd/MTU	21052.4
Exposure: MWd/MTU (GWd)	3500.0 (354.78)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-25.27		
Flow: Mlb/hr	66.22 (86.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.133 3.700 1 0.290 0.291 17 52
		24	0.316 8.862 2 0.454 0.665 37 6
		23	0.473 13.457 3 0.432 0.512 47 14
		22	0.558 15.982 4 1.168 1.335 25 28
		21	0.609 17.710 5 1.003 1.251 23 42
		20	0.658 19.123 6 0.865 1.052 25 48
		19	0.698 20.131 7 1.233 1.424 33 26
		18	0.743 21.143 8 1.154 1.370 41 26
		17	0.792 22.087 9 1.199 1.223 23 46
		16	0.854 22.558
		15	0.948 22.839
		14	1.021 24.008
		13	1.088 24.926
		12	1.163 25.936
		11	1.228 26.477
		10	1.361 25.418
		9	1.442 25.909
		8	1.508 26.356
		7	1.584 26.969
		6	1.648 27.395*
		5	1.665* 27.200
		4	1.652 26.536
		3	1.562 24.416
		2	1.002 14.977
		Bottom 1	0.296 4.790
Control Rod Density: %	5.35		
k-effective:	0.99953		
Void Fraction:	0.532		
Core Delta-P: psia	19.160	% AXIAL TILT	-34.740 -14.344
Core Plate Delta-P: psia	14.612	AVG BOT 8ft/12ft	1.2076 1.0878
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	57.52	Active Channel Flow: Mlb/hr	55.33
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00043		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.424	7	33	26	1.422	0.942	8	11	9.53	0.803	7.2	7	23	28	6	12.31
1.411	7	37	26	1.423	0.942	7	19	8.44	0.803	37.2	4	21	26	6	12.12
1.394	7	27	30	1.442	0.929	7	37	9.52	0.801	7.7	7	37	26	4	12.07
1.384	7	35	24	1.447	0.926	7	27	8.22	0.781	36.9	4	35	26	4	11.99
1.383	7	29	26	1.449	0.925	8	27	9.27	0.780	7.6	7	33	26	5	11.88
1.382	7	31	24	1.453	0.922	7	21	9.25	0.779	7.6	7	35	24	4	11.86
1.370	8	41	26	1.458	0.919	7	35	8.10	0.768	36.6	4	39	26	4	11.85
1.364	8	25	42	1.469	0.912	7	29	8.12	0.767	36.0	4	27	26	5	11.76
1.351	7	39	24	1.478	0.907	8	21	9.05	0.763	7.3	7	39	24	4	11.69
1.344	8	21	42	1.481	0.905	8	29	8.04	0.759	36.1	4	37	24	4	11.61

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.9 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 3,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-13

Cycle:	28	Core Average Exposure: MWd/MTU	21552.3
Exposure: MWd/MTU (GWd)	4000.0 (405.46)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-25.60		
Flow: Mlb/hr	65.45 (85.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.133 3.772 1 0.288 0.289 17 52
		24	0.316 9.035 2 0.450 0.663 37 6
		23	0.471 13.716 3 0.428 0.509 47 14
		22	0.555 16.289 4 1.164 1.327 25 28
		21	0.605 18.045 5 1.000 1.247 23 42
		20	0.652 19.485 6 0.861 1.047 25 48
		19	0.691 20.514 7 1.238 1.428 33 26
		18	0.735 21.551 8 1.160 1.375 41 26
		17	0.782 22.522 9 1.206 1.230 23 46
		16	0.843 23.015
		15	0.936 23.317
		14	1.008 24.522
		13	1.076 25.474
		12	1.153 26.523
		11	1.221 27.096
		10	1.357 26.038
		9	1.444 26.561
		8	1.518 27.039
		7	1.600 27.687
		6	1.666 28.143*
		5	1.683* 27.957
		4	1.669 27.287
		3	1.576 25.124
		2	1.011 15.430
		Bottom 1	0.300 4.939
Control Rod Density: %	5.35		
k-effective:	0.99931		
Void Fraction:	0.535		
Core Delta-P: psia	18.874	% AXIAL TILT	-35.403 -14.661
Core Plate Delta-P: psia	14.326	AVG BOT 8ft/12ft	1.2100 1.0893
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	56.82	Active Channel Flow: Mlb/hr	54.66
Total Bypass Flow (%):	13.2	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00044		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.428	7	33	26	1.422	0.942	8	11	8.43	0.808	38.2	4	21	26	6	12.28
1.415	7	37	26	1.425	0.941	7	19	9.62	0.807	8.4	7	23	28	6	12.07
1.397	7	27	30	1.441	0.930	7	37	9.62	0.806	8.9	7	37	26	4	12.05
1.388	7	35	24	1.448	0.925	8	27	8.21	0.786	37.9	4	35	26	4	11.98
1.385	7	31	24	1.449	0.924	7	27	9.37	0.785	8.7	7	33	26	5	11.85
1.385	7	29	26	1.455	0.921	7	21	9.35	0.783	8.7	7	35	24	4	11.83
1.375	8	41	26	1.458	0.919	7	35	8.11	0.775	37.6	4	39	26	4	11.82
1.370	8	25	42	1.473	0.909	7	29	8.10	0.770	37.0	4	27	26	5	11.75
1.355	7	39	24	1.477	0.907	8	21	9.16	0.768	8.4	7	39	24	4	11.71
1.350	8	21	42	1.478	0.906	8	29	8.04	0.765	37.1	4	37	24	4	11.61

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.10 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial
Distributions at 4,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	21553.4
Exposure: MWd/MTU (GWd)	4001.0 (405.56)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.163 3.772 1 0.287 0.293 17 2
		24	0.387 9.036 2 0.463 0.691 5 16
		23	0.578 13.716 3 0.435 0.550 5 14
		22	0.685 16.290 4 1.145 1.313 21 22
		21	0.753 18.046 5 1.018 1.336 13 18
		20	0.791 19.486 6 0.861 1.032 25 6
		19	0.804 20.515 7 1.224 1.423 23 22
		18	0.816 21.552 8 1.163 1.379 13 16
		17	0.831 22.523 9 1.176 1.202 7 24
		16	0.864 23.016
		15	0.934 23.318
		14	0.986 24.523
		13	1.036 25.475
		12	1.098 26.524
		11	1.154 27.098
		10	1.279 26.039
		9	1.360 26.562
		8	1.430 27.040
		7	1.510 27.689
		6	1.578 28.145*
		5	1.601* 27.959
		4	1.598 27.289
		3	1.510 25.125
		2	0.967 15.431
		Bottom 1	0.287 4.939
			% AXIAL TILT -28.294 -14.662
			AVG BOT 8ft/12ft 1.1591 1.0893
Control Rod Density: %	5.69		
k-effective:	0.99939		
Void Fraction:	0.520		
Core Delta-P: psia	19.599		
Core Plate Delta-P: psia	15.050		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.96	Active Channel Flow: Mlb/hr	56.77
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.423	7	23	22	1.427	0.939	7	21	9.33	0.782	8.5	7	31	30	4	11.99
1.419	7	21	24	1.448	0.925	7	23	9.31	0.782	8.2	7	29	32	4	11.94
1.413	7	21	20	1.450	0.924	7	15	9.23	0.778	7.2	7	29	28	4	11.66
1.401	7	19	22	1.450	0.924	7	21	9.15	0.774	6.4	7	31	34	4	11.64
1.396	7	15	18	1.476	0.908	7	19	8.00	0.766	37.8	4	29	30	4	11.64
1.393	7	25	24	1.477	0.907	7	17	9.12	0.765	8.4	7	27	30	4	11.63
1.392	7	23	26	1.483	0.904	7	19	7.95	0.764	38.4	4	31	32	4	11.61
1.390	7	17	16	1.485	0.902	8	13	9.08	0.763	8.2	7	33	32	4	11.59
1.379	7	19	18	1.491	0.899	7	17	8.98	0.760	6.2	7	37	36	4	11.53
1.379	8	13	16	1.491	0.899	7	23	7.97	0.753	36.2	4	31	28	4	11.35

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.11 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 4,001.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-15

Cycle:	28	Core Average Exposure: MWd/MTU	22052.4
Exposure: MWd/MTU (GWd)	4500.0 (456.14)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.78		
Flow: Mlb/hr	67.38 (87.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.163 3.861 1 0.285 0.290 17 2
		24	0.388 9.247 2 0.459 0.688 5 16
		23	0.578 14.033 3 0.432 0.546 5 14
		22	0.683 16.667 4 1.142 1.306 21 22
		21	0.749 18.459 5 1.015 1.329 13 18
		20	0.786 19.920 6 0.857 1.029 25 6
		19	0.798 20.956 7 1.228 1.426 23 22
		18	0.809 22.000 8 1.168 1.382 13 16
		17	0.823 22.978 9 1.182 1.209 7 24
		16	0.855 23.479
		15	0.925 23.788
		14	0.977 25.019
		13	1.028 25.997
		12	1.092 27.077
		11	1.150 27.679
		10	1.276 26.620
		9	1.362 27.175
		8	1.437 27.686
		7	1.521 28.372
		6	1.592 28.859*
		5	1.615* 28.685
		4	1.611 28.013
		3	1.520 25.807
		2	0.973 15.866
		Bottom 1	0.289 5.083
			% AXIAL TILT -28.801 -14.812
			AVG BOT 8ft/12ft 1.1609 1.0897
Control Rod Density: %	5.69		
k-effective:	0.99923		
Void Fraction:	0.522		
Core Delta-P: psia	19.462		
Core Plate Delta-P: psia	14.913		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.62	Active Channel Flow: Mlb/hr	56.43
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00048		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.426	7	23	22	1.425	0.940	7	21	9.38	0.783	9.6	7	31	30	4	11.88
1.421	7	21	24	1.450	0.924	7	15	9.35	0.782	9.3	7	29	32	4	11.83
1.414	7	21	20	1.452	0.923	7	23	9.25	0.776	8.4	7	29	28	4	11.60
1.404	7	19	22	1.453	0.922	7	21	9.19	0.773	7.6	7	31	34	4	11.58
1.397	7	15	18	1.480	0.906	7	19	7.96	0.767	38.8	4	29	30	4	11.57
1.395	7	25	24	1.481	0.905	7	17	7.92	0.766	39.4	4	31	32	4	11.56
1.394	7	23	26	1.486	0.902	7	19	9.15	0.765	9.5	7	27	30	4	11.51
1.393	7	17	16	1.489	0.900	7	23	9.14	0.764	9.3	7	33	32	4	11.48
1.382	7	19	18	1.491	0.899	8	13	9.03	0.761	7.4	7	37	36	4	11.47
1.382	8	13	16	1.495	0.896	7	17	7.92	0.754	37.2	4	31	28	4	11.30

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.12 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial
Distributions at 4,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-16

Cycle:	28	Core Average Exposure: MWd/MTU	22552.4
Exposure: MWd/MTU (GWd)	5000.0 (506.82)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.94		
Flow: Mlb/hr	66.99 (87.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.164 3.950 1 0.282 0.288 17 2
		24	0.388 9.459 2 0.456 0.685 5 16
		23	0.578 14.350 3 0.429 0.542 5 14
		22	0.682 17.044 4 1.138 1.301 21 22
		21	0.746 18.872 5 1.012 1.324 13 18
		20	0.782 20.353 6 0.853 1.025 25 6
		19	0.793 21.395 7 1.232 1.429 23 22
		18	0.803 22.445 8 1.173 1.386 13 16
		17	0.817 23.431 9 1.189 1.215 7 24
		16	0.848 23.939
		15	0.917 24.255
		14	0.970 25.512
		13	1.022 26.516
		12	1.086 27.629
		11	1.145 28.260
		10	1.272 27.201
		9	1.362 27.790
		8	1.440 28.336
		7	1.528 29.061
		6	1.601 29.580*
		5	1.628* 29.419
		4	1.626 28.746
		3	1.532 26.496
		2	0.980 16.305
		Bottom 1	0.291 5.228
Control Rod Density: %	5.69		
k-effective:	0.99897		
Void Fraction:	0.523		
Core Delta-P: psia	19.322	% AXIAL TILT	-29.217 -14.967
Core Plate Delta-P: psia	14.774	AVG BOT 8ft/12ft	1.1626 1.0902
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.27	Active Channel Flow: Mlb/hr	56.09
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.429	7	23	22	1.438	0.932	7	21	9.44	0.787	10.8	7	31	11.78	0.866	12.7
1.425	7	21	24	1.454	0.922	7	23	9.42	0.785	10.5	7	29	11.72	0.861	13.6
1.417	7	21	20	1.455	0.921	7	21	9.28	0.775	9.5	7	29	11.55	0.849	13.0
1.408	7	19	22	1.469	0.912	7	15	9.24	0.774	8.7	7	31	11.53	0.848	12.2
1.401	7	15	18	1.482	0.904	7	19	7.93	0.769	39.8	4	29	11.51	0.847	13.7
1.398	7	25	24	1.484	0.903	7	17	7.89	0.769	40.4	4	31	11.50	0.846	13.9
1.397	7	17	16	1.488	0.900	7	19	9.21	0.768	10.5	7	33	11.47	0.843	13.8
1.396	7	23	26	1.493	0.897	8	13	9.21	0.767	10.6	7	27	11.42	0.840	14.0
1.386	8	13	16	1.496	0.895	7	17	9.11	0.764	8.5	7	37	11.36	0.836	14.1
1.385	7	19	18	1.498	0.894	8	15	9.11	0.759	10.3	7	35	11.26	0.828	10.9

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.13 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial
Distributions at 5,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-17

Cycle:	28	Core Average Exposure: MWd/MTU	23052.3
Exposure: MWd/MTU (GWd)	5500.0 (557.51)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.79		
Flow: Mlb/hr	67.38 (87.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.165 4.039 1 0.279 0.285 17 2
		24	0.390 9.672 2 0.452 0.682 5 16
		23	0.579 14.667 3 0.425 0.539 5 14
		22	0.682 17.420 4 1.135 1.296 21 22
		21	0.745 19.283 5 1.009 1.320 13 18
		20	0.780 20.784 6 0.849 1.021 25 6
		19	0.790 21.832 7 1.236 1.433 23 22
		18	0.800 22.887 8 1.178 1.391 13 16
		17	0.813 23.880 9 1.195 1.221 7 24
		16	0.844 24.395
		15	0.912 24.719
		14	0.964 26.001
		13	1.017 27.032
		12	1.082 28.177
		11	1.141 28.839
		10	1.269 27.780
		9	1.360 28.404
		8	1.441 28.987
		7	1.531 29.751
		6	1.607 30.305*
		5	1.637* 30.158
		4	1.636 29.484
		3	1.540 27.189
		2	0.983 16.746
		Bottom 1	0.293 5.373
			% AXIAL TILT -29.416 -15.122
			AVG BOT 8ft/12ft 1.1630 1.0906
Control Rod Density: %	5.69		
k-effective:	0.99899		
Void Fraction:	0.523		
Core Delta-P: psia	19.488		
Core Plate Delta-P: psia	14.938		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.61	Active Channel Flow: Mlb/hr	56.42
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00032		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.433	7	23	22	1.463	0.916	7	23	22	9.51	0.792	12.0	7	31	30	4	11.67	0.858	14.2	7	21	20	4
1.429	7	21	24	1.464	0.915	7	21	24	9.48	0.790	11.7	7	29	32	4	11.59	0.852	15.1	7	29	28	4
1.420	7	21	20	1.468	0.913	7	21	20	9.32	0.777	10.7	7	29	28	4	11.52	0.847	14.9	8	39	38	4
1.412	7	19	22	1.489	0.900	7	15	18	9.29	0.775	9.9	7	31	34	4	11.47	0.843	15.1	8	37	40	4
1.404	7	15	18	1.492	0.898	7	19	18	9.28	0.773	11.6	7	33	32	4	11.46	0.843	13.6	7	37	36	4
1.402	7	17	16	1.493	0.897	7	17	20	9.26	0.772	11.8	7	27	30	4	11.45	0.842	15.1	7	29	32	4
1.402	7	25	24	1.498	0.895	7	19	22	7.89	0.771	40.8	4	29	30	4	11.44	0.841	15.4	7	31	30	4
1.400	7	23	26	1.503	0.892	8	13	16	7.86	0.771	41.3	4	31	32	4	11.32	0.832	15.4	7	19	22	4
1.391	8	13	16	1.505	0.890	7	17	16	9.18	0.766	9.6	7	37	36	4	11.26	0.828	15.5	7	27	30	4
1.389	7	19	18	1.508	0.889	8	15	14	9.19	0.766	11.4	7	35	38	4	11.21	0.824	12.3	7	33	36	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.14 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 5,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-18

Cycle:	28	Core Average Exposure: MWd/MTU	23552.3
Exposure: MWd/MTU (GWd)	6000.0 (608.19)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.165 4.129 1 0.276 0.281 17 2
		24	0.391 9.885 2 0.449 0.679 5 16
		23	0.580 14.985 3 0.421 0.535 5 14
		22	0.682 17.796 4 1.132 1.292 21 22
		21	0.744 19.694 5 1.006 1.316 13 18
		20	0.778 21.214 6 0.844 1.017 25 6
		19	0.787 22.267 7 1.241 1.438 23 22
		18	0.796 23.328 8 1.182 1.396 13 16
		17	0.809 24.328 9 1.202 1.227 7 24
		16	0.839 24.849
		15	0.907 25.180
		14	0.959 26.488
		13	1.012 27.546
		12	1.078 28.724
		11	1.137 29.415
		10	1.264 28.358
		9	1.356 29.018
		8	1.439 29.637
		7	1.532 30.443
		6	1.612 31.031*
		5	1.648 30.901
		4	1.650* 30.227
		3	1.552 27.887
		2	0.989 17.189
		Bottom 1	0.294 5.520
Control Rod Density: %	5.69		
k-effective:	0.99905		
Void Fraction:	0.522		
Core Delta-P: psia	19.656	% AXIAL TILT	-29.659 -15.275
Core Plate Delta-P: psia	15.106	AVG BOT 8ft/12ft	1.1638 1.0910
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.94	Active Channel Flow: Mlb/hr	56.74
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00049		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.438	7	23	22	1.472	0.910	7	23	22	9.59	0.799	13.2	7	31	30	4	11.57	0.851	15.6	7	21	20	4
1.434	7	21	24	1.473	0.910	7	21	24	9.56	0.797	12.9	7	29	32	4	11.55	0.849	16.4	8	39	38	4
1.424	7	21	20	1.478	0.907	7	21	20	9.38	0.782	11.9	7	29	28	4	11.50	0.845	16.6	8	37	40	4
1.417	7	19	22	1.498	0.894	7	15	18	9.37	0.781	12.8	7	33	32	4	11.49	0.845	16.5	7	29	28	4
1.409	7	15	18	1.502	0.892	7	19	18	9.36	0.780	11.0	7	31	34	4	11.41	0.839	16.5	7	29	32	4
1.407	7	17	16	1.502	0.892	7	17	20	9.34	0.778	12.9	7	27	30	4	11.41	0.839	15.1	7	37	36	4
1.406	7	25	24	1.507	0.889	7	19	22	7.84	0.775	42.3	4	31	32	4	11.40	0.838	16.8	7	31	30	4
1.404	7	23	26	1.511	0.887	8	13	16	9.30	0.775	12.6	7	35	38	4	11.24	0.826	16.9	7	19	22	4
1.396	8	13	16	1.514	0.885	8	15	14	7.87	0.775	41.8	4	29	30	4	11.18	0.822	13.7	7	33	36	4
1.394	8	15	14	1.514	0.885	7	17	16	9.27	0.773	10.8	7	37	36	4	11.17	0.821	16.9	7	27	30	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A-15 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 6,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	24052.3
Exposure: MWd/MTU (GWd)	6500.0 (658.87)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.166 4.219 1 0.274 0.279 17 2
		24	0.391 10.099 2 0.445 0.676 5 16
		23	0.580 15.303 3 0.418 0.531 5 14
		22	0.681 18.173 4 1.129 1.288 21 22
		21	0.742 20.104 5 1.003 1.311 13 18
		20	0.775 21.642 6 0.840 1.013 25 6
		19	0.784 22.701 7 1.245 1.443 23 22
		18	0.792 23.766 8 1.187 1.401 13 16
		17	0.804 24.773 9 1.208 1.233 7 24
		16	0.833 25.300
		15	0.900 25.638
		14	0.953 26.973
		13	1.006 28.057
		12	1.071 29.268
		11	1.131 29.990
		10	1.257 28.933
		9	1.350 29.628
		8	1.435 30.286
		7	1.531 31.135
		6	1.616 31.760*
		5	1.661 31.650
		4	1.669* 30.978
		3	1.571 28.591
		2	1.000 17.636
		Bottom 1	0.298 5.668
			% AXIAL TILT -29.952 -15.428
			AVG BOT 8ft/12ft 1.1647 1.0914
Control Rod Density: %	5.69		
k-effective:	0.99899		
Void Fraction:	0.522		
Core Delta-P: psia	19.670		
Core Plate Delta-P: psia	15.120		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.94	Active Channel Flow: Mlb/hr	56.74
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.443	7	23	22	1.476	0.908	7	23	9.69	0.807	14.4	7	31	30	4	11.60
1.440	7	21	24	1.477	0.907	7	21	9.65	0.805	14.1	7	29	32	4	11.55
1.428	7	21	20	1.484	0.903	7	21	9.47	0.789	13.9	7	33	32	4	11.49
1.422	7	19	22	1.504	0.891	7	15	9.46	0.788	13.0	7	29	28	4	11.40
1.413	7	15	18	1.507	0.889	7	19	9.44	0.787	12.2	7	31	34	4	11.39
1.412	7	17	16	1.508	0.889	7	17	9.42	0.785	14.1	7	27	30	4	11.37
1.411	7	25	24	1.512	0.887	7	19	9.42	0.785	13.7	7	35	38	4	11.36
1.408	7	23	26	1.513	0.886	8	13	9.38	0.782	12.0	7	37	36	4	11.17
1.401	8	13	16	1.515	0.884	8	15	7.83	0.780	43.3	4	31	32	4	11.16
1.399	8	15	14	1.519	0.882	7	17	7.85	0.779	42.8	4	29	30	4	11.15

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.16 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 6,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page A-20

Cycle:	28	Core Average Exposure: MWd/MTU	24053.3
Exposure: MWd/MTU (GWd)	6501.0 (658.97)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.126 4.219 1 0.266 0.269 17 52
		24	0.298 10.100 2 0.437 0.663 5 38
		23	0.446 15.304 3 0.410 0.514 5 40
		22	0.532 18.173 4 1.146 1.324 25 36
		21	0.593 20.105 5 0.987 1.250 13 36
		20	0.641 21.643 6 0.842 1.026 25 48
		19	0.682 22.702 7 1.257 1.463 25 34
		18	0.729 23.767 8 1.183 1.423 25 42
		17	0.778 24.774 9 1.234 1.252 23 46
		16	0.840 25.301
		15	0.936 25.639
		14	1.014 26.974
		13	1.090 28.058
		12	1.174 29.269
		11	1.248 29.991
		10	1.388 28.934
		9	1.486 29.630
		8	1.569 30.288
		7	1.652 31.136
		6	1.708* 31.762*
		5	1.695 31.651
		4	1.645 30.980
		3	1.508 28.592
		2	0.943 17.637
		Bottom 1	0.278 5.668
			% AXIAL TILT -36.285 -15.428
			AVG BOT 8ft/12ft 1.2166 1.0914
Control Rod Density: %	6.33		
k-effective:	0.99903		
Void Fraction:	0.526		
Core Delta-P: psia	19.825		
Core Plate Delta-P: psia	15.271		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.87	Active Channel Flow: Mlb/hr	56.65
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00038		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.463	7	25	34	1.447	0.926	7	29	10.07	0.839	13.1	7	27	16	4	12.18
1.461	7	25	38	1.448	0.926	7	27	8.36	0.830	42.9	4	27	22	6	12.02
1.434	7	23	36	1.448	0.925	7	29	9.92	0.827	12.7	7	27	24	6	12.00
1.423	8	25	42	1.449	0.925	8	27	9.77	0.814	11.5	7	29	18	4	11.95
1.419	7	23	32	1.452	0.923	7	27	9.75	0.812	13.2	7	27	20	5	11.89
1.415	7	23	28	1.484	0.903	7	29	8.20	0.808	41.8	4	27	18	5	11.86
1.409	7	23	40	1.487	0.901	8	11	9.67	0.805	11.6	7	29	14	4	11.85
1.401	7	25	30	1.488	0.901	7	29	8.02	0.797	43.1	4	27	14	4	11.72
1.367	8	11	28	1.509	0.888	7	25	8.05	0.791	41.5	4	29	16	4	11.68
1.348	7	21	34	1.520	0.882	8	29	9.46	0.788	11.7	7	29	22	5	11.63

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.17 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 6,501.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-21

Cycle:	28	Core Average Exposure: MWd/MTU	24552.3
Exposure: MWd/MTU (GWd)	7000.0 (709.55)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.47		
Flow: Mlb/hr	68.14 (88.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.127 4.287 1 0.263 0.266 17 52
		24	0.299 10.262 2 0.434 0.660 5 38
		23	0.447 15.548 3 0.407 0.511 5 40
		22	0.532 18.466 4 1.142 1.316 25 36
		21	0.592 20.431 5 0.984 1.246 13 36
		20	0.640 21.996 6 0.838 1.022 25 48
		19	0.680 23.077 7 1.261 1.465 25 34
		18	0.726 24.168 8 1.188 1.427 25 42
		17	0.775 25.202 9 1.241 1.259 23 46
		16	0.836 25.752
		15	0.931 26.112
		14	1.008 27.485
		13	1.084 28.607
		12	1.167 29.861
		11	1.241 30.619
		10	1.380 29.564
		9	1.478 30.298
		8	1.563 30.993
		7	1.650 31.880
		6	1.712* 32.533*
		5	1.708 32.420
		4	1.664 31.726
		3	1.527 29.276
		2	0.954 18.063
		Bottom 1	0.281 5.807
			% AXIAL TILT -36.520 -15.712
			AVG BOT 8ft/12ft 1.2172 1.0928
Control Rod Density: %	6.33		
k-effective:	0.99904		
Void Fraction:	0.526		
Core Delta-P: psia	19.997		
Core Plate Delta-P: psia	15.443		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	59.21	Active Channel Flow: Mlb/hr	56.97
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00048		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.465	7	25	34	1.460	0.918	7	29	10.15	0.846	14.3	7	27	16	4	12.13
1.463	7	25	38	1.461	0.917	8	27	8.29	0.830	43.9	4	27	22	6	11.91
1.435	7	23	36	1.462	0.917	7	27	9.94	0.828	14.0	7	27	24	6	11.89
1.427	8	25	42	1.463	0.916	7	29	9.84	0.820	12.8	7	29	18	4	11.84
1.420	7	23	32	1.466	0.914	7	27	9.79	0.816	14.4	7	27	20	5	11.84
1.417	7	23	28	1.497	0.895	7	29	9.75	0.812	12.8	7	29	14	4	11.78
1.410	7	23	40	1.499	0.894	8	11	8.23	0.810	41.8	4	27	18	4	11.74
1.404	7	25	30	1.502	0.892	7	29	8.00	0.802	44.1	4	25	14	4	11.70
1.371	8	11	28	1.525	0.879	7	25	9.53	0.794	12.7	8	27	12	4	11.64
1.353	8	23	44	1.529	0.876	8	29	8.01	0.793	42.5	4	29	16	4	11.51

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.18 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial
Distributions at 7,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-22

Cycle:	28	Core Average Exposure: MWd/MTU	25052.2
Exposure: MWd/MTU (GWd)	7500.0 (760.23)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.47		
Flow: Mlb/hr	68.14 (88.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.127 4.356 1 0.261 0.264 17 52
		24	0.298 10.426 2 0.431 0.657 5 38
		23	0.446 15.793 3 0.404 0.507 5 40
		22	0.530 18.759 4 1.138 1.310 25 36
		21	0.590 20.758 5 0.982 1.242 13 36
		20	0.637 22.348 6 0.834 1.018 25 48
		19	0.677 23.452 7 1.264 1.468 25 34
		18	0.722 24.567 8 1.194 1.433 25 42
		17	0.770 25.628 9 1.249 1.267 23 46
		16	0.830 26.201
		15	0.924 26.582
		14	1.002 27.994
		13	1.078 29.154
		12	1.162 30.451
		11	1.235 31.246
		10	1.372 30.191
		9	1.470 30.963
		8	1.556 31.698
		7	1.648 32.625
		6	1.716 33.307*
		5	1.721* 33.196
		4	1.685 32.484
		3	1.549 29.970
		2	0.967 18.495
		Bottom 1	0.285 5.948
Control Rod Density: %	6.33		
k-effective:	0.99908		
Void Fraction:	0.527		
Core Delta-P: psia	20.013	% AXIAL TILT	-36.833 -15.992
Core Plate Delta-P: psia	15.459	AVG BOT 8ft/12ft	1.2183 1.0942
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	59.20	Active Channel Flow: Mlb/hr	56.96
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.468	7	25	34	1.466	0.914	8	27	10.24	0.854	15.6	7	27	12.12	0.891	19.9
1.467	7	25	38	1.469	0.912	7	29	8.21	0.830	45.2	4	25	11.81	0.869	19.0
1.438	7	23	36	1.470	0.911	7	27	9.95	0.829	15.2	7	27	11.79	0.867	19.6
1.433	8	25	42	1.473	0.910	7	27	9.92	0.827	14.0	7	29	11.77	0.865	19.4
1.422	7	23	32	1.474	0.909	7	29	9.87	0.823	14.1	7	29	11.76	0.865	20.0
1.419	7	23	28	1.505	0.890	7	29	9.83	0.819	15.6	7	27	11.76	0.865	18.8
1.414	7	23	40	1.507	0.889	8	11	8.20	0.814	42.8	4	27	11.70	0.860	18.8
1.407	7	25	30	1.514	0.885	7	29	9.75	0.812	13.9	8	27	11.62	0.855	19.5
1.376	8	11	28	1.532	0.874	8	29	8.02	0.810	45.1	4	25	11.62	0.855	20.0
1.361	8	23	44	1.536	0.872	7	25	8.00	0.797	43.5	4	29	11.54	0.849	19.8

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.19 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 7,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page A-23

Cycle:	28	Core Average Exposure: MWd/MTU	25552.2
Exposure: MWd/MTU (GWd)	8000.0 (810.92)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.126 4.425 1 0.259 0.261 17 52
		24	0.297 10.588 2 0.428 0.654 5 38
		23	0.444 16.038 3 0.401 0.504 5 40
		22	0.527 19.051 4 1.134 1.304 25 36
		21	0.586 21.082 5 0.979 1.238 13 36
		20	0.633 22.699 6 0.830 1.015 25 48
		19	0.673 23.824 7 1.268 1.470 25 38
		18	0.718 24.964 8 1.200 1.439 25 42
		17	0.766 26.052 9 1.257 1.276 23 46
		16	0.826 26.648
		15	0.920 27.050
		14	0.998 28.500
		13	1.074 29.699
		12	1.158 31.038
		11	1.232 31.870
		10	1.367 30.816
		9	1.464 31.626
		8	1.551 32.400
		7	1.645 33.369
		6	1.719 34.083*
		5	1.733* 33.978
		4	1.704 33.251
		3	1.570 30.674
		2	0.979 18.932
		Bottom 1	0.288 6.091
Control Rod Density: %	6.33		
k-effective:	0.99902		
Void Fraction:	0.528		
Core Delta-P: psia	19.870	% AXIAL TILT	-37.190 -16.267
Core Plate Delta-P: psia	15.316	AVG BOT 8ft/12ft	1.2200 1.0956
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.86	Active Channel Flow: Mlb/hr	56.63
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00048		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.470	7	25	38	1.465	0.914	8	27	10.27	0.856	16.9	7	27	16	4	12.10
1.470	7	25	34	1.473	0.910	7	29	9.96	0.830	15.3	7	29	14	4	11.86
1.441	7	23	36	1.475	0.908	7	27	9.96	0.830	15.1	8	27	12	4	11.70
1.439	8	25	42	1.476	0.908	7	27	9.96	0.830	15.2	7	29	18	4	11.70
1.423	7	23	32	1.481	0.905	7	29	8.13	0.826	46.0	4	27	22	6	11.67
1.420	7	23	28	1.507	0.889	7	29	9.91	0.826	16.5	7	27	24	6	11.67
1.418	7	23	40	1.510	0.888	8	11	9.80	0.816	16.8	7	27	20	5	11.61
1.408	7	25	30	1.521	0.881	7	29	8.02	0.816	46.1	4	27	14	4	8.01
1.381	8	11	28	1.529	0.876	8	29	8.07	0.813	44.9	4	27	18	5	11.57
1.370	8	23	44	1.544	0.868	7	25	9.73	0.810	15.5	8	29	10	4	11.56

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.20 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 8,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-24

Cycle:	28	Core Average Exposure: MWd/MTU	26052.2
Exposure: MWd/MTU (GWd)	8500.0 (861.60)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.127 4.494 1 0.257 0.259 17 52
		24	0.298 10.751 2 0.425 0.653 5 38
		23	0.445 16.282 3 0.398 0.501 5 40
		22	0.528 19.343 4 1.129 1.296 25 36
		21	0.586 21.406 5 0.976 1.234 13 36
		20	0.633 23.048 6 0.827 1.012 25 48
		19	0.672 24.195 7 1.269 1.471 25 38
		18	0.716 25.360 8 1.206 1.445 25 42
		17	0.764 26.475 9 1.266 1.285 23 46
		16	0.824 27.093
		15	0.917 27.515
		14	0.996 29.005
		13	1.072 30.243
		12	1.157 31.625
		11	1.229 32.493
		10	1.362 31.438
		9	1.458 32.286
		8	1.545 33.099
		7	1.640 34.111
		6	1.717 34.858*
		5	1.739* 34.763
		4	1.715 34.024
		3	1.582 31.385
		2	0.987 19.374
		Bottom 1	0.290 6.236
			% AXIAL TILT -37.257 -16.536
			AVG BOT 8ft/12ft 1.2200 1.0969
Control Rod Density: %	6.33		
k-effective:	0.99905		
Void Fraction:	0.528		
Core Delta-P: psia	19.875		
Core Plate Delta-P: psia	15.321		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.85	Active Channel Flow: Mlb/hr	56.62
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.471	7	25	38	1.470	0.912	8	27	10.17	0.851	18.1	7	27	11.98	0.894	22.9
1.469	7	25	34	1.483	0.903	7	29	10.11	0.843	16.4	8	27	11.88	0.886	22.8
1.445	8	25	42	1.486	0.902	7	27	9.98	0.832	16.5	7	29	11.70	0.873	22.9
1.442	7	23	36	1.487	0.901	7	27	9.95	0.829	16.7	8	29	7.93	0.868	57.3
1.422	7	23	32	1.493	0.898	7	29	9.90	0.825	16.5	7	29	11.61	0.861	22.1
1.420	7	23	40	1.515	0.884	8	11	7.99	0.819	47.0	4	27	11.55	0.860	22.5
1.418	7	23	28	1.516	0.884	7	29	9.79	0.817	17.7	7	27	11.57	0.856	21.8
1.407	7	25	30	1.531	0.875	8	29	8.04	0.816	45.8	5	27	11.46	0.853	22.5
1.387	8	11	28	1.536	0.873	7	29	7.95	0.816	47.1	4	27	11.50	0.851	21.8
1.378	8	23	44	1.557	0.860	8	43	7.85	0.809	47.8	5	29	11.48	0.851	22.1

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.21 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 8,500.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	26552.2
Exposure: MWd/MTU (GWd)	9000.0 (912.28)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.128 4.563 1 0.255 0.258 17 52
		24	0.300 10.915 2 0.423 0.651 5 38
		23	0.448 16.527 3 0.396 0.499 5 40
		22	0.531 19.635 4 1.124 1.289 25 36
		21	0.589 21.730 5 0.975 1.230 13 36
		20	0.636 23.398 6 0.825 1.010 25 48
		19	0.675 24.567 7 1.270 1.469 25 38
		18	0.720 25.756 8 1.212 1.449 25 42
		17	0.768 26.897 9 1.275 1.294 23 46
		16	0.827 27.538
		15	0.921 27.982
		14	1.000 29.511
		13	1.077 30.787
		12	1.161 32.211
		11	1.233 33.116
		10	1.363 32.059
		9	1.455 32.943
		8	1.540 33.796
		7	1.633 34.850
		6	1.708 35.632*
		5	1.733* 35.549
		4	1.709 34.799
		3	1.576 32.097
		2	0.982 19.817
		Bottom 1	0.288 6.380
			% AXIAL TILT -36.948 -16.792
			AVG BOT 8ft/12ft 1.2186 1.0982
Control Rod Density: %	6.33		
k-effective:	0.99905		
Void Fraction:	0.527		
Core Delta-P: psia	19.865		
Core Plate Delta-P: psia	15.311		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	58.86	Active Channel Flow: Mlb/hr	56.63
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.469	7	25	38	1.474	0.909	8	27	10.14	0.846	17.7	8	27	12.03	0.894	22.4
1.467	7	25	34	1.494	0.897	7	29	10.04	0.839	18.0	8	29	11.77	0.888	24.3
1.449	8	25	42	1.497	0.895	7	27	9.95	0.839	19.4	7	27	7.84	0.881	58.3
1.442	7	23	36	1.500	0.893	7	27	9.87	0.823	17.8	7	29	11.56	0.873	24.3
1.421	7	23	40	1.504	0.891	7	29	8.02	0.820	46.8	5	27	11.51	0.866	24.0
1.421	7	23	32	1.520	0.882	8	11	9.72	0.811	17.7	7	29	11.54	0.865	23.5
1.414	7	23	28	1.524	0.879	7	29	7.77	0.807	48.8	5	29	7.96	0.864	57.0
1.405	7	25	30	1.533	0.874	8	29	9.59	0.807	18.9	7	27	7.86	0.862	57.4
1.393	8	11	28	1.550	0.864	7	29	7.81	0.807	48.1	4	27	11.45	0.859	23.5
1.385	8	23	44	1.558	0.860	8	43	7.81	0.806	48.0	4	27	11.41	0.854	23.2

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.22 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 9,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-26

Cycle:	28	Core Average Exposure: MWd/MTU	26553.3
Exposure: MWd/MTU (GWd)	9001.0 (912.38)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.126 4.564 1 0.266 0.267 17 52
		24	0.296 10.915 2 0.434 0.661 47 16
		23	0.441 16.527 3 0.408 0.509 47 14
		22	0.520 19.635 4 1.067 1.214 39 22
		21	0.574 21.731 5 1.012 1.259 35 14
		20	0.620 23.399 6 0.835 1.009 25 48
		19	0.659 24.568 7 1.220 1.391 33 14
		18	0.703 25.757 8 1.250 1.418 41 22
		17	0.751 26.898 9 1.295 1.302 45 24
		16	0.810 27.539
		15	0.904 27.983
		14	0.983 29.512
		13	1.060 30.788
		12	1.145 32.213
		11	1.216 33.117
		10	1.347 32.061
		9	1.442 32.945
		8	1.529 33.797
		7	1.628 34.851
		6	1.714 35.633*
		5	1.757 35.550
		4	1.765* 34.800
		3	1.654 32.099
		2	1.045 19.818
		Bottom 1	0.309 6.380
Control Rod Density: %	6.02		
k-effective:	0.99912		
Void Fraction:	0.533		
Core Delta-P: psia	19.918	% AXIAL TILT	-38.281 -16.793
Core Plate Delta-P: psia	15.366	AVG BOT 8ft/12ft	1.2247 1.0982
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	58.83	Active Channel Flow: Mlb/hr	56.59
Total Bypass Flow (%):	13.2	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00049		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.418	8	41	22	1.516	0.884	8	41	9.97	0.833	18.0	8	11	36	4	11.81
1.412	8	31	12	1.523	0.880	8	21	9.90	0.828	18.2	8	35	12	4	11.84
1.392	8	41	18	1.527	0.878	8	43	9.87	0.827	18.3	8	13	38	4	11.76
1.391	7	33	14	1.527	0.877	8	29	9.86	0.826	18.3	8	37	14	4	11.67
1.388	8	35	12	1.540	0.870	8	43	9.88	0.823	17.1	8	9	34	4	11.65
1.384	7	39	20	1.544	0.868	8	19	9.81	0.820	17.9	8	33	10	4	11.54
1.384	8	39	16	1.546	0.867	8	11	9.84	0.820	17.1	7	13	34	4	11.54
1.383	8	37	14	1.548	0.865	8	35	9.83	0.819	17.5	7	19	40	4	8.03
1.382	8	43	24	1.575	0.851	8	15	9.78	0.815	16.0	8	11	32	4	7.89
1.375	8	29	10	1.575	0.851	8	39	7.92	0.811	46.8	5	11	34	4	7.70

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.23 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 9,001.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-27

Cycle:	28	Core Average Exposure: MWd/MTU	27052.2
Exposure: MWd/MTU (GWd)	9500.0 (962.96)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.63		
Flow: Mlb/hr	67.76 (88.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.128 4.633 1 0.265 0.266 17 52
		24	0.301 11.078 2 0.432 0.660 47 16
		23	0.448 16.770 3 0.406 0.507 47 14
		22	0.528 19.924 4 1.063 1.209 39 22
		21	0.583 22.050 5 1.010 1.252 35 14
		20	0.629 23.743 6 0.834 1.008 25 48
		19	0.668 24.933 7 1.220 1.389 33 14
		18	0.713 26.147 8 1.255 1.420 41 22
		17	0.761 27.315 9 1.303 1.311 45 24
		16	0.821 27.978
		15	0.915 28.443
		14	0.995 30.012
		13	1.073 31.327
		12	1.157 32.794
		11	1.226 33.734
		10	1.353 32.675
		9	1.443 33.594
		8	1.525 34.485
		7	1.617 35.583
		6	1.697 36.402*
		5	1.736 36.339
		4	1.737* 35.591
		3	1.622 32.836
		2	1.023 20.282
		Bottom 1	0.302 6.533
Control Rod Density: %	6.02		
k-effective:	0.99900		
Void Fraction:	0.530		
Core Delta-P: psia	19.884	% AXIAL TILT	-37.397 -17.053
Core Plate Delta-P: psia	15.331	AVG BOT 8ft/12ft	1.2208 1.0994
Coolant Temp: Deg-F	548.4		
In Channel Flow: Mlb/hr	58.85	Active Channel Flow: Mlb/hr	56.62
Total Bypass Flow (%):	13.2	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.420	8	41	22	1.522	0.880	8	41	22	9.83	0.829	19.2	8	11	36	4	7.90	0.881	58.0	5	9	28	7
1.415	8	31	12	1.528	0.877	8	29	44	9.86	0.826	18.4	8	9	34	4	7.79	0.879	58.4	5	25	10	7
1.393	8	41	18	1.528	0.877	8	43	30	9.73	0.821	19.4	8	35	12	4	11.55	0.876	24.9	8	9	34	4
1.389	7	33	14	1.529	0.877	8	21	42	9.74	0.820	19.1	8	33	10	4	7.59	0.873	59.1	5	23	12	6
1.389	8	35	12	1.541	0.869	8	43	20	9.69	0.818	19.5	8	13	38	4	11.47	0.872	25.2	8	41	18	4
1.388	8	43	24	1.546	0.867	8	19	44	9.66	0.815	19.6	8	37	14	4	11.52	0.870	24.4	8	11	22	4
1.385	7	39	20	1.551	0.864	8	11	36	9.69	0.808	17.2	8	11	32	4	7.66	0.870	58.6	5	19	42	5
1.384	8	39	16	1.554	0.862	8	35	12	9.63	0.807	18.3	7	13	34	4	11.34	0.866	25.7	8	33	10	4
1.383	8	37	14	1.582	0.847	8	39	16	9.57	0.804	18.7	7	19	40	4	11.34	0.865	25.7	8	17	42	4
1.382	8	29	10	1.583	0.846	8	15	40	9.51	0.803	19.5	8	31	12	4	7.43	0.864	59.5	5	9	32	6

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.24 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 9,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-28

Cycle:	28	Core Average Exposure: MWd/MTU	27552.3
Exposure: MWd/MTU (GWd)	10000.0 (1013.65)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.47		
Flow: Mlb/hr	68.14 (88.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.131 4.703 1 0.263 0.265 17 52
		24	0.308 11.245 2 0.431 0.660 47 16
		23	0.458 17.019 3 0.405 0.506 47 14
		22	0.540 20.219 4 1.060 1.205 39 22
		21	0.596 22.375 5 1.009 1.247 35 14
		20	0.643 24.094 6 0.833 1.008 25 48
		19	0.683 25.306 7 1.220 1.388 33 14
		18	0.729 26.545 8 1.259 1.423 41 22
		17	0.778 27.740 9 1.310 1.318 45 24
		16	0.839 28.425
		15	0.934 28.912
		14	1.016 30.521
		13	1.093 31.875
		12	1.177 33.385
		11	1.243 34.358
		10	1.364 33.294
		9	1.446 34.247
		8	1.520 35.173
		7	1.602 36.310
		6	1.670 37.163*
		5	1.700* 37.116
		4	1.688 36.366
		3	1.565 33.555
		2	0.986 20.733
		Bottom 1	0.290 6.680
			% AXIAL TILT -35.949 -17.283
			AVG BOT 8ft/12ft 1.2143 1.1006
Control Rod Density: %	6.02		
k-effective:	0.99897		
Void Fraction:	0.526		
Core Delta-P: psia	19.985		
Core Plate Delta-P: psia	15.433		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	59.22	Active Channel Flow: Mlb/hr	56.98
Total Bypass Flow (%):	13.1	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.423	8	41	22	1.531	0.875	8	41	9.69	0.819	19.6	8	9	7.67	0.889	59.3
1.415	8	31	12	1.532	0.875	8	43	9.57	0.812	20.5	8	11	7.75	0.888	58.9
1.394	8	41	18	1.533	0.874	8	29	9.51	0.807	20.3	8	19	7.40	0.875	60.0
1.394	8	43	24	1.539	0.871	8	21	9.43	0.802	20.6	8	35	7.24	0.871	60.6
1.389	8	35	12	1.546	0.867	8	43	9.38	0.798	20.7	8	13	7.47	0.871	59.6
1.388	7	33	14	1.551	0.864	8	19	9.50	0.796	18.4	8	11	7.28	0.863	60.1
1.386	7	39	20	1.560	0.859	8	11	9.34	0.795	20.7	8	37	7.37	0.861	59.6
1.386	8	29	10	1.564	0.857	8	35	9.32	0.787	19.5	7	13	11.17	0.857	26.3
1.384	8	39	16	1.594	0.841	8	39	9.21	0.783	20.7	8	31	11.08	0.852	26.6
1.383	8	37	14	1.595	0.840	8	15	7.53	0.782	48.7	5	11	11.34	0.849	23.2

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.25 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 10,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-29

Cycle:	28	Core Average Exposure: MWd/MTU	28052.2
Exposure: MWd/MTU (GWd)	10500.0 (1064.33)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.02		
Flow: Mlb/hr	69.30 (90.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.136 4.776 1 0.262 0.263 17 52
		24	0.318 11.416 2 0.430 0.659 47 16
		23	0.474 17.274 3 0.403 0.504 47 14
		22	0.558 20.522 4 1.057 1.202 39 22
		21	0.615 22.709 5 1.008 1.243 35 14
		20	0.664 24.455 6 0.832 1.007 25 48
		19	0.705 25.690 7 1.220 1.387 33 14
		18	0.752 26.954 8 1.263 1.423 41 22
		17	0.803 28.176 9 1.315 1.323 45 24
		16	0.864 28.884
		15	0.961 29.392
		14	1.044 31.042
		13	1.122 32.436
		12	1.204 33.988
		11	1.264 34.993
		10	1.379 33.920
		9	1.453 34.901
		8	1.514 35.858
		7	1.582 37.029
		6	1.634 37.909*
		5	1.648* 37.874
		4	1.617 37.113
		3	1.484 34.243
		2	0.932 21.165
		Bottom 1	0.274 6.821
Control Rod Density: %	6.02		
k-effective:	0.99913		
Void Fraction:	0.518		
Core Delta-P: psia	20.383	% AXIAL TILT	-33.886 -17.472
Core Plate Delta-P: psia	15.830	AVG BOT 8ft/12ft	1.2051 1.1015
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	60.28	Active Channel Flow: Mlb/hr	58.03
Total Bypass Flow (%):	13.0	(of total core flow)	
Total Water Rod Flow (%):	3.3	(of total core flow)	
Source Convergence	0.00042		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.423	8	41	22	1.544	0.868	8	43	9.38	0.798	20.8	8	9	7.53	0.897	60.3
1.416	8	31	12	1.545	0.867	8	29	9.17	0.785	21.6	8	11	7.58	0.893	59.9
1.398	8	43	24	1.549	0.865	8	41	9.15	0.782	21.5	8	19	7.20	0.875	60.9
1.394	8	41	18	1.555	0.862	8	21	9.17	0.774	19.6	8	11	7.07	0.873	61.5
1.390	8	29	10	1.560	0.859	8	43	9.01	0.772	21.8	8	35	7.16	0.867	60.8
1.389	8	35	12	1.564	0.857	8	19	9.10	0.768	19.4	9	7	7.10	0.865	61.0
1.387	7	33	14	1.577	0.850	8	11	8.96	0.768	21.8	8	13	7.20	0.864	60.5
1.386	7	39	20	1.580	0.848	8	35	8.91	0.764	21.9	8	15	7.23	0.844	59.6
1.383	8	13	38	1.606	0.835	9	45	7.22	0.763	50.9	5	9	10.94	0.830	24.9
1.383	8	43	20	1.611	0.832	8	45	9.05	0.762	19.2	8	7	10.66	0.827	27.7

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.26 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 10,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-30

Cycle:	28	Core Average Exposure: MWd/MTU	28552.1
Exposure: MWd/MTU (GWd)	11000.0 (1115.01)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.58		
Flow: Mlb/hr	70.46 (91.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.141 4.851 1 0.261 0.262 17 52
		24	0.331 11.594 2 0.429 0.659 47 16
		23	0.493 17.540 3 0.402 0.503 47 14
		22	0.580 20.836 4 1.055 1.198 39 22
		21	0.639 23.055 5 1.007 1.240 35 14
		20	0.690 24.828 6 0.831 1.007 25 48
		19	0.733 26.087 7 1.221 1.386 33 14
		18	0.782 27.378 8 1.266 1.423 41 22
		17	0.834 28.628 9 1.317 1.326 45 24
		16	0.896 29.359
		15	0.995 29.888
		14	1.079 31.580
		13	1.155 33.013
		12	1.234 34.605
		11	1.288 35.639
		10	1.395 34.552
		9	1.458 35.558
		8	1.506 36.540
		7	1.556 37.738
		6	1.588* 38.637*
		5	1.583 38.605
		4	1.531 37.825
		3	1.388 34.891
		2	0.870 21.570
		Bottom 1	0.255 6.953
			% AXIAL TILT -31.283 -17.612
			AVG BOT 8ft/12ft 1.1933 1.1023
Control Rod Density: %	6.02		
k-effective:	0.99920		
Void Fraction:	0.508		
Core Delta-P: psia	20.765		
Core Plate Delta-P: psia	16.211		
Coolant Temp: Deg-F	548.3		
In Channel Flow: Mlb/hr	61.35	Active Channel Flow: Mlb/hr	59.08
Total Bypass Flow (%):	12.9	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00045		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.423	8	41	22	1.559	0.859	8	43	8.93	0.766	21.9	8	43	7.36	0.901	61.2
1.416	8	31	12	1.559	0.859	8	29	7.08	0.752	51.4	5	25	7.37	0.893	60.9
1.400	8	43	24	1.567	0.855	8	41	8.81	0.749	20.7	8	27	6.96	0.869	61.8
1.394	8	41	18	1.573	0.852	8	21	8.69	0.749	22.7	8	11	6.84	0.868	62.3
1.392	8	29	10	1.574	0.851	8	43	8.69	0.748	22.6	8	19	6.92	0.861	61.7
1.389	8	35	12	1.576	0.851	8	19	7.01	0.746	51.6	5	43	6.87	0.859	61.9
1.386	7	33	14	1.592	0.842	8	11	8.74	0.743	20.5	9	7	6.97	0.859	61.4
1.386	7	39	20	1.595	0.840	8	35	8.71	0.742	20.9	8	11	6.99	0.838	60.5
1.383	8	43	20	1.614	0.830	9	45	8.72	0.742	20.7	8	11	10.66	0.818	26.3
1.383	8	39	16	1.618	0.828	9	21	6.96	0.741	51.8	5	43	10.54	0.810	26.5

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.27 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 11,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-31

Cycle:	28	Core Average Exposure: MWd/MTU	29052.1
Exposure: MWd/MTU (GWd)	11500.0 (1165.69)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.01		
Flow: Mlb/hr	72.00 (93.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.147 4.930 1 0.260 0.261 17 52
		24	0.346 11.779 2 0.427 0.658 47 16
		23	0.516 17.816 3 0.401 0.502 47 14
		22	0.607 21.164 4 1.054 1.196 39 22
		21	0.669 23.416 5 1.006 1.238 35 14
		20	0.722 25.218 6 0.831 1.007 25 48
		19	0.767 26.500 7 1.222 1.386 33 14
		18	0.818 27.819 8 1.268 1.422 41 22
		17	0.872 29.099 9 1.319 1.327 45 24
		16	0.934 29.852
		15	1.035 30.403
		14	1.119 32.136
		13	1.193 33.608
		12	1.268 35.239
		11	1.313 36.297
		10	1.411 35.192
		9	1.462 36.217
		8	1.493 37.217
		7	1.524 38.433
		6	1.535* 39.342*
		5	1.506 39.304
		4	1.431 38.495
		3	1.279 35.493
		2	0.798 21.945
		Bottom 1	0.234 7.075
Control Rod Density: %	6.02		
k-effective:	0.99939		
Void Fraction:	0.497		
Core Delta-P: psia	21.294	% AXIAL TILT	-28.158 -17.697
Core Plate Delta-P: psia	16.739	AVG BOT 8ft/12ft	1.1791 1.1028
Coolant Temp: Deg-F	548.2		
In Channel Flow: Mlb/hr	62.77	Active Channel Flow: Mlb/hr	60.48
Total Bypass Flow (%):	12.8	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00030		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.422	8	41	22	1.574	0.851	8	29	44	6.92	0.739	52.3	5	25	44	7	7.16	0.901	62.1	5	25	10	7
1.416	8	31	12	1.575	0.851	8	43	30	8.60	0.737	21.8	8	25	42	7	7.07	0.891	62.1	5	9	26	7
1.400	8	43	24	1.582	0.847	8	41	22	6.83	0.731	52.5	5	43	26	7	6.59	0.859	63.2	5	43	32	6
1.394	8	29	10	1.585	0.845	8	21	12	8.48	0.727	22.0	8	41	26	7	6.69	0.857	62.6	5	23	12	6
1.393	8	41	18	1.592	0.842	8	43	20	8.41	0.726	23.0	8	9	34	4	6.68	0.853	62.6	5	19	42	6
1.389	8	35	12	1.593	0.841	8	19	44	8.29	0.716	23.1	8	19	44	5	6.62	0.851	62.8	5	41	34	6
1.386	7	33	14	1.604	0.835	8	11	36	6.65	0.712	52.6	5	9	32	5	6.72	0.851	62.2	5	31	10	6
1.386	7	13	34	1.607	0.834	8	35	12	8.23	0.712	23.3	8	11	36	5	6.78	0.837	61.4	5	11	30	7
1.383	8	43	20	1.629	0.822	9	45	22	8.27	0.710	22.0	8	11	32	5	10.34	0.801	27.6	8	25	42	7
1.382	8	13	38	1.632	0.821	9	21	46	6.58	0.709	53.3	5	21	44	6	10.19	0.791	27.8	8	41	26	7

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.28 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 11,500.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	29053.1
Exposure: MWd/MTU (GWd)	11501.0 (1165.79)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.47		
Flow: Mlb/hr	68.14 (88.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.152 4.930 1 0.260 0.260 35 2
		24	0.355 11.779 2 0.426 0.655 47 38
		23	0.528 17.817 3 0.401 0.502 47 40
		22	0.619 21.164 4 1.054 1.216 37 34
		21	0.680 23.417 5 1.007 1.280 39 36
		20	0.731 25.219 6 0.826 1.004 27 48
		19	0.767 26.501 7 1.226 1.435 37 36
		18	0.810 27.820 8 1.268 1.425 27 42
		17	0.857 29.099 9 1.304 1.323 29 46
		16	0.913 29.853
		15	1.006 30.404
		14	1.083 32.137
		13	1.151 33.609
		12	1.220 35.240
		11	1.262 36.298
		10	1.356 35.193
		9	1.407 36.219
		8	1.444 37.219
		7	1.488 38.435
		6	1.526 39.343*
		5	1.548* 39.305
		4	1.522 38.497
		3	1.405 35.494
		2	0.901 21.945
		Bottom 1	0.267 7.076
Control Rod Density: %	5.23		
k-effective:	0.99940		
Void Fraction:	0.509		
Core Delta-P: psia	19.736	% AXIAL TILT	-28.700 -17.697
Core Plate Delta-P: psia	15.189	AVG BOT 8ft/12ft	1.1772 1.1028
Coolant Temp: Deg-F	548.2		
In Channel Flow: Mlb/hr	59.33	Active Channel Flow: Mlb/hr	57.13
Total Bypass Flow (%):	12.9	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00049		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.435	7	37	36	1.521	0.881	8	37	14	8.67	0.750	23.3	8	23	44	4	6.72	0.858	62.5	5	19	42	6
1.426	7	35	38	1.525	0.879	8	13	38	8.64	0.746	23.0	8	9	34	4	6.68	0.855	62.6	5	23	12	6
1.425	8	27	42	1.535	0.873	8	35	12	8.75	0.746	21.0	8	9	30	4	6.75	0.853	62.2	5	31	10	6
1.424	8	31	42	1.539	0.870	8	27	12	8.52	0.739	23.7	8	19	44	4	6.62	0.849	62.7	5	11	34	6
1.423	8	39	38	1.541	0.870	8	21	12	8.54	0.734	22.3	9	29	8	4	6.67	0.849	62.5	5	25	10	6
1.423	7	39	34	1.541	0.870	8	29	44	8.59	0.733	21.3	8	27	12	4	6.46	0.841	63.2	5	43	32	6
1.422	8	37	40	1.544	0.868	8	11	36	8.45	0.733	23.8	8	11	36	4	6.28	0.795	62.2	5	9	26	6
1.418	7	33	40	1.552	0.863	7	37	18	8.57	0.733	21.4	9	7	30	4	6.45	0.794	61.3	5	41	24	6
1.408	8	41	36	1.555	0.862	7	35	38	8.56	0.732	21.6	9	7	32	4	7.11	0.789	57.8	5	13	36	6
1.407	8	35	42	1.560	0.859	7	39	34	8.54	0.732	21.8	8	11	32	4	10.26	0.788	26.5	8	43	30	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.29 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 11,501.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-33

Cycle:	28	Core Average Exposure: MWd/MTU	29552.1
Exposure: MWd/MTU (GWd)	12000.0 (1216.38)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.87		
Flow: Mlb/hr	69.68 (90.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.160 5.014 1 0.259 0.259 35 2
		24	0.374 11.979 2 0.425 0.655 47 38
		23	0.557 18.114 3 0.399 0.501 47 40
		22	0.653 21.515 4 1.054 1.214 37 34
		21	0.717 23.802 5 1.006 1.277 39 36
		20	0.770 25.632 6 0.825 1.003 27 48
		19	0.808 26.935 7 1.227 1.434 37 36
		18	0.854 28.278 8 1.268 1.422 27 42
		17	0.902 29.584 9 1.304 1.322 29 46
		16	0.958 30.357
		15	1.053 30.925
		14	1.129 32.696
		13	1.193 34.201
		12	1.255 35.865
		11	1.288 36.942
		10	1.372 35.814
		9	1.410 36.853
		8	1.429 37.866
		7	1.452 39.097
		6	1.465* 40.017*
		5	1.460 39.985
		4	1.407 39.158
		3	1.278 36.098
		2	0.814 22.330
		Bottom 1	0.241 7.202
			% AXIAL TILT -24.931 -17.727
			AVG BOT 8ft/12ft 1.1597 1.1030
Control Rod Density: %	5.23		
k-effective:	0.99944		
Void Fraction:	0.496		
Core Delta-P: psia	20.232		
Core Plate Delta-P: psia	15.684		
Coolant Temp: Deg-F	548.1		
In Channel Flow: Mlb/hr	60.76	Active Channel Flow: Mlb/hr	58.54
Total Bypass Flow (%):	12.8	(of total core flow)	
Total Water Rod Flow (%):	3.2	(of total core flow)	
Source Convergence	0.00029		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.434	7	37	36	1.531	0.875	8	37	14	8.06	0.701	24.1	8	23	44	5	6.44	0.845	63.4	5	19	42	6
1.425	7	35	38	1.534	0.873	8	13	38	8.16	0.700	22.1	8	9	30	4	6.47	0.840	63.1	5	31	10	6
1.423	7	39	34	1.546	0.867	8	35	12	8.05	0.700	24.1	8	9	34	4	6.39	0.839	63.4	5	23	12	6
1.422	8	27	42	1.552	0.864	8	21	12	8.00	0.696	24.1	8	19	44	5	6.35	0.836	63.5	5	11	34	6
1.422	8	31	42	1.552	0.863	8	29	44	6.43	0.693	53.4	5	21	44	5	6.37	0.833	63.3	5	25	10	6
1.422	8	39	38	1.553	0.863	8	27	12	7.93	0.690	24.3	8	11	36	5	6.20	0.828	64.0	5	43	32	6
1.420	8	37	40	1.555	0.862	8	11	36	7.91	0.689	24.4	8	13	38	5	6.02	0.781	63.0	5	9	26	6
1.417	7	33	40	1.562	0.858	7	37	18	8.01	0.689	22.4	9	7	30	4	6.18	0.779	62.1	5	41	24	6
1.406	8	41	36	1.568	0.854	7	39	34	7.90	0.689	24.5	8	21	42	5	6.56	0.772	59.9	5	13	14	6
1.406	8	35	42	1.569	0.854	7	35	38	8.00	0.689	22.6	9	7	32	4	6.79	0.772	58.6	5	13	36	6

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.30 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 12,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-34

Cycle:	28	Core Average Exposure: MWd/MTU	30052.0
Exposure: MWd/MTU (GWd)	12500.0 (1267.06)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.29		
Flow: Mlb/hr	71.22 (92.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.168 5.103 1 0.257 0.258 35 2
		24	0.395 12.189 2 0.424 0.654 47 38
		23	0.588 18.428 3 0.398 0.499 47 40
		22	0.690 21.885 4 1.054 1.213 37 34
		21	0.757 24.209 5 1.005 1.275 39 36
		20	0.813 26.069 6 0.824 1.002 27 48
		19	0.853 27.394 7 1.230 1.434 37 36
		18	0.901 28.763 8 1.268 1.420 39 38
		17	0.950 30.095 9 1.304 1.321 29 46
		16	1.005 30.886
		15	1.099 31.471
		14	1.172 33.279
		13	1.231 34.815
		12	1.284 36.508
		11	1.305 37.598
		10	1.380 36.442
		9	1.405 37.489
		8	1.407 38.507
		7	1.411* 39.744
		6	1.402 40.665*
		5	1.373 40.626
		4	1.298 39.770
		3	1.160 36.648
		2	0.735 22.678
		Bottom 1	0.217 7.317
			% AXIAL TILT -20.981 -17.691
			AVG BOT 8ft/12ft 1.1408 1.1029
Control Rod Density: %	5.23		
k-effective:	0.99956		
Void Fraction:	0.483		
Core Delta-P: psia	20.731		
Core Plate Delta-P: psia	16.183		
Coolant Temp: Deg-F	548.1		
In Channel Flow: Mlb/hr	62.19	Active Channel Flow: Mlb/hr	59.96
Total Bypass Flow (%):	12.7	(of total core flow)	
Total Water Rod Flow (%):	3.1	(of total core flow)	
Source Convergence	0.00033		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.434	7	37	36	1.539	0.870	8	39	38	6.33	0.668	50.7	5	33	12	11	6.16	0.829	64.1	5	19	42	6
1.425	7	35	38	1.540	0.870	8	37	14	6.67	0.668	44.1	5	35	14	11	6.18	0.825	63.9	5	31	10	6
1.423	7	39	34	1.554	0.862	8	35	12	7.84	0.668	21.0	8	31	12	11	6.09	0.822	64.2	5	23	12	6
1.420	8	39	38	1.558	0.860	8	21	12	7.62	0.667	25.1	8	23	44	5	6.07	0.820	64.3	5	11	34	6
1.420	8	31	42	1.558	0.860	8	41	36	7.83	0.666	20.6	8	37	14	11	6.09	0.817	64.0	5	25	10	6
1.420	8	27	42	1.562	0.858	8	29	44	6.29	0.665	50.9	5	23	42	11	5.93	0.813	64.7	5	43	32	6
1.419	8	37	40	1.564	0.857	8	27	12	6.09	0.665	54.9	5	21	44	6	5.76	0.764	63.7	5	9	26	6
1.416	7	33	40	1.570	0.854	7	37	18	7.57	0.663	25.1	8	19	44	5	5.90	0.762	62.9	5	41	24	7
1.405	8	41	36	1.576	0.851	7	39	34	7.80	0.663	20.6	8	39	16	11	6.28	0.756	60.7	5	13	14	6
1.405	8	35	42	1.579	0.848	8	19	44	7.77	0.662	20.9	8	25	42	11	6.48	0.754	59.5	5	13	36	6

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.31 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 12,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-35

Cycle:	28	Core Average Exposure: MWd/MTU	30552.1
Exposure: MWd/MTU (GWd)	13000.0 (1317.74)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.74		
Flow: Mlb/hr	72.76 (94.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.178 5.198 1 0.256 0.256 35 2
		24	0.418 12.412 2 0.423 0.653 47 38
		23	0.623 18.760 3 0.397 0.498 47 40
		22	0.729 22.277 4 1.055 1.213 37 34
		21	0.801 24.639 5 1.003 1.274 39 36
		20	0.860 26.531 6 0.823 1.000 27 48
		19	0.902 27.878 7 1.233 1.435 37 36
		18	0.951 29.274 8 1.268 1.420 39 38
		17	1.001 30.633 9 1.303 1.320 29 46
		16	1.054 31.441
		15	1.147 32.040
		14	1.215 33.883
		13	1.265 35.447
		12	1.309 37.165
		11	1.317 38.262
		10	1.381 37.071
		9	1.393* 38.120
		8	1.379 39.136
		7	1.364 40.371
		6	1.336 41.283*
		5	1.285 41.228
		4	1.190 40.333
		3	1.047 37.146
		2	0.661 22.992
		Bottom 1	0.195 7.420
			% AXIAL TILT -16.768 -17.586
			AVG BOT 8ft/12ft 1.1202 1.1025
Control Rod Density: %	5.23		
k-effective:	0.99966		
Void Fraction:	0.469		
Core Delta-P: psia	21.232		
Core Plate Delta-P: psia	16.683		
Coolant Temp: Deg-F	548.0		
In Channel Flow: Mlb/hr	63.63	Active Channel Flow: Mlb/hr	61.38
Total Bypass Flow (%):	12.6	(of total core flow)	
Total Water Rod Flow (%):	3.1	(of total core flow)	
Source Convergence	0.00043		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.435	7	37	36	1.538	0.871	8	39	38	6.37	0.677	51.5	5	33	12	11	6.07	0.811	63.9	5	31	10	7
1.425	7	35	38	1.540	0.870	8	37	14	6.71	0.676	44.9	5	35	14	11	5.87	0.810	64.9	5	19	42	6
1.424	7	39	34	1.556	0.861	8	41	36	7.88	0.676	22.0	8	31	12	11	5.94	0.805	64.4	5	25	10	7
1.420	8	39	38	1.557	0.861	8	21	12	7.88	0.674	21.6	8	37	14	11	6.00	0.805	64.1	5	23	12	7
1.418	8	31	42	1.558	0.860	8	35	12	6.33	0.673	51.7	5	23	42	11	5.92	0.805	64.5	5	11	34	7
1.418	8	37	40	1.565	0.856	8	27	12	7.85	0.672	21.6	8	39	16	11	5.66	0.795	65.4	5	43	32	6
1.417	8	27	42	1.565	0.856	8	29	44	6.34	0.669	50.8	4	37	16	11	5.69	0.752	63.6	5	41	24	7
1.416	7	33	40	1.574	0.851	7	37	18	7.81	0.669	21.9	8	25	42	11	5.48	0.745	64.4	5	9	26	6
1.404	8	41	36	1.580	0.848	7	39	34	7.82	0.669	21.5	8	35	12	11	5.98	0.738	61.4	5	13	14	6
1.403	8	35	42	1.584	0.846	8	19	44	6.64	0.669	44.7	5	39	18	11	6.40	0.738	59.2	5	13	36	7

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.32 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 13,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
 Fuel Cycle Design

Page A-36

Cycle:	28	Core Average Exposure: MWd/MTU	31052.0
Exposure: MWd/MTU (GWd)	13500.0 (1368.42)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.21		
Flow: Mlb/hr	74.31 (96.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.189 5.297 1 0.254 0.255 35 2
		24	0.444 12.647 2 0.421 0.652 47 38
		23	0.662 19.113 3 0.395 0.496 47 40
		22	0.775 22.692 4 1.056 1.213 37 34
		21	0.851 25.094 5 1.002 1.272 39 36
		20	0.914 27.020 6 0.821 0.998 27 48
		19	0.957 28.391 7 1.236 1.436 37 36
		18	1.007 29.814 8 1.267 1.419 39 38
		17	1.056 31.201 9 1.303 1.319 29 46
		16	1.106 32.024
		15	1.195 32.634
		14	1.255 34.509
		13	1.294 36.095
		12	1.326 37.832
		11	1.320 38.929
		10	1.374* 37.699
		9	1.372 38.744
		8	1.343 39.751
		7	1.312 40.975
		6	1.265 41.871*
		5	1.194 41.789
		4	1.085 40.847
		3	0.940 37.594
		2	0.590 23.273
		Bottom 1	0.174 7.512
Control Rod Density: %	5.23		
k-effective:	0.99977		
Void Fraction:	0.455		
Core Delta-P: psia	21.727	% AXIAL TILT	-12.164 -17.413
Core Plate Delta-P: psia	17.178	AVG BOT 8ft/12ft	1.0970 1.1018
Coolant Temp: Deg-F	547.9		
In Channel Flow: Mlb/hr	65.07	Active Channel Flow: Mlb/hr	62.80
Total Bypass Flow (%):	12.4	(of total core flow)	
Total Water Rod Flow (%):	3.0	(of total core flow)	
Source Convergence	0.00034		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.436	7	37	36	1.535	0.873	8	39	38	7.94	0.681	22.0	8	31	12	12	6.41	0.805	62.0	5	31	10	11
1.426	7	35	38	1.537	0.872	8	37	14	6.43	0.681	51.1	5	33	12	12	6.45	0.805	61.8	5	25	10	11
1.425	7	39	34	1.553	0.863	8	41	36	6.76	0.680	44.6	5	35	14	12	6.38	0.800	62.0	5	41	34	11
1.419	8	39	38	1.555	0.862	8	35	12	7.95	0.680	21.6	8	37	14	12	6.49	0.797	61.3	5	19	12	11
1.417	8	37	40	1.556	0.861	8	21	12	6.39	0.678	51.4	5	23	42	12	6.51	0.795	61.1	5	29	42	11
1.417	8	31	42	1.562	0.858	8	29	44	7.92	0.678	21.6	8	39	16	12	6.17	0.785	62.5	5	43	32	11
1.416	7	33	40	1.564	0.857	8	27	12	7.89	0.676	21.8	8	25	42	12	5.98	0.752	62.1	5	11	30	11
1.415	8	27	42	1.579	0.849	7	37	18	7.88	0.674	21.6	8	35	12	12	5.96	0.742	61.7	5	43	28	11
1.403	8	41	36	1.584	0.846	7	39	34	6.71	0.674	44.5	5	39	18	12	6.45	0.739	58.9	4	37	38	11
1.402	8	35	42	1.587	0.844	8	19	44	6.34	0.674	51.6	4	37	16	11	9.43	0.738	28.8	8	37	14	12

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.33 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 13,500.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	31552.1
Exposure: MWd/MTU (GWd)	14000.0 (1419.10)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-21.57		
Flow: Mlb/hr	76.23 (99.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.200 5.403 1 0.252 0.253 35 2
		24	0.472 12.898 2 0.420 0.651 47 38
		23	0.704 19.488 3 0.393 0.495 47 40
		22	0.824 23.134 4 1.057 1.213 37 34
		21	0.904 25.579 5 1.001 1.271 39 36
		20	0.971 27.541 6 0.819 0.996 27 48
		19	1.016 28.936 7 1.239 1.437 37 36
		18	1.067 30.387 8 1.267 1.419 39 38
		17	1.115 31.800 9 1.303 1.319 29 46
		16	1.158 32.634
		15	1.242 33.252
		14	1.292 35.154
		13	1.318 36.756
		12	1.335 38.506
		11	1.315 39.596
		10	1.358* 38.322
		9	1.345 39.358
		8	1.302 40.348
		7	1.257 41.555
		6	1.192 42.426*
		5	1.105 42.309
		4	0.984 41.315
		3	0.841 37.996
		2	0.526 23.524
		Bottom 1	0.155 7.594
Control Rod Density: %	5.23		
k-effective:	0.99996		
Void Fraction:	0.441		
Core Delta-P: psia	22.390	% AXIAL TILT	-7.388 -17.169
Core Plate Delta-P: psia	17.841	AVG BOT 8ft/12ft	1.0721 1.1008
Coolant Temp: Deg-F	547.8		
In Channel Flow: Mlb/hr	66.86	Active Channel Flow: Mlb/hr	64.57
Total Bypass Flow (%):	12.3	(of total core flow)	
Total Water Rod Flow (%):	3.0	(of total core flow)	
Source Convergence	0.00031		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.437	7	37	36	1.533	0.874	8	39	38	6.46	0.688	51.9	5	33	12	12	6.38	0.821	62.8	5	31	10	11
1.427	7	35	38	1.536	0.872	8	37	14	7.97	0.688	23.0	8	31	12	12	6.42	0.818	62.5	5	27	44	11
1.426	7	39	34	1.550	0.864	8	41	36	7.98	0.687	22.6	8	37	14	12	6.34	0.815	62.8	5	41	34	11
1.419	8	39	38	1.554	0.862	8	35	12	6.78	0.687	45.5	5	35	14	12	6.44	0.811	62.1	5	19	12	11
1.417	7	33	40	1.556	0.861	8	21	12	7.96	0.685	22.6	8	39	16	12	6.40	0.807	62.2	5	23	42	11
1.416	8	37	40	1.561	0.858	8	29	44	6.41	0.684	52.2	5	23	42	12	6.13	0.800	63.2	5	43	32	11
1.416	8	31	42	1.566	0.856	8	27	12	7.91	0.682	22.8	8	25	42	12	6.11	0.771	62.2	5	11	30	12
1.413	8	27	42	1.581	0.848	7	37	36	7.92	0.682	22.5	8	35	12	12	6.55	0.757	59.2	4	37	38	12
1.403	8	41	36	1.584	0.846	8	19	44	6.73	0.681	45.3	5	39	18	12	5.93	0.756	62.5	5	43	28	11
1.401	8	35	42	1.585	0.846	8	43	20	6.33	0.678	52.5	5	31	10	12	6.86	0.744	57.0	5	13	36	11

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.34 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 14,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	31553.1
Exposure: MWd/MTU (GWd)	14001.0 (1419.21)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.60		
Flow: Mlb/hr	73.15 (95.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.212 5.403 1 0.243 0.244 17 52
		24	0.499 12.899 2 0.397 0.611 47 16
		23	0.739 19.488 3 0.375 0.453 47 14
		22	0.855 23.134 4 1.133 1.263 23 38
		21	0.921 25.580 5 0.955 1.235 41 24
		20	0.978 27.542 6 0.797 0.995 25 48
		19	1.023 28.937 7 1.330 1.483 15 28
		18	1.073 30.388 8 1.196 1.470 41 26
		17	1.118 31.801 9 1.304 1.320 45 24
		16	1.159 32.635
		15	1.239 33.253
		14	1.285 35.155
		13	1.306 36.757
		12	1.320 38.507
		11	1.298 39.597
		10	1.338* 38.323
		9	1.323 39.359
		8	1.281 40.349
		7	1.238 41.556
		6	1.178 42.427*
		5	1.097 42.310
		4	0.984 41.316
		3	0.846 37.997
		2	0.531 23.525
		Bottom 1	0.157 7.594
Control Rod Density: %	5.05		
k-effective:	1.00002		
Void Fraction:	0.442		
Core Delta-P: psia	21.062	% AXIAL TILT	-6.285 -17.168
Core Plate Delta-P: psia	16.519	AVG BOT 8ft/12ft	1.0639 1.1008
Coolant Temp: Deg-F	547.7		
In Channel Flow: Mlb/hr	64.12	Active Channel Flow: Mlb/hr	61.91
Total Bypass Flow (%):	12.3	(of total core flow)	
Total Water Rod Flow (%):	3.0	(of total core flow)	
Source Convergence	0.00039		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR						
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.483	7	15	28	1.446	0.926	8	27	8.09	0.698	22.8	8	25	42	12	6.61	0.834	62.2	5	11	30	12
1.470	8	41	26	1.447	0.926	8	11	6.49	0.693	52.2	5	23	42	12	6.44	0.824	62.6	5	25	10	11
1.470	7	27	16	1.485	0.902	8	21	8.03	0.691	22.6	8	41	26	12	6.84	0.816	60.3	5	29	42	12
1.470	7	13	30	1.489	0.900	8	11	6.50	0.685	50.6	4	25	40	12	6.54	0.812	61.7	5	9	26	12
1.467	7	29	14	1.491	0.899	7	37	6.40	0.685	52.5	5	41	24	12	6.14	0.801	63.2	5	43	32	11
1.464	8	27	12	1.500	0.894	7	29	7.99	0.683	21.4	7	23	40	12	6.30	0.799	62.3	5	31	10	11
1.452	7	29	18	1.500	0.894	8	29	7.90	0.682	23.0	8	21	42	12	6.64	0.787	60.1	5	19	42	12
1.452	7	31	16	1.500	0.893	8	43	6.54	0.682	49.3	4	39	26	12	6.58	0.784	60.3	5	41	20	12
1.447	7	15	32	1.503	0.891	7	29	7.94	0.680	21.7	7	25	38	12	9.52	0.758	30.8	8	27	12	12
1.433	7	35	24	1.504	0.891	7	13	7.99	0.678	20.4	7	37	26	12	6.56	0.757	59.2	4	25	14	12

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.35 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 14,001.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-39

Cycle:	28	Core Average Exposure: MWd/MTU	32052.2
Exposure: MWd/MTU (GWd)	14500.0 (1469.79)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-22.02		
Flow: Mlb/hr	74.84 (97.20 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.226 5.522 1 0.242 0.243 17 52
		24	0.531 13.180 2 0.397 0.611 47 16
		23	0.788 19.907 3 0.375 0.453 47 14
		22	0.912 23.621 4 1.132 1.260 23 38
		21	0.981 26.104 5 0.955 1.231 41 24
		20	1.041 28.098 6 0.796 0.994 25 48
		19	1.087 29.518 7 1.331 1.478 37 26
		18	1.136 30.997 8 1.197 1.465 41 26
		17	1.178 32.434 9 1.304 1.318 45 24
		16	1.211 33.274
		15	1.283 33.891
		14	1.315 35.812
		13	1.321* 37.421
		12	1.320 39.174
		11	1.284 40.249
		10	1.314 38.926
		9	1.289 39.948
		8	1.236 40.917
		7	1.179 42.101
		6	1.105 42.941*
		5	1.010 42.786
		4	0.888 41.739
		3	0.753 38.357
		2	0.471 23.749
		Bottom 1	0.140 7.668
			% AXIAL TILT -1.260 -16.836
			AVG BOT 8ft/12ft 1.0365 1.0992
Control Rod Density: %	5.05		
k-effective:	1.00002		
Void Fraction:	0.428		
Core Delta-P: psia	21.615		
Core Plate Delta-P: psia	17.071		
Coolant Temp: Deg-F	547.6		
In Channel Flow: Mlb/hr	65.70	Active Channel Flow: Mlb/hr	63.48
Total Bypass Flow (%):	12.2	(of total core flow)	
Total Water Rod Flow (%):	3.0	(of total core flow)	
Source Convergence	0.00048		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.478	7	37	26	1.451	0.924	8	27	12	8.04	0.698	23.8	8	25	42	12	6.58	0.852	63.0	5	11	30	12
1.468	7	27	16	1.452	0.923	8	11	28	6.46	0.694	53.0	5	23	42	12	6.61	0.840	62.4	5	27	44	12
1.466	7	39	24	1.486	0.901	8	21	12	7.98	0.692	23.6	8	41	26	12	6.82	0.833	61.1	5	29	42	12
1.465	8	41	26	1.491	0.899	8	11	22	6.37	0.687	53.3	5	41	24	12	6.54	0.830	62.3	5	43	28	12
1.465	7	29	14	1.499	0.894	8	29	44	6.45	0.685	51.4	4	25	40	12	6.32	0.818	63.0	5	31	10	12
1.461	8	27	12	1.501	0.893	8	43	30	7.87	0.684	24.0	8	21	42	12	6.28	0.818	63.2	5	43	32	12
1.452	7	31	16	1.504	0.891	7	37	28	7.95	0.684	22.4	7	23	40	12	6.64	0.806	60.9	5	19	42	12
1.451	7	29	18	1.506	0.890	7	29	14	6.49	0.681	50.1	4	39	26	12	6.57	0.803	61.1	5	41	20	12
1.446	7	37	22	1.510	0.888	7	29	36	6.32	0.681	53.2	5	25	44	12	6.62	0.770	59.5	4	27	14	12
1.432	7	35	24	1.512	0.887	7	13	30	7.88	0.679	22.7	7	25	38	12	9.56	0.757	30.2	8	27	12	13

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.36 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 14,500.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	32552.1
Exposure: MWd/MTU (GWd)	15000.0 (1520.47)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-21.45		
Flow: Mlb/hr	76.61 (99.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.240 5.648 1 0.241 0.242 17 52
		24	0.565 13.480 2 0.395 0.610 47 16
		23	0.839 20.353 3 0.373 0.452 47 14
		22	0.970 24.140 4 1.132 1.258 23 38
		21	1.044 26.662 5 0.954 1.229 41 24
		20	1.106 28.691 6 0.795 0.993 25 48
		19	1.152 30.136 7 1.333 1.476 37 26
		18	1.199 31.641 8 1.198 1.463 41 26
		17	1.237 33.100 9 1.305 1.319 45 24
		16	1.261 33.940
		15	1.322 34.552
		14	1.339* 36.484
		13	1.328 38.092
		12	1.312 39.841
		11	1.263 40.894
		10	1.283 39.518
		9	1.250 40.521
		8	1.187 41.464
		7	1.119 42.620
		6	1.034 43.424*
		5	0.929 43.224
		4	0.803 42.121
		3	0.674 38.679
		2	0.421 23.950
		Bottom 1	0.125 7.734
			% AXIAL TILT 3.693 -16.436
			AVG BOT 8ft/12ft 1.0086 1.0974
Control Rod Density: %	5.05		
k-effective:	1.00008		
Void Fraction:	0.413		
Core Delta-P: psia	22.212		
Core Plate Delta-P: psia	17.668		
Coolant Temp: Deg-F	547.5		
In Channel Flow: Mlb/hr	67.35	Active Channel Flow: Mlb/hr	65.11
Total Bypass Flow (%):	12.1	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00041		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.476	7	37	26	1.457	0.920	8	27	12	8.46	0.710	18.6	7	27	38	17	6.52	0.866	63.8	5	11	30	12
1.466	7	25	38	1.458	0.919	8	11	28	6.99	0.705	45.0	4	27	40	17	6.57	0.855	63.1	5	27	44	12
1.465	7	39	24	1.490	0.899	8	21	12	7.15	0.702	41.5	4	29	38	17	6.75	0.846	62.0	5	29	42	12
1.463	8	41	26	1.495	0.896	8	11	22	8.08	0.699	23.3	8	25	42	13	6.50	0.845	63.1	5	43	28	12
1.463	7	29	14	1.499	0.894	8	29	44	6.68	0.698	49.4	5	23	42	14	6.37	0.833	63.3	5	21	44	12
1.459	8	25	42	1.501	0.893	8	43	30	7.01	0.697	43.1	4	25	36	17	6.23	0.832	63.9	5	43	32	12
1.451	7	21	38	1.513	0.886	7	37	28	8.31	0.696	18.4	7	23	14	17	6.59	0.820	61.7	5	19	42	12
1.450	7	23	36	1.515	0.884	7	29	14	8.36	0.696	17.3	7	37	28	17	6.53	0.817	61.9	5	41	20	12
1.446	7	37	22	1.517	0.884	7	29	36	6.99	0.695	43.2	4	37	30	17	6.54	0.780	60.3	4	27	14	12
1.433	7	35	24	1.521	0.881	7	13	30	6.89	0.695	45.0	4	39	28	17	9.71	0.765	29.6	8	27	12	14

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.37 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 15,000.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-41

Cycle:	28	Core Average Exposure: MWd/MTU	33052.0
Exposure: MWd/MTU (GWd)	15500.0 (1571.15)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.85		
Flow: Mlb/hr	78.54 (102.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.255 5.783 1 0.240 0.240 17 52
		24	0.602 13.799 2 0.394 0.609 47 16
		23	0.895 20.828 3 0.372 0.451 47 14
		22	1.034 24.693 4 1.130 1.255 23 38
		21	1.111 27.257 5 0.954 1.226 41 24
		20	1.175 29.320 6 0.794 0.992 25 48
		19	1.220 30.791 7 1.334 1.474 37 26
		18	1.264 32.321 8 1.200 1.461 41 26
		17	1.294 33.799 9 1.307 1.321 45 30
		16	1.306 34.632
		15	1.355* 35.230
		14	1.355 37.166
		13	1.326 38.764
		12	1.295 40.501
		11	1.235 41.526
		10	1.247 40.095
		9	1.207 41.076
		8	1.136 41.988
		7	1.058 43.112
		6	0.964 43.875*
		5	0.852 43.628
		4	0.725 42.467
		3	0.603 38.967
		2	0.376 24.129
		Bottom 1	0.111 7.793
			% AXIAL TILT 8.678 -15.971
			AVG BOT 8ft/12ft 0.9791 1.0951
Control Rod Density: %	5.05		
k-effective:	1.00006		
Void Fraction:	0.399		
Core Delta-P: psia	22.881		
Core Plate Delta-P: psia	18.337		
Coolant Temp: Deg-F	547.4		
In Channel Flow: Mlb/hr	69.14	Active Channel Flow: Mlb/hr	66.88
Total Bypass Flow (%):	12.0	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00026		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.474	7	37	26	1.466	0.914	8	27	8.81	0.745	19.6	7	27	38	17	6.42
1.464	7	25	38	1.466	0.914	8	11	7.26	0.737	45.9	4	27	40	17	6.48
1.463	7	39	24	1.497	0.895	8	21	7.41	0.734	42.4	4	29	38	17	6.41
1.461	7	23	40	1.501	0.893	8	11	8.71	0.733	19.1	7	29	40	17	6.64
1.461	8	41	26	1.501	0.893	8	29	8.73	0.732	18.4	7	37	28	17	6.30
1.457	8	27	42	1.503	0.891	8	43	7.26	0.727	44.1	4	37	30	17	6.15
1.451	7	21	38	1.519	0.882	7	37	7.16	0.727	45.9	4	39	28	17	6.50
1.449	7	23	36	1.519	0.882	7	29	7.26	0.727	44.0	4	25	36	17	6.44
1.446	7	37	22	1.521	0.881	7	29	8.62	0.724	18.7	7	39	30	17	10.11
1.433	7	35	24	1.524	0.879	7	27	8.60	0.721	18.5	7	31	38	17	6.43

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.38 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 15,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-42

Cycle:	28	Core Average Exposure: MWd/MTU	33053.0
Exposure: MWd/MTU (GWd)	15501.0 (1571.25)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.33		
Flow: Mlb/hr	73.92 (96.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.263 5.783 1 0.240 0.241 17 52
		24	0.619 13.799 2 0.395 0.609 47 38
		23	0.922 20.829 3 0.372 0.453 47 40
		22	1.072 24.695 4 1.137 1.255 23 38
		21	1.163 27.258 5 0.951 1.220 41 24
		20	1.212 29.322 6 0.790 0.983 27 48
		19	1.241 30.792 7 1.340 1.473 37 28
		18	1.273 32.322 8 1.194 1.452 41 28
		17	1.293 33.800 9 1.293 1.309 45 30
		16	1.298 34.634
		15	1.340* 35.232
		14	1.335 37.168
		13	1.303 38.766
		12	1.270 40.502
		11	1.211 41.527
		10	1.223 40.096
		9	1.185 41.077
		8	1.118 41.989
		7	1.044 43.113
		6	0.954 43.876*
		5	0.847 43.628
		4	0.724 42.468
		3	0.603 38.967
		2	0.376 24.130
		Bottom 1	0.111 7.793
			% AXIAL TILT 9.975 -15.970
			AVG BOT 8ft/12ft 0.9667 1.0951
Control Rod Density: %	4.84		
k-effective:	1.00005		
Void Fraction:	0.405		
Core Delta-P: psia	20.898		
Core Plate Delta-P: psia	16.359		
Coolant Temp: Deg-F	547.2		
In Channel Flow: Mlb/hr	65.02	Active Channel Flow: Mlb/hr	62.87
Total Bypass Flow (%):	12.0	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00048		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.473	7	37	28	1.435	0.934	8	27	8.85	0.748	19.6	7	27	38	17	6.28
1.464	7	27	38	1.441	0.930	8	11	7.26	0.737	45.9	4	27	40	17	6.34
1.458	7	39	30	1.451	0.924	7	29	7.45	0.737	42.5	4	29	38	17	6.28
1.457	7	29	40	1.460	0.918	7	37	8.77	0.735	18.4	7	37	28	17	6.51
1.455	7	29	36	1.464	0.916	8	31	8.72	0.734	19.1	7	29	40	17	6.17
1.452	8	41	28	1.466	0.914	7	27	7.32	0.732	44.0	4	25	36	17	6.02
1.451	7	31	38	1.468	0.913	8	41	7.29	0.731	44.1	4	37	30	17	6.36
1.448	8	27	42	1.469	0.912	7	21	7.56	0.729	38.9	4	29	30	21	6.31
1.446	7	37	32	1.473	0.910	7	35	7.16	0.727	45.9	4	39	28	17	9.99
1.439	7	35	30	1.476	0.908	8	29	7.23	0.726	44.4	4	35	28	17	9.94

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.39 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 15,501.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	33552.0
Exposure: MWd/MTU (GWd)	16000.0 (1621.83)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-21.57		
Flow: Mlb/hr	76.23 (99.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.280 5.930 1 0.238 0.240 17 52
		24	0.661 14.149 2 0.394 0.609 47 38
		23	0.984 21.351 3 0.371 0.452 47 40
		22	1.143 25.305 4 1.135 1.251 23 38
		21	1.239 27.920 5 0.951 1.217 41 24
		20	1.288 30.010 6 0.789 0.983 25 48
		19	1.312 31.495 7 1.340 1.469 37 28
		18	1.338 33.041 8 1.197 1.450 41 28
		17	1.348 34.527 9 1.296 1.312 45 30
		16	1.340 35.344
		15	1.369* 35.917
		14	1.346 37.845
		13	1.297 39.423
		12	1.250 41.139
		11	1.180 42.131
		10	1.184 40.644
		9	1.139 41.600
		8	1.063 42.481
		7	0.981 43.569
		6	0.881 44.290*
		5	0.768 43.993
		4	0.646 42.777
		3	0.534 39.223
		2	0.333 24.289
		Bottom 1	0.099 7.846
			% AXIAL TILT 15.142 -15.422
			AVG BOT 8ft/12ft 0.9349 1.0923
Control Rod Density: %	4.84		
k-effective:	1.00008		
Void Fraction:	0.389		
Core Delta-P: psia	21.703		
Core Plate Delta-P: psia	17.163		
Coolant Temp: Deg-F	547.1		
In Channel Flow: Mlb/hr	67.16	Active Channel Flow: Mlb/hr	64.97
Total Bypass Flow (%):	11.9	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00044		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR						
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.469	7	37	28	1.438	0.932	8	27	9.15	0.779	20.8	7	27	38	17	6.17	0.865	65.3	5	11	30	12
1.459	7	27	38	1.444	0.928	8	11	7.95	0.772	39.9	4	29	30	21	6.25	0.856	64.7	5	27	44	12
1.455	7	39	24	1.457	0.920	7	29	9.11	0.769	19.5	7	37	28	17	6.19	0.847	64.7	5	43	28	12
1.454	7	29	40	1.462	0.916	8	31	9.06	0.768	20.2	7	29	40	17	6.39	0.844	63.6	5	29	42	12
1.453	7	29	36	1.467	0.914	8	41	7.50	0.767	46.8	4	27	40	17	6.09	0.836	64.8	5	21	44	12
1.450	8	41	28	1.468	0.913	7	37	7.69	0.766	43.4	4	29	38	17	5.93	0.832	65.4	5	43	32	12
1.449	7	31	38	1.472	0.910	8	29	7.59	0.762	44.4	4	27	36	18	6.27	0.819	63.3	5	19	42	12
1.446	8	27	42	1.473	0.910	7	27	8.99	0.760	19.8	7	39	30	17	6.22	0.818	63.5	5	41	20	12
1.444	7	37	32	1.474	0.909	7	21	7.53	0.760	45.0	4	37	30	17	10.17	0.799	29.2	8	27	12	16
1.437	7	35	30	1.477	0.908	8	43	8.99	0.759	19.6	7	31	38	17	8.88	0.792	43.5	4	29	30	21

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.40 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 16,000.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	34052.0
Exposure: MWd/MTU (GWd)	16500.0 (1672.52)		
Delta E: MWd/MTU, (GWd)	500.0 (50.68)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.62		
Flow: Mlb/hr	79.31 (103.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.297 6.087 1 0.237 0.239 17 52
		24	0.703 14.522 2 0.393 0.610 47 38
		23	1.048 21.909 3 0.370 0.452 47 40
		22	1.216 25.956 4 1.131 1.246 23 38
		21	1.314 28.624 5 0.951 1.215 41 24
		20	1.361 30.741 6 0.789 0.984 25 48
		19	1.378 32.238 7 1.338 1.463 37 26
		18	1.395* 33.795 8 1.201 1.448 41 28
		17	1.393 35.284 9 1.300 1.316 45 30
		16	1.370 36.075
		15	1.387 36.616
		14	1.347 38.527
		13	1.283 40.076
		12	1.224 41.765
		11	1.146 42.719
		10	1.145 41.175
		9	1.096 42.105
		8	1.013 42.950
		7	0.923 43.999
		6	0.816 44.673*
		5	0.700 44.325
		4	0.581 43.054
		3	0.477 39.451
		2	0.298 24.430
		Bottom 1	0.088 7.892
			% AXIAL TILT 19.815 -14.815
			AVG BOT 8ft/12ft 0.9044 1.0892
Control Rod Density: %	4.84		
k-effective:	1.00005		
Void Fraction:	0.373		
Core Delta-P: psia	22.865		
Core Plate Delta-P: psia	18.324		
Coolant Temp: Deg-F	547.1		
In Channel Flow: Mlb/hr	69.98	Active Channel Flow: Mlb/hr	67.75
Total Bypass Flow (%):	11.8	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00031		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.463	7	37	26	1.449	0.925	8	27	8.31	0.813	40.9	4	29	30	21	6.04
1.453	7	27	38	1.454	0.922	8	11	9.63	0.805	18.0	7	29	32	21	6.12
1.451	7	39	24	1.468	0.913	8	31	9.58	0.801	18.0	7	31	30	21	6.07
1.450	7	23	40	1.471	0.911	7	29	9.41	0.801	20.8	7	27	38	18	6.25
1.449	7	29	36	1.473	0.909	8	41	8.15	0.797	40.7	4	31	32	21	5.98
1.448	8	41	28	1.474	0.909	8	29	9.30	0.794	21.3	7	29	40	17	5.81
1.446	7	31	38	1.479	0.906	8	43	9.33	0.793	20.7	7	37	28	17	9.27
1.444	8	27	42	1.484	0.903	7	37	8.00	0.791	42.5	4	29	38	18	6.14
1.440	7	37	32	1.486	0.902	7	21	7.66	0.790	47.8	4	27	40	17	6.09
1.433	7	35	30	1.488	0.900	7	27	7.80	0.789	45.3	4	27	36	18	10.24

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.41 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 16,500.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-45

Cycle:	28	Core Average Exposure: MWd/MTU	34053.1
Exposure: MWd/MTU (GWd)	16501.0 (1672.62)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.56		
Flow: Mlb/hr	70.46 (91.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.253 6.088 1 0.239 0.241 17 52
		24	0.594 14.523 2 0.397 0.622 15 48
		23	0.888 21.910 3 0.373 0.465 47 14
		22	1.041 25.957 4 1.116 1.241 25 36
		21	1.148 28.626 5 0.959 1.238 17 40
		20	1.241 30.743 6 0.782 0.960 25 48
		19	1.301 32.239 7 1.318 1.466 23 36
		18	1.349 33.797 8 1.225 1.420 25 42
		17	1.373 35.285 9 1.258 1.288 23 46
		16	1.373 36.076
		15	1.402* 36.617
		14	1.373 38.528
		13	1.317 40.077
		12	1.263 41.767
		11	1.190 42.720
		10	1.194 41.176
		9	1.150 42.106
		8	1.079 42.951
		7	1.004 44.000
		6	0.915 44.674*
		5	0.811 44.326
		4	0.692 43.055
		3	0.579 39.452
		2	0.364 24.431
		Bottom 1	0.109 7.892
			% AXIAL TILT 12.600 -14.814
			AVG BOT 8ft/12ft 0.9585 1.0892
Control Rod Density: %	2.74		
k-effective:	1.00006		
Void Fraction:	0.407		
Core Delta-P: psia	19.461		
Core Plate Delta-P: psia	14.930		
Coolant Temp: Deg-F	547.0		
In Channel Flow: Mlb/hr	61.94	Active Channel Flow: Mlb/hr	59.87
Total Bypass Flow (%):	12.1	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00044		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	IR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.466	7	23	36	1.434	0.934	8	27	12	9.07	0.778	21.9	7	25	38	17	6.07	0.853	65.4	5	27	44	12
1.450	7	25	34	1.442	0.929	8	37	14	7.59	0.771	45.9	4	25	36	17	6.05	0.852	65.5	5	21	44	12
1.450	7	21	38	1.443	0.928	8	21	42	9.10	0.770	19.8	7	23	36	17	6.25	0.846	64.3	5	29	42	12
1.447	7	25	38	1.447	0.926	7	23	36	9.00	0.769	21.3	7	23	40	17	6.28	0.842	64.0	5	19	42	12
1.439	7	23	40	1.457	0.920	7	21	38	9.02	0.768	20.8	7	25	34	17	5.66	0.814	66.1	5	11	30	12
1.424	7	19	40	1.461	0.917	7	27	20	9.01	0.765	20.6	7	21	38	17	5.63	0.810	66.1	5	43	32	12
1.420	8	25	42	1.463	0.916	8	13	38	7.63	0.765	44.3	4	23	38	17	5.74	0.809	65.5	5	41	34	12
1.418	7	17	38	1.467	0.913	8	29	44	7.40	0.762	47.7	4	25	40	17	5.70	0.800	65.4	5	43	28	12
1.417	7	23	32	1.468	0.913	8	35	12	7.41	0.752	45.9	4	21	40	17	10.03	0.796	30.5	8	27	12	16
1.416	7	19	36	1.470	0.912	7	27	38	7.43	0.751	45.2	4	23	34	17	7.56	0.787	55.4	4	27	36	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.42 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 16,501.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-46

Cycle:	28	Core Average Exposure: MWd/MTU	34452.0
Exposure: MWd/MTU (GWd)	16900.0 (1713.06)		
Delta E: MWd/MTU, (GWd)	399.0 (40.44)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.21		
Flow: Mlb/hr	74.31 (96.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.267 6.200 1 0.238 0.240 17 52
		24	0.630 14.790 2 0.397 0.622 15 48
		23	0.942 22.311 3 0.373 0.465 47 14
		22	1.102 26.429 4 1.112 1.235 23 38
		21	1.211 29.145 5 0.961 1.237 17 40
		20	1.303 31.303 6 0.783 0.963 25 48
		19	1.358 32.825 7 1.314 1.459 23 36
		18	1.398 34.402 8 1.230 1.418 25 42
		17	1.410 35.898 9 1.265 1.294 23 46
		16	1.398 36.672
		15	1.418* 37.188
		14	1.374 39.083
		13	1.307 40.608
		12	1.244 42.273
		11	1.165 43.196
		10	1.165 41.605
		9	1.117 42.514
		8	1.040 43.333
		7	0.957 44.353
		6	0.859 44.994*
		5	0.749 44.608
		4	0.631 43.294
		3	0.524 39.650
		2	0.330 24.555
		Bottom 1	0.099 7.934
			% AXIAL TILT 16.601 -14.378
			AVG BOT 8ft/12ft 0.9326 1.0870
Control Rod Density: %	2.74		
k-effective:	1.00002		
Void Fraction:	0.390		
Core Delta-P: psia	20.895		
Core Plate Delta-P: psia	16.362		
Coolant Temp: Deg-F	547.0		
In Channel Flow: Mlb/hr	65.43	Active Channel Flow: Mlb/hr	63.29
Total Bypass Flow (%):	11.9	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00045		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.459	7	23	36	1.457	0.920	8	27	9.21	0.794	22.8	7	25	5.98	0.861	66.1
1.445	7	21	38	1.458	0.919	8	37	9.18	0.789	22.2	7	23	5.99	0.860	66.0
1.440	7	25	34	1.463	0.916	8	21	9.26	0.787	20.7	7	23	6.15	0.851	64.9
1.439	7	25	38	1.478	0.907	8	13	7.69	0.786	46.6	4	25	6.20	0.848	64.6
1.435	7	23	40	1.481	0.905	7	23	9.18	0.785	21.5	7	21	5.60	0.821	66.6
1.423	7	19	40	1.482	0.904	8	29	7.75	0.782	45.1	4	23	5.57	0.818	66.7
1.418	8	25	42	1.483	0.903	8	35	9.13	0.782	21.7	7	25	5.67	0.815	66.1
1.417	7	17	38	1.485	0.902	7	21	7.53	0.780	48.5	4	25	5.65	0.809	65.9
1.412	7	19	36	1.496	0.896	7	27	9.00	0.773	22.3	8	25	10.08	0.807	31.5
1.408	8	21	42	1.501	0.893	7	27	7.56	0.773	46.7	4	21	7.58	0.805	56.2

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.43 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 16,900.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-47

Cycle:	28	Core Average Exposure: MWd/MTU	34851.9
Exposure: MWd/MTU (GWd)	17300.0 (1753.61)		
Delta E: MWd/MTU, (GWd)	400.0 (40.55)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.86		
Flow: Mlb/hr	78.54 (102.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.282 6.320 1 0.237 0.239 17 52
		24	0.667 15.074 2 0.397 0.623 15 48
		23	0.998 22.737 3 0.372 0.466 47 14
		22	1.165 26.929 4 1.106 1.228 23 38
		21	1.275 29.694 5 0.963 1.236 17 40
		20	1.365 31.892 6 0.785 0.965 25 48
		19	1.411 33.436 7 1.309 1.451 23 36
		18	1.441 35.029 8 1.235 1.417 25 42
		17	1.441* 36.528 9 1.272 1.301 23 46
		16	1.417 37.280
		15	1.427 37.765
		14	1.372 39.639
		13	1.293 41.134
		12	1.224 42.773
		11	1.140 43.663
		10	1.137 42.025
		9	1.086 42.912
		8	1.002 43.701
		7	0.911 44.691
		6	0.807 45.295*
		5	0.693 44.869
		4	0.578 43.513
		3	0.477 39.831
		2	0.300 24.668
		Bottom 1	0.090 7.971
			% AXIAL TILT 20.309 -13.905
			AVG BOT 8ft/12ft 0.9075 1.0847
Control Rod Density: %	2.74		
k-effective:	0.99998		
Void Fraction:	0.374		
Core Delta-P: psia	22.550		
Core Plate Delta-P: psia	18.015		
Coolant Temp: Deg-F	547.1		
In Channel Flow: Mlb/hr	69.28	Active Channel Flow: Mlb/hr	67.06
Total Bypass Flow (%):	11.8	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00044		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.451	7	23	36	1.473	0.917	8	37	14	9.29	0.806	23.7	7	25	38	17	5.91	0.867	66.7	5	21	44	12
1.440	7	21	38	1.479	0.913	8	27	12	9.30	0.804	23.1	7	23	40	17	6.76	0.866	62.7	5	27	44	14
1.432	7	25	38	1.482	0.911	8	21	42	9.35	0.800	21.6	7	23	36	17	7.52	0.864	59.0	5	23	42	16
1.430	7	23	40	1.492	0.905	8	13	38	9.30	0.800	22.4	7	21	38	17	6.11	0.853	65.2	5	19	42	12
1.429	7	25	34	1.496	0.902	8	29	44	7.85	0.798	46.0	4	25	36	18	6.33	0.830	63.4	5	11	30	14
1.421	7	19	40	1.497	0.902	8	35	12	7.95	0.796	43.9	4	23	38	18	5.50	0.824	67.2	5	43	32	12
1.417	8	25	42	1.513	0.892	8	19	44	7.62	0.795	49.2	4	25	40	17	7.57	0.820	56.9	4	27	36	16
1.415	7	17	38	1.515	0.891	7	21	38	9.16	0.792	23.2	8	25	42	17	6.39	0.819	62.7	5	41	34	14
1.409	8	21	42	1.515	0.891	7	23	36	9.19	0.791	22.7	7	25	34	17	6.39	0.817	62.6	5	43	28	14
1.408	7	19	36	1.530	0.882	7	27	20	9.19	0.790	22.3	7	19	40	17	10.08	0.814	32.5	8	27	12	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.44 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 17,300.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-48

Cycle:	28	Core Average Exposure: MWd/MTU	34852.9
Exposure: MWd/MTU (GWd)	17301.0 (1753.71)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.38		
Flow: Mlb/hr	73.77 (95.80 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.297 6.320 1 0.235 0.237 17 52
		24	0.701 15.075 2 0.395 0.616 15 48
		23	1.043 22.738 3 0.370 0.462 47 14
		22	1.214 26.931 4 1.121 1.222 23 38
		21	1.320 29.695 5 0.956 1.224 17 40
		20	1.390 31.894 6 0.777 0.951 25 48
		19	1.422 33.437 7 1.324 1.448 23 36
		18	1.441* 35.030 8 1.223 1.400 25 42
		17	1.433 36.530 9 1.259 1.281 23 46
		16	1.403 37.281
		15	1.408 37.766
		14	1.349 39.641
		13	1.270 41.136
		12	1.200 42.775
		11	1.118 43.664
		10	1.115 42.026
		9	1.066 42.913
		8	0.985 43.702
		7	0.899 44.691
		6	0.799 45.295*
		5	0.688 44.869
		4	0.574 43.513
		3	0.475 39.832
		2	0.299 24.669
		Bottom 1	0.089 7.971
			% AXIAL TILT 21.545 -13.904
			AVG BOT 8ft/12ft 0.8949 1.0846
Control Rod Density: %	2.46		
k-effective:	1.00001		
Void Fraction:	0.380		
Core Delta-P: psia	20.527		
Core Plate Delta-P: psia	15.997		
Coolant Temp: Deg-F	546.8		
In Channel Flow: Mlb/hr	65.02	Active Channel Flow: Mlb/hr	62.91
Total Bypass Flow (%):	11.9	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.448	7	23	36	1.446	0.933	8	37	9.32	0.803	22.6	7	25	38	18	7.41
1.431	7	25	34	1.450	0.931	8	27	7.87	0.800	46.0	4	25	36	18	6.61
1.431	7	21	38	1.455	0.928	8	21	9.40	0.799	20.7	7	23	36	18	5.77
1.423	7	25	38	1.457	0.926	8	13	9.31	0.797	21.7	7	25	34	18	6.85
1.417	7	23	40	1.466	0.921	7	23	9.21	0.796	23.1	7	23	40	17	6.23
1.408	7	19	40	1.473	0.916	7	21	9.23	0.794	22.4	7	21	38	17	7.50
1.408	7	23	32	1.474	0.916	8	35	7.93	0.794	43.9	4	23	38	18	7.78
1.407	7	19	36	1.477	0.914	8	29	7.67	0.788	47.4	4	25	40	18	5.38
1.406	7	17	38	1.478	0.914	7	27	7.76	0.784	45.3	4	23	34	18	8.09
1.400	8	25	42	1.493	0.904	7	27	9.04	0.782	23.2	8	25	42	17	9.95

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.45 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 17,301.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-49

Cycle:	28	Core Average Exposure: MWd/MTU	35352.0
Exposure: MWd/MTU (GWd)	17800.0 (1804.29)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.29		
Flow: Mlb/hr	80.46 (104.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.315 6.486 1 0.234 0.235 17 52
		24	0.749 15.470 2 0.394 0.617 15 48
		23	1.116 23.329 3 0.369 0.463 47 14
		22	1.295 27.622 4 1.114 1.213 23 38
		21	1.399 30.444 5 0.959 1.224 17 40
		20	1.463 32.679 6 0.779 0.954 25 48
		19	1.482 34.237 7 1.317 1.436 23 36
		18	1.486* 35.837 8 1.230 1.398 25 42
		17	1.463 37.328 9 1.269 1.289 23 46
		16	1.419 38.041
		15	1.413 38.480
		14	1.342 40.321
		13	1.252 41.773
		12	1.176 43.375
		11	1.089 44.221
		10	1.083 42.526
		9	1.028 43.385
		8	0.940 44.136
		7	0.845 45.085
		6	0.737 45.642*
		5	0.624 45.166
		4	0.515 43.759
		3	0.424 40.034
		2	0.267 24.796
		Bottom 1	0.080 8.014
			% AXIAL TILT 25.836 -13.253
			AVG BOT 8ft/12ft 0.8648 1.0812
Control Rod Density: %	2.46		
k-effective:	0.99987		
Void Fraction:	0.358		
Core Delta-P: psia	23.192		
Core Plate Delta-P: psia	18.658		
Coolant Temp: Deg-F	547.0		
In Channel Flow: Mlb/hr	71.09	Active Channel Flow: Mlb/hr	68.85
Total Bypass Flow (%):	11.7	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00043		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.436	7	23	36	1.476	0.914	8	37	9.45	0.820	23.8	7	25	38	18	8.33
1.423	7	21	38	1.487	0.908	8	13	9.54	0.818	21.9	7	23	36	18	8.20
1.416	7	25	34	1.491	0.905	8	27	9.45	0.817	23.1	7	23	40	18	8.19
1.411	7	25	38	1.494	0.904	8	21	9.48	0.816	22.5	7	21	38	18	8.23
1.410	7	23	40	1.503	0.898	8	35	7.95	0.815	46.9	4	25	36	18	7.97
1.405	7	19	40	1.507	0.896	8	29	8.06	0.813	44.9	4	23	38	18	7.98
1.403	7	17	38	1.519	0.888	8	19	9.39	0.810	22.9	7	25	34	18	7.93
1.400	7	19	36	1.523	0.887	7	23	7.81	0.809	48.3	4	25	40	18	7.83
1.398	8	25	42	1.524	0.886	7	21	7.87	0.804	46.7	4	21	40	18	8.17
1.392	7	23	32	1.530	0.882	8	11	9.35	0.803	22.3	7	19	40	18	8.98

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.46 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 17,800.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	35353.1
Exposure: MWd/MTU (GWd)	17801.0 (1804.39)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.86		
Flow: Mlb/hr	72.38 (94.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.302 6.487 1 0.228 0.229 35 52
		24	0.712 15.471 2 0.387 0.607 47 38
		23	1.061 23.330 3 0.361 0.457 47 40
		22	1.237 27.623 4 1.144 1.225 29 34
		21	1.351 30.446 5 0.940 1.212 35 40
		20	1.427 32.681 6 0.760 0.928 27 48
		19	1.457 34.239 7 1.354 1.460 31 34
		18	1.469* 35.838 8 1.206 1.369 37 40
		17	1.452 37.329 9 1.240 1.254 29 46
		16	1.414 38.042
		15	1.410 38.481
		14	1.341 40.322
		13	1.254 41.774
		12	1.180 43.376
		11	1.095 44.222
		10	1.091 42.527
		9	1.041 43.386
		8	0.962 44.137
		7	0.877 45.085
		6	0.779 45.642*
		5	0.671 45.166
		4	0.562 43.759
		3	0.468 40.034
		2	0.296 24.796
		Bottom 1	0.089 8.014
			% AXIAL TILT 23.255 -13.251
			AVG BOT 8ft/12ft 0.8825 1.0812
Control Rod Density: %	1.22		
k-effective:	0.99983		
Void Fraction:	0.377		
Core Delta-P: psia	19.935		
Core Plate Delta-P: psia	15.411		
Coolant Temp: Deg-F	546.7		
In Channel Flow: Mlb/hr	63.79	Active Channel Flow: Mlb/hr	61.73
Total Bypass Flow (%):	11.9	(of total core flow)	
Total Water Rod Flow (%):	2.9	(of total core flow)	
Source Convergence	0.00043		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR								LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K	
1.460	7	31	34	1.446	0.934	7	29	36	9.52	0.814	21.5	7	31	34	18	8.09	0.864	56.4	5	29	42	17	
1.449	7	33	32	1.447	0.933	7	21	20	9.48	0.813	22.0	7	29	36	18	7.96	0.854	56.6	5	41	30	17	
1.447	7	29	36	1.452	0.930	7	19	22	9.48	0.811	21.6	7	33	32	18	7.90	0.842	56.3	5	27	44	17	
1.447	7	33	36	1.456	0.927	8	39	38	9.42	0.810	22.4	7	29	32	18	7.87	0.841	56.4	5	31	44	17	
1.442	7	35	34	1.457	0.927	8	37	40	9.44	0.809	21.8	7	33	36	18	7.15	0.838	59.7	5	41	34	16	
1.434	7	29	32	1.463	0.922	7	33	36	7.90	0.808	46.7	4	29	34	18	7.99	0.835	55.6	5	33	42	17	
1.429	7	27	34	1.467	0.920	7	35	34	9.34	0.807	23.0	7	27	34	18	7.00	0.829	60.1	5	43	32	16	
1.423	7	31	30	1.474	0.916	7	35	30	9.42	0.807	21.7	7	35	34	18	7.54	0.826	57.3	4	35	36	16	
1.422	7	31	38	1.476	0.915	8	21	12	7.85	0.805	47.1	4	31	36	18	7.76	0.824	56.2	5	43	28	17	
1.418	7	35	30	1.479	0.913	7	37	36	9.35	0.805	22.6	7	31	38	18	8.55	0.820	50.9	4	31	36	18	

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.47 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 17,801.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-51

Cycle:	28	Core Average Exposure: MWd/MTU	35852.0
Exposure: MWd/MTU (GWd)	18300.0 (1854.97)		
Delta E: MWd/MTU, (GWd)	499.0 (50.58)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.29		
Flow: Mlb/hr	80.46 (104.50 %)		
2 6 10 14 18 22 26 30 34 38 42 46 50		Axial Profile	Edit Radial Power
51	-- -- -- -- --	N(PRA) Power Exposure	Zone Avg. Max. IR JR
47	-- -- -- -- --	Top 25 0.321 6.656	1 0.227 0.228 17 52
43	-- -- -- -- --	24 0.762 15.873	2 0.387 0.608 47 38
39	-- -- -- -- --	23 1.134 23.931	3 0.360 0.458 47 40
35	-- -- -- -- --	22 1.319 28.327	4 1.135 1.207 29 34
31	-- -- -- -- 8 -- -- -- --	21 1.430 31.212	5 0.945 1.210 35 40
27	-- -- -- -- --	20 1.497 33.486	6 0.764 0.933 27 48
23	-- -- -- -- --	19 1.512* 35.057	7 1.344 1.440 31 34
19	-- -- -- -- --	18 1.507 36.658	8 1.215 1.372 37 40
15	-- -- -- -- --	17 1.475 38.135	9 1.252 1.265 29 46
11	-- -- -- -- --	16 1.423 38.806	
7	-- -- -- -- --	15 1.411 39.195	
3	-- -- -- -- --	14 1.331 40.998	
2 6 10 14 18 22 26 30 34 38 42 46 50		13 1.236 42.403	
		12 1.156 43.967	
		11 1.069 44.769	
		10 1.062 43.017	
		9 1.008 43.848	
		8 0.920 44.561	
		7 0.826 45.469	
		6 0.720 45.980*	
		5 0.610 45.456	
		4 0.505 44.001	
		3 0.418 40.234	
		2 0.265 24.922	
		Bottom 1 0.080 8.056	
Control Rod Density: %	1.22	% AXIAL TILT	27.277 -12.596
k-effective:	0.99952	AVG BOT 8ft/12ft	0.8535 1.0777
Void Fraction:	0.354		
Core Delta-P: psia	23.158		
Core Plate Delta-P: psia	18.630		
Coolant Temp: Deg-F	546.9		
In Channel Flow: Mlb/hr	71.10	Active Channel Flow: Mlb/hr	68.87
Total Bypass Flow (%):	11.6	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00028		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.440	7	31	34	1.503	0.898	8	39	9.54	0.825	23.2	7	29	36	18	8.21
1.433	7	33	36	1.503	0.898	8	37	9.57	0.825	22.7	7	31	34	18	8.09
1.430	7	29	36	1.520	0.888	7	29	9.54	0.823	22.9	7	33	36	18	8.04
1.429	7	33	32	1.524	0.886	7	21	9.51	0.821	22.9	7	35	34	18	8.05
1.428	7	35	34	1.525	0.885	8	21	9.51	0.820	22.8	7	33	32	18	8.06
1.410	7	29	32	1.529	0.883	7	19	9.45	0.820	23.8	7	31	38	18	8.15
1.410	7	31	38	1.533	0.881	8	27	7.91	0.818	48.1	4	31	36	18	7.96
1.409	7	27	34	1.534	0.880	8	29	7.92	0.816	47.7	4	29	34	18	7.91
1.405	7	35	38	1.537	0.878	7	33	9.41	0.816	23.6	7	29	32	18	7.50
1.403	7	37	36	1.538	0.878	8	11	7.93	0.815	47.3	4	33	34	18	7.34

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.48 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,300.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-52

Cycle:	28	Core Average Exposure: MWd/MTU	35853.0
Exposure: MWd/MTU (GWd)	18301.0 (1855.07)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.59		
Flow: Mlb/hr	73.15 (95.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.306 6.656 1 0.222 0.224 17 52
		24	0.721 15.874 2 0.380 0.596 47 16
		23	1.073 23.932 3 0.353 0.448 47 14
		22	1.253 28.329 4 1.163 1.216 23 34
		21	1.370 31.213 5 0.928 1.186 39 18
		20	1.452 33.488 6 0.747 0.907 25 48
		19	1.480 35.058 7 1.380 1.448 19 32
		18	1.486* 36.660 8 1.192 1.349 41 26
		17	1.462 38.137 9 1.225 1.236 45 24
		16	1.418 38.807
		15	1.409 39.197
		14	1.334 40.999
		13	1.242 42.405
		12	1.165 43.968
		11	1.080 44.770
		10	1.076 43.018
		9	1.026 43.848
		8	0.946 44.562
		7	0.862 45.470
		6	0.766 45.981*
		5	0.662 45.456
		4	0.557 44.001
		3	0.467 40.234
		2	0.298 24.922
		Bottom 1	0.090 8.056
Control Rod Density: %	0.00		
k-effective:	0.99947		
Void Fraction:	0.373		
Core Delta-P: psia	20.224	% AXIAL TILT	24.286 -12.595
Core Plate Delta-P: psia	15.704	AVG BOT 8ft/12ft	0.8746 1.0777
Coolant Temp: Deg-F	546.7		
In Channel Flow: Mlb/hr	64.49	Active Channel Flow: Mlb/hr	62.41
Total Bypass Flow (%):	11.8	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR						LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.448	7	19	32	1.468	0.920	7	21	9.42	0.809	22.1	7	33	22	18	7.07	0.871	61.4	5	11	30	16
1.446	7	21	34	1.472	0.917	7	19	9.38	0.808	22.6	7	23	32	18	7.89	0.866	57.4	5	29	42	17
1.445	7	21	30	1.473	0.916	7	21	9.39	0.807	22.3	7	21	34	18	7.82	0.851	57.0	5	41	20	17
1.440	7	23	32	1.481	0.912	7	29	9.37	0.806	22.5	7	35	24	18	7.77	0.850	57.3	5	21	44	17
1.433	7	35	24	1.482	0.911	8	37	9.39	0.806	22.2	7	21	30	18	7.74	0.847	57.3	5	27	44	17
1.426	7	33	26	1.484	0.910	8	13	9.31	0.804	23.0	7	23	36	18	7.77	0.845	57.0	5	43	22	17
1.424	7	23	36	1.484	0.910	7	35	7.82	0.802	47.1	4	33	24	18	7.74	0.844	57.1	5	43	28	17
1.423	7	35	20	1.488	0.907	7	19	7.82	0.802	47.0	4	21	32	18	7.84	0.840	56.5	5	19	42	17
1.420	7	19	36	1.488	0.907	7	35	9.21	0.801	24.1	7	25	34	18	7.46	0.826	57.7	4	35	22	16
1.415	7	25	34	1.492	0.905	7	19	7.81	0.801	47.0	4	35	22	18	7.30	0.821	58.2	4	35	36	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.49 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,301.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-53

Cycle:	28	Core Average Exposure: MWd/MTU	36151.9
Exposure: MWd/MTU (GWd)	18600.0 (1885.38)		
Delta E: MWd/MTU, (GWd)	299.0 (30.31)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.8		
Inlet Subcooling: Btu/lbm	-20.63		
Flow: Mlb/hr	79.31 (103.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.317 6.757 1 0.221 0.223 17 52
		24	0.752 16.115 2 0.380 0.597 47 16
		23	1.120 24.292 3 0.353 0.448 47 14
		22	1.305 28.751 4 1.157 1.205 23 34
		21	1.419 31.674 5 0.931 1.187 39 18
		20	1.496 33.974 6 0.749 0.912 25 48
		19	1.513* 35.552 7 1.373 1.436 19 32
		18	1.509 37.154 8 1.199 1.349 41 26
		17	1.476 38.622 9 1.233 1.245 45 24
		16	1.424 39.266
		15	1.410 39.624
		14	1.329 41.402
		13	1.232 42.779
		12	1.152 44.319
		11	1.065 45.094
		10	1.059 43.309
		9	1.005 44.123
		8	0.920 44.814
		7	0.830 45.698
		6	0.729 46.183*
		5	0.623 45.630
		4	0.520 44.147
		3	0.434 40.356
		2	0.277 24.999
		Bottom 1	0.084 8.082
			% AXIAL TILT 26.811 -12.209
			AVG BOT 8ft/12ft 0.8565 1.0756
Control Rod Density: %	0.00		
k-effective:	0.99945		
Void Fraction:	0.357		
Core Delta-P: psia	22.691		
Core Plate Delta-P: psia	18.169		
Coolant Temp: Deg-F	546.9		
In Channel Flow: Mlb/hr	70.05	Active Channel Flow: Mlb/hr	67.84
Total Bypass Flow (%):	11.7	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00028		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	Value	Margin	Exp.
1.436	7	19	32	1.515	0.891	8	37	9.45	0.815	22.8	7	33	7.98	0.893	58.1
1.435	7	21	34	1.518	0.889	8	13	9.42	0.813	23.0	7	21	7.98	0.891	58.0
1.431	7	21	30	1.526	0.885	7	21	9.40	0.813	23.2	7	35	7.89	0.876	57.8
1.426	7	23	32	1.531	0.882	7	19	9.39	0.812	23.3	7	23	7.93	0.876	57.6
1.422	7	35	24	1.531	0.882	7	21	9.35	0.811	23.7	7	23	7.84	0.872	57.9
1.415	7	35	20	1.538	0.878	7	29	9.39	0.810	22.9	7	21	7.89	0.871	57.6
1.414	7	23	36	1.540	0.877	7	35	9.35	0.809	23.4	7	35	7.84	0.868	57.7
1.413	7	19	36	1.540	0.877	7	19	9.34	0.808	23.4	7	19	7.95	0.865	57.1
1.413	7	33	26	1.541	0.876	7	35	7.84	0.807	47.6	4	35	7.30	0.833	58.8
1.403	7	25	34	1.548	0.872	7	19	7.83	0.807	47.6	4	21	7.42	0.833	58.2

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.50 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,600.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-54

Cycle:	28	Core Average Exposure: MWd/MTU	36152.9
Exposure: MWd/MTU (GWd)	18601.0 (1885.48)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-22.91		
Flow: Mlb/hr	76.61 (99.50 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.316 6.757 1 0.222 0.223 17 52
		24	0.752 16.116 2 0.381 0.599 47 16
		23	1.116 24.293 3 0.353 0.449 47 14
		22	1.297 28.752 4 1.157 1.205 23 34
		21	1.408 31.675 5 0.931 1.186 39 18
		20	1.483 33.976 6 0.751 0.913 25 48
		19	1.501* 35.554 7 1.372 1.435 19 32
		18	1.497 37.156 8 1.198 1.348 41 26
		17	1.465 38.623 9 1.232 1.243 45 24
		16	1.414 39.267
		15	1.402 39.626
		14	1.323 41.404
		13	1.229 42.781
		12	1.152 44.320
		11	1.068 45.095
		10	1.066 43.310
		9	1.016 44.124
		8	0.933 44.815
		7	0.844 45.699
		6	0.742 46.183*
		5	0.635 45.631
		4	0.530 44.147
		3	0.443 40.356
		2	0.282 25.000
		Bottom 1	0.085 8.082
			% AXIAL TILT 25.994 -12.208
			AVG BOT 8ft/12ft 0.8607 1.0756
Control Rod Density: %	0.00		
k-effective:	0.99947		
Void Fraction:	0.357		
Core Delta-P: psia	21.475		
Core Plate Delta-P: psia	16.942		
Coolant Temp: Deg-F	546.4		
In Channel Flow: Mlb/hr	67.66	Active Channel Flow: Mlb/hr	65.52
Total Bypass Flow (%):	11.7	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00049		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR						LHGR								
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.435	7	19	32	1.506	0.896	8	37	14	9.36	0.807	22.8	7	33	22	18	7.91	0.885	58.1	5	41	24	17
1.434	7	21	34	1.509	0.894	8	13	38	9.33	0.806	23.0	7	21	34	18	7.91	0.883	58.0	5	29	42	17
1.430	7	21	30	1.513	0.892	7	21	30	9.31	0.805	23.2	7	35	24	18	7.82	0.869	57.8	5	21	44	17
1.426	7	23	32	1.518	0.890	7	19	32	9.30	0.804	23.3	7	23	32	18	7.85	0.868	57.6	5	41	20	17
1.421	7	35	24	1.518	0.889	7	21	34	9.26	0.803	23.7	7	23	36	18	7.77	0.864	57.9	5	27	44	17
1.414	7	35	20	1.525	0.885	7	29	22	9.30	0.803	22.9	7	21	30	18	7.81	0.863	57.6	5	43	22	17
1.413	7	23	36	1.527	0.884	7	35	30	9.26	0.801	23.4	7	35	20	18	7.77	0.860	57.7	5	43	28	17
1.412	7	33	26	1.528	0.884	7	19	36	9.25	0.801	23.4	7	19	36	18	7.88	0.858	57.1	5	19	42	17
1.412	7	19	36	1.528	0.883	7	35	20	7.77	0.800	47.6	4	35	22	18	7.24	0.825	58.8	4	35	36	16
1.402	7	25	34	1.536	0.879	7	19	28	7.76	0.799	47.6	4	21	32	18	7.35	0.825	58.2	4	35	22	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A-51 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,601.0 MWd/MTU

Cycle:	28	Core Average Exposure: MWd/MTU	36302.0
Exposure: MWd/MTU (GWd)	18750.0 (1900.59)		
Delta E: MWd/MTU, (GWd)	149.0 (15.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-21.91		
Flow: Mlb/hr	79.69 (103.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.322 6.809 1 0.221 0.223 17 52
		24	0.767 16.240 2 0.381 0.600 47 16
		23	1.140 24.478 3 0.353 0.449 47 14
		22	1.322 28.968 4 1.154 1.200 23 34
		21	1.432 31.909 5 0.933 1.186 39 18
		20	1.504 34.222 6 0.752 0.915 25 48
		19	1.516* 35.802 7 1.368 1.429 19 32
		18	1.507 37.403 8 1.201 1.348 41 26
		17	1.470 38.865 9 1.237 1.248 45 24
		16	1.416 39.495
		15	1.402 39.838
		14	1.320 41.603
		13	1.224 42.966
		12	1.146 44.493
		11	1.061 45.256
		10	1.058 43.454
		9	1.007 44.260
		8	0.921 44.940
		7	0.829 45.812
		6	0.725 46.282*
		5	0.616 45.715
		4	0.513 44.218
		3	0.427 40.415
		2	0.273 25.037
		Bottom 1	0.083 8.094
Control Rod Density: %	0.00		
k-effective:	0.99940		
Void Fraction:	0.349		
Core Delta-P: psia	22.728	% AXIAL TILT	27.172 -12.013
Core Plate Delta-P: psia	18.194	AVG BOT 8ft/12ft	0.8522 1.0746
Coolant Temp: Deg-F	546.5		
In Channel Flow: Mlb/hr	70.44	Active Channel Flow: Mlb/hr	68.24
Total Bypass Flow (%):	11.6	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00032		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.429	7	19	32	1.521	0.888	8	37	9.36	0.809	23.2	7	33	22	18	7.94
1.429	7	21	34	1.525	0.885	8	13	9.34	0.808	23.4	7	21	34	18	7.94
1.423	7	21	30	1.540	0.876	7	21	9.32	0.807	23.6	7	35	24	18	7.87
1.419	7	23	32	1.545	0.874	7	21	9.27	0.806	24.1	7	23	36	18	7.90
1.415	7	35	24	1.546	0.873	7	19	9.29	0.806	23.6	7	23	32	18	7.81
1.410	7	35	20	1.553	0.869	7	19	9.28	0.805	23.7	7	35	20	18	7.86
1.409	7	23	36	1.553	0.869	7	29	9.27	0.804	23.8	7	19	36	18	7.81
1.408	7	19	36	1.554	0.869	7	35	9.30	0.804	23.3	7	21	30	18	7.92
1.405	7	33	26	1.554	0.869	7	35	7.78	0.803	47.9	4	35	22	18	7.23
1.396	7	25	34	1.560	0.866	8	35	7.85	0.801	46.5	4	23	34	19	7.33

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.52 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,750.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-56

Cycle:	28	Core Average Exposure: MWd/MTU	36302.9
Exposure: MWd/MTU (GWd)	18751.0 (1900.69)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-25.01		
Flow: Mlb/hr	76.61 (99.50 %)		
2 6 10 14 18 22 26 30 34 38 42 46 50		Axial Profile	Edit Radial Power
51	-- -- -- -- --	N(PRA) Power Exposure	Zone Avg. Max. IR JR
47	-- -- -- -- --	Top 25 0.319 6.810	1 0.221 0.223 17 52
43	-- -- -- -- --	24 0.758 16.241	2 0.382 0.603 47 16
39	-- -- -- -- --	23 1.124 24.479	3 0.354 0.450 47 14
35	-- -- -- -- --	22 1.303 28.969	4 1.152 1.199 23 34
31	-- -- -- -- --	21 1.412 31.910	5 0.934 1.185 39 18
27	-- -- -- -- --	20 1.483 34.223	6 0.756 0.917 25 48
23	-- -- -- -- --	19 1.496* 35.804	7 1.366 1.426 19 32
19	-- -- -- -- --	18 1.488 37.404	8 1.202 1.345 41 26
15	-- -- -- -- --	17 1.454 38.866	9 1.237 1.247 45 24
11	-- -- -- -- --	16 1.403 39.496	
7	-- -- -- -- --	15 1.392 39.839	
3	-- -- -- -- --	14 1.314 41.604	
2 6 10 14 18 22 26 30 34 38 42 46 50		13 1.222 42.967	
		12 1.148 44.494	
		11 1.069 45.257	
		10 1.072 43.455	
		9 1.026 44.261	
		8 0.944 44.941	
		7 0.853 45.812	
		6 0.747 46.283*	
		5 0.635 45.716	
		4 0.529 44.218	
		3 0.441 40.415	
		2 0.281 25.037	
		Bottom 1 0.085 8.094	
Control Rod Density: %	0.00	% AXIAL TILT	25.708 -12.012
k-effective:	0.99935	AVG BOT 8ft/12ft	0.8608 1.0746
Void Fraction:	0.348		
Core Delta-P: psia	21.327		
Core Plate Delta-P: psia	16.782		
Coolant Temp: Deg-F	545.9		
In Channel Flow: Mlb/hr	67.72	Active Channel Flow: Mlb/hr	65.59
Total Bypass Flow (%):	11.6	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00047		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.426	7	19	32	1.517	0.890	8	37	14	9.22	0.797	23.2	7	33	22	18	7.84	0.885	58.4	5	41	24	17
1.426	7	21	34	1.520	0.888	8	13	38	9.20	0.796	23.4	7	21	34	18	7.84	0.883	58.3	5	29	42	17
1.420	7	21	30	1.533	0.881	7	21	30	9.17	0.795	23.6	7	35	24	18	7.77	0.870	58.1	5	21	44	17
1.416	7	23	32	1.537	0.878	7	21	34	9.13	0.794	24.1	7	23	36	18	7.80	0.869	57.9	5	41	20	17
1.413	7	35	24	1.538	0.878	7	19	32	9.15	0.793	23.6	7	23	32	18	7.72	0.865	58.2	5	27	44	17
1.407	7	35	20	1.545	0.874	7	19	36	9.14	0.793	23.7	7	35	20	18	7.76	0.864	57.9	5	43	22	17
1.406	7	23	36	1.546	0.873	7	29	22	9.13	0.792	23.8	7	19	36	18	7.71	0.861	58.0	5	43	28	17
1.405	7	19	36	1.547	0.873	7	35	20	9.15	0.792	23.3	7	21	30	18	7.82	0.859	57.4	5	19	42	17
1.403	7	33	26	1.547	0.873	7	35	30	7.67	0.791	47.9	4	35	22	18	7.14	0.821	59.0	4	35	36	16
1.393	7	25	34	1.555	0.868	8	35	12	7.65	0.789	47.9	4	21	32	18	7.64	0.819	56.5	4	27	40	17

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.53 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,751.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-57

Cycle:	28	Core Average Exposure: MWd/MTU	36452.0
Exposure: MWd/MTU (GWd)	18900.0 (1915.79)		
Delta E: MWd/MTU, (GWd)	149.0 (15.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-23.93		
Flow: Mlb/hr	79.69 (103.50 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.324 6.862 1 0.221 0.222 17 52
		24	0.775 16.365 2 0.382 0.604 47 16
		23	1.148 24.665 3 0.354 0.450 47 14
		22	1.330 29.186 4 1.149 1.194 23 34
		21	1.436 32.145 5 0.935 1.185 39 18
		20	1.504 34.469 6 0.756 0.918 25 48
		19	1.512* 36.051 7 1.363 1.422 21 34
		18	1.499 37.650 8 1.205 1.346 39 16
		17	1.460 39.106 9 1.241 1.251 45 24
		16	1.406 39.722
		15	1.392 40.049
		14	1.312 41.802
		13	1.218 43.151
		12	1.143 44.667
		11	1.062 45.418
		10	1.065 43.600
		9	1.016 44.398
		8	0.931 45.067
		7	0.836 45.926
		6	0.727 46.382*
		5	0.615 45.800
		4	0.511 44.288
		3	0.425 40.473
		2	0.271 25.074
		Bottom 1	0.082 8.107
Control Rod Density: %	0.00		
k-effective:	0.99930		
Void Fraction:	0.340		
Core Delta-P: psia	22.571	% AXIAL TILT	26.963 -11.820
Core Plate Delta-P: psia	18.025	AVG BOT 8ft/12ft	0.8518 1.0735
Coolant Temp: Deg-F	546.0		
In Channel Flow: Mlb/hr	70.50	Active Channel Flow: Mlb/hr	68.31
Total Bypass Flow (%):	11.5	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00045		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.422	7	21	34	1.531	0.882	8	37	9.23	0.800	23.5	7	33	22	18	7.88
1.421	7	19	32	1.535	0.879	8	13	9.21	0.799	23.7	7	21	34	18	7.88
1.414	7	21	30	1.560	0.865	7	21	9.23	0.799	23.4	7	23	36	19	7.82
1.410	7	23	32	1.564	0.863	7	21	9.19	0.798	23.9	7	35	24	18	7.85
1.408	7	35	24	1.566	0.862	7	19	9.17	0.797	24.1	7	35	20	18	7.82
1.404	7	35	20	1.569	0.861	8	35	9.16	0.796	24.1	7	19	36	18	7.76
1.402	7	19	36	1.570	0.860	7	19	9.22	0.796	23.0	7	23	32	19	7.75
1.402	7	23	36	1.571	0.859	8	11	7.79	0.795	46.5	4	35	22	19	7.87
1.397	7	33	26	1.572	0.859	7	35	9.15	0.795	23.9	7	21	38	19	7.14
1.388	7	25	34	1.572	0.859	7	29	7.76	0.794	46.8	4	23	34	19	7.66

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.54 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial
Distributions at 18,900.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-58

Cycle:	28	Core Average Exposure: MWd/MTU	36453.0
Exposure: MWd/MTU (GWd)	18901.0 (1915.89)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-27.81		
Flow: Mlb/hr	76.23 (99.00 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.318 6.862 1 0.221 0.223 17 52
		24	0.760 16.366 2 0.384 0.608 47 16
		23	1.128 24.666 3 0.355 0.451 47 14
		22	1.306 29.187 4 1.147 1.191 23 34
		21	1.412 32.146 5 0.937 1.183 39 18
		20	1.479 34.471 6 0.761 0.921 25 48
		19	1.489* 36.053 7 1.359 1.417 21 34
		18	1.478 37.652 8 1.206 1.344 39 16
		17	1.442 39.107 9 1.241 1.251 45 24
		16	1.392 39.724
		15	1.382 40.051
		14	1.306 41.804
		13	1.218 43.152
		12	1.148 44.668
		11	1.073 45.419
		10	1.083 43.601
		9	1.041 44.399
		8	0.959 45.068
		7	0.864 45.927
		6	0.752 46.382*
		5	0.636 45.801
		4	0.528 44.289
		3	0.440 40.474
		2	0.280 25.074
		Bottom 1	0.085 8.107
			% AXIAL TILT 25.250 -11.819
			AVG BOT 8ft/12ft 0.8622 1.0735
Control Rod Density: %	0.00		
k-effective:	0.99938		
Void Fraction:	0.339		
Core Delta-P: psia	20.994		
Core Plate Delta-P: psia	16.438		
Coolant Temp: Deg-F	545.2		
In Channel Flow: Mlb/hr	67.44	Active Channel Flow: Mlb/hr	65.34
Total Bypass Flow (%):	11.5	(of total core flow)	
Total Water Rod Flow (%):	2.8	(of total core flow)	
Source Convergence	0.00045		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.417	7	21	34	1.528	0.884	8	37	14	9.06	0.785	23.5	7	33	22	18	7.77	0.884	58.7	5	41	24	17
1.417	7	19	32	1.532	0.881	8	13	38	9.04	0.784	23.7	7	21	34	18	7.77	0.882	58.6	5	29	42	17
1.409	7	21	30	1.555	0.868	7	21	30	9.03	0.784	23.9	7	35	24	18	7.71	0.871	58.4	5	21	44	17
1.405	7	23	32	1.558	0.866	7	21	34	9.05	0.784	23.4	7	23	36	19	7.74	0.870	58.2	5	41	20	17
1.403	7	35	24	1.560	0.865	7	19	32	9.00	0.783	24.1	7	35	20	18	7.66	0.865	58.5	5	27	44	17
1.400	7	35	20	1.565	0.863	7	19	36	8.99	0.782	24.1	7	19	36	18	7.71	0.865	58.2	5	43	22	17
1.398	7	19	36	1.565	0.862	8	35	12	7.55	0.781	48.2	4	35	22	18	7.65	0.861	58.3	5	43	28	17
1.398	7	23	36	1.566	0.862	7	35	20	8.99	0.781	23.9	7	23	32	18	7.76	0.859	57.7	5	19	42	17
1.392	7	33	26	1.568	0.861	7	29	22	8.98	0.780	23.9	7	21	38	19	7.05	0.816	59.3	4	35	36	16
1.383	7	25	34	1.568	0.861	8	11	36	7.62	0.780	46.8	4	23	34	19	7.55	0.815	56.8	4	27	40	17

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.55 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 18,901.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-59

Cycle:	28	Core Average Exposure: MWd/MTU	36632.0
Exposure: MWd/MTU (GWd)	19080.0 (1934.04)		
Delta E: MWd/MTU, (GWd)	179.0 (18.14)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-26.48		
Flow: Mlb/hr	79.69 (103.50 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.326 6.925 1 0.221 0.222 17 52
		24	0.780 16.517 2 0.384 0.608 47 16
		23	1.157 24.890 3 0.354 0.452 47 14
		22	1.338 29.449 4 1.144 1.186 23 34
		21	1.441 32.428 5 0.939 1.184 39 18
		20	1.505 34.766 6 0.762 0.923 25 48
		19	1.508* 36.349 7 1.356 1.411 21 34
		18	1.492 37.945 8 1.209 1.347 39 16
		17	1.451 39.393 9 1.246 1.256 45 24
		16	1.396 39.993
		15	1.384 40.302
		14	1.305 42.040
		13	1.214 43.373
		12	1.142 44.876
		11	1.066 45.612
		10	1.074 43.777
		9	1.028 44.566
		8	0.941 45.221
		7	0.841 46.065
		6	0.727 46.502*
		5	0.611 45.902
		4	0.506 44.372
		3	0.421 40.543
		2	0.268 25.119
		Bottom 1	0.081 8.122
Control Rod Density: %	0.00		
k-effective:	0.99925		
Void Fraction:	0.330		
Core Delta-P: psia	22.377	% AXIAL TILT	26.794 -11.592
Core Plate Delta-P: psia	17.821	AVG BOT 8ft/12ft	0.8513 1.0723
Coolant Temp: Deg-F	545.3		
In Channel Flow: Mlb/hr	70.57	Active Channel Flow: Mlb/hr	68.40
Total Bypass Flow (%):	11.4	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00044		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.411	7	21	34	1.543	0.875	8	37	14	9.11	0.791	23.8	7	23	36	19	7.82	0.899	59.0	5	41	24	17
1.411	7	19	32	1.548	0.872	8	13	38	9.13	0.789	23.2	7	21	34	19	7.82	0.896	59.0	5	29	42	17
1.402	7	21	30	1.580	0.854	8	35	12	9.09	0.789	23.9	7	33	22	18	7.78	0.887	58.8	5	21	44	17
1.398	7	23	32	1.583	0.853	8	11	36	9.11	0.789	23.5	7	35	20	19	7.80	0.885	58.6	5	41	20	17
1.398	7	35	24	1.586	0.851	7	21	30	9.10	0.788	23.5	7	19	36	19	7.77	0.881	58.5	5	43	22	17
1.396	7	35	20	1.588	0.850	7	21	34	9.06	0.788	24.3	7	21	38	19	7.71	0.880	58.8	5	27	44	17
1.394	7	19	36	1.590	0.849	7	33	22	9.05	0.788	24.3	7	35	24	18	7.70	0.875	58.6	5	43	28	17
1.393	7	23	36	1.590	0.849	8	43	20	7.70	0.788	46.8	4	35	22	19	7.82	0.874	58.0	5	19	42	17
1.386	7	33	26	1.592	0.848	8	43	30	7.64	0.787	47.7	4	21	36	19	7.57	0.825	57.1	4	27	40	17
1.377	7	25	34	1.593	0.847	8	41	22	7.62	0.786	47.8	4	25	36	19	6.94	0.823	60.1	4	37	38	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.56 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,080.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-60

Cycle:	28	Core Average Exposure: MWd/MTU	36633.0
Exposure: MWd/MTU (GWd)	19081.0 (1934.14)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-29.37		
Flow: Mlb/hr	77.00 (100.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.321 6.925 1 0.221 0.222 17 52
		24	0.769 16.518 2 0.385 0.611 47 16
		23	1.140 24.892 3 0.355 0.453 47 14
		22	1.319 29.450 4 1.142 1.184 23 34
		21	1.421 32.430 5 0.940 1.182 39 18
		20	1.485 34.767 6 0.765 0.925 25 48
		19	1.489* 36.351 7 1.353 1.408 21 34
		18	1.475 37.947 8 1.210 1.345 39 16
		17	1.436 39.395 9 1.246 1.256 45 24
		16	1.385 39.994
		15	1.376 40.303
		14	1.301 42.042
		13	1.214 43.374
		12	1.146 44.877
		11	1.075 45.614
		10	1.089 43.778
		9	1.048 44.567
		8	0.963 45.222
		7	0.863 46.065
		6	0.746 46.503*
		5	0.628 45.902
		4	0.520 44.373
		3	0.433 40.544
		2	0.276 25.119
		Bottom 1	0.083 8.122
Control Rod Density: %	0.00		
k-effective:	0.99921		
Void Fraction:	0.329		
Core Delta-P: psia	21.169	% AXIAL TILT	25.422 -11.591
Core Plate Delta-P: psia	16.605	AVG BOT 8ft/12ft	0.8597 1.0723
Coolant Temp: Deg-F	544.7		
In Channel Flow: Mlb/hr	68.18	Active Channel Flow: Mlb/hr	66.08
Total Bypass Flow (%):	11.5	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00029		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR						LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.408	7	21	34	1.541	0.876	8	37	8.97	0.779	23.8	7	23	36	19	7.73	0.889	59.1	5	41	24	17
1.408	7	19	32	1.545	0.874	8	13	8.96	0.778	23.9	7	33	22	18	7.74	0.887	59.0	5	29	42	17
1.399	7	21	30	1.577	0.856	8	35	8.99	0.778	23.2	7	21	34	19	7.69	0.877	58.8	5	21	44	17
1.395	7	23	32	1.580	0.854	8	11	8.92	0.777	24.5	7	35	20	18	7.72	0.875	58.6	5	41	20	17
1.395	7	35	24	1.581	0.854	7	21	8.92	0.777	24.3	7	35	24	18	7.69	0.871	58.5	5	43	22	17
1.393	7	35	20	1.583	0.853	7	21	8.92	0.777	24.3	7	21	38	19	7.63	0.870	58.8	5	27	44	17
1.391	7	19	36	1.585	0.852	7	33	8.97	0.777	23.5	7	19	36	19	7.60	0.866	58.7	5	43	28	17
1.390	7	23	36	1.587	0.851	8	43	7.59	0.777	46.8	4	35	22	19	7.71	0.865	58.2	5	19	42	17
1.383	7	33	26	1.589	0.850	8	43	7.53	0.776	47.7	4	21	36	19	7.49	0.816	57.1	4	27	40	17
1.374	7	25	34	1.589	0.850	7	19	7.52	0.775	47.8	4	25	36	19	6.87	0.815	60.1	4	37	38	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.57 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,081.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page A-61

Cycle:	28	Core Average Exposure: MWd/MTU	36771.9
Exposure: MWd/MTU (GWd)	19220.0 (1948.23)		
Delta E: MWd/MTU, (GWd)	139.0 (14.09)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-28.13		
Flow: Mlb/hr	80.08 (104.00 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.327 6.974 1 0.220 0.222 17 52
		24	0.785 16.636 2 0.385 0.611 47 16
		23	1.164 25.067 3 0.355 0.453 47 14
		22	1.345 29.654 4 1.139 1.180 23 34
		21	1.446 32.650 5 0.941 1.183 39 18
		20	1.506* 34.997 6 0.765 0.927 25 48
		19	1.506 36.580 7 1.351 1.404 21 34
		18	1.487 38.174 8 1.213 1.347 39 16
		17	1.444 39.616 9 1.250 1.260 45 24
		16	1.389 40.202
		15	1.378 40.497
		14	1.301 42.225
		13	1.211 43.545
		12	1.142 45.038
		11	1.070 45.764
		10	1.081 43.916
		9	1.037 44.698
		8	0.947 45.342
		7	0.843 46.173
		6	0.724 46.595*
		5	0.606 45.980
		4	0.501 44.437
		3	0.416 40.597
		2	0.265 25.153
		Bottom 1	0.080 8.133
Control Rod Density: %	0.00		
k-effective:	0.99916		
Void Fraction:	0.321		
Core Delta-P: psia	22.401	% AXIAL TILT	26.752 -11.416
Core Plate Delta-P: psia	17.838	AVG BOT 8ft/12ft	0.8506 1.0713
Coolant Temp: Deg-F	544.8		
In Channel Flow: Mlb/hr	70.97	Active Channel Flow: Mlb/hr	68.81
Total Bypass Flow (%):	11.4	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00031		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp. FT	IR	Value	Margin	Exp. FT	IR
1.404	7	21	34	1.555	0.868	8	37	9.02	0.785	24.1	7	7.78	0.901	59.3	5
1.403	7	19	32	1.560	0.865	8	13	8.99	0.784	24.6	7	7.78	0.899	59.2	5
1.394	7	21	30	1.590	0.849	8	35	9.03	0.784	23.8	7	7.75	0.891	59.0	5
1.391	7	35	24	1.594	0.847	8	11	9.03	0.784	23.8	7	7.77	0.889	58.8	5
1.390	7	35	20	1.599	0.844	8	43	9.04	0.783	23.5	7	7.75	0.884	58.8	5
1.390	7	23	32	1.602	0.843	8	43	7.64	0.783	47.1	4	7.68	0.883	59.1	5
1.388	7	19	36	1.603	0.842	8	19	9.04	0.783	23.3	7	7.65	0.878	59.0	5
1.386	7	23	36	1.605	0.841	8	29	7.57	0.782	48.0	4	7.77	0.878	58.4	5
1.378	7	33	26	1.607	0.840	8	41	9.02	0.782	23.7	7	7.52	0.825	57.4	4
1.371	7	37	22	1.607	0.840	7	21	8.98	0.782	24.3	7	6.89	0.823	60.4	4

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.58 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,220.0 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-62

Cycle:	28	Core Average Exposure: MWd/MTU	36772.9
Exposure: MWd/MTU (GWd)	19221.0 (1948.33)		
Delta E: MWd/MTU, (GWd)	1.0 (0.10)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-30.99		
Flow: Mlb/hr	77.39 (100.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.322 6.974 1 0.220 0.222 17 52
		24	0.775 16.637 2 0.386 0.614 47 16
		23	1.148 25.069 3 0.356 0.454 47 14
		22	1.328 29.656 4 1.138 1.178 23 34
		21	1.428 32.651 5 0.943 1.182 39 18
		20	1.488 34.998 6 0.768 0.929 25 48
		19	1.489* 36.582 7 1.348 1.401 21 34
		18	1.472 38.176 8 1.213 1.346 39 16
		17	1.431 39.618 9 1.250 1.260 45 24
		16	1.379 40.204
		15	1.371 40.499
		14	1.297 42.226
		13	1.211 43.546
		12	1.146 45.040
		11	1.078 45.766
		10	1.094 43.917
		9	1.055 44.699
		8	0.967 45.343
		7	0.862 46.173
		6	0.741 46.596*
		5	0.621 45.980
		4	0.513 44.437
		3	0.427 40.597
		2	0.272 25.153
		Bottom 1	0.082 8.133
Control Rod Density: %	0.00		
k-effective:	0.99912		
Void Fraction:	0.321		
Core Delta-P: psia	21.198	% AXIAL TILT	25.512 -11.415
Core Plate Delta-P: psia	16.627	AVG BOT 8ft/12ft	0.8582 1.0713
Coolant Temp: Deg-F	544.1		
In Channel Flow: Mlb/hr	68.57	Active Channel Flow: Mlb/hr	66.48
Total Bypass Flow (%):	11.4	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00027		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.401	7	21	34	1.551	0.870	8	37	8.90	0.774	24.1	7	23	36	19	7.70
1.400	7	19	32	1.556	0.867	8	13	8.87	0.773	24.6	7	21	38	19	7.71
1.391	7	21	30	1.587	0.851	8	35	8.91	0.773	23.8	7	35	20	19	7.68
1.388	7	35	24	1.591	0.849	8	11	8.90	0.773	23.8	7	19	36	19	7.70
1.388	7	35	20	1.595	0.846	8	43	7.54	0.773	47.1	4	35	22	19	7.67
1.387	7	23	32	1.598	0.845	8	43	8.92	0.773	23.5	7	21	34	19	7.60
1.386	7	19	36	1.600	0.844	8	19	7.47	0.772	48.0	4	21	36	19	7.58
1.383	7	23	36	1.601	0.843	8	29	8.92	0.772	23.3	7	19	32	19	7.69
1.375	7	33	26	1.602	0.843	7	21	8.89	0.771	23.7	7	35	24	19	7.45
1.368	7	37	22	1.602	0.842	7	21	8.85	0.771	24.3	7	37	22	19	6.83

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.59 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,221.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-63

Cycle:	28	Core Average Exposure: MWd/MTU	36872.4
Exposure: MWd/MTU (GWd)	19320.4 (1958.41)		
Delta E: MWd/MTU, (GWd)	99.4 (10.08)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-30.01		
Flow: Mlb/hr	79.69 (103.50 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.326 7.009 1 0.220 0.221 17 52
		24	0.786 16.722 2 0.386 0.614 47 16
		23	1.166 25.195 3 0.355 0.453 47 14
		22	1.347 29.803 4 1.136 1.175 23 34
		21	1.445 32.809 5 0.943 1.182 39 18
		20	1.504* 35.163 6 0.769 0.930 25 48
		19	1.501 36.746 7 1.347 1.398 21 34
		18	1.480 38.338 8 1.215 1.347 39 16
		17	1.437 39.775 9 1.253 1.263 45 24
		16	1.382 40.352
		15	1.373 40.637
		14	1.297 42.357
		13	1.210 43.668
		12	1.144 45.155
		11	1.074 45.874
		10	1.089 44.016
		9	1.046 44.793
		8	0.955 45.429
		7	0.847 46.250
		6	0.725 46.661*
		5	0.605 46.036
		4	0.499 44.483
		3	0.415 40.635
		2	0.265 25.177
		Bottom 1	0.080 8.141
			% AXIAL TILT 26.480 -11.291
			AVG BOT 8ft/12ft 0.8516 1.0706
Control Rod Density: %	0.00		
k-effective:	0.99910		
Void Fraction:	0.315		
Core Delta-P: psia	22.121		
Core Plate Delta-P: psia	17.550		
Coolant Temp: Deg-F	544.3		
In Channel Flow: Mlb/hr	70.66	Active Channel Flow: Mlb/hr	68.53
Total Bypass Flow (%):	11.3	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00038		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.398	7	21	34	1.562	0.864	8	37	8.91	0.779	24.8	7	21	38	19	7.74
1.397	7	19	32	1.568	0.861	8	13	8.94	0.779	24.4	7	23	36	19	7.74
1.387	7	21	30	1.597	0.845	8	35	8.95	0.778	24.0	7	35	20	19	7.72
1.386	7	35	20	1.601	0.843	8	11	8.95	0.778	24.0	7	19	36	19	7.74
1.386	7	35	24	1.604	0.842	8	43	7.57	0.778	47.3	4	35	22	19	7.71
1.384	7	19	36	1.609	0.839	8	19	8.95	0.777	23.7	7	21	34	19	7.64
1.383	7	23	32	1.609	0.839	8	43	7.51	0.777	48.2	4	21	36	19	7.62
1.381	7	23	36	1.611	0.838	8	29	8.86	0.777	25.2	7	23	40	19	7.74
1.372	7	33	26	1.615	0.836	8	41	8.93	0.777	24.1	7	37	18	19	7.47
1.367	7	37	22	1.619	0.834	8	21	8.90	0.776	24.5	7	37	22	19	6.85

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A-60 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,320.4 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-64

Cycle:	28	Core Average Exposure: MWd/MTU	36901.3
Exposure: MWd/MTU (GWd)	19349.3 (1961.33)		
Delta E: MWd/MTU, (GWd)	28.8 (2.92)		
Power: MWt	2923.0 (100.00 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-29.69		
Flow: Mlb/hr	80.46 (104.50 %)		
		Axial Profile	Edit Radial Power
		N (PRA)	Power Exposure Zone Avg. Max. IR JR
		Top 25	0.328 7.020 1 0.220 0.221 17 52
		24	0.790 16.747 2 0.385 0.614 47 16
		23	1.171 25.232 3 0.355 0.453 47 14
		22	1.353 29.846 4 1.136 1.174 23 34
		21	1.451 32.855 5 0.944 1.182 39 18
		20	1.508* 35.211 6 0.769 0.930 25 48
		19	1.504 36.794 7 1.346 1.398 21 34
		18	1.483 38.385 8 1.215 1.348 39 16
		17	1.439 39.821 9 1.254 1.264 45 24
		16	1.384 40.395
		15	1.374 40.677
		14	1.298 42.395
		13	1.210 43.703
		12	1.144 45.188
		11	1.074 45.905
		10	1.088 44.044
		9	1.044 44.820
		8	0.951 45.454
		7	0.842 46.272
		6	0.719 46.680*
		5	0.600 46.051
		4	0.494 44.496
		3	0.411 40.646
		2	0.262 25.184
		Bottom 1	0.079 8.144
Control Rod Density: %	0.00		
k-effective:	0.99916		
Void Fraction:	0.314		
Core Delta-P: psia	22.433	% AXIAL TILT	26.798 -11.255
Core Plate Delta-P: psia	17.862	AVG BOT 8ft/12ft	0.8495 1.0704
Coolant Temp: Deg-F	544.3		
In Channel Flow: Mlb/hr	71.36	Active Channel Flow: Mlb/hr	69.21
Total Bypass Flow (%):	11.3	(of total core flow)	
Total Water Rod Flow (%):	2.7	(of total core flow)	
Source Convergence	0.00049		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.398	7	21	34	1.565	0.863	8	37	14	8.93	0.781	24.9	7	21	38	19	7.75	0.904	59.6	5	41	24	17
1.397	7	19	32	1.571	0.859	8	13	38	8.95	0.780	24.4	7	23	36	19	7.75	0.902	59.5	5	29	42	17
1.386	7	21	30	1.600	0.844	8	35	12	8.97	0.780	24.1	7	35	20	19	7.73	0.895	59.3	5	21	44	17
1.386	7	35	20	1.604	0.842	8	11	36	8.96	0.780	24.1	7	19	36	19	7.75	0.893	59.1	5	41	20	17
1.385	7	35	24	1.606	0.840	8	43	20	7.58	0.779	47.4	4	35	22	19	7.73	0.889	59.1	5	43	22	17
1.383	7	19	36	1.611	0.838	8	19	44	8.95	0.779	24.2	7	37	18	19	7.65	0.886	59.3	5	27	44	17
1.382	7	23	32	1.612	0.838	8	43	30	8.88	0.779	25.3	7	23	40	19	7.63	0.882	59.2	5	43	28	17
1.380	7	23	36	1.614	0.836	8	29	44	7.52	0.778	48.2	4	21	36	19	7.75	0.882	58.7	5	19	42	17
1.371	7	33	26	1.619	0.834	8	41	22	8.96	0.778	23.8	7	21	34	19	7.47	0.826	57.6	4	27	40	17
1.367	7	37	22	1.623	0.832	8	21	42	8.92	0.778	24.6	7	37	22	19	6.85	0.824	60.6	4	37	38	16

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.61 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,349.3 MWd/MTU

Framatome Inc.

ANP-3661NP
Revision 0Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-65

Cycle:	28	Core Average Exposure: MWd/MTU	37304.9
Exposure: MWd/MTU (GWd)	19753.0 (2002.26)		
Delta E: MWd/MTU, (GWd)	403.7 (40.92)		
Power: MWt	2708.4 (92.66 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-27.35		
Flow: Mlb/hr	80.46 (104.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.344 7.167 1 0.219 0.221 17 52
		24	0.836 17.106 2 0.386 0.616 47 16
		23	1.238 25.765 3 0.355 0.455 47 14
		22	1.426 30.465 4 1.128 1.162 23 34
		21	1.517 33.516 5 0.947 1.183 39 18
		20	1.563* 35.895 6 0.771 0.933 25 48
		19	1.545 37.473 7 1.338 1.386 21 34
		18	1.510 39.052 8 1.223 1.353 39 16
		17	1.455 40.466 9 1.264 1.274 45 24
		16	1.390 40.999
		15	1.376 41.240
		14	1.293 42.924
		13	1.200 44.196
		12	1.130 45.653
		11	1.053 46.340
		10	1.060 44.440
		9	1.008 45.194
		8	0.906 45.793
		7	0.789 46.570
		6	0.666 46.933*
		5	0.552 46.262
		4	0.454 44.669
		3	0.377 40.789
		2	0.241 25.275
		Bottom 1	0.073 8.174
Control Rod Density: %	0.00		
k-effective:	0.99900		
Void Fraction:	0.295		
Core Delta-P: psia	22.068	% AXIAL TILT	30.189 -10.732
Core Plate Delta-P: psia	17.507	AVG BOT 8ft/12ft	0.8253 1.0675
Coolant Temp: Deg-F	544.6		
In Channel Flow: Mlb/hr	71.54	Active Channel Flow: Mlb/hr	69.45
Total Bypass Flow (%):	11.1	(of total core flow)	
Total Water Rod Flow (%):	2.6	(of total core flow)	
Source Convergence	0.00045		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR				LHGR			
Value	FT	IR	JR	Value	Margin	FT	IR	Value	Margin	Exp.	FT	IR	JR	K	Value
1.386	7	21	34	1.670	0.809	8	37	7.28	0.744	46.6	5	23	42	20	7.27
1.385	7	19	32	1.677	0.805	8	13	8.49	0.743	25.0	7	23	40	20	7.27
1.378	7	35	20	1.703	0.793	8	35	7.19	0.743	48.0	4	25	40	20	7.28
1.375	7	19	36	1.706	0.791	8	43	8.48	0.742	25.1	7	37	18	19	7.30
1.374	7	35	24	1.710	0.790	8	11	7.24	0.741	46.9	4	21	40	20	7.28
1.371	7	21	30	1.712	0.789	8	19	8.48	0.741	24.7	7	21	38	20	7.19
1.369	7	23	36	1.717	0.786	8	43	7.36	0.740	44.7	4	23	38	20	7.30
1.367	7	23	32	1.720	0.785	8	29	8.48	0.740	24.7	8	25	42	20	7.17
1.362	7	37	18	1.733	0.779	8	41	8.44	0.740	25.3	7	39	20	19	7.22
1.360	7	35	16	1.738	0.777	8	21	7.25	0.740	46.6	4	37	20	20	6.96

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.62 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 19,753.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle
Fuel Cycle Design

Page A-66

Cycle:	28	Core Average Exposure: MWd/MTU	37824.1
Exposure: MWd/MTU (GWd)	20272.0 (2054.87)		
Delta E: MWd/MTU, (GWd)	519.1 (52.61)		
Power: MWt	2434.3 (83.28 %)		
Core Pressure: psia	1044.7		
Inlet Subcooling: Btu/lbm	-24.36		
Flow: Mlb/hr	80.46 (104.50 %)		
		Axial Profile	Edit Radial Power
		N(PRA) Power Exposure	Zone Avg. Max. IR JR
		Top 25	0.366 7.367 1 0.218 0.220 17 52
		24	0.900 17.598 2 0.386 0.618 47 16
		23	1.332 26.497 3 0.356 0.457 47 14
		22	1.526 31.310 4 1.117 1.149 35 22
		21	1.606 34.411 5 0.951 1.185 39 18
		20	1.636* 36.812 6 0.774 0.939 25 48
		19	1.596 38.373 7 1.328 1.369 21 34
		18	1.543 39.926 8 1.234 1.360 39 16
		17	1.473 41.305 9 1.279 1.289 45 24
		16	1.396 41.779
		15	1.374 41.964
		14	1.283 43.602
		13	1.182 44.822
		12	1.104 46.240
		11	1.019 46.884
		10	1.016 44.931
		9	0.953 45.654
		8	0.841 46.202
		7	0.722 46.924
		6	0.603 47.230*
		5	0.497 46.508
		4	0.408 44.872
		3	0.340 40.957
		2	0.217 25.382
		Bottom 1	0.066 8.210
Control Rod Density: %	0.00		
k-effective:	0.99886		
Void Fraction:	0.271		
Core Delta-P: psia	21.621	% AXIAL TILT	34.622 -10.022
Core Plate Delta-P: psia	17.073	AVG BOT 8ft/12ft	0.7929 1.0635
Coolant Temp: Deg-F	544.9		
In Channel Flow: Mlb/hr	71.77	Active Channel Flow: Mlb/hr	69.74
Total Bypass Flow (%):	10.8	(of total core flow)	
Total Water Rod Flow (%):	2.5	(of total core flow)	
Source Convergence	0.00046		

Top Ten Thermal Limits Summary - Sorted by Margin

Power				MCPR				APLHGR							LHGR							
Value	FT	IR	JR	Value	Margin	FT	IR	JR	Value	Margin	Exp.	FT	IR	JR	K	Value	Margin	Exp.	FT	IR	JR	K
1.369	7	21	34	1.829	0.738	8	37	14	6.82	0.703	47.7	5	23	42	20	6.63	0.816	61.4	5	41	24	17
1.368	7	19	32	1.840	0.734	8	13	38	7.96	0.700	25.7	8	21	42	20	6.66	0.813	61.1	5	21	44	17
1.367	7	35	20	1.858	0.727	8	43	20	7.95	0.700	25.9	8	25	42	20	6.61	0.812	61.3	5	29	42	17
1.363	7	19	36	1.862	0.725	8	35	12	6.83	0.699	46.9	5	41	20	20	6.68	0.811	60.9	5	41	20	17
1.360	8	39	16	1.866	0.724	8	19	44	6.74	0.698	48.3	4	37	16	20	6.67	0.808	60.8	5	43	22	17
1.359	7	35	24	1.870	0.722	8	11	36	7.95	0.698	25.6	8	41	22	20	6.68	0.800	60.5	5	19	42	17
1.358	7	37	18	1.879	0.719	8	43	30	7.97	0.698	25.2	7	37	18	20	6.54	0.799	61.1	5	27	44	17
1.358	8	37	14	1.882	0.717	8	29	44	7.96	0.698	25.3	7	39	20	20	6.54	0.797	61.0	5	43	28	17
1.357	7	35	16	1.891	0.714	9	45	22	7.07	0.698	42.0	5	39	18	20	7.97	0.742	48.0	5	35	14	20
1.354	7	23	36	1.898	0.711	9	21	46	6.81	0.697	47.0	5	19	42	20	6.92	0.742	56.5	4	37	16	18

* LHGR calculated with pin-power reconstruction

* CPR calculated with pin-power reconstruction & CPR limit type 3

Figure A.63 Brunswick Unit 1 Cycle 28 Control Rod Pattern and Axial Distributions at 20,272.0 MWd/MTU

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page B-1

**Appendix B Elevation Views of the Brunswick Unit 1 ATRIUM 11 Equilibrium Design
Fresh Reload Batch Fuel Assemblies**



**Figure B.1 Elevation View for the Brunswick Unit 1 ATRIUM 11 Equilibrium
Cycle Fresh Fuel Reload Batch [] Fuel Assembly Design**

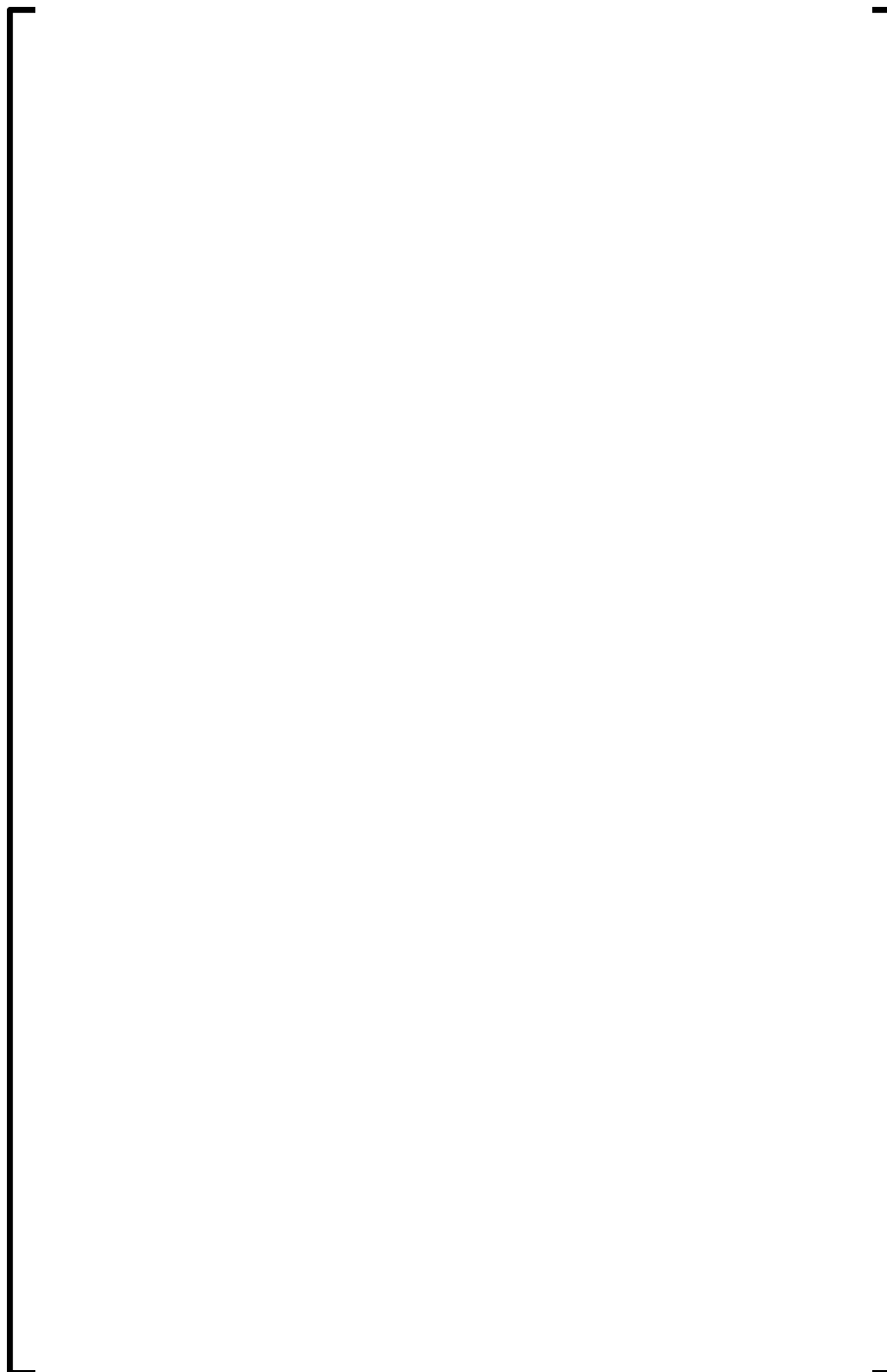


**Figure B.2 Elevation View for the Brunswick Unit 1 ATRIUM 11 Equilibrium
Cycle Fresh Fuel Reload Batch [] Fuel Assembly Design**

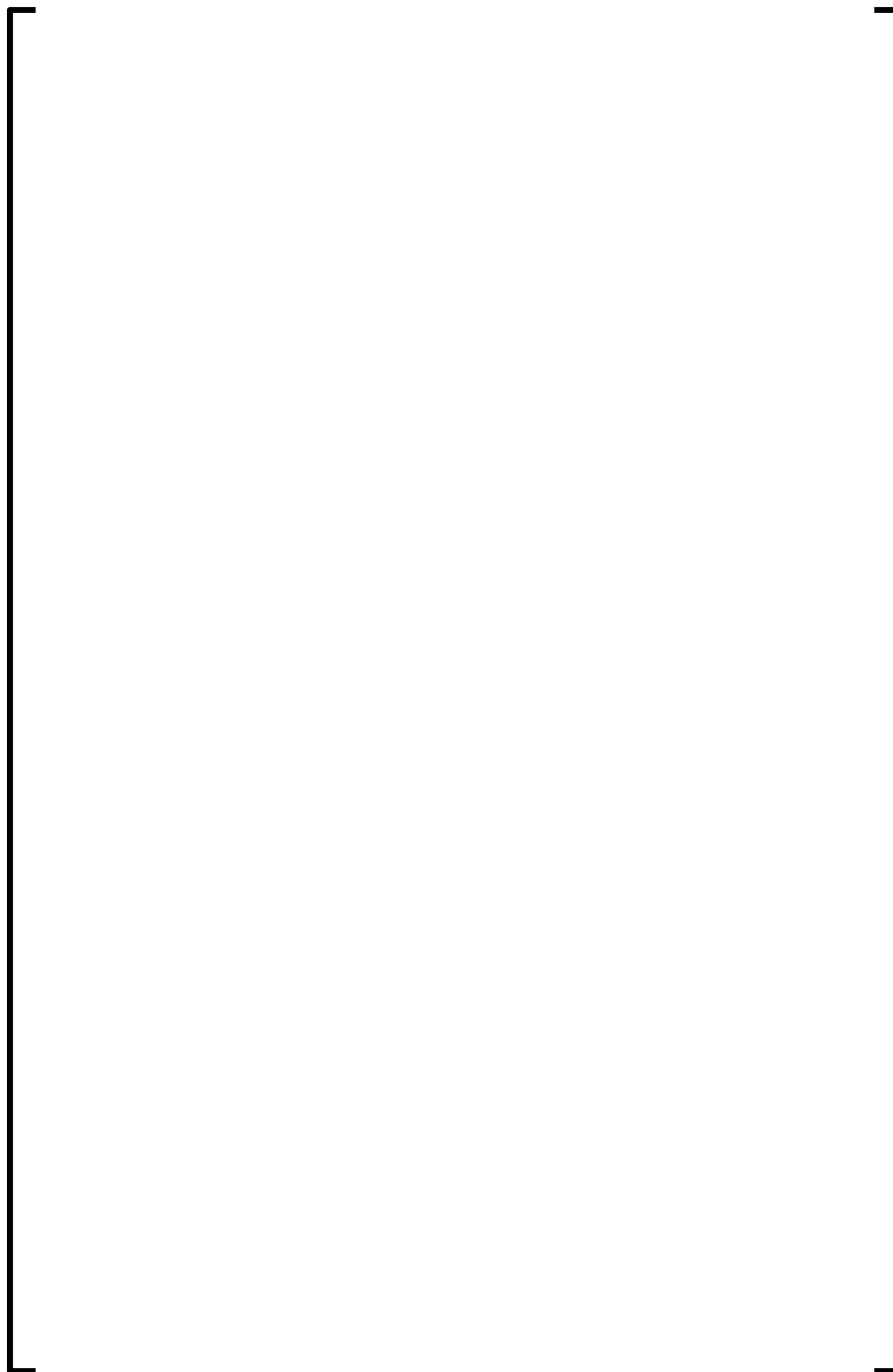


**Figure B.3 Elevation View for the Brunswick Unit 1 ATRIUM 11 Equilibrium
Cycle Fresh Fuel Reload Batch [] Fuel Assembly Design**

Framatome Inc.

ANP-3661NP

Revision 0

Brunswick ATRIUM 11 Equilibrium Cycle

Fuel Cycle Design

Page C-1

Appendix C Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Radial Exposure and Power Distributions

[

]

Figure C.1 Brunswick Unit 1 Cycle 28 BOC Exposure Distribution (GWd/MTU)

[

]

Figure C.1 Brunswick Unit 1 Cycle 28 BOC Exposure Distribution (GWd/MTU) (Continued)

]

Figure C.2 Brunswick Unit 1 Cycle 28 Long EOC Exposure Distribution (20.3 GWd/MTU)

[

[

]

Figure C.2 Brunswick Unit 1 Cycle 28 Long EOC Exposure Distribution (20.3 GWd/MTU) (Continued)

]

**Figure C.3 Brunswick Unit 1 Cycle 28 Radial Power Distribution
at 0.0 MWd/MTU**

[

]

**Figure C.3 Brunswick Unit 1 Cycle 28 Radial Power Distribution
at 0.0 MWd/MTU (Continued)**

[

]

**Figure C.4 Brunswick Unit 1 Cycle 28 Radial Power Distribution
at 19,349.3 MWd/MTU (EOFP)**

[

]

**Figure C.4 Brunswick Unit 1 Cycle 28 Radial Power Distribution
at 19,349.3 MWd/MTU (EOFP) (Continued)**

[

Affidavit for ANP-3661P, Brunswick ATRIUM 11 Equilibrium
Cycle Fuel Cycle Design

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3661P, Revision 0, "Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design," dated July 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

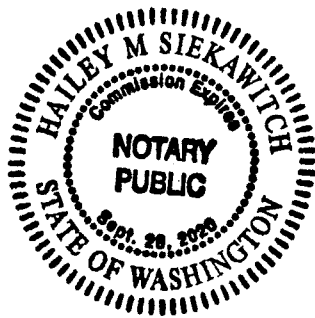
9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Alan B. Meyer

SUBSCRIBED before me this 30th
day of July, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3667NP, Brunswick Unit 1 ATRIUM 11 Equilibrium
Cycle Nuclear Fuel Design Report



Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

ANP-3667NP
Revision 0

March 2018

Framatome Inc.

(c) 2018 Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION.....	1-1
2.0 NEUTRONIC DESIGN	2-1
2.1 Neutronic Design Description	2-1
2.2 Lattice Control Blade Worths and Kinetics Parameters.....	2-2
2.3 Enriched Lattice Uncontrolled Reactivities and Isotopic Data	2-2
3.0 REFERENCES.....	3-1
APPENDIX A ENRICHED LATTICE HOT UNCONTROLLED REACTIVITY AND LPF PLOTS	A-1
APPENDIX B ENRICHED LATTICE HOT UNCONTROLLED REACTIVITY AND LPF TABLES	B-1
APPENDIX C ENRICHED LATTICE ISOTOPIC DATA TABLES	B-1
APPENDIX D LATTICE ENRICHMENT DISTRIBUTION MAPS.....	D-1

List of Tables

Table 2.1	Neutronic Design Parameters	2-3
Table 2.2	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-7
Table 2.3	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-8
Table 2.4	Lattice [] Kinetics Parameters at BOL	2-8
Table 2.5	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-9
Table 2.6	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-10
Table 2.7	Lattice [] Kinetics Parameters at BOL	2-10
Table 2.8	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-11
Table 2.9	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-12
Table 2.10	Lattice [] Kinetics Parameters at BOL	2-12
Table 2.11	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-13
Table 2.12	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-14
Table 2.13	Lattice [] Kinetics Parameters at BOL	2-14
Table 2.14	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-15
Table 2.15	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-16
Table 2.16	Lattice [] Kinetics Parameters at BOL	2-16
Table 2.17	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-17
Table 2.18	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-18
Table 2.19	Lattice [] Kinetics Parameters at BOL	2-18
Table 2.20	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-19
Table 2.21	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-20
Table 2.22	Lattice [] Kinetics Parameters at BOL	2-20

Table 2.23	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-21
Table 2.24	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-22
Table 2.25	Lattice [] Kinetics Parameters at BOL	2-22
Table 2.26	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-23
Table 2.27	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-24
Table 2.28	Lattice [] Kinetics Parameters at BOL	2-24
Table 2.29	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-25
Table 2.30	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-26
Table 2.31	Lattice [] Kinetics Parameters at BOL	2-26
Table 2.32	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-27
Table 2.33	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-28
Table 2.34	Lattice [] Kinetics Parameters at BOL	2-28
Table 2.35	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-29
Table 2.36	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-30
Table 2.37	Lattice [] Kinetics Parameters at BOL	2-30
Table 2.38	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-31
Table 2.39	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-32
Table 2.40	Lattice [] Kinetics Parameters at BOL	2-32
Table 2.41	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-33
Table 2.42	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-34
Table 2.43	Lattice [] Kinetics Parameters at BOL	2-34
Table 2.44	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-35
Table 2.45	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-36

Table 2.46	Lattice [] Kinetics Parameters at BOL	2-36
Table 2.47	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-37
Table 2.48	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-38
Table 2.49	Lattice [] Kinetics Parameters at BOL	2-38
Table 2.50	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99	2-39
Table 2.51	Lattice [] Control Blade Worths at BOL for Control Blade Type Westinghouse-ABB CR99 TIP	2-40
Table 2.52	Lattice [] Kinetics Parameters at BOL	2-40

List of Figures

Figure 2.7	Fuel Rod Axial Description	2-47

Nomenclature

Acronym	Definition
BOL	beginning of life
BWR	boiling water reactor
EVC	plenum region in a fuel pin modeled as an evacuated section
kg/MTU	kilograms per metric ton of initial uranium
LHGR	linear heat generation rate
LPF	local peaking factor
MCPR	minimum critical power ratio
MWd/MTU	megawatt days per metric ton of initial uranium
NRC	(United States) Nuclear Regulatory Commission
SLC	standby liquid boron control

1.0 INTRODUCTION

This report provides results of the neutronic design analyses performed by Framatome for the Brunswick Unit 1 ATRIUM™* 11 Equilibrium Cycle design. The mechanical design parameters for the fuel are from Reference 1 and are shown in Table 2.1.

Applicable neutronic design criteria are provided in the approved topical report ANF-89-98(P)(A) Revision 1 and Supplement 1 (Reference 2). Neutronic design analysis methodology used to determine conformance to design criteria has been reviewed and approved by the NRC in the topical report EMF-2158(P)(A) (Reference 3).

The fuel design assumes advanced fuel channels made of Zry-4 and/or Z4B^{†‡} with a beta quench treatment.

The neutronic design for the fabrication batch includes axially-varying enrichment and gadolinia designs with natural UO₂ blankets at the top and bottom of the assembly. Pertinent fuel and reactor core design information associated with this fabrication batch is given in Section 2.0 and in Appendices A through D.

* ATRIUM is a trademark of Framatome Inc., registered in the United States and various other countries.

† The NRC has not yet approved Z4B for full reload use.

‡ Z4B is a trademark of Framatome Inc.

2.0 NEUTRONIC DESIGN

The results of the Brunswick Unit 1 neutronic design analyses are presented in this section. The fuel was designed to meet applicable design criteria, as well as reactivity and control requirements. Reactor core loading patterns and the number of assemblies to be loaded will depend upon final cycle energy requirements as specified by the utility. Applicable neutronic design criteria outlined in Reference 2 are summarized below:

- **Power Distribution.** The local power distribution in the fuel assembly combined with the core power distribution shall result in Linear Heat Generation Rate (LHGR) and Minimum Critical Power Ratio (MCPR) values that are within the limits established for each fuel design.
- **Kinetics Parameters.** The moderator void reactivity coefficient due to boiling in the active channels and the Doppler fuel temperature reactivity coefficient shall be negative. The negative void and Doppler reactivity coefficients ensure a negative power coefficient during reactor operation. (Calculation results show that the assembly average Doppler and void reactivity coefficients remain negative for the life of the assembly. These results demonstrate that the Reference 2 Section 5 kinetics criteria are met on a bundle average basis).
- **Control Blade Reactivity.** The design of the fuel assembly and the reactor core loading shall be such that the technical specification shutdown margin requirement is met for all reactor conditions.

2.1 *Neutronic Design Description*

The neutronic design parameters for these ATRIUM 11 assemblies are presented in Table 2.1. The key nuclear design characteristics are summarized below:

- The fuel assembly contains []
- Each fuel assembly has top and bottom natural uranium blankets.
- The enrichments are designed to yield a local power distribution which results in a balanced design relative to MCPR, LHGR, and other reactor operating requirements, e.g., power peaking.
- Gadolinia (Gd_2O_3 blended with UO_2) rods are designed to control assembly reactivity in order to meet reactivity control requirements in the reactor, e.g. cold shutdown margin.
- The reload batch consists of 3 assembly designs which vary axially in enrichment and/or gadolinia. The axial distributions of the lattices in the assemblies are shown in Figures 2.1, 2.2, and 2.3. The fuel rod distribution and axial descriptions are presented in Figures 2.4 through 2.7. The enrichment and gadolinia distribution maps for each of the reload assembly lattices are displayed in Appendix D.
- The fuel assembly incorporates an advanced fuel channel which improves uranium utilization. For this D-lattice plant, the fuel assembly is offset 40 mils toward the control blade.

2.2 *Lattice Control Blade Worths and Kinetics Parameters*

Beginning of life (BOL) lattice reactivities (k_{∞}) have been calculated for moderator and fuel conditions ranging from cold to hot operating conditions. From these reactivities, BOL control blade worths and kinetics parameters have been determined based on the Westinghouse-ABB CR99 control blade. Kinetics parameters are calculated for fuel temperature (Doppler), moderator void, and moderator temperature. The Doppler reactivity was calculated over a fuel temperature range from hot standby to hot operating. The moderator void reactivity was evaluated between the 0% and 40% voided hot operating cases, and the moderator temperature reactivity was calculated from the cold to hot standby condition. The calculations neglect the spacer material and assume zero void in the coolant outside the fuel assembly channel as well as inside the internal water channel. The results of these calculations are presented in Tables 2.2 through 2.52.

2.3 *Enriched Lattice Uncontrolled Reactivities and Isotopic Data*

The enriched lattice exposure-dependent uncontrolled reactivities calculated at three void fractions are presented graphically in Appendix A, and in tabular format in Appendix B. The enriched lattice exposure-dependent isotopic data calculated at three void fractions are presented in Appendix C.

† Includes dishing and outward land taper as a percentage of cylindrical volume.



Table 2.1 Neutronic Design Parameters *(continued)*

Parameter	Design Value
Control Blade Data for Westinghouse-ABB CR99 Main	
Total span, cm	Westinghouse Proprietary
Total support span, cm	"
Total thickness, cm	"
Total face-to-face internal dimension, inch	"
B ₄ C rod absorber (wing absorber zone 1) Number of rods Diameter of rod, cm Diameter of sheath, inch Theoretical density B ₄ C, % B ₄ C zone span, cm	"
Control Blade Data for Westinghouse-ABB CR99 TIP	
Total span, cm	Westinghouse Proprietary
Total support span, cm	"
Total thickness, cm	"
Total face-to-face internal dimension, inch	"
B ₄ C rod absorber (wing absorber zone 1) Number of rods Diameter of rod, cm Diameter of sheath, inch Theoretical density B ₄ C, % B ₄ C zone span, cm	"

Table 2.1 Neutronic Design Parameters *(continued)*

Parameter	Design Value
Core Data*	
Number of fuel assemblies in the core	560
Rated thermal power level, MWt	2923.0
Rated core flow, Mlbm/hr	77.00
Inlet subcooling, Btu/lbm	21.3
Dome pressure, psia	1045.0
Boron concentration for the SLC calculation, PPM	720
Intermediate temperature, °F	200.00
Warm temperature, °F	360.00

* Some values are representative of rated conditions and may vary depending on the core statepoint.

**Table 2.2 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.91217	1.09752	-0.1689
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89872	1.08949	-0.1751
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84586	1.06077	-0.2026
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.84201	1.05599	-0.2026
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.84209	1.05599	-0.2026
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.80100	1.04002	-0.2298
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.75156	1.02244	-0.2649

**Table 2.3 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.91396	1.09752	-0.1673
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.90056	1.08949	-0.1734
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84810	1.06077	-0.2005
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.84424	1.05599	-0.2005
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.84432	1.05599	-0.2004
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.80364	1.04002	-0.2273
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.75475	1.02244	-0.2618

Table 2.4 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.05599	1.06077	-0.0045
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.04002	1.05599	-0.0151
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.06077	1.09752	-0.0335

**Table 2.5 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.96886	1.16188	-0.1661
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.95465	1.15394	-0.1727
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.89474	1.12102	-0.2019
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.89060	1.11590	-0.2019
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.89069	1.11590	-0.2018
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.84237	1.09512	-0.2308
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.78258	1.07124	-0.2695

**Table 2.6 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.97087	1.16188	-0.1644
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.95671	1.15394	-0.1709
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.89722	1.12102	-0.1996
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.89306	1.11590	-0.1997
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.89315	1.11590	-0.1996
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.84527	1.09512	-0.2281
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.78608	1.07124	-0.2662

Table 2.7 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.11590	1.12102	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.09512	1.11590	-0.0186
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.12102	1.16188	-0.0352

**Table 2.8 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92966	1.12278	-0.1720
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.91664	1.11640	-0.1789
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.86330	1.09111	-0.2088
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.85922	1.08602	-0.2088
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.85931	1.08602	-0.2087
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.81436	1.06960	-0.2386
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.75638	1.04980	-0.2795

**Table 2.9 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.93162	1.12278	-0.1703
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.91866	1.11640	-0.1771
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.86574	1.09111	-0.2066
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.86165	1.08602	-0.2066
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.86173	1.08602	-0.2065
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.81725	1.06960	-0.2359
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.75990	1.04980	-0.2762

Table 2.10 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.08602	1.09111	-0.0047
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.06960	1.08602	-0.0151
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.09111	1.12278	-0.0282

**Table 2.11 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92357	1.11290	-0.1701
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.91019	1.10626	-0.1772
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.85632	1.08073	-0.2077
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.85230	1.07574	-0.2077
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.85239	1.07574	-0.2076
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.80709	1.05913	-0.2380
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.74780	1.03835	-0.2798

**Table 2.12 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92547	1.11290	-0.1684
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.91214	1.10626	-0.1755
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.85868	1.08073	-0.2055
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.85465	1.07574	-0.2055
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.85473	1.07574	-0.2054
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.80990	1.05913	-0.2353
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.75125	1.03835	-0.2765

Table 2.13 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.07574	1.08073	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.05913	1.07574	-0.0154
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.08073	1.11290	-0.0289

**Table 2.14 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.89545	1.08703	-0.1762
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.88162	1.07986	-0.1836
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.82821	1.05445	-0.2146
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.82419	1.04940	-0.2146
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.82427	1.04940	-0.2145
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.78120	1.03512	-0.2453
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.72328	1.01633	-0.2883

**Table 2.15 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.89735	1.08703	-0.1745
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.88357	1.07986	-0.1818
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.83057	1.05445	-0.2123
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.82654	1.04940	-0.2124
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.82662	1.04940	-0.2123
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.78401	1.03512	-0.2426
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.72674	1.01633	-0.2849

Table 2.16 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$		k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$		1.04940	1.05445	-0.0048
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$		1.03512	1.04940	-0.0136
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$		1.05445	1.08703	-0.0300

**Table 2.17 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.89851	1.08391	-0.1711
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.88457	1.07676	-0.1785
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.83201	1.05271	-0.2097
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.82808	1.04780	-0.2097
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.82816	1.04780	-0.2096
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.78512	1.03458	-0.2411
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.72541	1.01632	-0.2862

**Table 2.18 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90034	1.08391	-0.1694
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.88646	1.07676	-0.1767
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.83431	1.05271	-0.2075
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.83036	1.04780	-0.2075
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.83044	1.04780	-0.2074
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.78789	1.03458	-0.2384
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.72888	1.01632	-0.2828

Table 2.19 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.04780	1.05271	-0.0047
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.03458	1.04780	-0.0126
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.05271	1.08391	-0.0288

**Table 2.20 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90358	1.08970	-0.1708
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89007	1.08315	-0.1783
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84037	1.06334	-0.2097
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.83647	1.05846	-0.2097
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.83655	1.05846	-0.2097
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.79497	1.04806	-0.2415
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.73621	1.03346	-0.2876

**Table 2.21 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90541	1.08970	-0.1691
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89196	1.08315	-0.1765
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84270	1.06334	-0.2075
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.83878	1.05846	-0.2076
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.83886	1.05846	-0.2075
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.79778	1.04806	-0.2388
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.73976	1.03346	-0.2842

Table 2.22 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$		k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$		1.05846	1.06334	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$		1.04806	1.05846	-0.0098
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$		1.06334	1.08970	-0.0242

**Table 2.23 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.97764	1.17442	-0.1676
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.96366	1.16674	-0.1741
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.90414	1.13375	-0.2025
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.89997	1.12859	-0.2026
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.90007	1.12859	-0.2025
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.85178	1.10771	-0.2310
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.79200	1.08376	-0.2692

**Table 2.24 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.97970	1.17442	-0.1658
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.96578	1.16674	-0.1722
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.90666	1.13375	-0.2003
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.90248	1.12859	-0.2004
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.90257	1.12859	-0.2003
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.85473	1.10771	-0.2284
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.79554	1.08376	-0.2659

Table 2.25 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.12859	1.13375	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.10771	1.12859	-0.0185
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.13375	1.17442	-0.0346

**Table 2.26 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90977	1.09746	-0.1710
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89587	1.08884	-0.1772
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84063	1.05623	-0.2041
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.83679	1.05145	-0.2042
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.83687	1.05145	-0.2041
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.79547	1.03399	-0.2307
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.74653	1.01459	-0.2642

**Table 2.27 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.91156	1.09746	-0.1694
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89771	1.08884	-0.1755
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84284	1.05623	-0.2020
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.83898	1.05145	-0.2021
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.83906	1.05145	-0.2020
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.79806	1.03399	-0.2282
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.74961	1.01459	-0.2612

Table 2.28 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.05145	1.05623	-0.0045
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.03399	1.05145	-0.0166
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.05623	1.09746	-0.0376

**Table 2.29 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92154	1.11169	-0.1711
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.90837	1.10400	-0.1772
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.85601	1.07533	-0.2040
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.85214	1.07051	-0.2040
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.85222	1.07051	-0.2039
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.81128	1.05465	-0.2308
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.76192	1.03721	-0.2654

**Table 2.30 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92338	1.11169	-0.1694
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.91025	1.10400	-0.1755
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.85830	1.07533	-0.2018
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.85441	1.07051	-0.2019
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.85449	1.07051	-0.2018
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.81397	1.05465	-0.2282
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.76516	1.03721	-0.2623

Table 2.31 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.07051	1.07533	-0.0045
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.05465	1.07051	-0.0148
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.07533	1.11169	-0.0327

**Table 2.32 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.97948	1.17700	-0.1678
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.96556	1.16938	-0.1743
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.90613	1.13636	-0.2026
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.90196	1.13119	-0.2026
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.90205	1.13119	-0.2026
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.85377	1.11029	-0.2310
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.79402	1.08634	-0.2691

**Table 2.33 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.98154	1.17700	-0.1661
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.96767	1.16938	-0.1725
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.90865	1.13636	-0.2004
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void, No xenon	0.90446	1.13119	-0.2004
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 0% Void	0.90456	1.13119	-0.2004
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 40% Void	0.85673	1.11029	-0.2284
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=932^{\circ}\text{ F}$ 80% Void	0.79756	1.08634	-0.2658

Table 2.34 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$		k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$		1.13119	1.13636	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$		1.11029	1.13119	-0.0185
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$		1.13636	1.17700	-0.0345

**Table 2.35 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.94229	1.14062	-0.1739
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.92958	1.13460	-0.1807
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.87665	1.10918	-0.2096
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.87253	1.10404	-0.2097
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.87262	1.10404	-0.2096
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.82762	1.08743	-0.2389
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.76949	1.06742	-0.2791

**Table 2.36 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.94431	1.14062	-0.1721
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.93166	1.13460	-0.1789
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.87915	1.10918	-0.2074
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.87501	1.10404	-0.2074
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.87510	1.10404	-0.2074
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.83057	1.08743	-0.2362
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.77307	1.06742	-0.2758

Table 2.37 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.10404	1.10918	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.08743	1.10404	-0.0150
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.10918	1.14062	-0.0276

**Table 2.38 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.94596	1.14127	-0.1711
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.93328	1.13547	-0.1781
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.88109	1.11149	-0.2073
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.87702	1.10643	-0.2073
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.87711	1.10643	-0.2073
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.83197	1.09023	-0.2369
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.77261	1.07002	-0.2779

**Table 2.39 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.94793	1.14127	-0.1694
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.93530	1.13547	-0.1763
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.88353	1.11149	-0.2051
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.87945	1.10643	-0.2051
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.87954	1.10643	-0.2051
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.83487	1.09023	-0.2342
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.77616	1.07002	-0.2746

Table 2.40 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.10643	1.11149	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.09023	1.10643	-0.0146
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.11149	1.14127	-0.0261

**Table 2.41 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.93872	1.13331	-0.1717
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.92569	1.12708	-0.1787
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.87167	1.10072	-0.2081
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.86760	1.09567	-0.2082
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.86769	1.09567	-0.2081
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.82167	1.07800	-0.2378
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.76179	1.05619	-0.2787

**Table 2.42 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.94068	1.13331	-0.1700
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.92770	1.12708	-0.1769
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.87409	1.10072	-0.2059
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void, No xenon	0.87001	1.09567	-0.2060
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 0% Void	0.87009	1.09567	-0.2059
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 40% Void	0.82454	1.07800	-0.2351
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=979^{\circ}\text{ F}$ 80% Void	0.76529	1.05619	-0.2754

Table 2.43 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.09567	1.10072	-0.0046
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.07800	1.09567	-0.0161
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.10072	1.13331	-0.0288

**Table 2.44 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.91246	1.10949	-0.1776
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89902	1.10282	-0.1848
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84552	1.07675	-0.2147
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.84144	1.07162	-0.2148
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.84153	1.07162	-0.2147
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.79761	1.05626	-0.2449
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.73890	1.03645	-0.2871

**Table 2.45 Lattice [] Control Blade Worths at BOL
for Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.91441	1.10949	-0.1758
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.90103	1.10282	-0.1830
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84795	1.07675	-0.2125
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.84385	1.07162	-0.2125
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.84394	1.07162	-0.2125
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.80049	1.05626	-0.2422
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.74243	1.03645	-0.2837

Table 2.46 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.07162	1.07675	-0.0048
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.05626	1.07162	-0.0143
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.07675	1.10949	-0.0295

**Table 2.47 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90673	1.09498	-0.1719
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89294	1.08806	-0.1793
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.83990	1.06321	-0.2100
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.83593	1.05825	-0.2101
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.83601	1.05825	-0.2100
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.79205	1.04384	-0.2412
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.73156	1.02436	-0.2858

**Table 2.48 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.90859	1.09498	-0.1702
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.89486	1.08806	-0.1776
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.84224	1.06321	-0.2078
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.83825	1.05825	-0.2079
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.83833	1.05825	-0.2078
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.79485	1.04384	-0.2385
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.73505	1.02436	-0.2824

Table 2.49 Lattice [] Kinetics Parameters at BOL

Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$		k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$		1.05825	1.06321	-0.0047
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$		1.04384	1.05825	-0.0136
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$		1.06321	1.09498	-0.0290

**Table 2.50 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99**

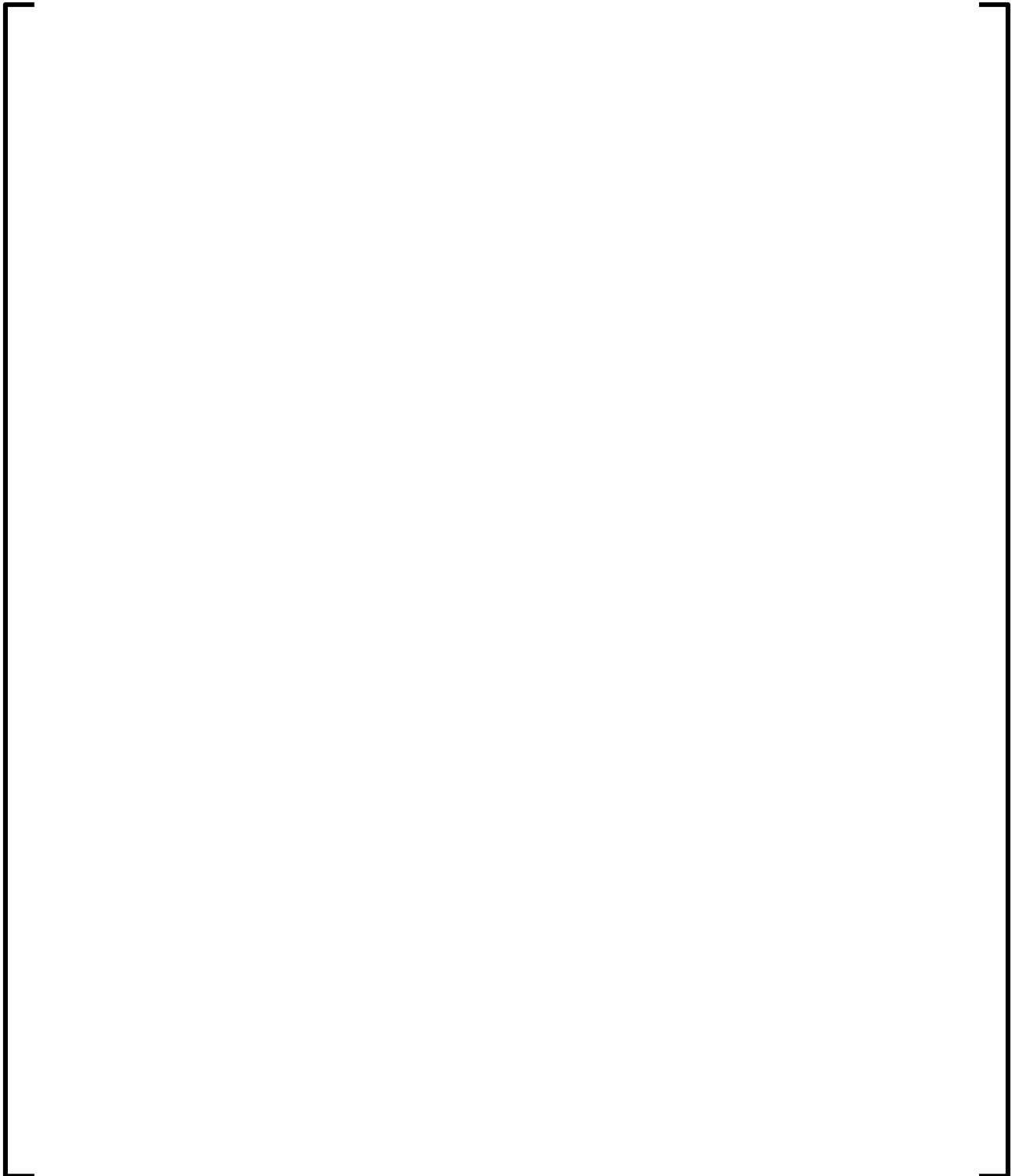
Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92092	1.10955	-0.1700
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.90796	1.10371	-0.1774
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.85927	1.08507	-0.2081
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.85531	1.08014	-0.2082
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.85539	1.08014	-0.2081
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.81323	1.06928	-0.2395
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.75381	1.05428	-0.2850

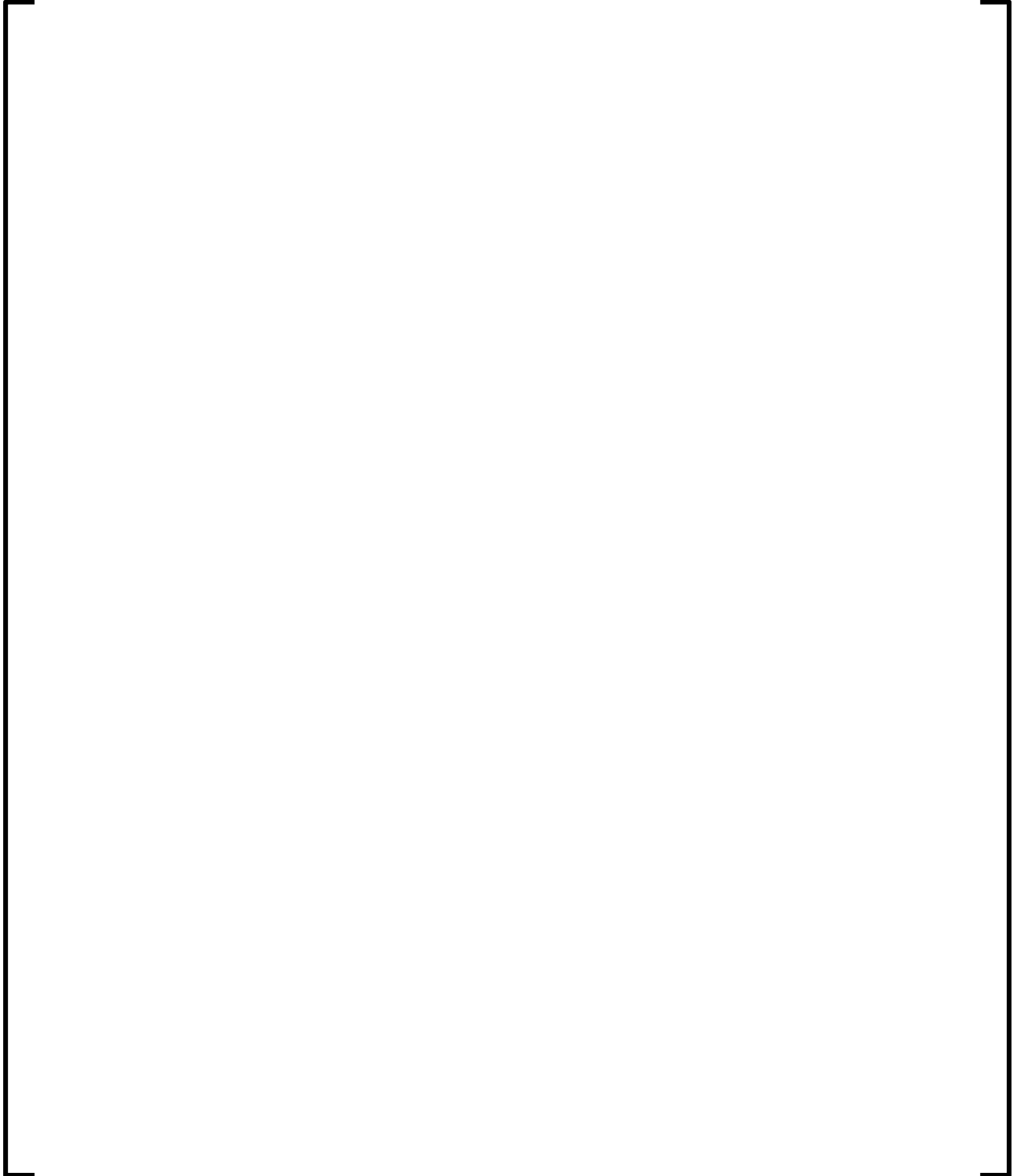
**Table 2.51 Lattice [] Control Blade Worths at BOL for
Control Blade Type Westinghouse-ABB CR99 TIP**

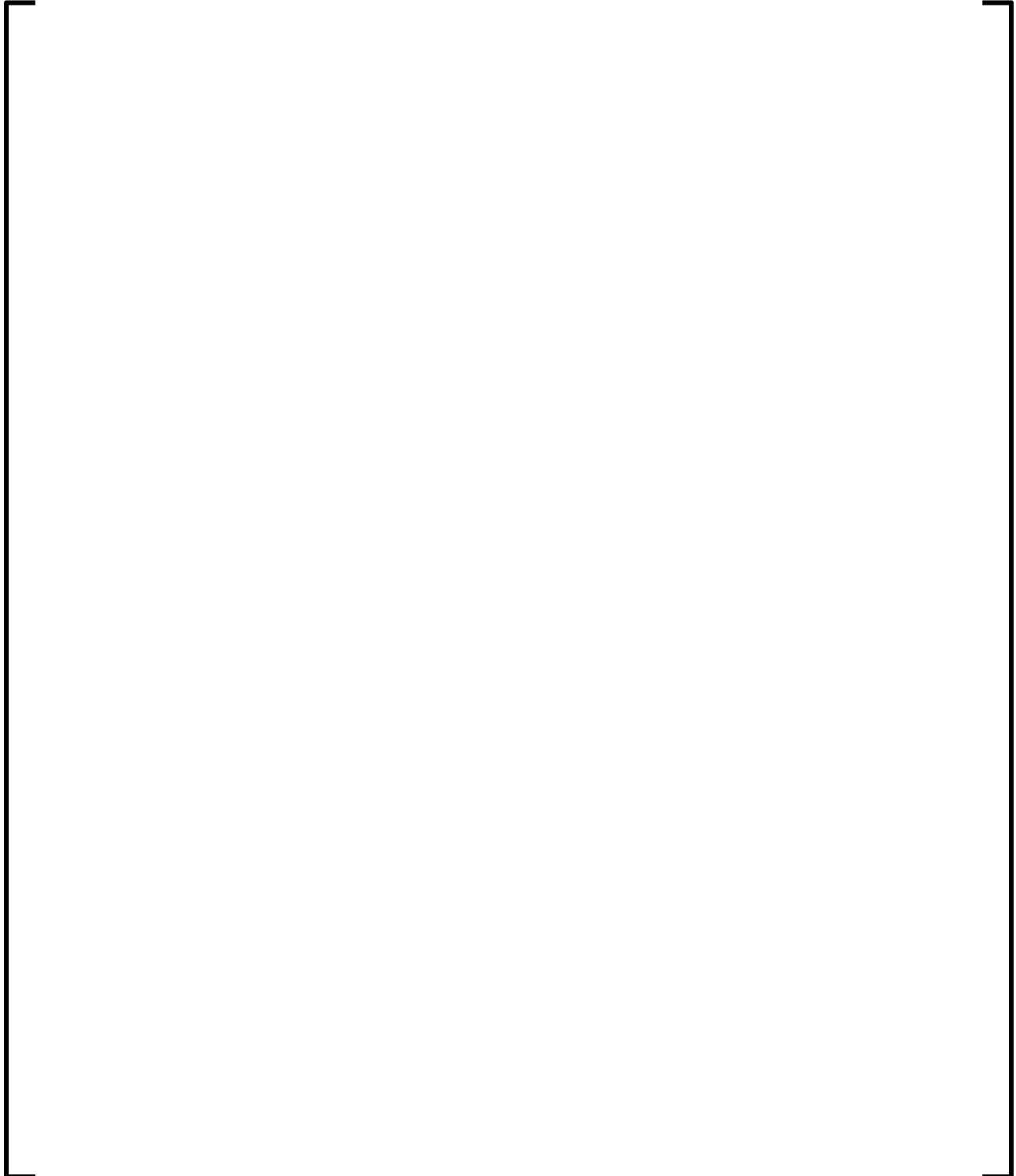
Blade Worth = $\frac{k_{\text{Controlled}} - k_{\text{Uncontrolled}}}{k_{\text{Uncontrolled}}}$		$k_{\text{Controlled}}$	$k_{\text{Uncontrolled}}$	Blade Worth ($\Delta k/k$)
Cold	$T_{\text{Moderator}}=68^{\circ}\text{ F}$ $T_{\text{Fuel}}=68^{\circ}\text{ F}$ 0% Void, No xenon	0.92280	1.10955	-0.1683
Intermediate	$T_{\text{Moderator}}=200^{\circ}\text{ F}$ $T_{\text{Fuel}}=200^{\circ}\text{ F}$ 0% Void, No xenon	0.90990	1.10371	-0.1756
Hot Standby	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=550^{\circ}\text{ F}$ 0% Void, No xenon	0.86164	1.08507	-0.2059
Hot Operating _{NoXe}	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void, No xenon	0.85767	1.08014	-0.2060
Hot Operating ₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 0% Void	0.85775	1.08014	-0.2059
Hot Operating ₄₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 40% Void	0.81610	1.06928	-0.2368
Hot Operating ₈₀	$T_{\text{Moderator}}=550^{\circ}\text{ F}$ $T_{\text{Fuel}}=1017^{\circ}\text{ F}$ 80% Void	0.75741	1.05428	-0.2816

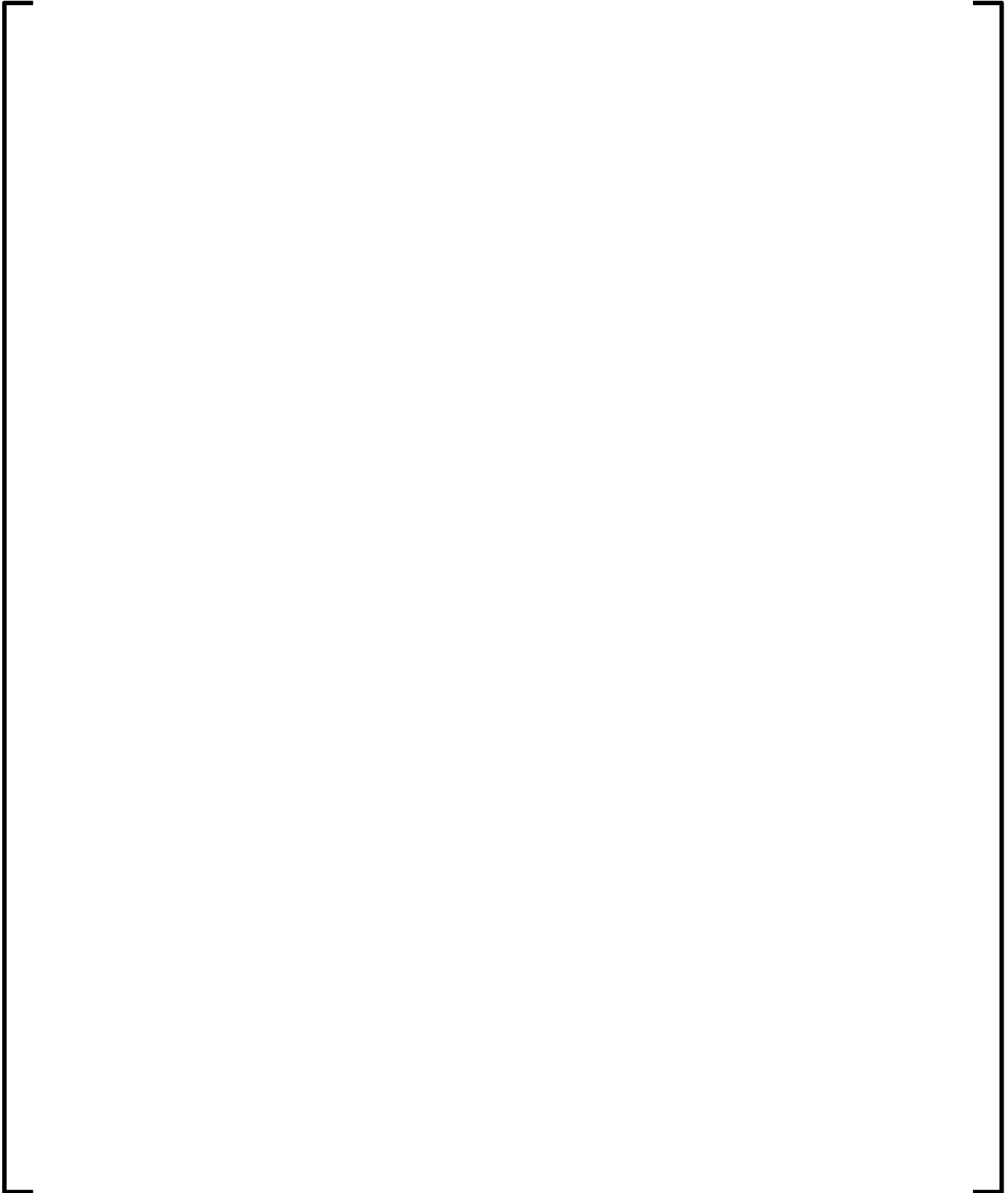
Table 2.52 Lattice [] Kinetics Parameters at BOL

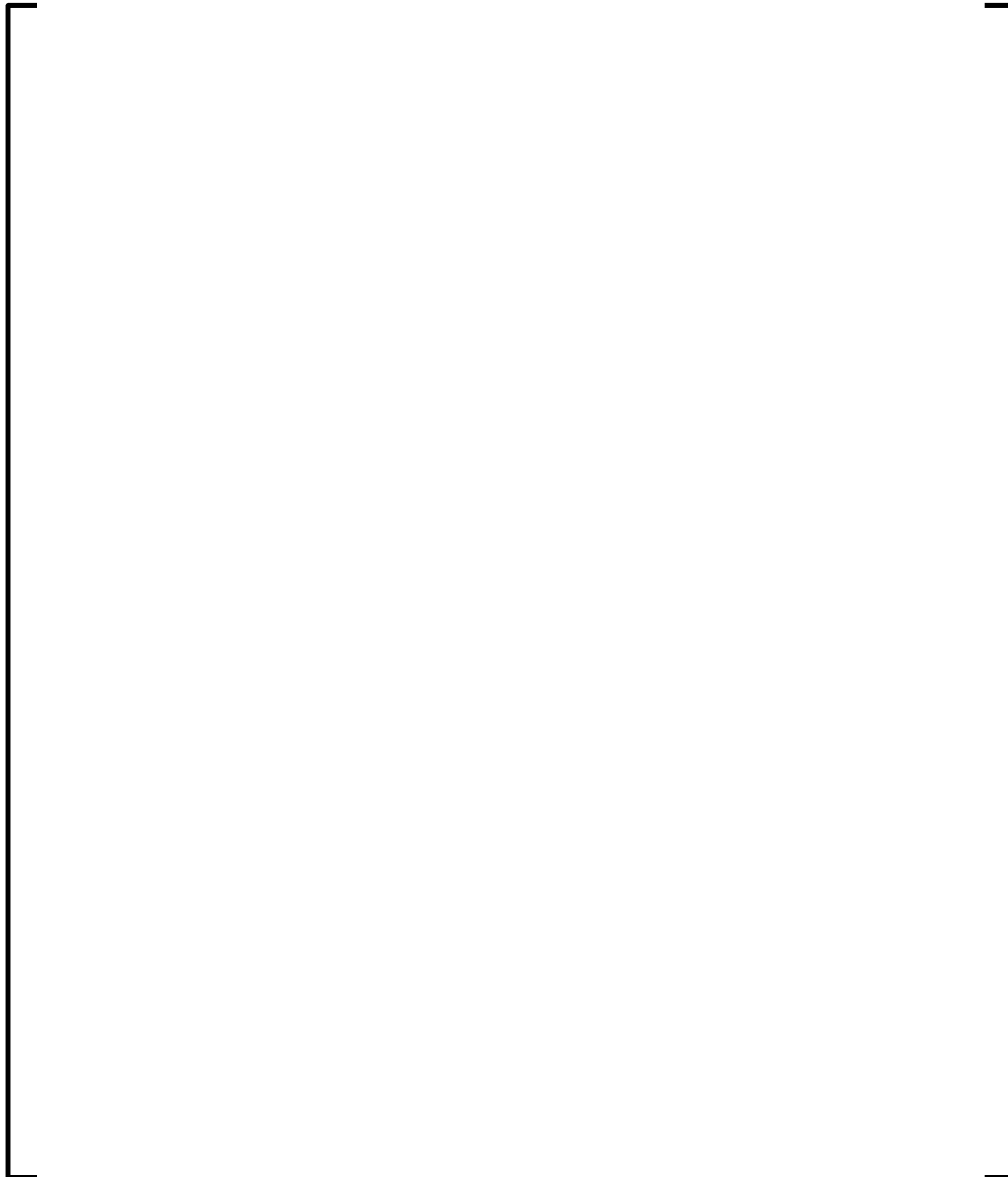
Kinetics Parameter = $\frac{k_{\alpha} - k_{\beta}}{k_{\beta}}$	k_{α}	k_{β}	Kinetics Parameter ($\Delta k/k$)
Doppler = $\frac{k_{\text{HotOperatingNoXe}} - k_{\text{HotStandby}}}{k_{\text{HotStandby}}}$	1.08014	1.08507	-0.0045
Moderator _{Void} = $\frac{k_{\text{HotOperating40}} - k_{\text{HotOperating0}}}{k_{\text{HotOperating0}}}$	1.06928	1.08014	-0.0100
Moderator _{Temperature} = $\frac{k_{\text{HotStandby}} - k_{\text{Cold}}}{k_{\text{Cold}}}$	1.08507	1.10955	-0.0221

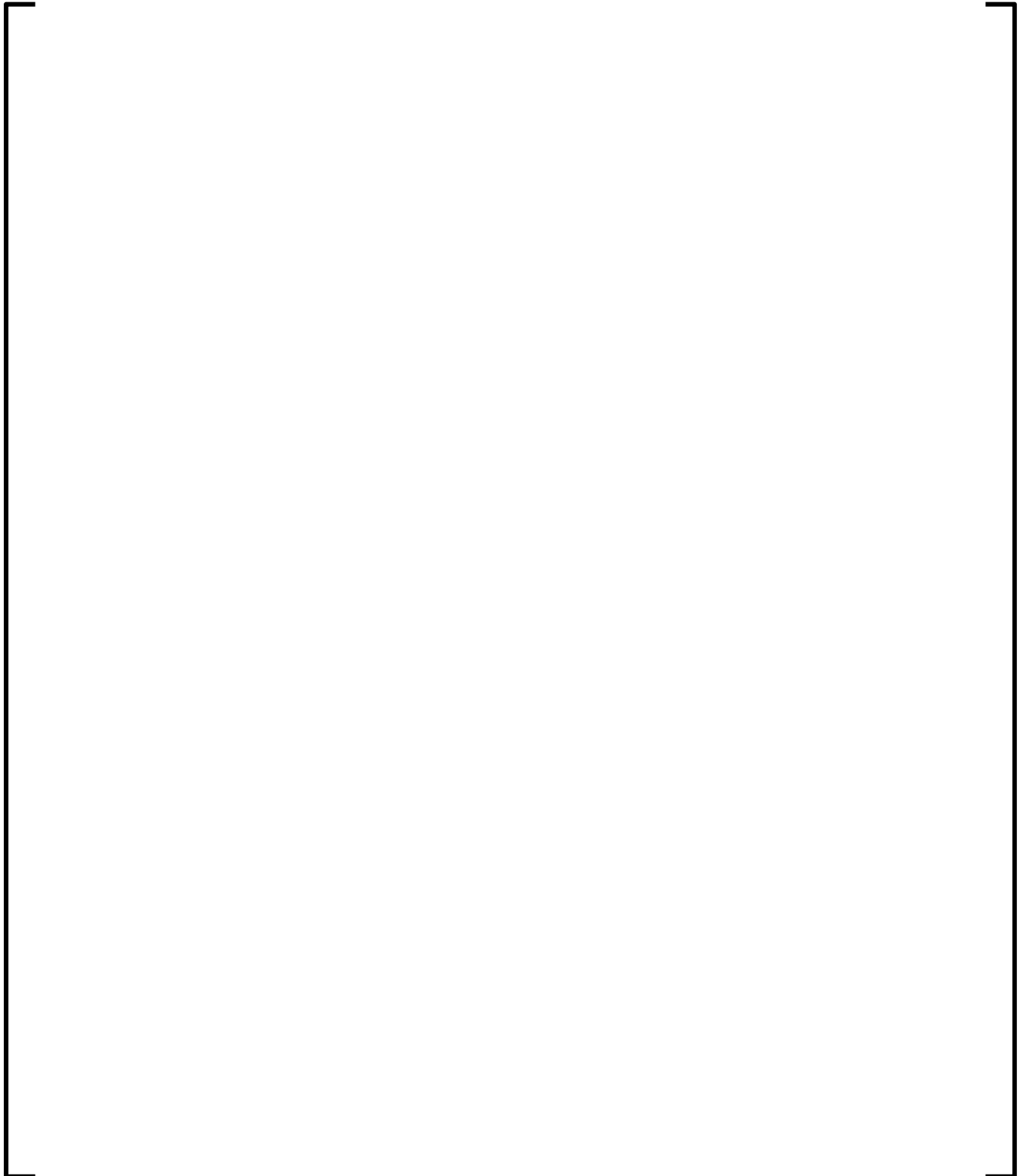












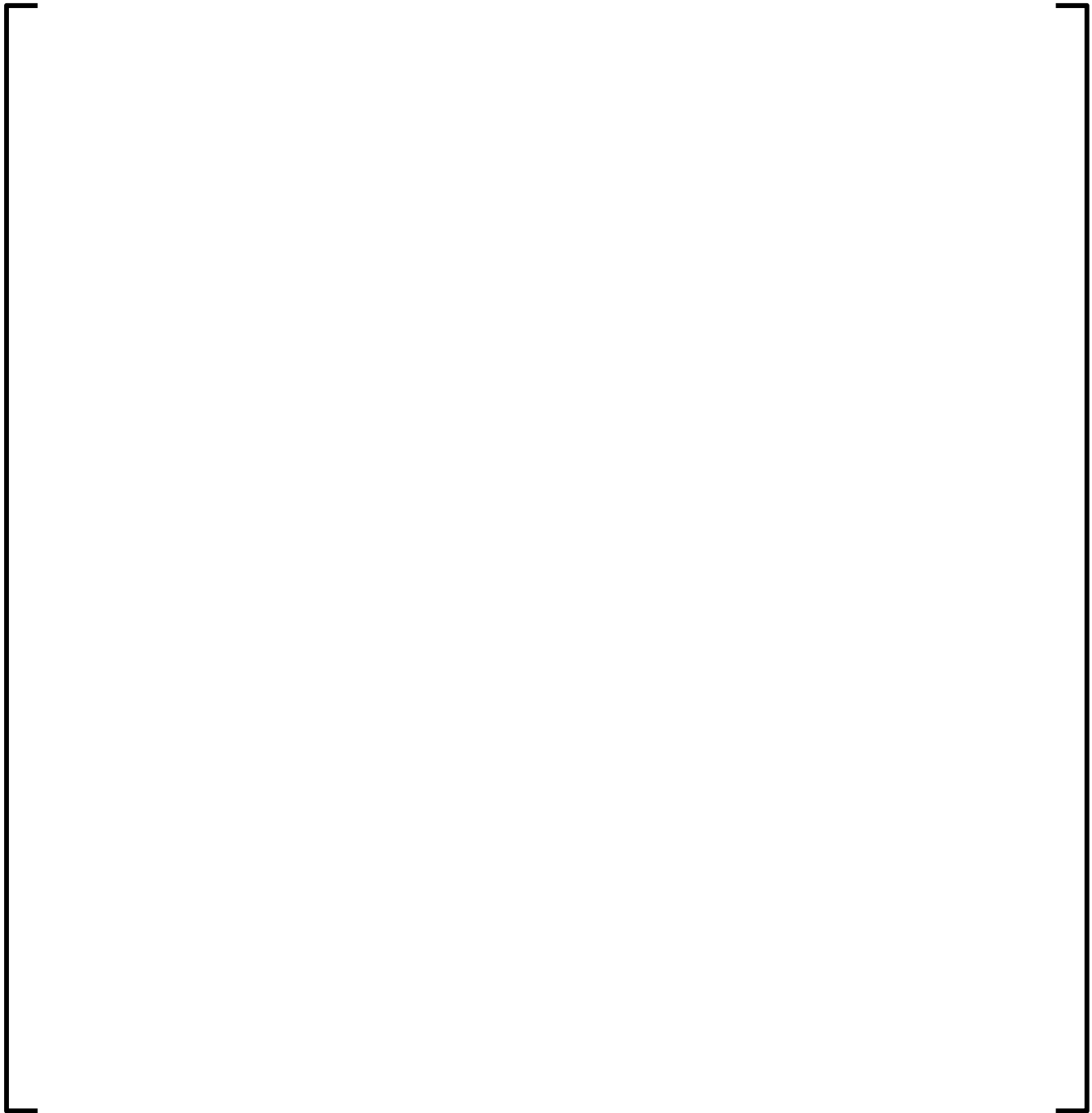


Figure 2.7 Fuel Rod Axial Description

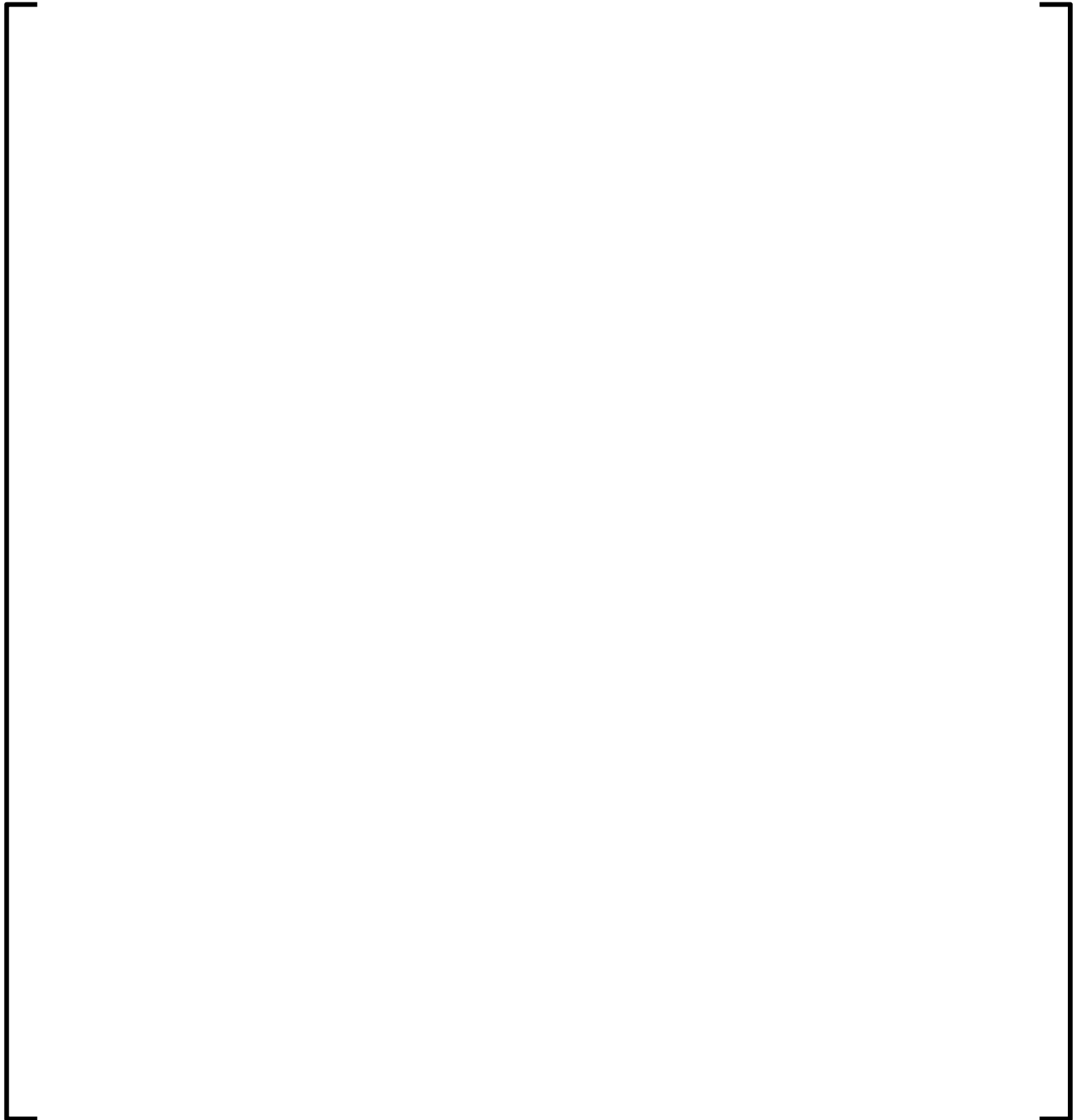


Figure 2.7 Fuel Rod Axial Description *(continued)*

3.0 REFERENCES

1. FS1-0034669 Revision 2.0, Brunswick Unit 1 LAR Equilibrium Cycle Specific ATRIUM 11 fuel Assembly Mechanical Data for Core Engineering, February 2018.
2. ANF-89-98(P)(A) Revision 1 and Supplement 1, *Generic Mechanical Design Criteria for BWR Fuel Designs*, Advanced Nuclear Fuels Corporation, May 1995.
3. EMF-2158(P)(A), Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2*, Siemens Power Corporation, October 1999.

Appendix A Enriched Lattice Hot Uncontrolled Reactivity and LPF Plots

The results in this appendix are based on hot operating and equilibrium xenon conditions.

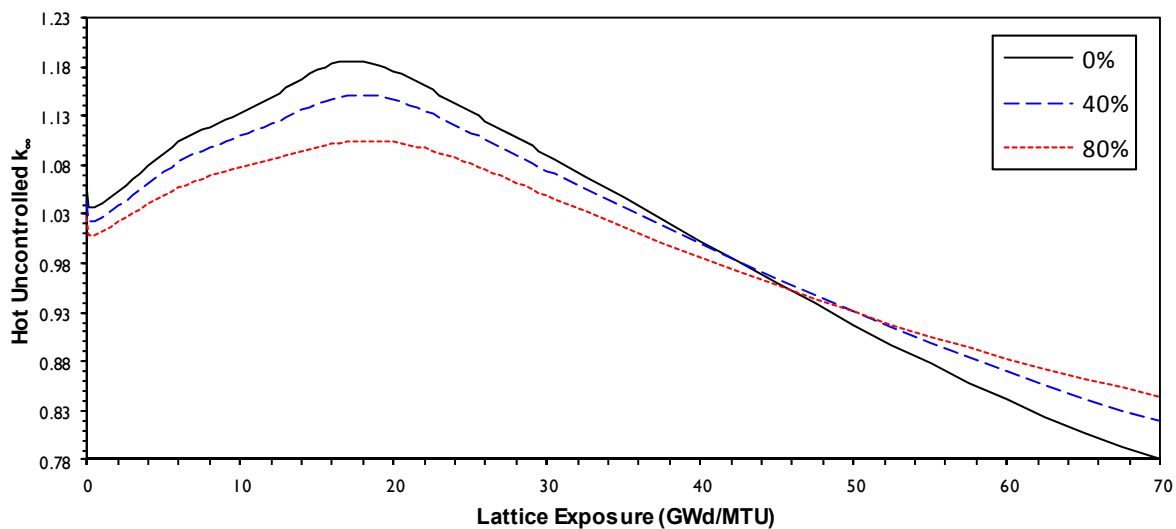


Figure A.1 [] Hot Uncontrolled k_{∞}

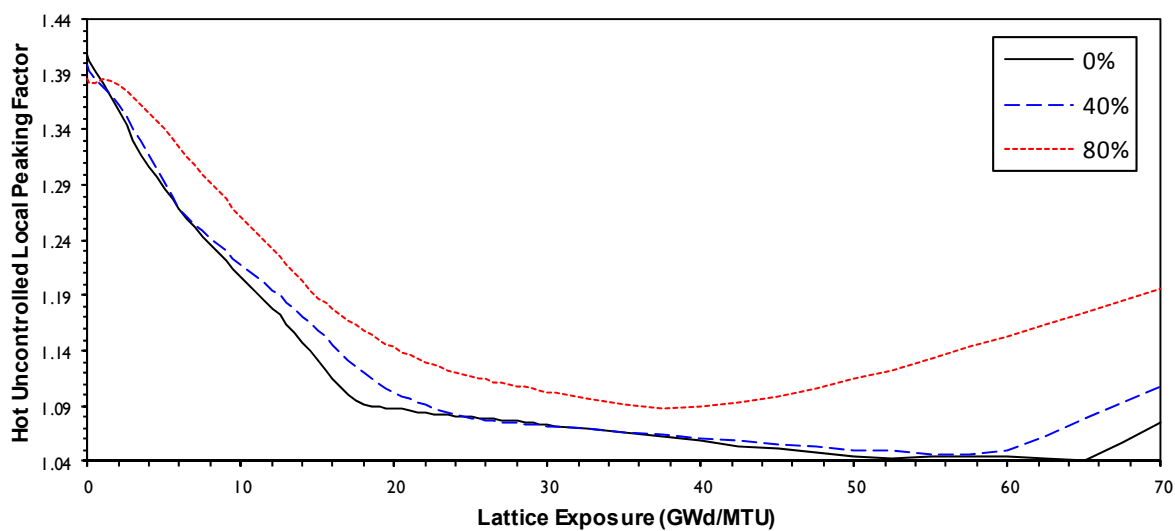


Figure A.2 [] Hot Uncontrolled LPF

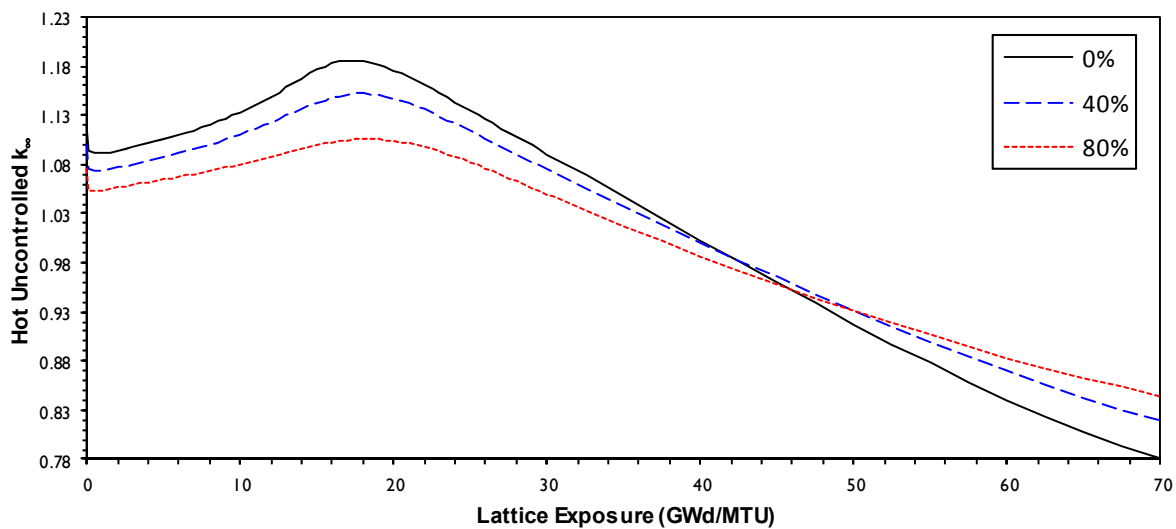


Figure A.3 [] Hot Uncontrolled k_{∞}

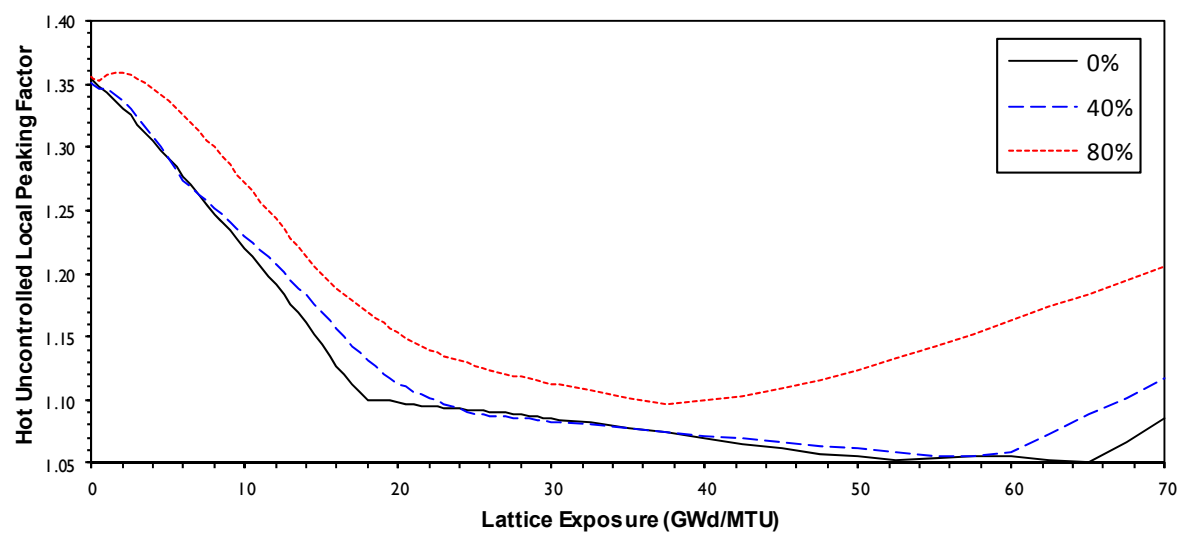


Figure A.4 [] Hot Uncontrolled LPF

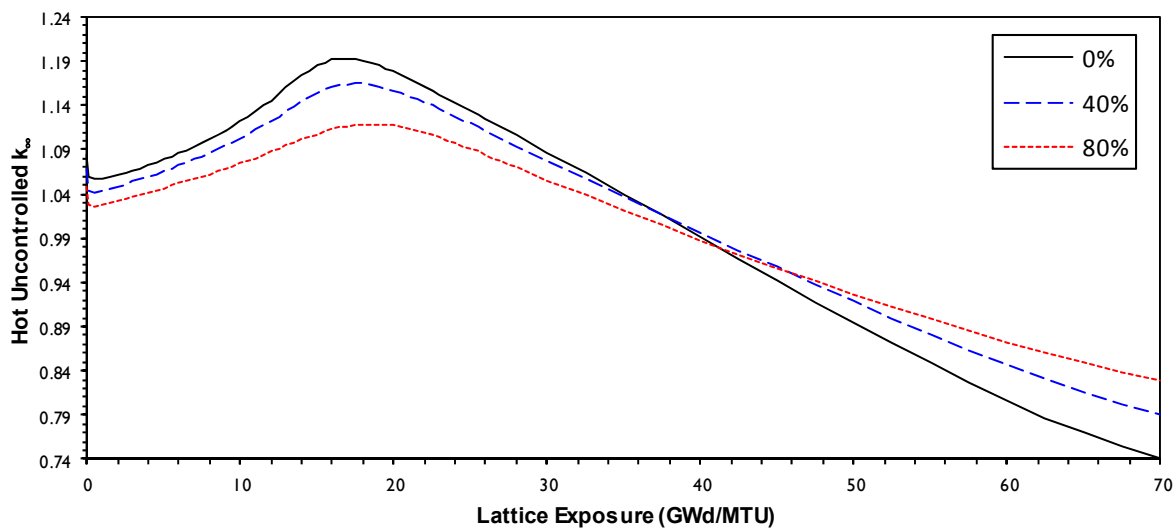


Figure A.5 [] Hot Uncontrolled k_{∞}

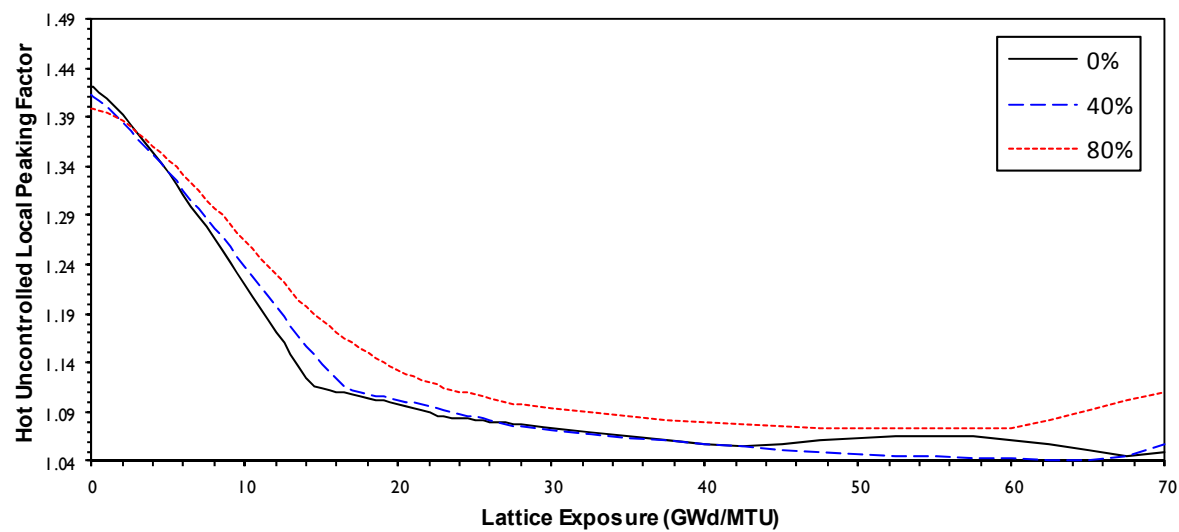


Figure A.6 [] Hot Uncontrolled LPF

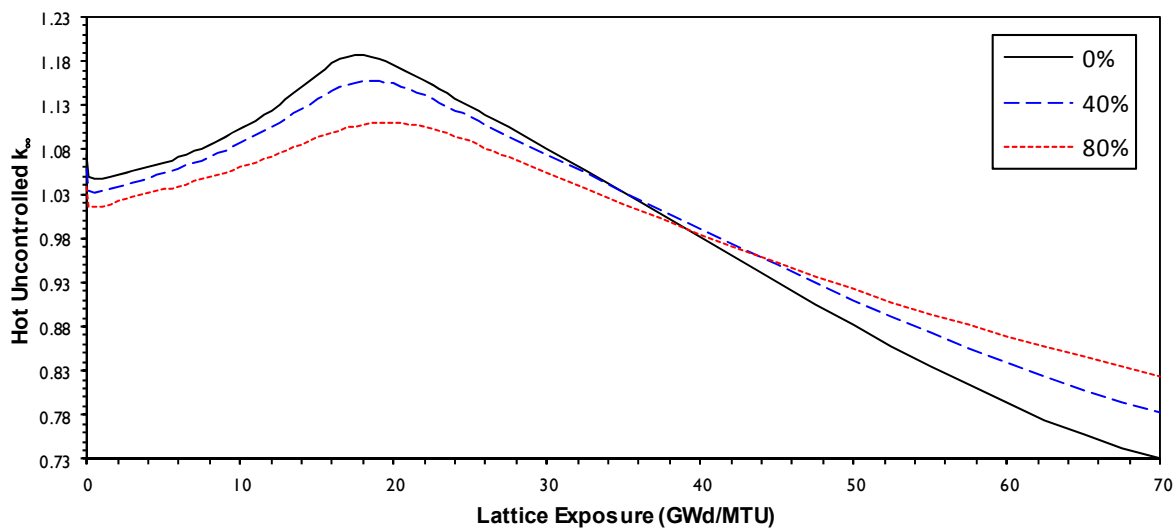


Figure A.7 [] Hot Uncontrolled k_{∞}

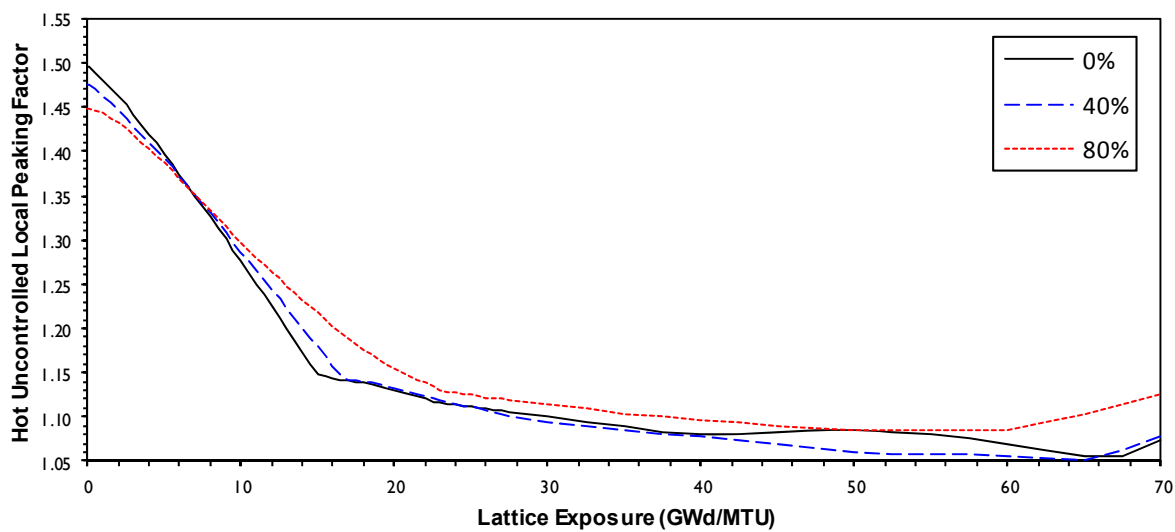


Figure A.8 [] Hot Uncontrolled LPF

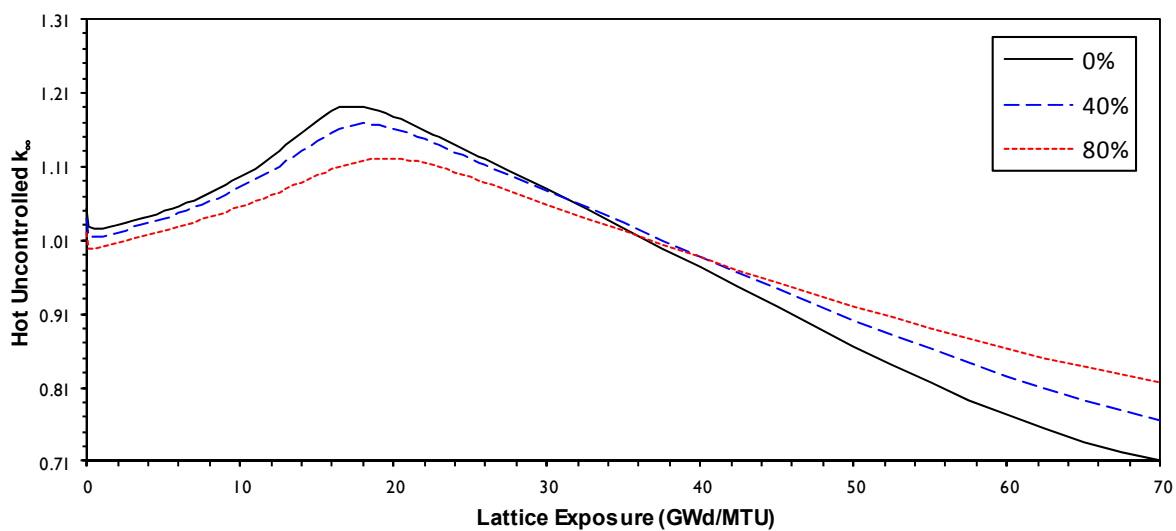


Figure A.9 [] Hot Uncontrolled k_{∞}

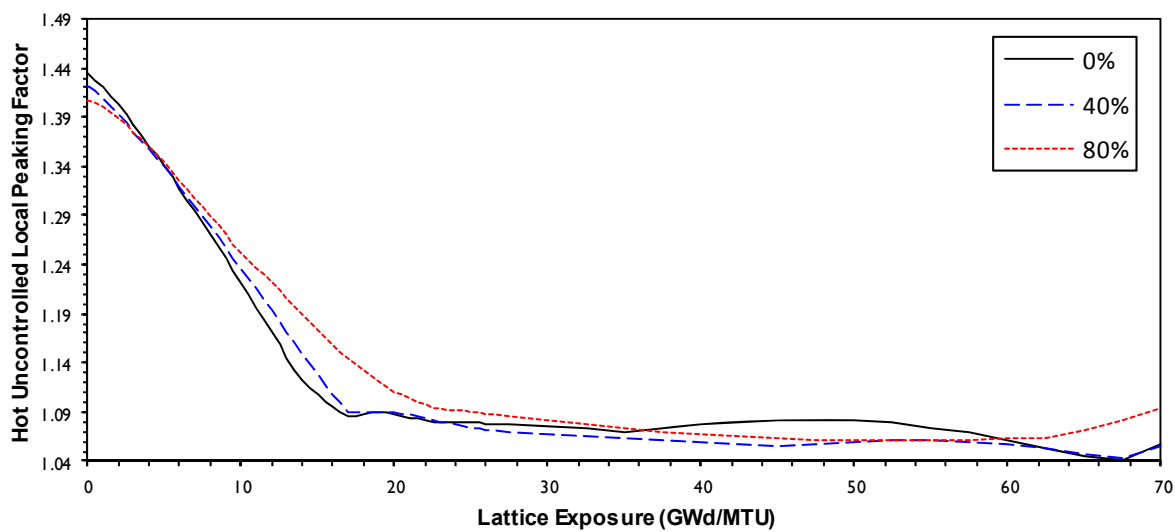


Figure A.10 [] Hot Uncontrolled LPF

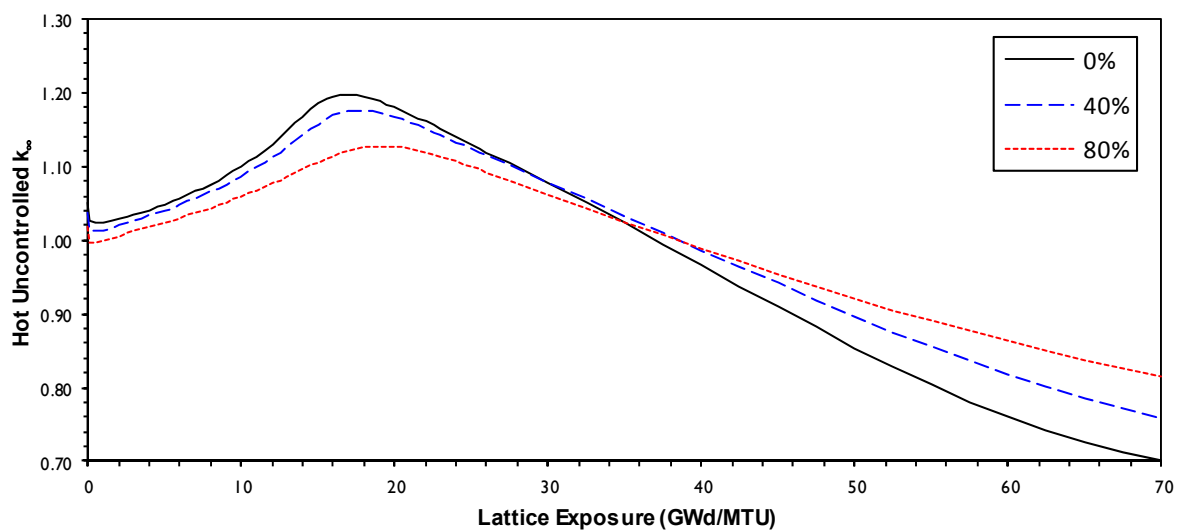


Figure A.11 [] Hot Uncontrolled k_{∞}

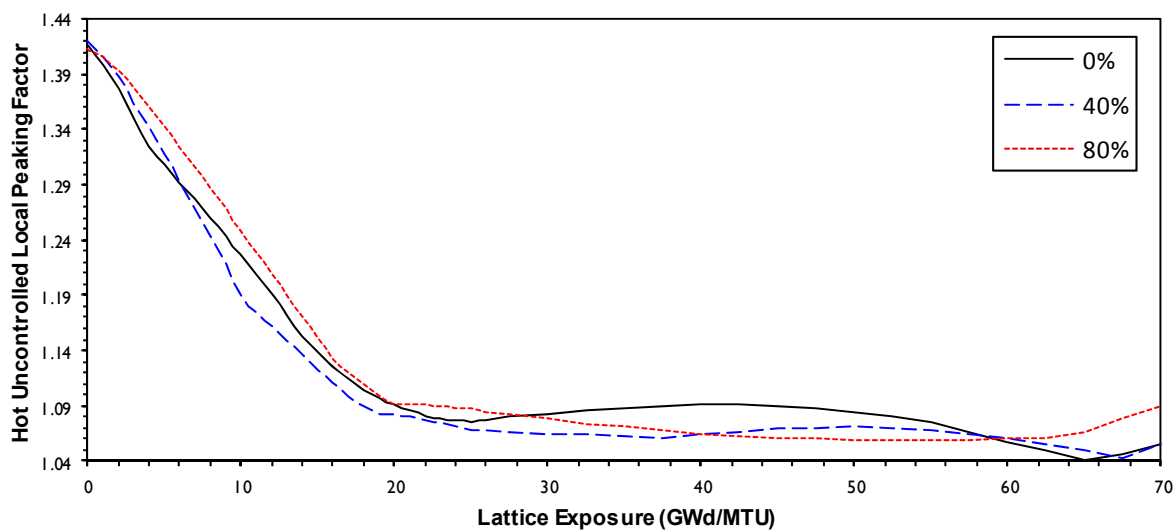


Figure A.12 [] Hot Uncontrolled LPF

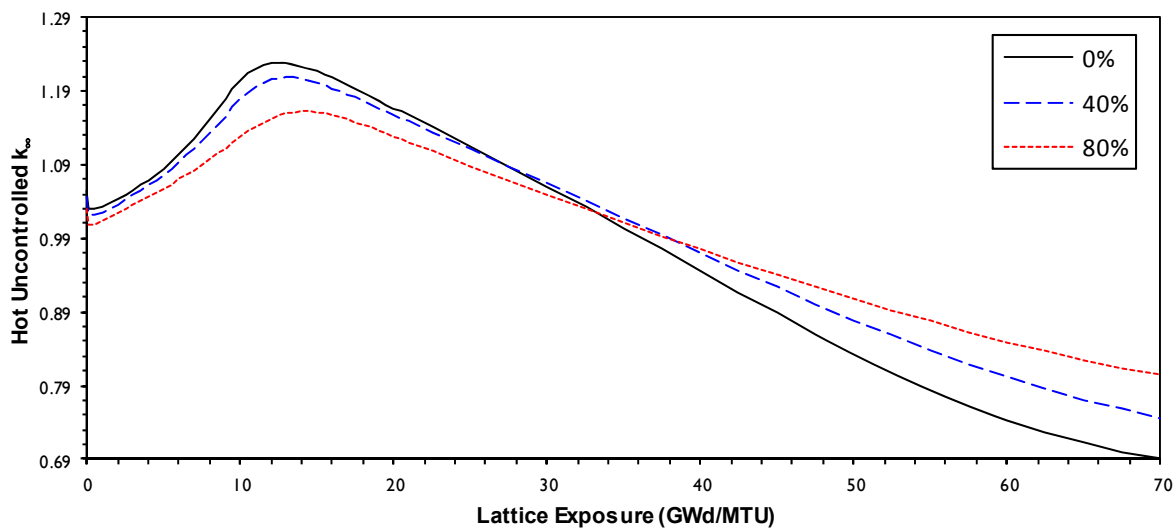


Figure A.13 [] Hot Uncontrolled k_{∞}

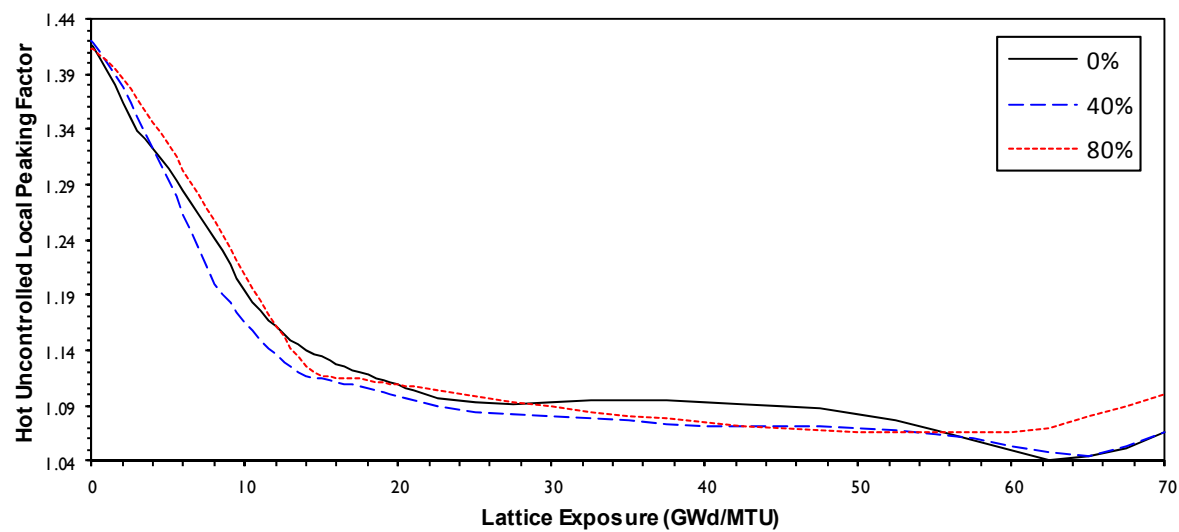


Figure A.14 [] Hot Uncontrolled LPF

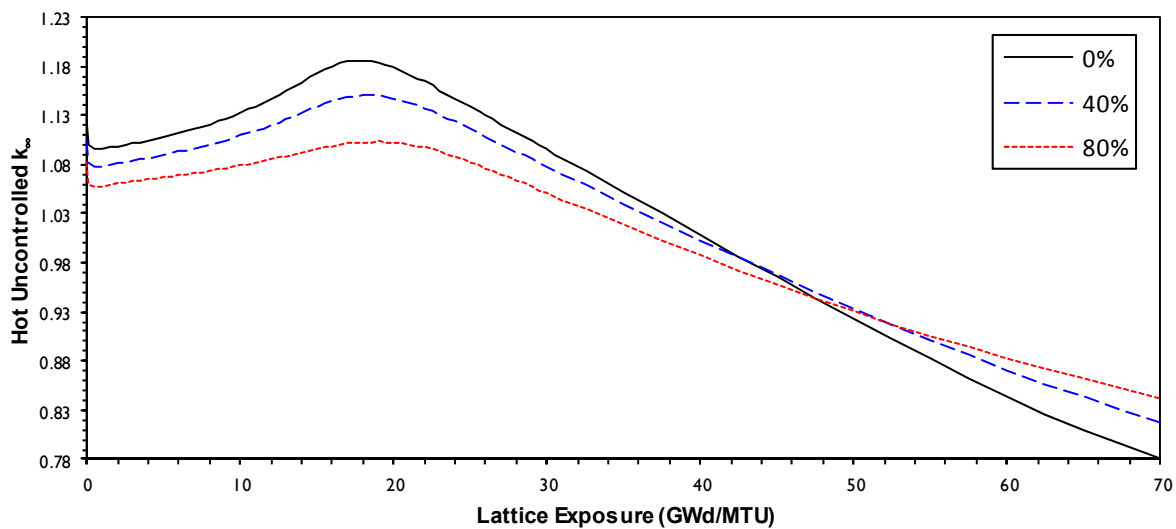


Figure A.15 [] Hot Uncontrolled k_{∞}

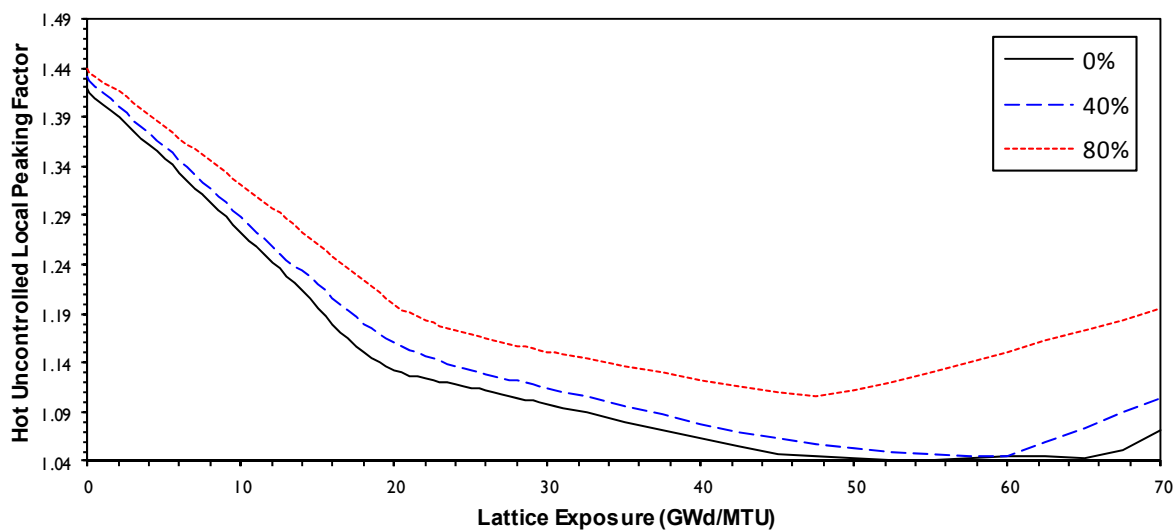


Figure A.16 [] Hot Uncontrolled LPF

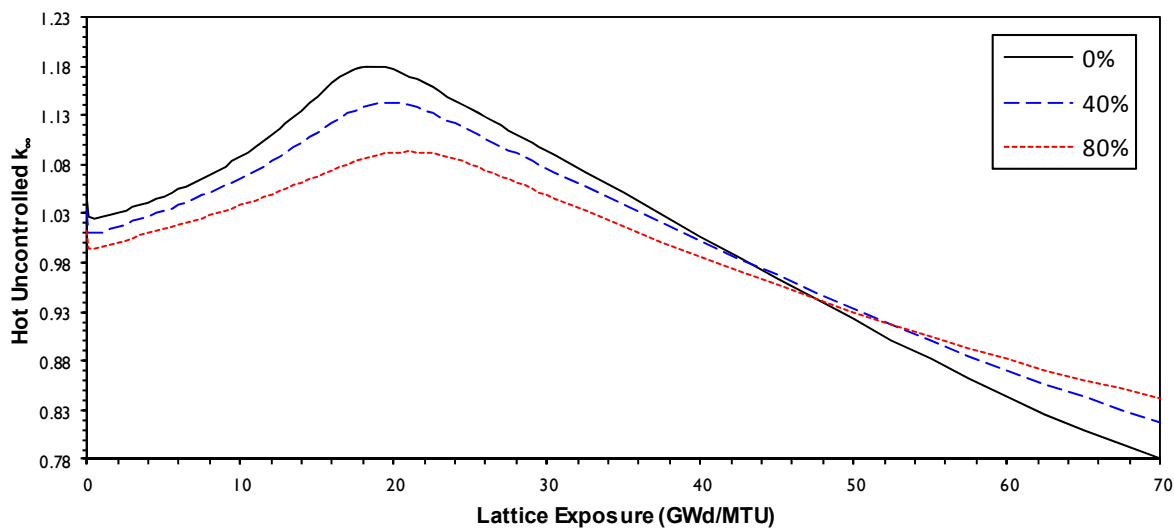


Figure A.17 [Hot Uncontrolled k_{∞}]

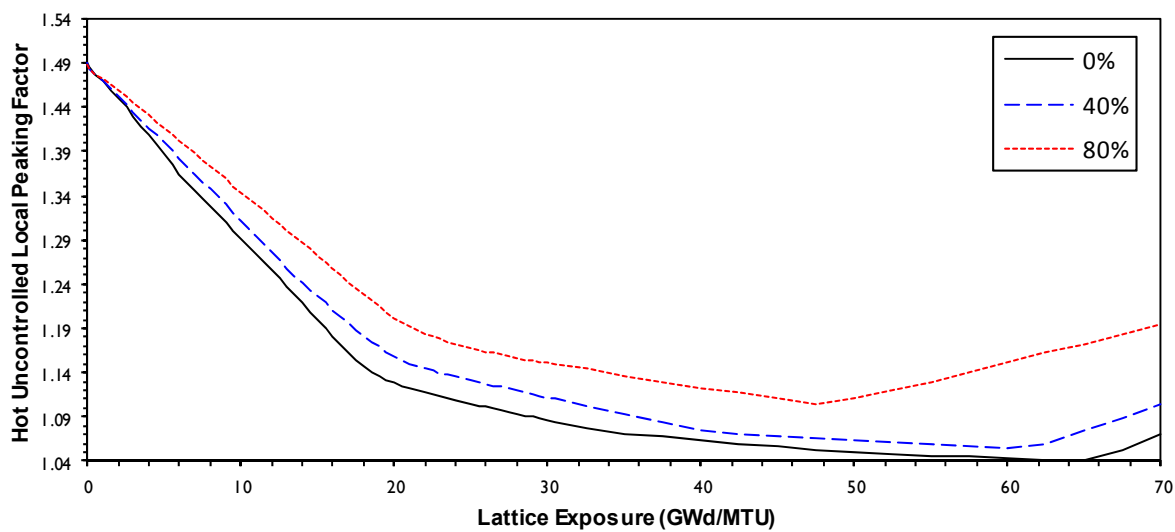


Figure A.18 [Hot Uncontrolled LPF]

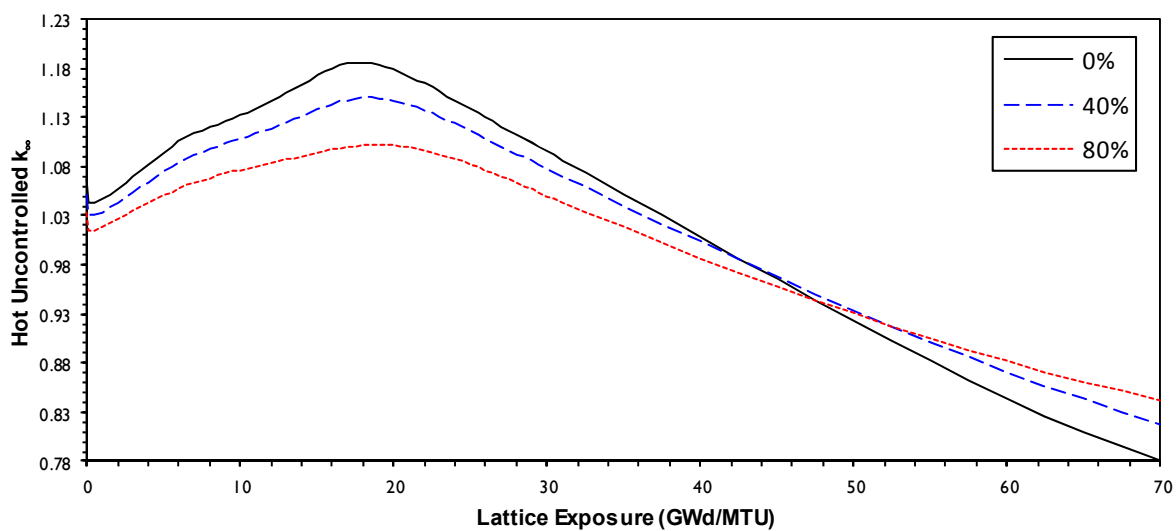


Figure A.19 [] Hot Uncontrolled k_{∞}

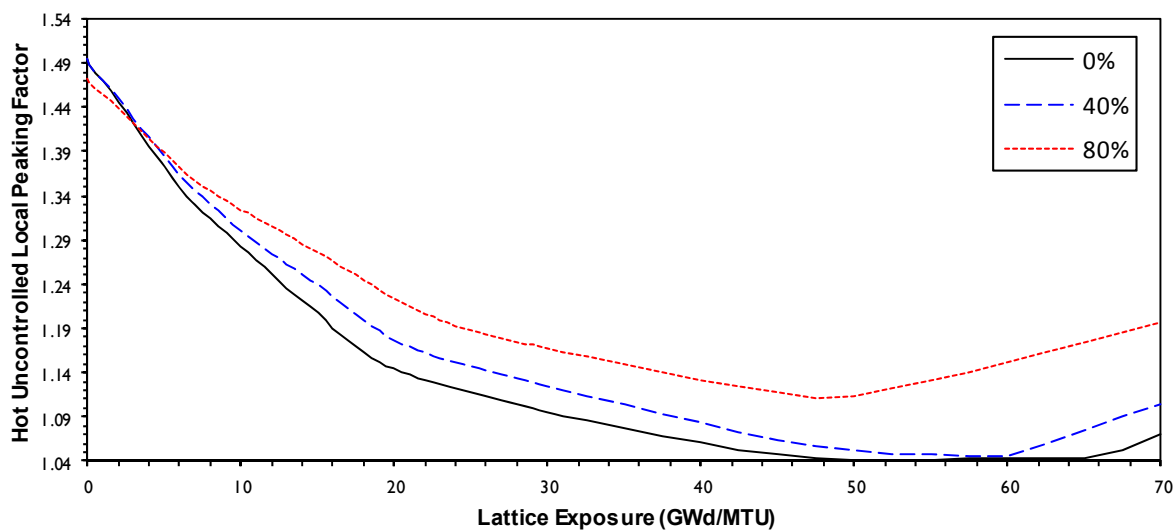


Figure A.20 [] Hot Uncontrolled LPF

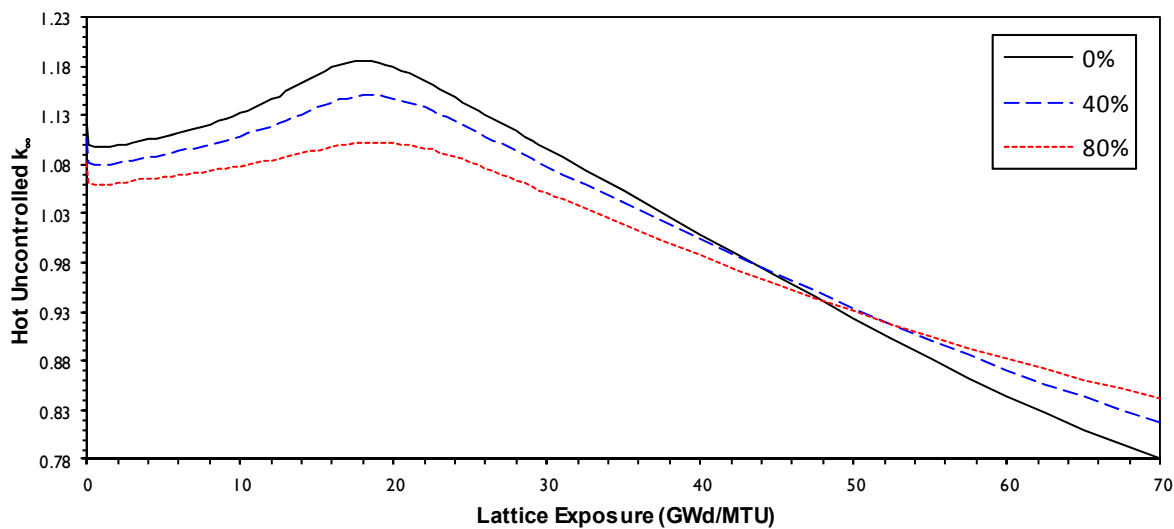


Figure A.21 [] Hot Uncontrolled k_{∞}

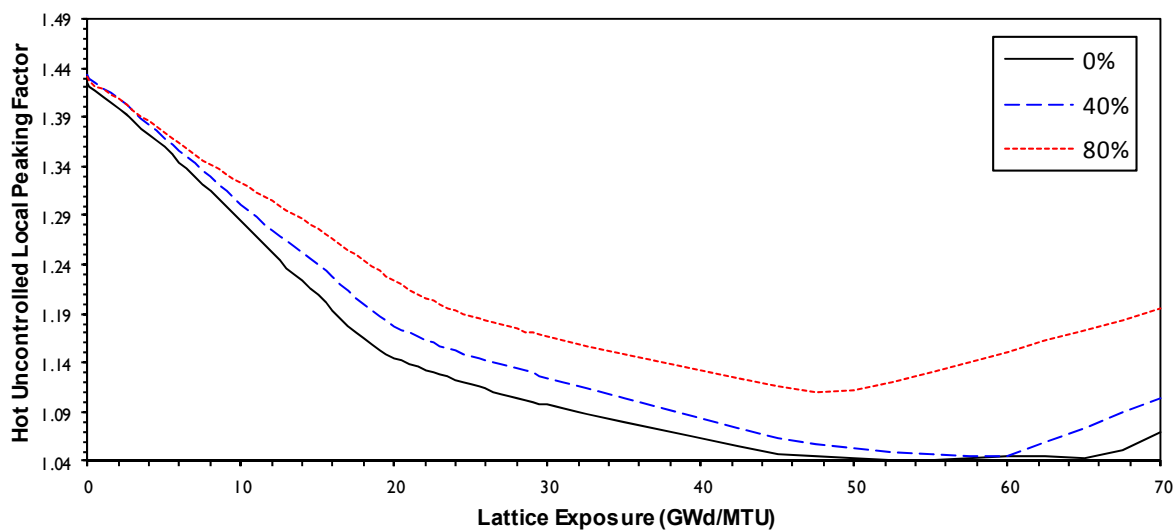


Figure A.22 [] Hot Uncontrolled LPF

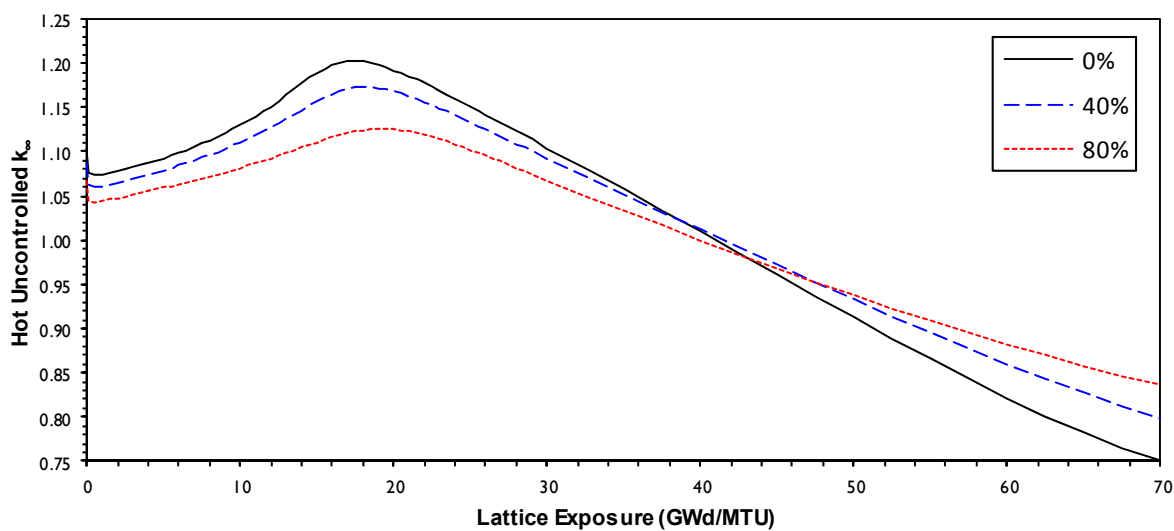


Figure A.23 [] Hot Uncontrolled k_{∞}

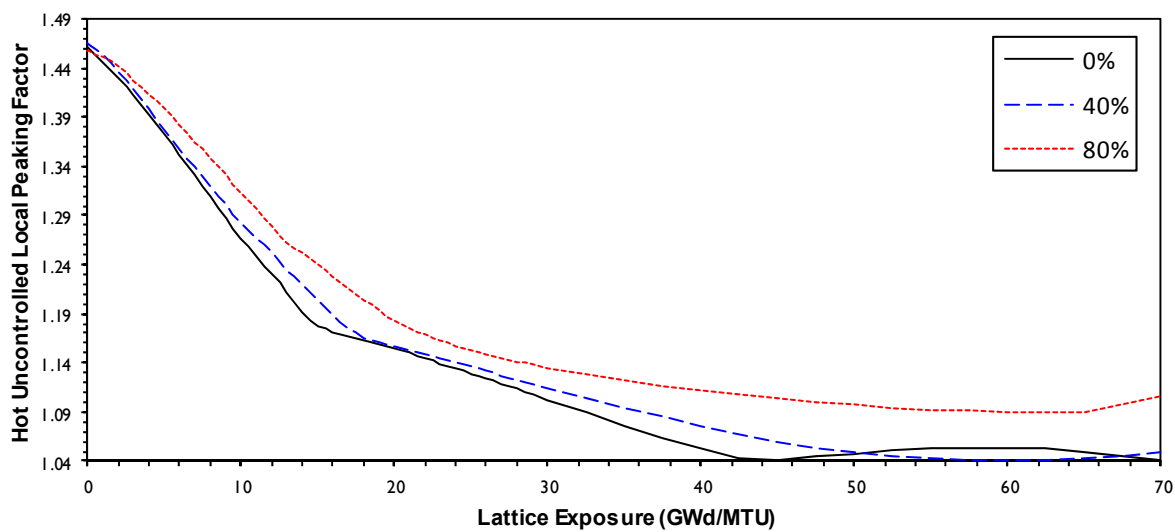


Figure A.24 [] Hot Uncontrolled LPF

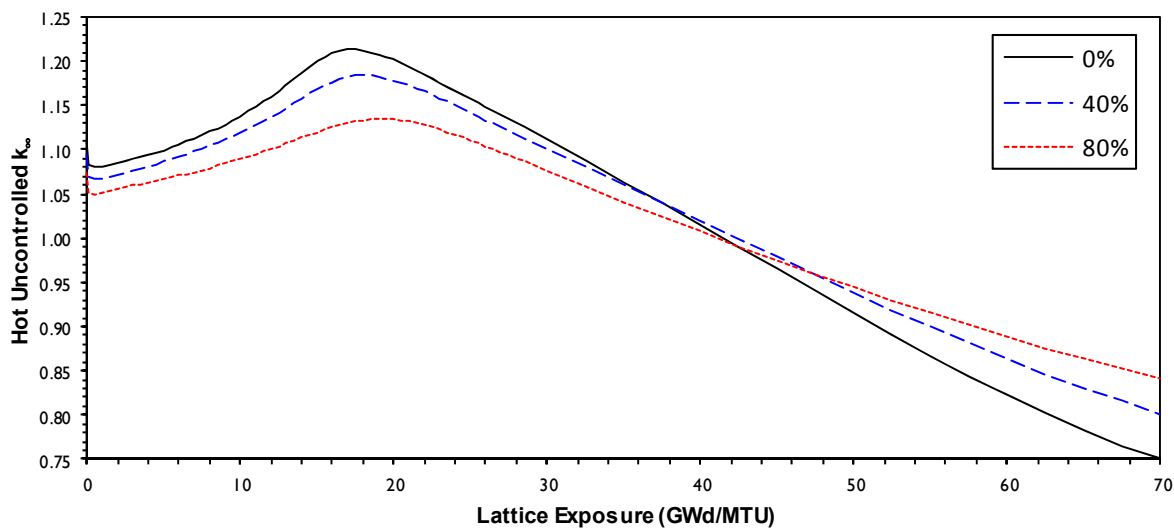


Figure A.25 [] Hot Uncontrolled k_{∞}

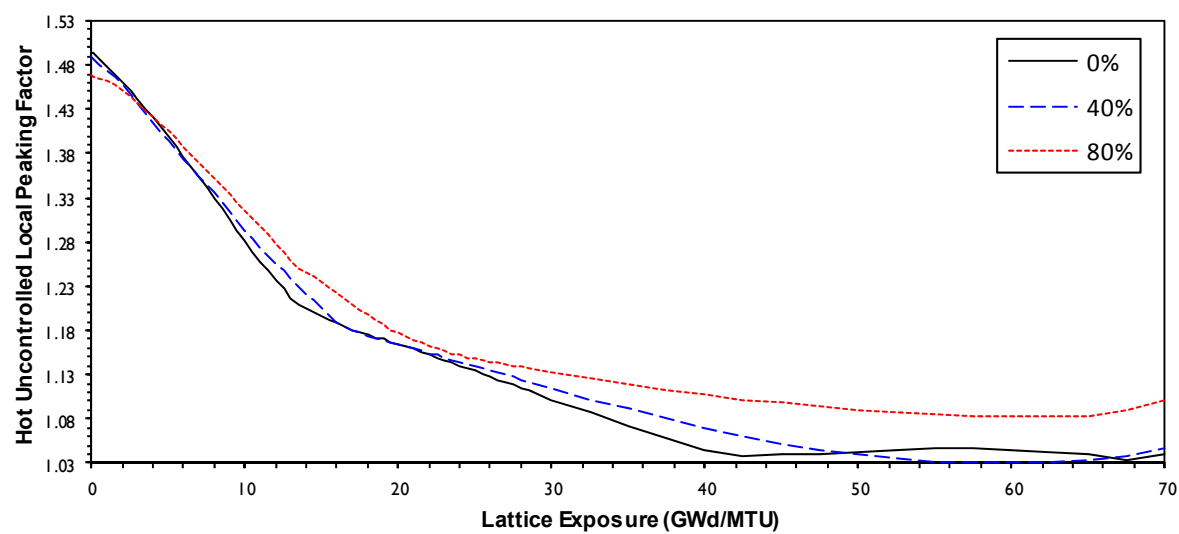


Figure A.26 [] Hot Uncontrolled LPF

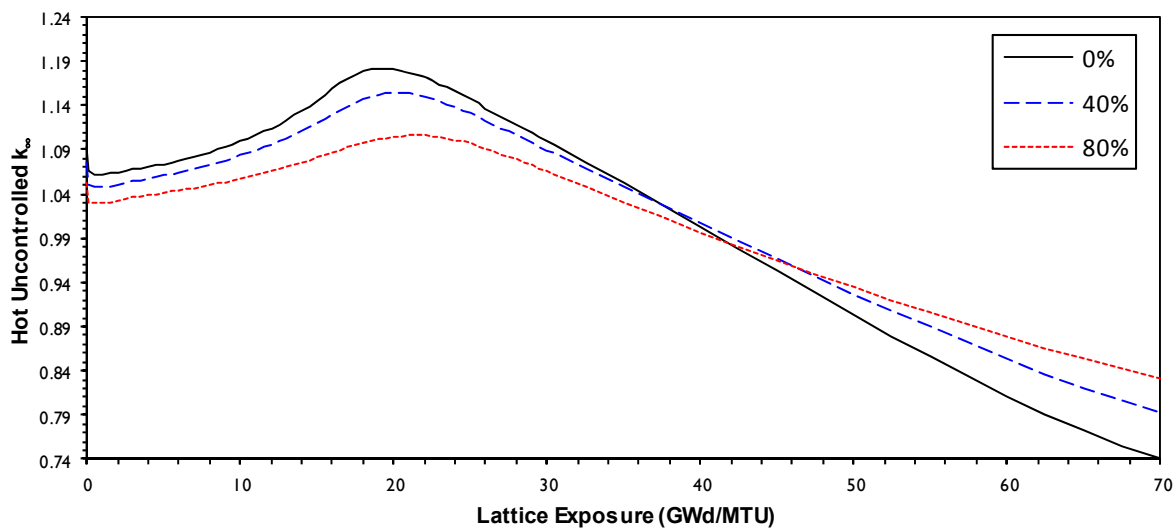


Figure A.27 [] Hot Uncontrolled k_{∞}

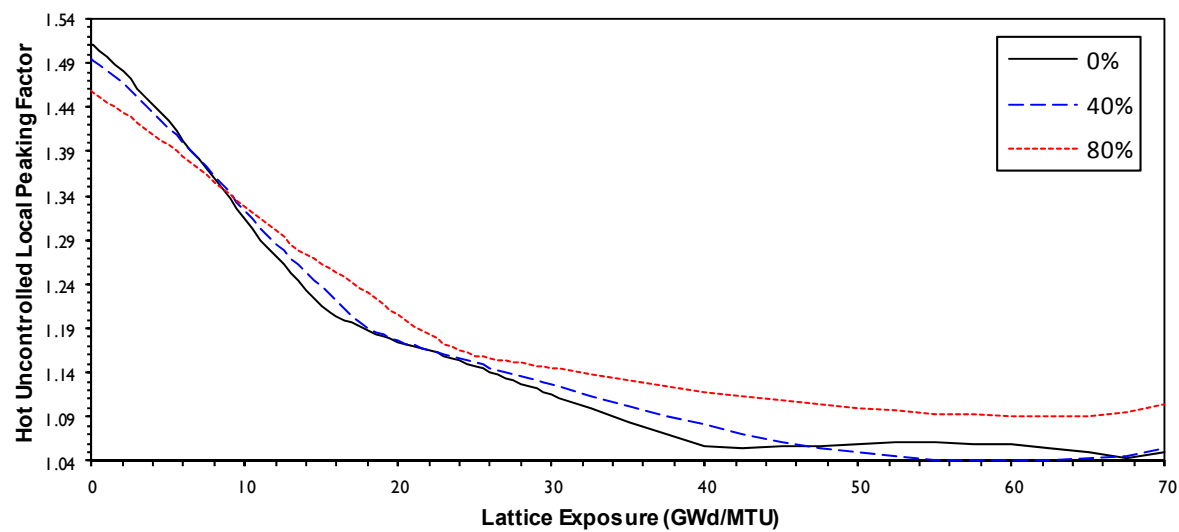


Figure A.28 [] Hot Uncontrolled LPF

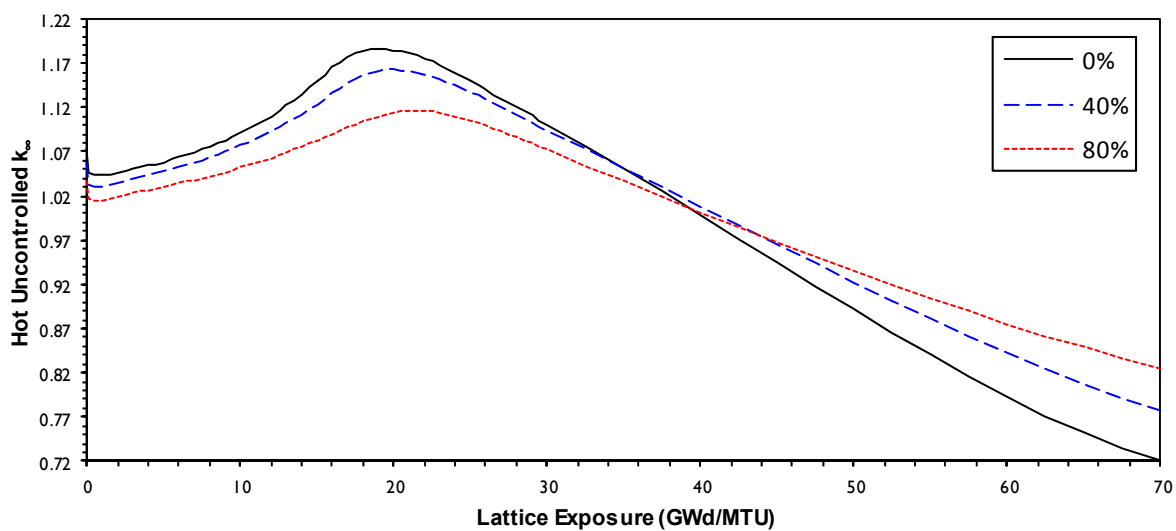


Figure A.29 [] Hot Uncontrolled k_{∞}

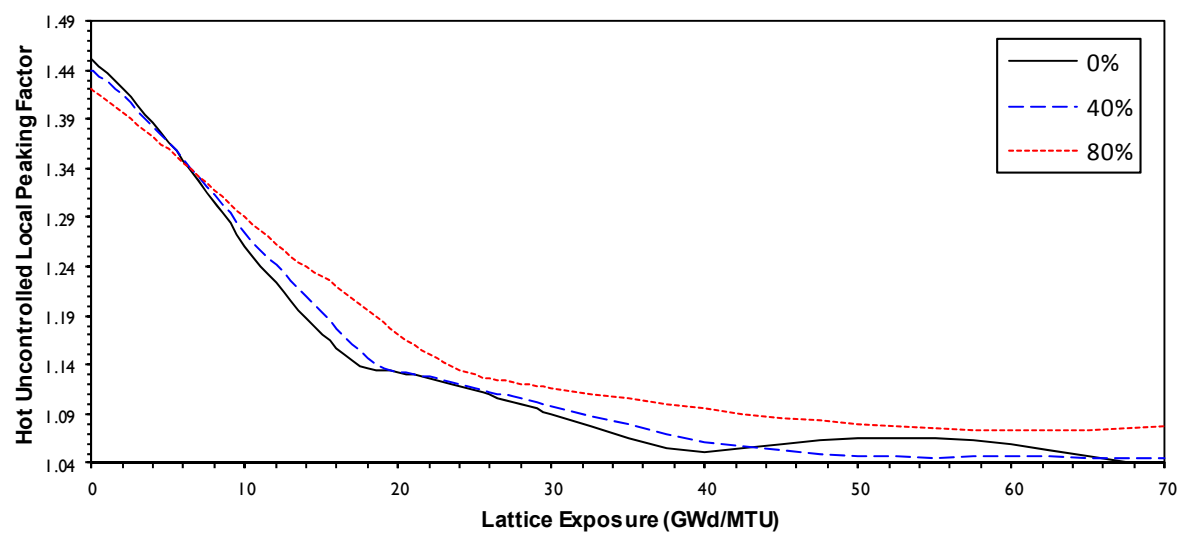


Figure A.30 [] Hot Uncontrolled LPF

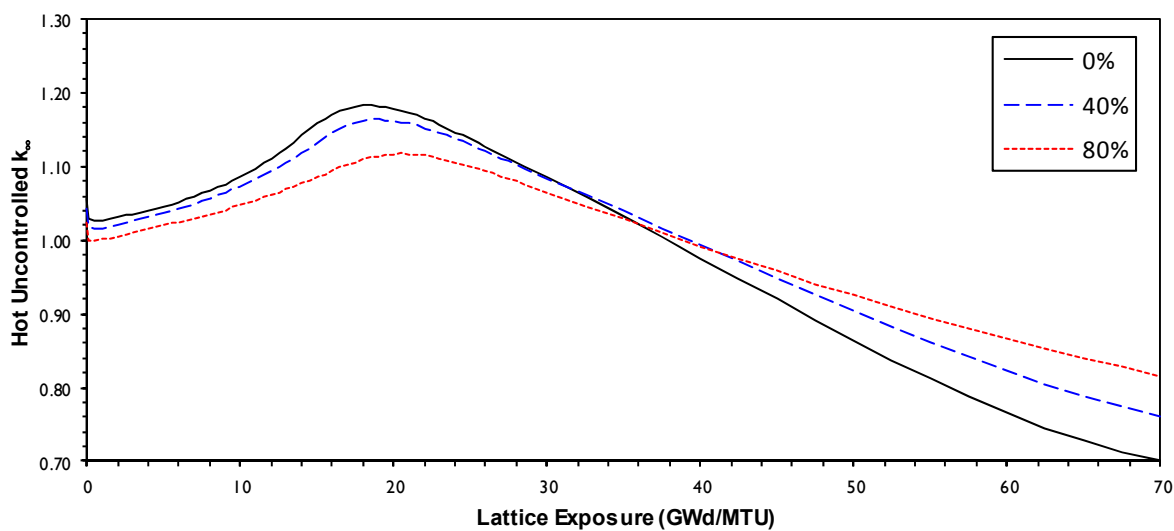


Figure A.31 [] Hot Uncontrolled k_{∞}

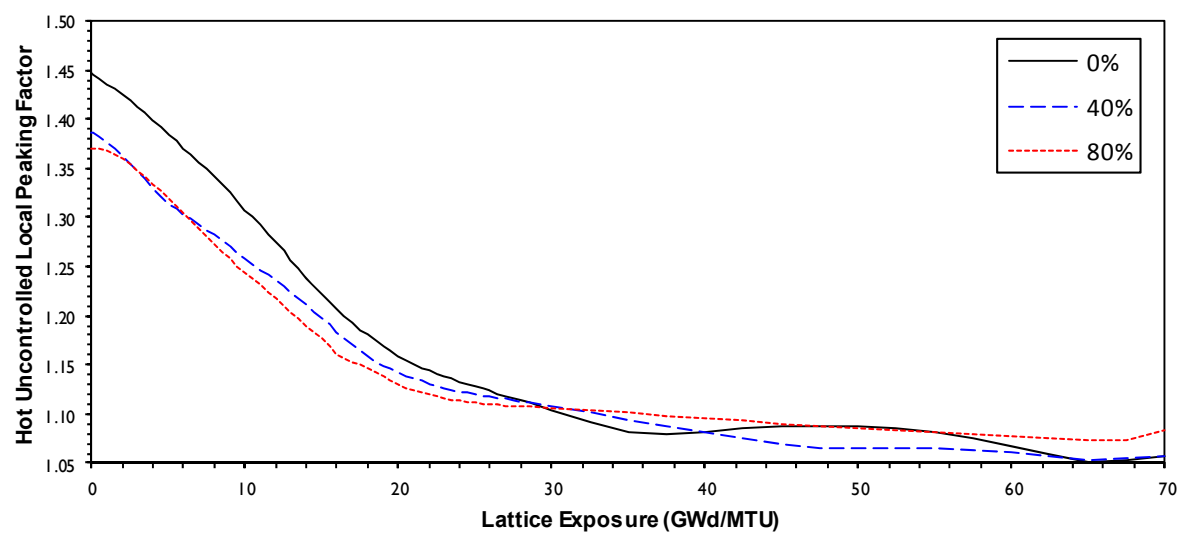


Figure A.32 [] Hot Uncontrolled LPF

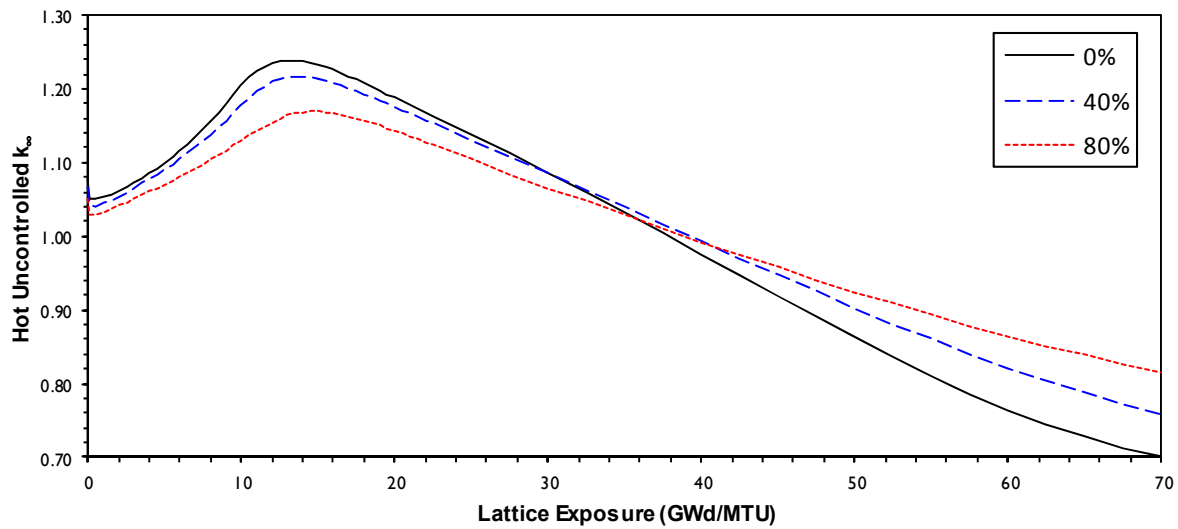


Figure A.33 [] Hot Uncontrolled k_{∞}

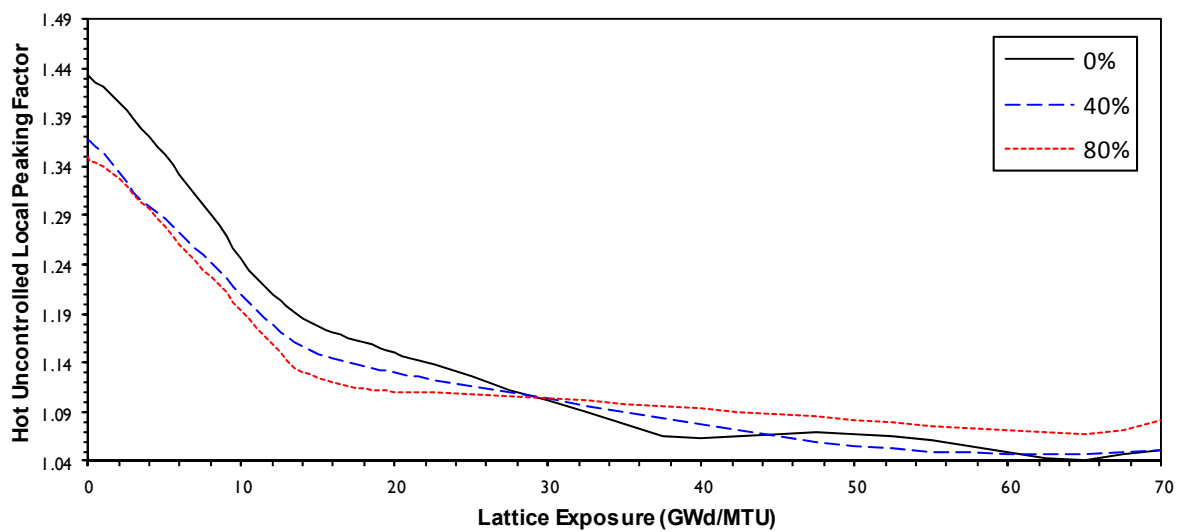


Figure A.34 [] Hot Uncontrolled LPF

Appendix B Enriched Lattice Hot Uncontrolled Reactivity and LPF Tables

The results in this appendix are based on hot operating and equilibrium xenon conditions.

Table B.1 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.05599	1.04002	1.02244
100.	1.03328	1.01908	1.00393
500.	1.03312	1.01948	1.00482
1000.	1.03714	1.02360	1.00877
1500.	1.04254	1.02879	1.01340
2000.	1.04848	1.03431	1.01813
2500.	1.05473	1.03998	1.02280
3000.	1.06127	1.04573	1.02739
3500.	1.06808	1.05157	1.03191
4000.	1.07509	1.05748	1.03637
4500.	1.08206	1.06336	1.04076
5000.	1.08858	1.06905	1.04503
5500.	1.09441	1.07430	1.04911
6000.	1.09957	1.07903	1.05288
6500.	1.10415	1.08328	1.05632
7000.	1.10824	1.08714	1.05945
7500.	1.11197	1.09066	1.06231
8000.	1.11546	1.09391	1.06497
8500.	1.11884	1.09698	1.06746
9000.	1.12219	1.09992	1.06981
9500.	1.12560	1.10281	1.07204
10000.	1.12910	1.10570	1.07419
10500.	1.13276	1.10865	1.07629
11000.	1.13662	1.11169	1.07836
11500.	1.14070	1.11485	1.08043
12000.	1.14501	1.11812	1.08253
12500.	1.14954	1.12149	1.08465
13000.	1.15425	1.12494	1.08676
13500.	1.15905	1.12842	1.08885
14000.	1.16381	1.13184	1.09087
14500.	1.16839	1.13513	1.09278
15000.	1.17257	1.13820	1.09454
15500.	1.17620	1.14098	1.09612
16000.	1.17908	1.14338	1.09752
16500.	1.18110	1.14530	1.09869
17000.	1.18219	1.14668	1.09962
17500.	1.18237	1.14749	1.10030
18000.	1.18165	1.14770	1.10071
18500.	1.18012	1.14733	1.10082
19000.	1.17790	1.14639	1.10062
19500.	1.17513	1.14492	1.10011
20000.	1.17193	1.14296	1.09930
20500.	1.16840	1.14057	1.09819
21000.	1.16461	1.13782	1.09679
21500.	1.16063	1.13479	1.09512
22000.	1.15650	1.13152	1.09319
22500.	1.15228	1.12808	1.09102
23000.	1.14787	1.12449	1.08863
23500.	1.14346	1.12080	1.08606
24000.	1.13906	1.11704	1.08332
24500.	1.13465	1.11323	1.08044
25000.	1.13024	1.10938	1.07746
25500.	1.12587	1.10546	1.07439
26000.	1.12150	1.10154	1.07124
26500.	1.11714	1.09763	1.06805
27000.	1.11277	1.09371	1.06481
27500.	1.10840	1.08979	1.06155
28000.	1.10403	1.08595	1.05826
28500.	1.09966	1.08211	1.05497
29000.	1.09530	1.07827	1.05167
29500.	1.09093	1.07443	1.04837
30000.	1.08656	1.07059	1.04507
30500.	1.08219	1.06680	1.04179
32500.	1.06473	1.05164	1.02868
35000.	1.04291	1.03294	1.01279
37500.	1.02110	1.01450	0.99731
40000.	0.99934	0.99635	0.98226
42500.	0.97770	0.97850	0.96765
45000.	0.95623	0.96100	0.95351
47500.	0.93504	0.94388	0.93984
50000.	0.91422	0.92719	0.92667
52500.	0.89390	0.91098	0.91401
55000.	0.87421	0.89530	0.90187
57500.	0.85528	0.88021	0.89027
60000.	0.83723	0.86576	0.87922
62500.	0.82020	0.85199	0.86870
65000.	0.80430	0.83895	0.85874
67500.	0.78960	0.82668	0.84932
70000.	0.77618	0.81519	0.84045

Table B.2 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.412	1.402	1.389
100.	1.406	1.397	1.386
500.	1.397	1.389	1.387
1000.	1.386	1.383	1.389
1500.	1.374	1.376	1.388
2000.	1.361	1.366	1.384
2500.	1.348	1.356	1.379
3000.	1.334	1.345	1.374
3500.	1.321	1.333	1.367
4000.	1.311	1.321	1.360
4500.	1.301	1.308	1.352
5000.	1.291	1.296	1.344
5500.	1.282	1.284	1.336
6000.	1.273	1.272	1.328
6500.	1.264	1.265	1.320
7000.	1.256	1.258	1.312
7500.	1.247	1.252	1.304
8000.	1.240	1.246	1.296
8500.	1.233	1.240	1.288
9000.	1.226	1.234	1.281
9500.	1.218	1.228	1.273
10000.	1.211	1.222	1.266
10500.	1.204	1.216	1.258
11000.	1.197	1.211	1.251
11500.	1.190	1.205	1.243
12000.	1.183	1.199	1.236
12500.	1.176	1.194	1.229
13000.	1.168	1.188	1.221
13500.	1.160	1.182	1.214
14000.	1.152	1.175	1.207
14500.	1.144	1.169	1.199
15000.	1.136	1.162	1.192
15500.	1.127	1.156	1.187
16000.	1.119	1.149	1.182
16500.	1.112	1.142	1.177
17000.	1.105	1.136	1.172
17500.	1.099	1.130	1.168
18000.	1.096	1.124	1.163
18500.	1.093	1.119	1.159
19000.	1.093	1.114	1.154
19500.	1.092	1.110	1.150
20000.	1.092	1.106	1.147
20500.	1.091	1.103	1.143
21000.	1.090	1.100	1.140
21500.	1.089	1.097	1.137
22000.	1.088	1.095	1.134
22500.	1.087	1.092	1.131
23000.	1.086	1.090	1.129
23500.	1.086	1.088	1.126
24000.	1.085	1.086	1.124
24500.	1.085	1.085	1.123
25000.	1.084	1.083	1.121
25500.	1.083	1.082	1.119
26000.	1.083	1.081	1.118
26500.	1.082	1.081	1.116
27000.	1.082	1.080	1.115
27500.	1.081	1.079	1.113
28000.	1.080	1.078	1.112
28500.	1.079	1.078	1.111
29000.	1.079	1.077	1.110
29500.	1.078	1.077	1.108
30000.	1.077	1.076	1.107
30500.	1.076	1.075	1.106
32500.	1.073	1.073	1.101
35000.	1.070	1.070	1.096
37500.	1.066	1.068	1.091
40000.	1.062	1.065	1.093
42500.	1.058	1.062	1.098
45000.	1.055	1.060	1.103
47500.	1.052	1.057	1.110
50000.	1.049	1.054	1.118
52500.	1.047	1.053	1.127
55000.	1.048	1.051	1.137
57500.	1.049	1.050	1.147
60000.	1.049	1.053	1.157
62500.	1.047	1.067	1.168
65000.	1.044	1.082	1.179
67500.	1.061	1.097	1.190
70000.	1.079	1.111	1.200

Table B.3 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.11590	1.09512	1.07124
100.	1.09008	1.07117	1.04986
500.	1.08689	1.06873	1.04819
1000.	1.08703	1.06933	1.04910
1500.	1.08832	1.07088	1.05068
2000.	1.08993	1.07264	1.05234
2500.	1.09162	1.07443	1.05391
3000.	1.09336	1.07618	1.05539
3500.	1.09517	1.07793	1.05679
4000.	1.09708	1.07971	1.05815
4500.	1.09910	1.08154	1.05949
5000.	1.10123	1.08342	1.06082
5500.	1.10345	1.08536	1.06216
6000.	1.10578	1.08737	1.06352
6500.	1.10822	1.08945	1.06490
7000.	1.11078	1.09161	1.06633
7500.	1.11347	1.09384	1.06782
8000.	1.11629	1.09617	1.06938
8500.	1.11926	1.09858	1.07099
9000.	1.12238	1.10108	1.07266
9500.	1.12564	1.10368	1.07437
10000.	1.12908	1.10640	1.07614
10500.	1.13270	1.10924	1.07796
11000.	1.13654	1.11221	1.07983
11500.	1.14062	1.11534	1.08178
12000.	1.14494	1.11860	1.08378
12500.	1.14948	1.12197	1.08583
13000.	1.15420	1.12542	1.08790
13500.	1.15899	1.12889	1.08995
14000.	1.16373	1.13230	1.09193
14500.	1.16827	1.13558	1.09380
15000.	1.17240	1.13863	1.09552
15500.	1.17599	1.14138	1.09707
16000.	1.17883	1.14374	1.09842
16500.	1.18082	1.14561	1.09955
17000.	1.18191	1.14696	1.10044
17500.	1.18209	1.14775	1.10108
18000.	1.18142	1.14794	1.10144
18500.	1.17996	1.14756	1.10151
19000.	1.17782	1.14662	1.10128
19500.	1.17512	1.14515	1.10074
20000.	1.17198	1.14321	1.09990
20500.	1.16851	1.14084	1.09876
21000.	1.16477	1.13811	1.09734
21500.	1.16082	1.13510	1.09565
22000.	1.15671	1.13185	1.09371
22500.	1.15250	1.12842	1.09153
23000.	1.14822	1.12485	1.08914
23500.	1.14377	1.12117	1.08656
24000.	1.13933	1.11741	1.08381
24500.	1.13488	1.11359	1.08093
25000.	1.13044	1.10973	1.07795
25500.	1.12605	1.10580	1.07487
26000.	1.12166	1.10187	1.07172
26500.	1.11726	1.09795	1.06852
27000.	1.11287	1.09402	1.06528
27500.	1.10848	1.09009	1.06201
28000.	1.10410	1.08624	1.05871
28500.	1.09971	1.08238	1.05541
29000.	1.09533	1.07853	1.05210
29500.	1.09094	1.07467	1.04879
30000.	1.08656	1.07082	1.04548
30500.	1.08218	1.06702	1.04219
32500.	1.06464	1.05180	1.02904
35000.	1.04273	1.03303	1.01309
37500.	1.02084	1.01453	0.99756
40000.	0.99901	0.99631	0.98247
42500.	0.97729	0.97841	0.96782
45000.	0.95576	0.96086	0.95364
47500.	0.93452	0.94369	0.93995
50000.	0.91366	0.92697	0.92675
52500.	0.89332	0.91072	0.91408
55000.	0.87362	0.89503	0.90193
57500.	0.85470	0.87994	0.89032
60000.	0.83668	0.86549	0.87926
62500.	0.81970	0.85174	0.86875
65000.	0.80385	0.83873	0.85880
67500.	0.78923	0.82649	0.84940
70000.	0.77589	0.81504	0.84055

Table B.4 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.351	1.346	1.351
100.	1.348	1.344	1.349
500.	1.343	1.342	1.348
1000.	1.338	1.341	1.353
1500.	1.332	1.337	1.354
2000.	1.326	1.332	1.354
2500.	1.320	1.326	1.352
3000.	1.313	1.319	1.349
3500.	1.307	1.311	1.346
4000.	1.300	1.303	1.342
4500.	1.293	1.295	1.337
5000.	1.286	1.286	1.332
5500.	1.279	1.277	1.326
6000.	1.272	1.269	1.320
6500.	1.265	1.264	1.314
7000.	1.257	1.258	1.308
7500.	1.250	1.253	1.301
8000.	1.242	1.247	1.295
8500.	1.236	1.242	1.288
9000.	1.229	1.236	1.281
9500.	1.222	1.230	1.274
10000.	1.215	1.225	1.267
10500.	1.208	1.219	1.260
11000.	1.201	1.213	1.252
11500.	1.193	1.208	1.245
12000.	1.186	1.202	1.238
12500.	1.179	1.196	1.231
13000.	1.171	1.190	1.223
13500.	1.164	1.184	1.216
14000.	1.156	1.178	1.209
14500.	1.147	1.171	1.201
15000.	1.139	1.165	1.194
15500.	1.130	1.158	1.188
16000.	1.122	1.151	1.183
16500.	1.115	1.145	1.179
17000.	1.108	1.138	1.174
17500.	1.101	1.132	1.169
18000.	1.095	1.126	1.165
18500.	1.095	1.121	1.160
19000.	1.095	1.116	1.156
19500.	1.094	1.112	1.152
20000.	1.093	1.108	1.148
20500.	1.092	1.105	1.144
21000.	1.091	1.101	1.141
21500.	1.090	1.099	1.138
22000.	1.090	1.096	1.135
22500.	1.090	1.094	1.132
23000.	1.089	1.092	1.130
23500.	1.089	1.090	1.128
24000.	1.088	1.088	1.126
24500.	1.087	1.086	1.124
25000.	1.087	1.084	1.122
25500.	1.086	1.083	1.120
26000.	1.086	1.083	1.119
26500.	1.085	1.082	1.117
27000.	1.085	1.082	1.116
27500.	1.084	1.081	1.114
28000.	1.083	1.080	1.113
28500.	1.082	1.080	1.112
29000.	1.082	1.079	1.110
29500.	1.081	1.079	1.109
30000.	1.080	1.078	1.108
30500.	1.079	1.077	1.107
32500.	1.077	1.075	1.102
35000.	1.073	1.073	1.097
37500.	1.069	1.070	1.092
40000.	1.065	1.067	1.094
42500.	1.060	1.064	1.098
45000.	1.056	1.061	1.104
47500.	1.052	1.059	1.111
50000.	1.050	1.056	1.119
52500.	1.047	1.053	1.128
55000.	1.049	1.051	1.137
57500.	1.050	1.050	1.147
60000.	1.050	1.053	1.158
62500.	1.048	1.068	1.169
65000.	1.045	1.083	1.179
67500.	1.062	1.097	1.190
70000.	1.080	1.112	1.201

Table B.5 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.08602	1.06960	1.04980
100.	1.06026	1.04556	1.02819
500.	1.05742	1.04349	1.02692
1000.	1.05808	1.04468	1.02849
1500.	1.06006	1.04699	1.03087
2000.	1.06243	1.04961	1.03341
2500.	1.06495	1.05232	1.03592
3000.	1.06761	1.05505	1.03837
3500.	1.07042	1.05785	1.04077
4000.	1.07340	1.06074	1.04317
4500.	1.07656	1.06374	1.04558
5000.	1.07989	1.06684	1.04800
5500.	1.08337	1.07004	1.05045
6000.	1.08700	1.07335	1.05293
6500.	1.09079	1.07676	1.05547
7000.	1.09476	1.08029	1.05808
7500.	1.09893	1.08395	1.06077
8000.	1.10330	1.08774	1.06354
8500.	1.10787	1.09165	1.06640
9000.	1.11264	1.09570	1.06933
9500.	1.11765	1.09991	1.07233
10000.	1.12291	1.10429	1.07543
10500.	1.12849	1.10887	1.07861
11000.	1.13443	1.11367	1.08191
11500.	1.14075	1.11870	1.08531
12000.	1.14742	1.12394	1.08879
12500.	1.15439	1.12935	1.09233
13000.	1.16154	1.13485	1.09587
13500.	1.16861	1.14034	1.09937
14000.	1.17529	1.14565	1.10275
14500.	1.18126	1.15064	1.10596
15000.	1.18628	1.15511	1.10896
15500.	1.19012	1.15892	1.11169
16000.	1.19266	1.16199	1.11409
16500.	1.19394	1.16420	1.11614
17000.	1.19405	1.16552	1.11777
17500.	1.19320	1.16598	1.11898
18000.	1.19156	1.16564	1.11973
18500.	1.18928	1.16457	1.12002
19000.	1.18649	1.16288	1.11985
19500.	1.18329	1.16066	1.11924
20000.	1.17973	1.15801	1.11821
20500.	1.17589	1.15502	1.11679
21000.	1.17182	1.15175	1.11500
21500.	1.16755	1.14827	1.11288
22000.	1.16316	1.14460	1.11047
22500.	1.15858	1.14080	1.10782
23000.	1.15391	1.13688	1.10496
23500.	1.14925	1.13288	1.10194
24000.	1.14458	1.12883	1.09879
24500.	1.13992	1.12463	1.09553
25000.	1.13525	1.12044	1.09218
25500.	1.13059	1.11628	1.08877
26000.	1.12594	1.11212	1.08531
26500.	1.12128	1.10797	1.08181
27000.	1.11663	1.10381	1.07830
27500.	1.11197	1.09965	1.07476
28000.	1.10727	1.09554	1.07122
30000.	1.08848	1.07909	1.05691
32500.	1.06477	1.05862	1.03949
35000.	1.04082	1.03824	1.02239
37500.	1.01666	1.01796	1.00563
40000.	0.99234	0.99780	0.98921
42500.	0.96793	0.97780	0.97315
45000.	0.94355	0.95803	0.95749
47500.	0.91933	0.93854	0.94226
50000.	0.89544	0.91941	0.92749
52500.	0.87209	0.90073	0.91322
55000.	0.84949	0.88261	0.89946
57500.	0.82786	0.86514	0.88626
60000.	0.80743	0.84841	0.87363
62500.	0.78839	0.83253	0.86160
65000.	0.77093	0.81757	0.85017
67500.	0.75516	0.80360	0.83939
70000.	0.74112	0.79067	0.82924

Table B.6 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.420	1.411	1.398
100.	1.419	1.410	1.398
500.	1.414	1.406	1.396
1000.	1.407	1.400	1.394
1500.	1.399	1.392	1.390
2000.	1.391	1.384	1.385
2500.	1.382	1.376	1.379
3000.	1.373	1.368	1.373
3500.	1.363	1.360	1.367
4000.	1.353	1.351	1.360
4500.	1.342	1.342	1.353
5000.	1.332	1.333	1.345
5500.	1.321	1.324	1.338
6000.	1.310	1.315	1.330
6500.	1.299	1.305	1.322
7000.	1.288	1.296	1.314
7500.	1.277	1.286	1.305
8000.	1.265	1.276	1.297
8500.	1.254	1.267	1.289
9000.	1.242	1.257	1.280
9500.	1.231	1.247	1.272
10000.	1.219	1.237	1.263
10500.	1.207	1.227	1.255
11000.	1.195	1.217	1.246
11500.	1.183	1.207	1.238
12000.	1.171	1.196	1.229
12500.	1.159	1.186	1.220
13000.	1.147	1.176	1.212
13500.	1.135	1.166	1.203
14000.	1.124	1.156	1.196
14500.	1.116	1.147	1.189
15000.	1.114	1.138	1.182
15500.	1.111	1.130	1.176
16000.	1.109	1.123	1.170
16500.	1.108	1.116	1.164
17000.	1.106	1.111	1.159
17500.	1.105	1.109	1.153
18000.	1.103	1.107	1.149
18500.	1.101	1.105	1.144
19000.	1.100	1.104	1.140
19500.	1.098	1.102	1.136
20000.	1.096	1.101	1.132
20500.	1.094	1.099	1.128
21000.	1.092	1.098	1.125
21500.	1.090	1.096	1.122
22000.	1.088	1.094	1.119
22500.	1.085	1.093	1.117
23000.	1.084	1.091	1.114
23500.	1.083	1.089	1.112
24000.	1.083	1.087	1.110
24500.	1.082	1.086	1.108
25000.	1.081	1.084	1.106
25500.	1.080	1.082	1.104
26000.	1.079	1.080	1.102
26500.	1.079	1.079	1.100
27000.	1.078	1.077	1.099
27500.	1.077	1.075	1.097
28000.	1.076	1.074	1.096
30000.	1.073	1.070	1.092
32500.	1.069	1.067	1.088
35000.	1.065	1.063	1.084
37500.	1.061	1.060	1.081
40000.	1.057	1.057	1.079
42500.	1.054	1.054	1.076
45000.	1.056	1.051	1.074
47500.	1.060	1.048	1.073
50000.	1.063	1.045	1.072
52500.	1.064	1.043	1.072
55000.	1.064	1.043	1.072
57500.	1.064	1.042	1.072
60000.	1.061	1.041	1.073
62500.	1.057	1.040	1.081
65000.	1.051	1.039	1.090
67500.	1.044	1.043	1.100
70000.	1.049	1.057	1.110

Table B.7 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.07574	1.05913	1.03835
100.	1.04993	1.03503	1.01673
500.	1.04695	1.03289	1.01547
1000.	1.04751	1.03409	1.01711
1500.	1.04941	1.03643	1.01958
2000.	1.05168	1.03906	1.02221
2500.	1.05398	1.04166	1.02474
3000.	1.05628	1.04416	1.02710
3500.	1.05863	1.04662	1.02931
4000.	1.06106	1.04909	1.03146
4500.	1.06359	1.05162	1.03357
5000.	1.06626	1.05422	1.03569
5500.	1.06912	1.05693	1.03783
6000.	1.07221	1.05980	1.04003
6500.	1.07553	1.06285	1.04233
7000.	1.07905	1.06606	1.04473
7500.	1.08276	1.06941	1.04723
8000.	1.08663	1.07287	1.04982
8500.	1.09069	1.07644	1.05247
9000.	1.09495	1.08016	1.05520
9500.	1.09944	1.08404	1.05800
10000.	1.10416	1.08810	1.06090
10500.	1.10913	1.09233	1.06391
11000.	1.11435	1.09674	1.06701
11500.	1.11985	1.10133	1.07021
12000.	1.12566	1.10611	1.07350
12500.	1.13183	1.11111	1.07688
13000.	1.13838	1.11633	1.08035
13500.	1.14522	1.12173	1.08390
14000.	1.15227	1.12721	1.08750
14500.	1.15938	1.13264	1.09105
15000.	1.16628	1.13789	1.09447
15500.	1.17265	1.14286	1.09767
16000.	1.17819	1.14739	1.10061
16500.	1.18258	1.15132	1.10326
17000.	1.18557	1.15448	1.10559
17500.	1.18706	1.15684	1.10756
18000.	1.18708	1.15833	1.10911
18500.	1.18579	1.15888	1.11026
19000.	1.18341	1.15852	1.11101
19500.	1.18024	1.15733	1.11135
20000.	1.17649	1.15538	1.11128
20500.	1.17235	1.15279	1.11078
21000.	1.16797	1.14968	1.10983
21500.	1.16322	1.14618	1.10845
22000.	1.15846	1.14241	1.10666
22500.	1.15371	1.13845	1.10452
23000.	1.14892	1.13437	1.10205
23500.	1.14412	1.13008	1.09931
24000.	1.13933	1.12578	1.09634
24500.	1.13453	1.12149	1.09317
25000.	1.12974	1.11720	1.08986
25500.	1.12492	1.11295	1.08644
26000.	1.12011	1.10871	1.08295
26500.	1.11529	1.10446	1.07941
27000.	1.11048	1.10022	1.07584
27500.	1.10566	1.09597	1.07219
30000.	1.08135	1.07486	1.05412
32500.	1.05678	1.05384	1.03647
35000.	1.03197	1.03291	1.01915
37500.	1.00695	1.01208	1.00218
40000.	0.98179	0.99138	0.98558
42500.	0.95658	0.97087	0.96936
45000.	0.93146	0.95061	0.95357
47500.	0.90662	0.93069	0.93823
50000.	0.88224	0.91118	0.92338
52500.	0.85855	0.89220	0.90905
55000.	0.83581	0.87386	0.89528
57500.	0.81426	0.85626	0.88208
60000.	0.79413	0.83952	0.86949
62500.	0.77561	0.82371	0.85752
65000.	0.75885	0.80894	0.84620
67500.	0.74393	0.79525	0.83554
70000.	0.73084	0.78270	0.82554

Table B.8 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.491	1.471	1.443
100.	1.490	1.470	1.443
500.	1.484	1.465	1.441
1000.	1.476	1.458	1.438
1500.	1.467	1.450	1.433
2000.	1.457	1.442	1.427
2500.	1.447	1.433	1.421
3000.	1.436	1.424	1.414
3500.	1.426	1.415	1.406
4000.	1.415	1.406	1.399
4500.	1.404	1.396	1.390
5000.	1.392	1.387	1.382
5500.	1.381	1.377	1.374
6000.	1.369	1.367	1.365
6500.	1.357	1.357	1.356
7000.	1.345	1.346	1.347
7500.	1.333	1.336	1.338
8000.	1.321	1.325	1.329
8500.	1.308	1.315	1.320
9000.	1.296	1.304	1.311
9500.	1.283	1.293	1.302
10000.	1.271	1.282	1.292
10500.	1.258	1.272	1.283
11000.	1.245	1.261	1.275
11500.	1.233	1.250	1.267
12000.	1.220	1.239	1.259
12500.	1.207	1.228	1.251
13000.	1.194	1.217	1.243
13500.	1.181	1.206	1.235
14000.	1.168	1.195	1.227
14500.	1.155	1.184	1.220
15000.	1.144	1.174	1.212
15500.	1.141	1.163	1.204
16000.	1.139	1.153	1.197
16500.	1.137	1.144	1.190
17000.	1.136	1.137	1.183
17500.	1.135	1.136	1.177
18000.	1.134	1.134	1.171
18500.	1.132	1.133	1.165
19000.	1.130	1.131	1.160
19500.	1.128	1.129	1.154
20000.	1.126	1.127	1.149
20500.	1.123	1.125	1.145
21000.	1.121	1.123	1.140
21500.	1.118	1.121	1.136
22000.	1.115	1.119	1.133
22500.	1.112	1.117	1.129
23000.	1.111	1.114	1.126
23500.	1.110	1.112	1.123
24000.	1.108	1.110	1.122
24500.	1.107	1.108	1.121
25000.	1.106	1.106	1.120
25500.	1.105	1.104	1.118
26000.	1.104	1.102	1.117
26500.	1.103	1.099	1.116
27000.	1.102	1.097	1.115
27500.	1.101	1.095	1.114
30000.	1.096	1.090	1.109
32500.	1.090	1.085	1.104
35000.	1.084	1.081	1.099
37500.	1.078	1.076	1.095
40000.	1.076	1.072	1.091
42500.	1.076	1.068	1.088
45000.	1.078	1.063	1.085
47500.	1.079	1.059	1.083
50000.	1.080	1.055	1.081
52500.	1.078	1.053	1.080
55000.	1.076	1.053	1.080
57500.	1.071	1.053	1.080
60000.	1.065	1.051	1.080
62500.	1.058	1.049	1.089
65000.	1.050	1.045	1.099
67500.	1.051	1.058	1.109
70000.	1.069	1.073	1.120

Table B.9 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.04940	1.03512	1.01633
100.	1.02384	1.01114	0.99473
500.	1.02111	1.00926	0.99376
1000.	1.02202	1.01087	0.99588
1500.	1.02435	1.01369	0.99888
2000.	1.02708	1.01682	1.00206
2500.	1.02984	1.01994	1.00515
3000.	1.03264	1.02297	1.00805
3500.	1.03552	1.02600	1.01083
4000.	1.03851	1.02908	1.01356
4500.	1.04164	1.03221	1.01626
5000.	1.04495	1.03545	1.01898
5500.	1.04849	1.03885	1.02172
6000.	1.05231	1.04243	1.02456
6500.	1.05639	1.04623	1.02750
7000.	1.06073	1.05022	1.03056
7500.	1.06527	1.05438	1.03375
8000.	1.07002	1.05867	1.03703
8500.	1.07500	1.06310	1.04039
9000.	1.08023	1.06770	1.04384
9500.	1.08573	1.07250	1.04739
10000.	1.09153	1.07752	1.05106
10500.	1.09763	1.08275	1.05485
11000.	1.10407	1.08821	1.05877
11500.	1.11090	1.09390	1.06280
12000.	1.11818	1.09986	1.06696
12500.	1.12598	1.10612	1.07124
13000.	1.13432	1.11270	1.07565
13500.	1.14310	1.11954	1.08018
14000.	1.15210	1.12654	1.08478
14500.	1.16092	1.13353	1.08935
15000.	1.16911	1.14031	1.09378
15500.	1.17620	1.14664	1.09800
16000.	1.18175	1.15227	1.10195
16500.	1.18554	1.15697	1.10559
17000.	1.18749	1.16050	1.10881
17500.	1.18776	1.16277	1.11154
18000.	1.18666	1.16382	1.11373
18500.	1.18451	1.16370	1.11535
19000.	1.18156	1.16254	1.11640
19500.	1.17800	1.16049	1.11687
20000.	1.17398	1.15777	1.11672
20500.	1.16963	1.15455	1.11598
21000.	1.16506	1.15095	1.11468
21500.	1.16012	1.14708	1.11288
22000.	1.15519	1.14302	1.11063
22500.	1.15025	1.13883	1.10801
23000.	1.14527	1.13439	1.10508
23500.	1.14029	1.12995	1.10191
24000.	1.13532	1.12552	1.09856
24500.	1.13034	1.12108	1.09507
25000.	1.12536	1.11664	1.09150
25500.	1.12034	1.11224	1.08785
26000.	1.11531	1.10784	1.08417
26500.	1.11029	1.10345	1.08046
27500.	1.10024	1.09465	1.07285
30000.	1.07472	1.07263	1.05418
32500.	1.04879	1.05058	1.03587
35000.	1.02244	1.02850	1.01784
37500.	0.99574	1.00641	1.00009
40000.	0.96875	0.98434	0.98266
42500.	0.94162	0.96236	0.96556
45000.	0.91453	0.94058	0.94886
47500.	0.88772	0.91908	0.93257
50000.	0.86147	0.89800	0.91676
52500.	0.83608	0.87748	0.90147
55000.	0.81188	0.85768	0.88673
57500.	0.78921	0.83875	0.87260
60000.	0.76834	0.82084	0.85911
62500.	0.74950	0.80407	0.84630
65000.	0.73281	0.78856	0.83420
67500.	0.71830	0.77437	0.82285
70000.	0.70591	0.76155	0.81224

Table B.10 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.437	1.424	1.409
100.	1.436	1.423	1.409
500.	1.430	1.418	1.406
1000.	1.422	1.411	1.402
1500.	1.413	1.403	1.397
2000.	1.404	1.395	1.391
2500.	1.394	1.386	1.384
3000.	1.384	1.377	1.377
3500.	1.374	1.368	1.370
4000.	1.363	1.359	1.362
4500.	1.353	1.350	1.353
5000.	1.342	1.341	1.345
5500.	1.331	1.331	1.336
6000.	1.319	1.321	1.328
6500.	1.308	1.311	1.319
7000.	1.296	1.301	1.310
7500.	1.284	1.291	1.301
8000.	1.272	1.280	1.291
8500.	1.260	1.270	1.282
9000.	1.248	1.259	1.273
9500.	1.235	1.249	1.263
10000.	1.223	1.238	1.254
10500.	1.211	1.227	1.246
11000.	1.198	1.217	1.239
11500.	1.186	1.206	1.231
12000.	1.173	1.195	1.223
12500.	1.160	1.184	1.215
13000.	1.147	1.173	1.207
13500.	1.134	1.162	1.199
14000.	1.125	1.151	1.191
14500.	1.117	1.140	1.183
15000.	1.109	1.130	1.175
15500.	1.102	1.119	1.167
16000.	1.097	1.110	1.160
16500.	1.092	1.101	1.153
17000.	1.087	1.092	1.146
17500.	1.088	1.091	1.140
18000.	1.090	1.091	1.134
18500.	1.091	1.091	1.128
19000.	1.091	1.091	1.123
19500.	1.091	1.091	1.118
20000.	1.090	1.091	1.113
20500.	1.088	1.090	1.109
21000.	1.086	1.089	1.105
21500.	1.085	1.087	1.102
22000.	1.083	1.086	1.099
22500.	1.082	1.084	1.096
23000.	1.082	1.082	1.095
23500.	1.082	1.081	1.094
24000.	1.081	1.079	1.094
24500.	1.081	1.078	1.093
25000.	1.081	1.076	1.092
25500.	1.081	1.075	1.091
26000.	1.080	1.074	1.090
26500.	1.080	1.073	1.089
27500.	1.079	1.071	1.088
30000.	1.077	1.069	1.083
32500.	1.075	1.067	1.079
35000.	1.072	1.065	1.076
37500.	1.075	1.063	1.072
40000.	1.079	1.061	1.070
42500.	1.082	1.059	1.068
45000.	1.084	1.057	1.066
47500.	1.084	1.060	1.064
50000.	1.083	1.062	1.063
52500.	1.081	1.063	1.063
55000.	1.076	1.063	1.063
57500.	1.071	1.062	1.063
60000.	1.063	1.059	1.065
62500.	1.055	1.055	1.066
65000.	1.047	1.050	1.073
67500.	1.042	1.044	1.084
70000.	1.059	1.058	1.095

Table B.11 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.04780	1.03458	1.01632
100.	1.02215	1.01050	0.99463
500.	1.01943	1.00868	0.99376
1000.	1.02048	1.01047	0.99610
1500.	1.02299	1.01352	0.99934
2000.	1.02590	1.01690	1.00276
2500.	1.02885	1.02024	1.00607
3000.	1.03187	1.02353	1.00920
3500.	1.03500	1.02684	1.01222
4000.	1.03826	1.03021	1.01518
4500.	1.04169	1.03367	1.01814
5000.	1.04534	1.03725	1.02111
5500.	1.04926	1.04102	1.02413
6000.	1.05348	1.04502	1.02725
6500.	1.05801	1.04925	1.03049
7000.	1.06280	1.05369	1.03387
7500.	1.06783	1.05830	1.03736
8000.	1.07309	1.06306	1.04095
8500.	1.07861	1.06799	1.04463
9000.	1.08443	1.07313	1.04841
9500.	1.09058	1.07849	1.05230
10000.	1.09707	1.08409	1.05633
10500.	1.10393	1.08994	1.06049
11000.	1.11123	1.09605	1.06478
11500.	1.11903	1.10245	1.06921
12000.	1.12742	1.10918	1.07377
12500.	1.13645	1.11628	1.07847
13000.	1.14605	1.12374	1.08331
13500.	1.15588	1.13146	1.08826
14000.	1.16554	1.13926	1.09324
14500.	1.17447	1.14687	1.09813
15000.	1.18197	1.15399	1.10281
15500.	1.18780	1.16035	1.10723
16000.	1.19172	1.16565	1.11133
16500.	1.19375	1.16959	1.11502
17000.	1.19412	1.17213	1.11818
17500.	1.19321	1.17331	1.12078
18000.	1.19133	1.17325	1.12278
18500.	1.18869	1.17210	1.12416
19000.	1.18539	1.17008	1.12490
19500.	1.18155	1.16740	1.12498
20000.	1.17727	1.16420	1.12443
20500.	1.17269	1.16060	1.12326
21000.	1.16791	1.15670	1.12155
21500.	1.16279	1.15259	1.11935
22000.	1.15766	1.14832	1.11674
22500.	1.15254	1.14395	1.11380
23000.	1.14738	1.13937	1.11060
23500.	1.14223	1.13478	1.10721
24000.	1.13707	1.13020	1.10368
24500.	1.13192	1.12561	1.10004
25000.	1.12676	1.12103	1.09634
25500.	1.12155	1.11650	1.09259
26000.	1.11633	1.11197	1.08881
27500.	1.10069	1.09837	1.07720
30000.	1.07414	1.07564	1.05826
32500.	1.04707	1.05282	1.03963
35000.	1.01952	1.02993	1.02127
37500.	0.99154	1.00698	1.00320
40000.	0.96325	0.98402	0.98544
42500.	0.93481	0.96114	0.96802
45000.	0.90646	0.93845	0.95099
47500.	0.87850	0.91608	0.93440
50000.	0.85124	0.89417	0.91830
52500.	0.82507	0.87291	0.90273
55000.	0.80036	0.85247	0.88775
57500.	0.77748	0.83303	0.87339
60000.	0.75672	0.81475	0.85971
62500.	0.73827	0.79778	0.84675
65000.	0.72222	0.78222	0.83454
67500.	0.70852	0.76814	0.82311
70000.	0.69703	0.75556	0.81246

Table B.12 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.420	1.424	1.417
100.	1.418	1.423	1.416
500.	1.411	1.417	1.413
1000.	1.402	1.410	1.409
1500.	1.391	1.401	1.403
2000.	1.380	1.391	1.397
2500.	1.367	1.380	1.389
3000.	1.355	1.369	1.382
3500.	1.342	1.358	1.373
4000.	1.328	1.346	1.365
4500.	1.319	1.334	1.356
5000.	1.312	1.322	1.347
5500.	1.304	1.310	1.338
6000.	1.296	1.297	1.329
6500.	1.289	1.285	1.320
7000.	1.281	1.272	1.310
7500.	1.273	1.259	1.301
8000.	1.264	1.247	1.291
8500.	1.256	1.234	1.281
9000.	1.248	1.221	1.272
9500.	1.239	1.208	1.262
10000.	1.230	1.195	1.252
10500.	1.222	1.184	1.242
11000.	1.213	1.178	1.233
11500.	1.204	1.172	1.223
12000.	1.194	1.166	1.213
12500.	1.185	1.159	1.203
13000.	1.176	1.153	1.194
13500.	1.166	1.147	1.184
14000.	1.157	1.140	1.174
14500.	1.149	1.134	1.165
15000.	1.143	1.127	1.155
15500.	1.136	1.121	1.146
16000.	1.130	1.115	1.137
16500.	1.124	1.109	1.130
17000.	1.118	1.103	1.124
17500.	1.113	1.098	1.119
18000.	1.108	1.094	1.113
18500.	1.104	1.090	1.108
19000.	1.101	1.087	1.103
19500.	1.098	1.086	1.099
20000.	1.095	1.086	1.095
20500.	1.092	1.085	1.095
21000.	1.090	1.084	1.095
21500.	1.088	1.083	1.095
22000.	1.085	1.081	1.095
22500.	1.083	1.080	1.094
23000.	1.082	1.078	1.094
23500.	1.082	1.077	1.093
24000.	1.081	1.075	1.092
24500.	1.081	1.074	1.092
25000.	1.080	1.072	1.091
25500.	1.081	1.072	1.090
26000.	1.082	1.071	1.089
27500.	1.084	1.070	1.087
30000.	1.087	1.069	1.082
32500.	1.090	1.068	1.078
35000.	1.092	1.067	1.075
37500.	1.094	1.065	1.072
40000.	1.095	1.068	1.069
42500.	1.095	1.071	1.067
45000.	1.094	1.073	1.065
47500.	1.092	1.074	1.064
50000.	1.089	1.075	1.063
52500.	1.085	1.074	1.062
55000.	1.079	1.072	1.062
57500.	1.070	1.069	1.063
60000.	1.061	1.065	1.064
62500.	1.053	1.060	1.065
65000.	1.044	1.054	1.071
67500.	1.050	1.047	1.082
70000.	1.060	1.059	1.093

Table B.13 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.05846	1.04806	1.03346
100.	1.03276	1.02384	1.01153
500.	1.03167	1.02357	1.01202
1000.	1.03528	1.02779	1.01640
1500.	1.04055	1.03345	1.02182
2000.	1.04621	1.03941	1.02734
2500.	1.05211	1.04545	1.03274
3000.	1.05833	1.05165	1.03806
3500.	1.06500	1.05811	1.04340
4000.	1.07224	1.06494	1.04887
4500.	1.08008	1.07220	1.05451
5000.	1.08851	1.07985	1.06036
5500.	1.09751	1.08790	1.06640
6000.	1.10716	1.09636	1.07263
6500.	1.11760	1.10532	1.07910
7000.	1.12894	1.11485	1.08583
7500.	1.14123	1.12497	1.09285
8000.	1.15443	1.13568	1.10014
8500.	1.16830	1.14692	1.10769
9000.	1.18222	1.15848	1.11540
9500.	1.19533	1.16992	1.12314
10000.	1.20676	1.18068	1.13072
10500.	1.21599	1.19022	1.13797
11000.	1.22279	1.19810	1.14466
11500.	1.22731	1.20409	1.15058
12000.	1.22991	1.20810	1.15557
12500.	1.23092	1.21032	1.15950
13000.	1.23056	1.21101	1.16233
13500.	1.22905	1.21046	1.16408
14000.	1.22660	1.20891	1.16481
14500.	1.22338	1.20659	1.16459
15000.	1.21956	1.20365	1.16354
15500.	1.21529	1.20023	1.16178
16000.	1.21069	1.19643	1.15945
16500.	1.20589	1.19234	1.15669
17000.	1.20077	1.18804	1.15357
17500.	1.19565	1.18360	1.15020
18000.	1.19047	1.17907	1.14663
18500.	1.18529	1.17435	1.14290
19000.	1.18010	1.16964	1.13906
19500.	1.17492	1.16492	1.13514
20000.	1.16974	1.16020	1.13118
20500.	1.16454	1.15554	1.12718
21000.	1.15934	1.15088	1.12316
22500.	1.14374	1.13691	1.11091
25000.	1.11731	1.11366	1.09098
27500.	1.09038	1.09037	1.07140
30000.	1.06293	1.06700	1.05212
32500.	1.03497	1.04355	1.03313
35000.	1.00653	1.02003	1.01442
37500.	0.97774	0.99649	0.99604
40000.	0.94874	0.97300	0.97801
42500.	0.91976	0.94968	0.96037
45000.	0.89109	0.92667	0.94319
47500.	0.86308	0.90410	0.92650
50000.	0.83610	0.88217	0.91037
52500.	0.81055	0.86108	0.89484
55000.	0.78683	0.84101	0.87998
57500.	0.76525	0.82212	0.86583
60000.	0.74603	0.80459	0.85243
62500.	0.72928	0.78853	0.83982
65000.	0.71497	0.77400	0.82803
67500.	0.70296	0.76103	0.81708
70000.	0.69302	0.74960	0.80697

Table B.14 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.419	1.423	1.416
100.	1.417	1.422	1.416
500.	1.408	1.414	1.411
1000.	1.396	1.404	1.405
1500.	1.383	1.393	1.398
2000.	1.368	1.381	1.389
2500.	1.353	1.368	1.380
3000.	1.342	1.354	1.370
3500.	1.334	1.341	1.360
4000.	1.325	1.326	1.350
4500.	1.316	1.312	1.340
5000.	1.307	1.297	1.329
5500.	1.297	1.282	1.318
6000.	1.287	1.266	1.306
6500.	1.277	1.251	1.295
7000.	1.266	1.235	1.284
7500.	1.255	1.219	1.272
8000.	1.244	1.203	1.260
8500.	1.233	1.194	1.248
9000.	1.221	1.186	1.236
9500.	1.209	1.178	1.224
10000.	1.198	1.169	1.212
10500.	1.187	1.161	1.200
11000.	1.179	1.153	1.188
11500.	1.171	1.145	1.176
12000.	1.165	1.139	1.165
12500.	1.158	1.133	1.155
13000.	1.153	1.128	1.145
13500.	1.148	1.123	1.137
14000.	1.144	1.119	1.129
14500.	1.140	1.118	1.123
15000.	1.137	1.117	1.119
15500.	1.134	1.116	1.119
16000.	1.131	1.115	1.118
16500.	1.128	1.113	1.118
17000.	1.125	1.112	1.117
17500.	1.123	1.110	1.117
18000.	1.121	1.108	1.116
18500.	1.119	1.106	1.115
19000.	1.116	1.105	1.114
19500.	1.114	1.103	1.113
20000.	1.112	1.101	1.112
20500.	1.110	1.099	1.111
21000.	1.107	1.098	1.110
22500.	1.100	1.093	1.107
25000.	1.096	1.088	1.102
27500.	1.095	1.086	1.097
30000.	1.097	1.084	1.092
32500.	1.098	1.082	1.088
35000.	1.098	1.080	1.084
37500.	1.098	1.077	1.081
40000.	1.097	1.075	1.078
42500.	1.095	1.074	1.075
45000.	1.093	1.075	1.073
47500.	1.091	1.075	1.071
50000.	1.086	1.073	1.070
52500.	1.080	1.071	1.069
55000.	1.071	1.067	1.069
57500.	1.061	1.063	1.069
60000.	1.053	1.057	1.070
62500.	1.043	1.051	1.072
65000.	1.048	1.047	1.083
67500.	1.055	1.057	1.093
70000.	1.069	1.070	1.103

Table B.15 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.12859	1.10771	1.08376
100.	1.10257	1.08359	1.06225
500.	1.09915	1.08087	1.06026
1000.	1.09894	1.08108	1.06071
1500.	1.09992	1.08227	1.06189
2000.	1.10125	1.08370	1.06317
2500.	1.10266	1.08517	1.06440
3000.	1.10413	1.08662	1.06554
3500.	1.10565	1.08805	1.06661
4000.	1.10726	1.08950	1.06763
4500.	1.10898	1.09100	1.06863
5000.	1.11080	1.09255	1.06964
5500.	1.11272	1.09417	1.07065
6000.	1.11474	1.09585	1.07168
6500.	1.11687	1.09759	1.07275
7000.	1.11910	1.09940	1.07385
7500.	1.12144	1.10129	1.07501
8000.	1.12391	1.10325	1.07623
8500.	1.12652	1.10531	1.07750
9000.	1.12926	1.10745	1.07884
9500.	1.13214	1.10969	1.08022
10000.	1.13517	1.11203	1.08164
10500.	1.13835	1.11448	1.08312
11000.	1.14172	1.11705	1.08465
11500.	1.14531	1.11974	1.08623
12000.	1.14912	1.12257	1.08788
12500.	1.15317	1.12554	1.08959
13000.	1.15745	1.12863	1.09135
13500.	1.16191	1.13181	1.09315
14000.	1.16649	1.13505	1.09495
14500.	1.17106	1.13829	1.09672
15000.	1.17545	1.14141	1.09842
15500.	1.17944	1.14436	1.10001
16000.	1.18289	1.14704	1.10146
16500.	1.18562	1.14932	1.10275
17000.	1.18751	1.15116	1.10384
17500.	1.18847	1.15247	1.10471
18000.	1.18854	1.15321	1.10534
18500.	1.18774	1.15336	1.10570
19000.	1.18617	1.15293	1.10576
19500.	1.18394	1.15193	1.10553
20000.	1.18118	1.15041	1.10499
20500.	1.17802	1.14841	1.10414
21000.	1.17453	1.14601	1.10300
21500.	1.17079	1.14326	1.10158
22000.	1.16687	1.14024	1.09989
22500.	1.16280	1.13700	1.09795
23000.	1.15863	1.13359	1.09578
23500.	1.15427	1.13004	1.09340
24000.	1.14990	1.12639	1.09083
24500.	1.14553	1.12266	1.08810
25000.	1.14117	1.11888	1.08524
25500.	1.13684	1.11507	1.08228
26000.	1.13250	1.11117	1.07922
26500.	1.12817	1.10727	1.07610
27000.	1.12383	1.10337	1.07292
27500.	1.11950	1.09947	1.06970
28000.	1.11517	1.09564	1.06645
28500.	1.11084	1.09181	1.06318
29000.	1.10651	1.08798	1.05990
29500.	1.10218	1.08415	1.05661
30000.	1.09785	1.08032	1.05331
30500.	1.09351	1.07654	1.05003
31000.	1.08918	1.07276	1.04675
32500.	1.07617	1.06141	1.03687
35000.	1.05446	1.04271	1.02088
37500.	1.03272	1.02424	1.00527
40000.	1.01099	1.00602	0.99008
42500.	0.98931	0.98807	0.97531
45000.	0.96774	0.97042	0.96098
47500.	0.94637	0.95311	0.94710
50000.	0.92531	0.93619	0.93369
52500.	0.90465	0.91971	0.92078
55000.	0.88455	0.90371	0.90838
57500.	0.86512	0.88827	0.89650
60000.	0.84652	0.87344	0.88514
62500.	0.82886	0.85926	0.87433
65000.	0.81227	0.84579	0.86406
67500.	0.79686	0.83305	0.85433
70000.	0.78270	0.82110	0.84515

Table B.16 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.415	1.429	1.437
100.	1.411	1.424	1.432
500.	1.406	1.418	1.428
1000.	1.400	1.412	1.423
1500.	1.393	1.405	1.418
2000.	1.387	1.398	1.413
2500.	1.380	1.391	1.407
3000.	1.373	1.384	1.401
3500.	1.366	1.377	1.395
4000.	1.359	1.371	1.390
4500.	1.352	1.364	1.384
5000.	1.345	1.357	1.378
5500.	1.338	1.350	1.372
6000.	1.330	1.343	1.366
6500.	1.323	1.336	1.360
7000.	1.315	1.328	1.354
7500.	1.308	1.321	1.349
8000.	1.300	1.314	1.342
8500.	1.292	1.307	1.336
9000.	1.285	1.300	1.330
9500.	1.277	1.292	1.324
10000.	1.270	1.285	1.318
10500.	1.262	1.278	1.312
11000.	1.255	1.270	1.306
11500.	1.248	1.263	1.300
12000.	1.240	1.256	1.294
12500.	1.233	1.248	1.289
13000.	1.225	1.242	1.283
13500.	1.218	1.236	1.277
14000.	1.210	1.230	1.270
14500.	1.202	1.224	1.264
15000.	1.193	1.217	1.258
15500.	1.185	1.210	1.252
16000.	1.177	1.203	1.246
16500.	1.169	1.197	1.239
17000.	1.161	1.190	1.233
17500.	1.154	1.184	1.226
18000.	1.148	1.177	1.220
18500.	1.142	1.172	1.214
19000.	1.137	1.166	1.208
19500.	1.133	1.162	1.202
20000.	1.130	1.157	1.197
20500.	1.127	1.153	1.191
21000.	1.124	1.150	1.188
21500.	1.123	1.147	1.184
22000.	1.121	1.144	1.181
22500.	1.120	1.141	1.178
23000.	1.118	1.139	1.175
23500.	1.117	1.136	1.172
24000.	1.115	1.134	1.170
24500.	1.113	1.132	1.167
25000.	1.112	1.130	1.165
25500.	1.110	1.128	1.163
26000.	1.108	1.126	1.161
26500.	1.107	1.124	1.160
27000.	1.105	1.122	1.158
27500.	1.103	1.120	1.156
28000.	1.101	1.118	1.154
28500.	1.100	1.116	1.153
29000.	1.098	1.115	1.151
29500.	1.097	1.113	1.150
30000.	1.095	1.111	1.148
30500.	1.093	1.109	1.147
31000.	1.091	1.107	1.145
32500.	1.086	1.102	1.141
35000.	1.077	1.093	1.134
37500.	1.069	1.084	1.127
40000.	1.060	1.075	1.120
42500.	1.052	1.067	1.114
45000.	1.045	1.061	1.108
47500.	1.042	1.055	1.102
50000.	1.039	1.050	1.109
52500.	1.037	1.046	1.118
55000.	1.038	1.043	1.128
57500.	1.040	1.042	1.138
60000.	1.041	1.042	1.148
62500.	1.041	1.057	1.159
65000.	1.039	1.071	1.170
67500.	1.049	1.086	1.181
70000.	1.068	1.101	1.192

Table B.17 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.05145	1.03399	1.01459
100.	1.02841	1.01280	0.99596
500.	1.02627	1.01144	0.99537
1000.	1.02737	1.01301	0.99726
1500.	1.02957	1.01543	0.99971
2000.	1.03211	1.01809	1.00222
2500.	1.03477	1.02079	1.00467
3000.	1.03749	1.02346	1.00703
3500.	1.04027	1.02612	1.00930
4000.	1.04318	1.02882	1.01151
4500.	1.04622	1.03157	1.01370
5000.	1.04939	1.03439	1.01588
5500.	1.05269	1.03729	1.01806
6000.	1.05612	1.04027	1.02028
6500.	1.05970	1.04333	1.02252
7000.	1.06342	1.04648	1.02481
7500.	1.06730	1.04973	1.02714
8000.	1.07134	1.05309	1.02954
8500.	1.07556	1.05656	1.03199
9000.	1.07996	1.06015	1.03451
9500.	1.08454	1.06387	1.03709
10000.	1.08932	1.06771	1.03973
10500.	1.09430	1.07168	1.04243
11000.	1.09952	1.07579	1.04518
11500.	1.10501	1.08006	1.04800
12000.	1.11078	1.08450	1.05090
12500.	1.11686	1.08912	1.05387
13000.	1.12326	1.09392	1.05692
13500.	1.12996	1.09887	1.06005
14000.	1.13690	1.10396	1.06323
14500.	1.14396	1.10912	1.06644
15000.	1.15099	1.11428	1.06965
15500.	1.15781	1.11935	1.07281
16000.	1.16417	1.12426	1.07589
16500.	1.16984	1.12890	1.07886
17000.	1.17454	1.13316	1.08170
17500.	1.17809	1.13689	1.08437
18000.	1.18037	1.13994	1.08684
18500.	1.18140	1.14223	1.08906
19000.	1.18121	1.14370	1.09097
19500.	1.17994	1.14435	1.09251
20000.	1.17776	1.14420	1.09362
20500.	1.17489	1.14327	1.09428
21000.	1.17151	1.14164	1.09447
21500.	1.16778	1.13943	1.09422
22000.	1.16382	1.13675	1.09352
22500.	1.15972	1.13370	1.09239
23000.	1.15539	1.13039	1.09088
23500.	1.15106	1.12689	1.08900
24000.	1.14672	1.12327	1.08682
24500.	1.14239	1.11956	1.08438
25000.	1.13806	1.11579	1.08172
25500.	1.13376	1.11192	1.07890
26000.	1.12946	1.10805	1.07594
26500.	1.12517	1.10419	1.07289
27000.	1.12087	1.10032	1.06975
27500.	1.11657	1.09645	1.06657
28000.	1.11227	1.09265	1.06335
28500.	1.10797	1.08886	1.06010
29000.	1.10368	1.08506	1.05684
29500.	1.09938	1.08127	1.05357
30000.	1.09508	1.07747	1.05030
30500.	1.09078	1.07372	1.04704
32500.	1.07357	1.05870	1.03397
35000.	1.05203	1.04015	1.01811
37500.	1.03046	1.02184	1.00265
40000.	1.00889	1.00377	0.98759
42500.	0.98738	0.98596	0.97295
45000.	0.96597	0.96846	0.95873
47500.	0.94475	0.95128	0.94497
50000.	0.92382	0.93448	0.93167
52500.	0.90329	0.91811	0.91885
55000.	0.88328	0.90221	0.90652
57500.	0.86393	0.88685	0.89471
60000.	0.84537	0.87208	0.88342
62500.	0.82774	0.85795	0.87266
65000.	0.81116	0.84450	0.86243
67500.	0.79573	0.83178	0.85274
70000.	0.78152	0.81982	0.84358

Table B.18 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.489	1.488	1.487
100.	1.483	1.481	1.481
500.	1.475	1.475	1.476
1000.	1.467	1.467	1.470
1500.	1.457	1.459	1.463
2000.	1.448	1.450	1.457
2500.	1.438	1.441	1.450
3000.	1.427	1.433	1.443
3500.	1.417	1.424	1.436
4000.	1.406	1.415	1.429
4500.	1.395	1.407	1.421
5000.	1.385	1.398	1.414
5500.	1.374	1.390	1.407
6000.	1.362	1.381	1.400
6500.	1.353	1.372	1.393
7000.	1.344	1.363	1.386
7500.	1.335	1.354	1.378
8000.	1.326	1.346	1.371
8500.	1.317	1.337	1.364
9000.	1.308	1.328	1.357
9500.	1.298	1.319	1.349
10000.	1.289	1.310	1.342
10500.	1.280	1.301	1.335
11000.	1.271	1.292	1.328
11500.	1.262	1.283	1.321
12000.	1.253	1.274	1.313
12500.	1.244	1.265	1.306
13000.	1.235	1.256	1.299
13500.	1.226	1.247	1.292
14000.	1.217	1.240	1.285
14500.	1.207	1.232	1.278
15000.	1.197	1.225	1.270
15500.	1.188	1.217	1.263
16000.	1.178	1.209	1.256
16500.	1.169	1.201	1.248
17000.	1.160	1.194	1.241
17500.	1.152	1.186	1.234
18000.	1.146	1.179	1.226
18500.	1.139	1.173	1.219
19000.	1.134	1.167	1.212
19500.	1.130	1.161	1.206
20000.	1.126	1.156	1.199
20500.	1.123	1.152	1.194
21000.	1.120	1.148	1.190
21500.	1.118	1.145	1.186
22000.	1.115	1.142	1.182
22500.	1.113	1.140	1.179
23000.	1.111	1.137	1.176
23500.	1.109	1.135	1.173
24000.	1.107	1.133	1.170
24500.	1.105	1.131	1.168
25000.	1.103	1.129	1.166
25500.	1.101	1.127	1.164
26000.	1.099	1.125	1.162
26500.	1.097	1.124	1.160
27000.	1.095	1.122	1.158
27500.	1.093	1.120	1.157
28000.	1.091	1.118	1.155
28500.	1.089	1.116	1.153
29000.	1.088	1.114	1.152
29500.	1.086	1.112	1.150
30000.	1.084	1.110	1.149
30500.	1.082	1.108	1.147
32500.	1.076	1.101	1.142
35000.	1.069	1.092	1.134
37500.	1.065	1.083	1.127
40000.	1.062	1.074	1.121
42500.	1.058	1.068	1.115
45000.	1.054	1.066	1.109
47500.	1.050	1.063	1.103
50000.	1.047	1.061	1.110
52500.	1.045	1.059	1.119
55000.	1.044	1.056	1.128
57500.	1.043	1.054	1.138
60000.	1.041	1.052	1.149
62500.	1.040	1.057	1.160
65000.	1.038	1.072	1.171
67500.	1.050	1.087	1.182
70000.	1.069	1.102	1.193

Table B.19 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.07051	1.05465	1.03721
100.	1.04750	1.03342	1.01844
500.	1.04697	1.03339	1.01883
1000.	1.05046	1.03692	1.02211
1500.	1.05537	1.04155	1.02612
2000.	1.06083	1.04653	1.03026
2500.	1.06661	1.05167	1.03437
3000.	1.07265	1.05689	1.03841
3500.	1.07895	1.06219	1.04239
4000.	1.08546	1.06756	1.04632
4500.	1.09198	1.07294	1.05018
5000.	1.09817	1.07818	1.05397
5500.	1.10374	1.08309	1.05761
6000.	1.10866	1.08752	1.06103
6500.	1.11301	1.09149	1.06416
7000.	1.11687	1.09506	1.06699
7500.	1.12033	1.09830	1.06956
8000.	1.12353	1.10126	1.07192
8500.	1.12657	1.10402	1.07411
9000.	1.12957	1.10664	1.07615
9500.	1.13258	1.10919	1.07808
10000.	1.13566	1.11172	1.07991
10500.	1.13886	1.11427	1.08168
11000.	1.14221	1.11688	1.08341
11500.	1.14575	1.11957	1.08513
12000.	1.14951	1.12238	1.08685
12500.	1.15350	1.12530	1.08860
13000.	1.15772	1.12835	1.09038
13500.	1.16214	1.13150	1.09219
14000.	1.16671	1.13471	1.09399
14500.	1.17130	1.13794	1.09577
15000.	1.17575	1.14109	1.09749
15500.	1.17982	1.14408	1.09912
16000.	1.18336	1.14681	1.10061
16500.	1.18620	1.14918	1.10196
17000.	1.18818	1.15111	1.10311
17500.	1.18924	1.15252	1.10405
18000.	1.18936	1.15335	1.10475
18500.	1.18858	1.15358	1.10518
19000.	1.18700	1.15321	1.10532
19500.	1.18476	1.15227	1.10516
20000.	1.18198	1.15078	1.10470
20500.	1.17879	1.14881	1.10392
21000.	1.17529	1.14642	1.10283
21500.	1.17153	1.14369	1.10147
22000.	1.16759	1.14067	1.09982
22500.	1.16351	1.13744	1.09792
23000.	1.15935	1.13403	1.09579
23500.	1.15500	1.13048	1.09343
24000.	1.15065	1.12684	1.09089
24500.	1.14629	1.12312	1.08819
25000.	1.14194	1.11935	1.08535
25500.	1.13763	1.11555	1.08240
26000.	1.13331	1.11166	1.07936
26500.	1.12900	1.10777	1.07625
27000.	1.12468	1.10388	1.07309
27500.	1.12037	1.09999	1.06988
28000.	1.11606	1.09618	1.06664
28500.	1.11175	1.09236	1.06338
29000.	1.10744	1.08855	1.06011
29500.	1.10313	1.08473	1.05683
30000.	1.09882	1.08092	1.05355
30500.	1.09450	1.07715	1.05027
31000.	1.09018	1.07338	1.04700
32500.	1.07723	1.06207	1.03715
35000.	1.05561	1.04344	1.02119
37500.	1.03395	1.02503	1.00563
40000.	1.01228	1.00686	0.99047
42500.	0.99065	0.98894	0.97572
45000.	0.96912	0.97132	0.96140
47500.	0.94778	0.95403	0.94753
50000.	0.92671	0.93711	0.93413
52500.	0.90604	0.92062	0.92122
55000.	0.88590	0.90461	0.90880
57500.	0.86641	0.88914	0.89690
60000.	0.84773	0.87426	0.88552
62500.	0.82997	0.86003	0.87467
65000.	0.81327	0.84649	0.86437
67500.	0.79773	0.83368	0.85460
70000.	0.78342	0.82164	0.84537

Table B.20 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.489	1.489	1.468
100.	1.483	1.483	1.463
500.	1.474	1.475	1.457
1000.	1.464	1.466	1.449
1500.	1.453	1.455	1.442
2000.	1.441	1.445	1.433
2500.	1.429	1.434	1.425
3000.	1.417	1.423	1.417
3500.	1.404	1.412	1.408
4000.	1.391	1.401	1.400
4500.	1.379	1.390	1.391
5000.	1.367	1.379	1.383
5500.	1.355	1.369	1.375
6000.	1.345	1.359	1.368
6500.	1.335	1.350	1.360
7000.	1.326	1.341	1.353
7500.	1.317	1.333	1.346
8000.	1.309	1.325	1.340
8500.	1.301	1.318	1.334
9000.	1.293	1.310	1.329
9500.	1.286	1.303	1.324
10000.	1.278	1.296	1.319
10500.	1.270	1.289	1.315
11000.	1.262	1.282	1.310
11500.	1.254	1.275	1.305
12000.	1.246	1.269	1.300
12500.	1.238	1.263	1.295
13000.	1.230	1.258	1.291
13500.	1.224	1.252	1.286
14000.	1.217	1.246	1.281
14500.	1.209	1.240	1.276
15000.	1.202	1.234	1.271
15500.	1.194	1.227	1.266
16000.	1.186	1.221	1.261
16500.	1.178	1.214	1.255
17000.	1.171	1.207	1.250
17500.	1.164	1.200	1.245
18000.	1.158	1.194	1.239
18500.	1.152	1.188	1.234
19000.	1.147	1.182	1.228
19500.	1.142	1.177	1.223
20000.	1.139	1.172	1.218
20500.	1.135	1.168	1.214
21000.	1.132	1.164	1.209
21500.	1.129	1.160	1.205
22000.	1.127	1.157	1.201
22500.	1.124	1.154	1.198
23000.	1.122	1.152	1.194
23500.	1.119	1.149	1.191
24000.	1.117	1.147	1.188
24500.	1.115	1.144	1.186
25000.	1.112	1.142	1.183
25500.	1.110	1.140	1.181
26000.	1.108	1.138	1.178
26500.	1.105	1.135	1.176
27000.	1.103	1.133	1.174
27500.	1.101	1.131	1.172
28000.	1.099	1.129	1.170
28500.	1.097	1.127	1.168
29000.	1.094	1.124	1.166
29500.	1.092	1.122	1.164
30000.	1.090	1.120	1.162
30500.	1.088	1.118	1.160
31000.	1.086	1.116	1.158
32500.	1.081	1.109	1.153
35000.	1.073	1.099	1.144
37500.	1.064	1.088	1.135
40000.	1.056	1.078	1.127
42500.	1.048	1.068	1.120
45000.	1.042	1.058	1.112
47500.	1.039	1.052	1.106
50000.	1.037	1.047	1.108
52500.	1.035	1.043	1.117
55000.	1.035	1.042	1.126
57500.	1.038	1.041	1.136
60000.	1.039	1.041	1.147
62500.	1.039	1.055	1.158
65000.	1.038	1.070	1.169
67500.	1.047	1.085	1.180
70000.	1.066	1.100	1.191

Table B.21 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.13119	1.11029	1.08634
100.	1.10514	1.08614	1.06480
500.	1.10167	1.08338	1.06274
1000.	1.10139	1.08350	1.06311
1500.	1.10231	1.08462	1.06420
2000.	1.10357	1.08599	1.06541
2500.	1.10494	1.08740	1.06657
3000.	1.10634	1.08878	1.06765
3500.	1.10780	1.09015	1.06865
4000.	1.10936	1.09153	1.06960
4500.	1.11101	1.09296	1.07054
5000.	1.11277	1.09445	1.07147
5500.	1.11463	1.09599	1.07242
6000.	1.11659	1.09760	1.07339
6500.	1.11864	1.09928	1.07439
7000.	1.12081	1.10102	1.07543
7500.	1.12308	1.10283	1.07652
8000.	1.12548	1.10473	1.07767
8500.	1.12801	1.10671	1.07888
9000.	1.13068	1.10878	1.08014
9500.	1.13348	1.11094	1.08145
10000.	1.13643	1.11321	1.08281
10500.	1.13953	1.11558	1.08422
11000.	1.14281	1.11806	1.08567
11500.	1.14629	1.12067	1.08719
12000.	1.15001	1.12341	1.08876
12500.	1.15395	1.12629	1.09040
13000.	1.15813	1.12930	1.09209
13500.	1.16250	1.13241	1.09382
14000.	1.16702	1.13559	1.09557
14500.	1.17156	1.13879	1.09730
15000.	1.17596	1.14191	1.09897
15500.	1.18001	1.14487	1.10055
16000.	1.18356	1.14758	1.10201
16500.	1.18642	1.14995	1.10331
17000.	1.18847	1.15188	1.10443
17500.	1.18961	1.15329	1.10534
18000.	1.18984	1.15415	1.10602
18500.	1.18921	1.15442	1.10643
19000.	1.18777	1.15410	1.10656
19500.	1.18566	1.15321	1.10639
20000.	1.18300	1.15179	1.10591
20500.	1.17992	1.14989	1.10513
21000.	1.17650	1.14757	1.10406
21500.	1.17281	1.14489	1.10270
22000.	1.16893	1.14193	1.10108
22500.	1.16489	1.13874	1.09920
23000.	1.16075	1.13537	1.09708
23500.	1.15640	1.13185	1.09475
24000.	1.15206	1.12823	1.09223
24500.	1.14771	1.12453	1.08954
25000.	1.14337	1.12077	1.08672
25500.	1.13905	1.11697	1.08378
26000.	1.13473	1.11314	1.08075
26500.	1.13041	1.10924	1.07765
27000.	1.12609	1.10533	1.07449
27500.	1.12177	1.10143	1.07128
28000.	1.11745	1.09760	1.06804
28500.	1.11313	1.09377	1.06478
29000.	1.10882	1.08995	1.06151
29500.	1.10450	1.08612	1.05822
30000.	1.10018	1.08229	1.05494
30500.	1.09586	1.07851	1.05165
31000.	1.09154	1.07473	1.04838
32500.	1.07857	1.06340	1.03851
35000.	1.05691	1.04473	1.02251
37500.	1.03521	1.02628	1.00689
40000.	1.01350	1.00807	0.99169
42500.	0.99184	0.99011	0.97690
45000.	0.97027	0.97245	0.96254
47500.	0.94889	0.95512	0.94863
50000.	0.92779	0.93816	0.93519
52500.	0.90708	0.92163	0.92223
55000.	0.88690	0.90559	0.90978
57500.	0.86737	0.89008	0.89784
60000.	0.84865	0.87517	0.88643
62500.	0.83086	0.86090	0.87556
65000.	0.81412	0.84733	0.86523
67500.	0.79854	0.83450	0.85543
70000.	0.78420	0.82243	0.84618

Table B.22 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.420	1.428	1.426
100.	1.416	1.424	1.422
500.	1.411	1.420	1.417
1000.	1.406	1.414	1.413
1500.	1.400	1.409	1.408
2000.	1.394	1.403	1.403
2500.	1.388	1.397	1.397
3000.	1.381	1.391	1.392
3500.	1.374	1.384	1.386
4000.	1.368	1.378	1.381
4500.	1.361	1.371	1.375
5000.	1.354	1.364	1.370
5500.	1.346	1.358	1.364
6000.	1.339	1.351	1.359
6500.	1.332	1.344	1.353
7000.	1.325	1.338	1.347
7500.	1.317	1.331	1.341
8000.	1.310	1.324	1.336
8500.	1.302	1.317	1.332
9000.	1.295	1.311	1.327
9500.	1.287	1.304	1.323
10000.	1.280	1.297	1.318
10500.	1.272	1.290	1.314
11000.	1.264	1.283	1.309
11500.	1.256	1.276	1.305
12000.	1.248	1.270	1.300
12500.	1.240	1.264	1.295
13000.	1.232	1.259	1.290
13500.	1.225	1.253	1.286
14000.	1.218	1.247	1.281
14500.	1.211	1.241	1.276
15000.	1.204	1.235	1.271
15500.	1.196	1.228	1.266
16000.	1.188	1.222	1.261
16500.	1.180	1.215	1.255
17000.	1.173	1.208	1.250
17500.	1.166	1.201	1.245
18000.	1.159	1.195	1.239
18500.	1.153	1.189	1.234
19000.	1.148	1.183	1.228
19500.	1.144	1.178	1.223
20000.	1.140	1.173	1.218
20500.	1.137	1.168	1.214
21000.	1.134	1.165	1.209
21500.	1.131	1.161	1.205
22000.	1.128	1.158	1.201
22500.	1.125	1.155	1.198
23000.	1.123	1.152	1.194
23500.	1.121	1.149	1.191
24000.	1.118	1.147	1.188
24500.	1.115	1.144	1.185
25000.	1.113	1.142	1.183
25500.	1.111	1.140	1.180
26000.	1.108	1.137	1.178
26500.	1.106	1.135	1.176
27000.	1.103	1.133	1.174
27500.	1.101	1.131	1.172
28000.	1.099	1.129	1.170
28500.	1.097	1.127	1.167
29000.	1.096	1.124	1.166
29500.	1.094	1.122	1.164
30000.	1.092	1.120	1.162
30500.	1.090	1.118	1.160
31000.	1.088	1.116	1.158
32500.	1.083	1.109	1.152
35000.	1.075	1.099	1.144
37500.	1.066	1.088	1.135
40000.	1.058	1.078	1.127
42500.	1.050	1.068	1.119
45000.	1.043	1.059	1.112
47500.	1.040	1.053	1.105
50000.	1.037	1.048	1.107
52500.	1.035	1.044	1.116
55000.	1.035	1.041	1.126
57500.	1.038	1.040	1.136
60000.	1.039	1.040	1.146
62500.	1.039	1.054	1.157
65000.	1.038	1.069	1.168
67500.	1.046	1.084	1.179
70000.	1.065	1.099	1.190

Table B.23 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.10404	1.08743	1.06742
100.	1.07790	1.06305	1.04554
500.	1.07474	1.06061	1.04383
1000.	1.07492	1.06125	1.04477
1500.	1.07645	1.06305	1.04657
2000.	1.07840	1.06519	1.04857
2500.	1.08052	1.06743	1.05057
3000.	1.08275	1.06969	1.05251
3500.	1.08512	1.07201	1.05442
4000.	1.08764	1.07440	1.05631
4500.	1.09033	1.07688	1.05820
5000.	1.09318	1.07947	1.06012
5500.	1.09619	1.08216	1.06207
6000.	1.09934	1.08495	1.06405
6500.	1.10262	1.08784	1.06608
7000.	1.10606	1.09082	1.06818
7500.	1.10967	1.09392	1.07035
8000.	1.11347	1.09713	1.07259
8500.	1.11746	1.10047	1.07491
9000.	1.12164	1.10394	1.07731
9500.	1.12600	1.10755	1.07978
10000.	1.13058	1.11130	1.08232
10500.	1.13540	1.11521	1.08493
11000.	1.14053	1.11930	1.08763
11500.	1.14599	1.12360	1.09043
12000.	1.15180	1.12811	1.09332
12500.	1.15796	1.13283	1.09631
13000.	1.16444	1.13776	1.09939
13500.	1.17113	1.14283	1.10251
14000.	1.17781	1.14798	1.10565
14500.	1.18419	1.15304	1.10874
15000.	1.18994	1.15787	1.11175
15500.	1.19486	1.16228	1.11460
16000.	1.19873	1.16611	1.11726
16500.	1.20140	1.16925	1.11965
17000.	1.20284	1.17160	1.12173
17500.	1.20315	1.17308	1.12343
18000.	1.20249	1.17370	1.12473
18500.	1.20102	1.17350	1.12560
19000.	1.19890	1.17257	1.12602
19500.	1.19625	1.17101	1.12598
20000.	1.19317	1.16891	1.12549
20500.	1.18973	1.16637	1.12459
21000.	1.18600	1.16349	1.12329
21500.	1.18203	1.16033	1.12162
22000.	1.17787	1.15694	1.11963
22500.	1.17359	1.15337	1.11733
23000.	1.16903	1.14965	1.11479
23500.	1.16447	1.14582	1.11203
24000.	1.15992	1.14191	1.10910
24500.	1.15536	1.13794	1.10603
25000.	1.15080	1.13385	1.10285
25500.	1.14625	1.12975	1.09958
26000.	1.14170	1.12564	1.09623
26500.	1.13716	1.12154	1.09283
27000.	1.13261	1.11743	1.08939
27500.	1.12806	1.11333	1.08593
28000.	1.12347	1.10928	1.08244
28500.	1.11887	1.10523	1.07895
29000.	1.11428	1.10118	1.07544
30000.	1.10509	1.09308	1.06833
32500.	1.08185	1.07288	1.05089
35000.	1.05834	1.05273	1.03383
37500.	1.03456	1.03262	1.01706
40000.	1.01052	1.01258	1.00059
42500.	0.98630	0.99264	0.98445
45000.	0.96198	0.97283	0.96866
47500.	0.93767	0.95323	0.95325
50000.	0.91352	0.93389	0.93825
52500.	0.88972	0.91490	0.92369
55000.	0.86646	0.89636	0.90961
57500.	0.84397	0.87837	0.89604
60000.	0.82249	0.86102	0.88300
62500.	0.80224	0.84442	0.87052
65000.	0.78342	0.82867	0.85862
67500.	0.76620	0.81384	0.84733
70000.	0.75069	0.80001	0.83666

Table B.24 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.458	1.461	1.454
100.	1.456	1.460	1.453
500.	1.449	1.455	1.450
1000.	1.441	1.449	1.447
1500.	1.434	1.441	1.443
2000.	1.425	1.432	1.437
2500.	1.417	1.423	1.431
3000.	1.408	1.414	1.424
3500.	1.399	1.404	1.417
4000.	1.389	1.394	1.409
4500.	1.379	1.383	1.402
5000.	1.369	1.373	1.394
5500.	1.359	1.362	1.386
6000.	1.348	1.353	1.378
6500.	1.338	1.344	1.370
7000.	1.327	1.335	1.361
7500.	1.316	1.325	1.353
8000.	1.305	1.316	1.344
8500.	1.294	1.306	1.335
9000.	1.283	1.297	1.327
9500.	1.272	1.287	1.318
10000.	1.263	1.279	1.309
10500.	1.254	1.271	1.301
11000.	1.245	1.263	1.292
11500.	1.235	1.256	1.283
12000.	1.226	1.248	1.274
12500.	1.217	1.239	1.265
13000.	1.207	1.231	1.258
13500.	1.197	1.223	1.253
14000.	1.188	1.215	1.248
14500.	1.179	1.207	1.242
15000.	1.174	1.199	1.236
15500.	1.171	1.192	1.230
16000.	1.168	1.185	1.224
16500.	1.165	1.178	1.218
17000.	1.163	1.172	1.212
17500.	1.161	1.166	1.206
18000.	1.159	1.161	1.200
18500.	1.157	1.159	1.195
19000.	1.155	1.157	1.189
19500.	1.152	1.155	1.184
20000.	1.150	1.153	1.180
20500.	1.148	1.151	1.175
21000.	1.146	1.149	1.171
21500.	1.143	1.147	1.167
22000.	1.141	1.145	1.164
22500.	1.138	1.143	1.161
23000.	1.135	1.141	1.158
23500.	1.133	1.139	1.156
24000.	1.130	1.136	1.153
24500.	1.128	1.134	1.151
25000.	1.125	1.132	1.149
25500.	1.122	1.130	1.147
26000.	1.120	1.128	1.145
26500.	1.117	1.125	1.143
27000.	1.115	1.123	1.141
27500.	1.112	1.121	1.139
28000.	1.109	1.119	1.137
28500.	1.106	1.117	1.136
29000.	1.104	1.114	1.134
30000.	1.098	1.110	1.131
32500.	1.085	1.100	1.125
35000.	1.072	1.090	1.119
37500.	1.060	1.081	1.113
40000.	1.049	1.072	1.108
42500.	1.039	1.064	1.104
45000.	1.037	1.056	1.100
47500.	1.040	1.050	1.096
50000.	1.044	1.045	1.093
52500.	1.047	1.041	1.090
55000.	1.049	1.038	1.088
57500.	1.050	1.036	1.087
60000.	1.050	1.036	1.086
62500.	1.049	1.037	1.085
65000.	1.045	1.039	1.086
67500.	1.040	1.041	1.093
70000.	1.036	1.045	1.102

Table B.25 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.10643	1.09023	1.07002
100.	1.08012	1.06568	1.04803
500.	1.07700	1.06331	1.04639
1000.	1.07735	1.06413	1.04749
1500.	1.07913	1.06618	1.04952
2000.	1.08134	1.06859	1.05176
2500.	1.08365	1.07104	1.05396
3000.	1.08599	1.07344	1.05603
3500.	1.08839	1.07581	1.05799
4000.	1.09087	1.07819	1.05987
4500.	1.09347	1.08062	1.06173
5000.	1.09621	1.08314	1.06358
5500.	1.09915	1.08577	1.06546
6000.	1.10231	1.08856	1.06741
6500.	1.10569	1.09151	1.06944
7000.	1.10928	1.09462	1.07156
7500.	1.11305	1.09786	1.07379
8000.	1.11700	1.10122	1.07611
8500.	1.12113	1.10470	1.07850
9000.	1.12547	1.10832	1.08098
9500.	1.13004	1.11209	1.08353
10000.	1.13486	1.11605	1.08617
10500.	1.13994	1.12018	1.08890
11000.	1.14533	1.12451	1.09173
11500.	1.15103	1.12903	1.09465
12000.	1.15709	1.13376	1.09767
12500.	1.16352	1.13871	1.10078
13000.	1.17031	1.14387	1.10397
13500.	1.17733	1.14920	1.10722
14000.	1.18433	1.15458	1.11049
14500.	1.19096	1.15986	1.11372
15000.	1.19688	1.16486	1.11684
15500.	1.20190	1.16941	1.11981
16000.	1.20575	1.17331	1.12257
16500.	1.20830	1.17647	1.12504
17000.	1.20954	1.17876	1.12718
17500.	1.20960	1.18014	1.12893
18000.	1.20867	1.18062	1.13026
18500.	1.20694	1.18025	1.13113
19000.	1.20456	1.17914	1.13152
19500.	1.20167	1.17738	1.13144
20000.	1.19835	1.17509	1.13090
20500.	1.19468	1.17238	1.12993
21000.	1.19074	1.16932	1.12855
21500.	1.18657	1.16600	1.12680
22000.	1.18226	1.16245	1.12471
22500.	1.17773	1.15873	1.12232
23000.	1.17309	1.15488	1.11968
23500.	1.16845	1.15093	1.11683
24000.	1.16382	1.14692	1.11382
24500.	1.15918	1.14275	1.11067
25000.	1.15454	1.13857	1.10741
25500.	1.14991	1.13442	1.10406
26000.	1.14528	1.13026	1.10065
26500.	1.14064	1.12611	1.09719
27000.	1.13601	1.12195	1.09370
27500.	1.13138	1.11780	1.09019
28000.	1.12669	1.11369	1.08665
28500.	1.12201	1.10957	1.08312
30000.	1.10795	1.09723	1.07233
32500.	1.08424	1.07669	1.05478
35000.	1.06022	1.05617	1.03756
37500.	1.03589	1.03569	1.02062
40000.	1.01129	1.01526	1.00399
42500.	0.98649	0.99491	0.98768
45000.	0.96158	0.97469	0.97172
47500.	0.93668	0.95466	0.95614
50000.	0.91196	0.93490	0.94097
52500.	0.88760	0.91550	0.92624
55000.	0.86383	0.89655	0.91198
57500.	0.84089	0.87817	0.89824
60000.	0.81902	0.86046	0.88504
62500.	0.79847	0.84354	0.87241
65000.	0.77945	0.82749	0.86036
67500.	0.76212	0.81242	0.84893
70000.	0.74659	0.79838	0.83813

Table B.26 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.498	1.492	1.472
100.	1.496	1.490	1.471
500.	1.490	1.484	1.468
1000.	1.482	1.477	1.465
1500.	1.473	1.469	1.460
2000.	1.464	1.460	1.454
2500.	1.454	1.450	1.447
3000.	1.444	1.440	1.440
3500.	1.434	1.429	1.432
4000.	1.424	1.418	1.424
4500.	1.413	1.407	1.416
5000.	1.402	1.397	1.408
5500.	1.391	1.387	1.399
6000.	1.380	1.378	1.391
6500.	1.368	1.368	1.382
7000.	1.357	1.358	1.373
7500.	1.345	1.348	1.364
8000.	1.333	1.338	1.355
8500.	1.321	1.328	1.346
9000.	1.308	1.317	1.337
9500.	1.296	1.307	1.328
10000.	1.284	1.296	1.318
10500.	1.271	1.286	1.309
11000.	1.260	1.275	1.300
11500.	1.250	1.267	1.291
12000.	1.240	1.258	1.281
12500.	1.230	1.250	1.272
13000.	1.219	1.241	1.262
13500.	1.212	1.233	1.254
14000.	1.207	1.224	1.249
14500.	1.203	1.216	1.243
15000.	1.199	1.207	1.237
15500.	1.195	1.199	1.231
16000.	1.191	1.192	1.225
16500.	1.187	1.187	1.219
17000.	1.184	1.184	1.213
17500.	1.181	1.180	1.206
18000.	1.178	1.177	1.200
18500.	1.175	1.174	1.195
19000.	1.173	1.172	1.189
19500.	1.170	1.169	1.184
20000.	1.167	1.167	1.180
20500.	1.164	1.164	1.176
21000.	1.162	1.162	1.172
21500.	1.159	1.160	1.169
22000.	1.156	1.157	1.166
22500.	1.152	1.155	1.163
23000.	1.149	1.152	1.160
23500.	1.146	1.150	1.157
24000.	1.143	1.147	1.155
24500.	1.140	1.145	1.152
25000.	1.137	1.142	1.151
25500.	1.134	1.140	1.149
26000.	1.131	1.137	1.148
26500.	1.127	1.135	1.146
27000.	1.124	1.132	1.145
27500.	1.121	1.130	1.143
28000.	1.118	1.127	1.142
28500.	1.115	1.125	1.141
30000.	1.105	1.117	1.136
32500.	1.090	1.105	1.129
35000.	1.075	1.094	1.123
37500.	1.061	1.083	1.116
40000.	1.048	1.073	1.110
42500.	1.041	1.063	1.105
45000.	1.042	1.055	1.101
47500.	1.043	1.048	1.097
50000.	1.045	1.042	1.093
52500.	1.048	1.038	1.090
55000.	1.049	1.035	1.088
57500.	1.049	1.033	1.086
60000.	1.048	1.033	1.085
62500.	1.046	1.034	1.085
65000.	1.042	1.037	1.085
67500.	1.036	1.040	1.093
70000.	1.042	1.049	1.103

Table B.27 [] Hot Uncontrolled k_{∞}

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.09567	1.07800	1.05619
100.	1.06939	1.05352	1.03428
500.	1.06581	1.05073	1.03230
1000.	1.06542	1.05093	1.03290
1500.	1.06636	1.05226	1.03435
2000.	1.06772	1.05395	1.03601
2500.	1.06919	1.05569	1.03766
3000.	1.07066	1.05735	1.03921
3500.	1.07215	1.05896	1.04063
4000.	1.07369	1.06056	1.04198
4500.	1.07531	1.06218	1.04328
5000.	1.07702	1.06385	1.04457
5500.	1.07883	1.06557	1.04587
6000.	1.08079	1.06738	1.04719
6500.	1.08293	1.06931	1.04857
7000.	1.08526	1.07138	1.05003
7500.	1.08779	1.07360	1.05158
8000.	1.09049	1.07596	1.05323
8500.	1.09334	1.07844	1.05497
9000.	1.09634	1.08103	1.05678
9500.	1.09948	1.08374	1.05866
10000.	1.10278	1.08656	1.06060
10500.	1.10627	1.08951	1.06261
11000.	1.10994	1.09259	1.06469
11500.	1.11381	1.09582	1.06685
12000.	1.11791	1.09920	1.06908
12500.	1.12224	1.10274	1.07140
13000.	1.12685	1.10644	1.07379
13500.	1.13178	1.11033	1.07627
14000.	1.13707	1.11443	1.07884
14500.	1.14277	1.11875	1.08151
15000.	1.14886	1.12330	1.08427
15500.	1.15521	1.12801	1.08709
16000.	1.16162	1.13281	1.08994
16500.	1.16776	1.13758	1.09277
17000.	1.17338	1.14217	1.09552
17500.	1.17813	1.14641	1.09816
18000.	1.18184	1.15013	1.10063
18500.	1.18429	1.15319	1.10289
19000.	1.18548	1.15550	1.10487
19500.	1.18554	1.15697	1.10655
20000.	1.18467	1.15760	1.10789
20500.	1.18305	1.15743	1.10886
21000.	1.18080	1.15655	1.10943
21500.	1.17805	1.15503	1.10958
22000.	1.17488	1.15298	1.10931
22500.	1.17135	1.15048	1.10864
23000.	1.16751	1.14763	1.10759
23500.	1.16342	1.14449	1.10619
24000.	1.15913	1.14111	1.10444
24500.	1.15453	1.13753	1.10237
25000.	1.14992	1.13379	1.10003
25500.	1.14523	1.12993	1.09744
26000.	1.14054	1.12597	1.09466
26500.	1.13585	1.12181	1.09172
27000.	1.13116	1.11765	1.08865
27500.	1.12647	1.11349	1.08547
28000.	1.12176	1.10936	1.08220
28500.	1.11706	1.10522	1.07887
29000.	1.11235	1.10109	1.07548
29500.	1.10765	1.09695	1.07205
30000.	1.10294	1.09282	1.06860
30500.	1.09818	1.08871	1.06513
32500.	1.07914	1.07225	1.05102
35000.	1.05503	1.05172	1.03381
37500.	1.03064	1.03123	1.01690
40000.	1.00598	1.01079	1.00030
42500.	0.98115	0.99045	0.98404
45000.	0.95622	0.97025	0.96813
47500.	0.93133	0.95025	0.95262
50000.	0.90665	0.93054	0.93752
52500.	0.88238	0.91121	0.92287
55000.	0.85874	0.89236	0.90871
57500.	0.83598	0.87409	0.89506
60000.	0.81434	0.85651	0.88195
62500.	0.79406	0.83974	0.86942
65000.	0.77534	0.82386	0.85748
67500.	0.75835	0.80897	0.84616
70000.	0.74317	0.79514	0.83548

Table B.28 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.509	1.492	1.457
100.	1.508	1.491	1.454
500.	1.502	1.486	1.449
1000.	1.495	1.480	1.444
1500.	1.487	1.473	1.439
2000.	1.479	1.465	1.433
2500.	1.470	1.457	1.427
3000.	1.460	1.449	1.421
3500.	1.451	1.441	1.414
4000.	1.441	1.433	1.408
4500.	1.432	1.424	1.401
5000.	1.422	1.415	1.395
5500.	1.411	1.407	1.388
6000.	1.401	1.398	1.382
6500.	1.390	1.388	1.375
7000.	1.379	1.379	1.368
7500.	1.368	1.370	1.361
8000.	1.357	1.360	1.354
8500.	1.346	1.351	1.347
9000.	1.335	1.341	1.340
9500.	1.323	1.331	1.333
10000.	1.312	1.321	1.326
10500.	1.300	1.312	1.319
11000.	1.288	1.302	1.312
11500.	1.279	1.292	1.305
12000.	1.270	1.284	1.298
12500.	1.260	1.276	1.291
13000.	1.251	1.268	1.284
13500.	1.242	1.260	1.277
14000.	1.232	1.252	1.272
14500.	1.222	1.243	1.267
15000.	1.212	1.235	1.261
15500.	1.206	1.227	1.256
16000.	1.202	1.219	1.251
16500.	1.198	1.210	1.246
17000.	1.194	1.202	1.240
17500.	1.190	1.194	1.234
18000.	1.186	1.188	1.228
18500.	1.182	1.184	1.222
19000.	1.179	1.181	1.216
19500.	1.176	1.177	1.209
20000.	1.173	1.174	1.203
20500.	1.170	1.171	1.197
21000.	1.168	1.169	1.191
21500.	1.165	1.166	1.186
22000.	1.163	1.164	1.181
22500.	1.160	1.161	1.176
23000.	1.157	1.159	1.171
23500.	1.154	1.157	1.167
24000.	1.151	1.154	1.163
24500.	1.148	1.152	1.160
25000.	1.145	1.149	1.157
25500.	1.142	1.147	1.156
26000.	1.139	1.144	1.154
26500.	1.135	1.142	1.153
27000.	1.132	1.139	1.152
27500.	1.129	1.137	1.150
28000.	1.126	1.134	1.149
28500.	1.123	1.132	1.147
29000.	1.119	1.129	1.146
29500.	1.116	1.127	1.145
30000.	1.113	1.124	1.143
30500.	1.110	1.122	1.142
32500.	1.097	1.112	1.136
35000.	1.082	1.100	1.129
37500.	1.068	1.089	1.122
40000.	1.054	1.079	1.116
42500.	1.053	1.069	1.111
45000.	1.054	1.060	1.106
47500.	1.055	1.053	1.102
50000.	1.057	1.047	1.098
52500.	1.059	1.043	1.095
55000.	1.059	1.040	1.092
57500.	1.058	1.038	1.091
60000.	1.056	1.038	1.089
62500.	1.053	1.039	1.089
65000.	1.048	1.041	1.089
67500.	1.041	1.044	1.093
70000.	1.047	1.052	1.103

Table B.29 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.07162	1.05626	1.03645
100.	1.04548	1.03179	1.01444
500.	1.04210	1.02922	1.01270
1000.	1.04200	1.02973	1.01367
1500.	1.04328	1.03146	1.01554
2000.	1.04502	1.03356	1.01765
2500.	1.04688	1.03574	1.01977
3000.	1.04877	1.03785	1.02178
3500.	1.05070	1.03993	1.02367
4000.	1.05272	1.04202	1.02549
4500.	1.05483	1.04416	1.02728
5000.	1.05706	1.04635	1.02906
5500.	1.05944	1.04862	1.03085
6000.	1.06199	1.05101	1.03268
6500.	1.06475	1.05354	1.03458
7000.	1.06774	1.05624	1.03656
7500.	1.07096	1.05911	1.03865
8000.	1.07438	1.06215	1.04085
8500.	1.07799	1.06533	1.04316
9000.	1.08177	1.06864	1.04556
9500.	1.08573	1.07208	1.04803
10000.	1.08989	1.07565	1.05057
10500.	1.09428	1.07939	1.05319
11000.	1.09891	1.08329	1.05590
11500.	1.10382	1.08738	1.05870
12000.	1.10902	1.09166	1.06160
12500.	1.11457	1.09615	1.06460
13000.	1.12051	1.10085	1.06771
13500.	1.12690	1.10582	1.07092
14000.	1.13379	1.11107	1.07425
14500.	1.14109	1.11664	1.07771
15000.	1.14863	1.12250	1.08129
15500.	1.15614	1.12857	1.08498
16000.	1.16327	1.13464	1.08873
16500.	1.16966	1.14057	1.09248
17000.	1.17505	1.14611	1.09617
17500.	1.17922	1.15101	1.09974
18000.	1.18215	1.15506	1.10311
18500.	1.18390	1.15816	1.10617
19000.	1.18463	1.16025	1.10886
19500.	1.18447	1.16134	1.11112
20000.	1.18355	1.16150	1.11290
20500.	1.18195	1.16089	1.11414
21000.	1.17975	1.15964	1.11482
21500.	1.17703	1.15785	1.11496
22000.	1.17387	1.15559	1.11458
22500.	1.17031	1.15296	1.11373
23000.	1.16641	1.14999	1.11244
23500.	1.16222	1.14674	1.11075
24000.	1.15781	1.14326	1.10871
24500.	1.15305	1.13956	1.10637
25000.	1.14830	1.13570	1.10377
25500.	1.14344	1.13170	1.10097
26000.	1.13858	1.12760	1.09799
26500.	1.13373	1.12329	1.09488
27000.	1.12887	1.11897	1.09164
27500.	1.12401	1.11466	1.08831
28000.	1.11911	1.11037	1.08490
28500.	1.11422	1.10609	1.08143
29000.	1.10932	1.10180	1.07791
29500.	1.10443	1.09752	1.07435
30000.	1.09953	1.09323	1.07077
32500.	1.07462	1.07183	1.05253
35000.	1.04926	1.05034	1.03471
37500.	1.02343	1.02878	1.01712
40000.	0.99719	1.00715	0.99978
42500.	0.97061	0.98550	0.98271
45000.	0.94382	0.96388	0.96594
47500.	0.91699	0.94238	0.94953
50000.	0.89033	0.92111	0.93349
52500.	0.86413	0.90019	0.91787
55000.	0.83867	0.87974	0.90272
57500.	0.81428	0.85993	0.88807
60000.	0.79131	0.84091	0.87399
62500.	0.77004	0.82283	0.86050
65000.	0.75072	0.80582	0.84764
67500.	0.73352	0.79000	0.83547
70000.	0.71849	0.77547	0.82399

Table B.30 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.450	1.439	1.421
100.	1.448	1.438	1.417
500.	1.443	1.433	1.413
1000.	1.436	1.428	1.408
1500.	1.429	1.421	1.402
2000.	1.421	1.413	1.396
2500.	1.412	1.406	1.390
3000.	1.403	1.398	1.384
3500.	1.394	1.390	1.377
4000.	1.385	1.382	1.371
4500.	1.376	1.373	1.364
5000.	1.366	1.365	1.358
5500.	1.356	1.356	1.351
6000.	1.347	1.348	1.344
6500.	1.336	1.339	1.338
7000.	1.326	1.330	1.331
7500.	1.315	1.321	1.324
8000.	1.304	1.312	1.317
8500.	1.294	1.302	1.310
9000.	1.283	1.293	1.303
9500.	1.272	1.283	1.296
10000.	1.260	1.274	1.289
10500.	1.249	1.264	1.282
11000.	1.240	1.256	1.276
11500.	1.231	1.248	1.269
12000.	1.222	1.241	1.262
12500.	1.213	1.233	1.255
13000.	1.204	1.225	1.249
13500.	1.194	1.217	1.244
14000.	1.186	1.209	1.239
14500.	1.178	1.201	1.234
15000.	1.171	1.192	1.229
15500.	1.163	1.184	1.224
16000.	1.156	1.176	1.218
16500.	1.149	1.168	1.213
17000.	1.144	1.160	1.207
17500.	1.138	1.153	1.201
18000.	1.135	1.146	1.195
18500.	1.134	1.140	1.189
19000.	1.133	1.135	1.183
19500.	1.133	1.134	1.176
20000.	1.131	1.132	1.170
20500.	1.130	1.131	1.164
21000.	1.129	1.130	1.159
21500.	1.127	1.128	1.154
22000.	1.126	1.127	1.149
22500.	1.124	1.125	1.145
23000.	1.122	1.123	1.141
23500.	1.120	1.122	1.137
24000.	1.118	1.120	1.134
24500.	1.115	1.118	1.131
25000.	1.113	1.116	1.129
25500.	1.111	1.114	1.126
26000.	1.108	1.112	1.125
26500.	1.106	1.110	1.124
27000.	1.103	1.108	1.123
27500.	1.101	1.106	1.122
28000.	1.099	1.104	1.120
28500.	1.096	1.102	1.119
29000.	1.094	1.101	1.118
29500.	1.091	1.099	1.117
30000.	1.089	1.097	1.116
32500.	1.077	1.087	1.110
35000.	1.065	1.078	1.104
37500.	1.055	1.069	1.098
40000.	1.050	1.061	1.094
42500.	1.055	1.056	1.089
45000.	1.059	1.052	1.085
47500.	1.062	1.049	1.082
50000.	1.064	1.047	1.079
52500.	1.065	1.045	1.077
55000.	1.065	1.044	1.075
57500.	1.062	1.046	1.073
60000.	1.059	1.046	1.073
62500.	1.053	1.045	1.072
65000.	1.047	1.043	1.073
67500.	1.040	1.043	1.074
70000.	1.039	1.044	1.076

Table B.31 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.05825	1.04384	1.02436
100.	1.03225	1.01943	1.00243
500.	1.02904	1.01710	1.00103
1000.	1.02932	1.01811	1.00258
1500.	1.03103	1.02035	1.00503
2000.	1.03317	1.02296	1.00771
2500.	1.03541	1.02560	1.01034
3000.	1.03768	1.02818	1.01283
3500.	1.04004	1.03075	1.01519
4000.	1.04251	1.03336	1.01750
4500.	1.04510	1.03603	1.01979
5000.	1.04785	1.03878	1.02208
5500.	1.05079	1.04165	1.02439
6000.	1.05396	1.04469	1.02675
6500.	1.05741	1.04791	1.02920
7000.	1.06112	1.05135	1.03177
7500.	1.06508	1.05498	1.03447
8000.	1.06928	1.05878	1.03728
8500.	1.07367	1.06272	1.04019
9000.	1.07829	1.06681	1.04320
9500.	1.08315	1.07106	1.04628
10000.	1.08828	1.07550	1.04946
10500.	1.09371	1.08014	1.05274
11000.	1.09947	1.08500	1.05613
11500.	1.10563	1.09010	1.05963
12000.	1.11223	1.09545	1.06324
12500.	1.11935	1.10109	1.06698
13000.	1.12702	1.10706	1.07085
13500.	1.13523	1.11341	1.07486
14000.	1.14373	1.12012	1.07901
14500.	1.15215	1.12712	1.08329
15000.	1.16018	1.13420	1.08765
15500.	1.16731	1.14108	1.09203
16000.	1.17326	1.14755	1.09636
16500.	1.17785	1.15327	1.10055
17000.	1.18115	1.15799	1.10452
17500.	1.18324	1.16157	1.10815
18000.	1.18427	1.16398	1.11137
18500.	1.18441	1.16525	1.11412
19000.	1.18380	1.16552	1.11632
19500.	1.18249	1.16498	1.11790
20000.	1.18052	1.16380	1.11886
20500.	1.17797	1.16206	1.11920
21000.	1.17491	1.15984	1.11896
21500.	1.17141	1.15720	1.11820
22000.	1.16751	1.15420	1.11695
22500.	1.16327	1.15090	1.11526
23000.	1.15874	1.14734	1.11319
23500.	1.15372	1.14354	1.11079
24000.	1.14869	1.13954	1.10813
24500.	1.14367	1.13539	1.10525
25000.	1.13865	1.13112	1.10219
25500.	1.13354	1.12661	1.09899
26000.	1.12844	1.12211	1.09566
26500.	1.12333	1.11760	1.09222
27000.	1.11823	1.11310	1.08871
27500.	1.11312	1.10859	1.08512
28000.	1.10792	1.10412	1.08149
28500.	1.10272	1.09966	1.07783
30000.	1.08713	1.08626	1.06650
32500.	1.06062	1.06381	1.04799
35000.	1.03359	1.04125	1.02976
37500.	1.00606	1.01858	1.01178
40000.	0.97812	0.99585	0.99408
42500.	0.94990	0.97313	0.97667
45000.	0.92160	0.95050	0.95961
47500.	0.89346	0.92807	0.94294
50000.	0.86581	0.90599	0.92671
52500.	0.83898	0.88441	0.91096
55000.	0.81336	0.86352	0.89574
57500.	0.78934	0.84349	0.88109
60000.	0.76725	0.82450	0.86707
62500.	0.74736	0.80671	0.85372
65000.	0.72983	0.79025	0.84108
67500.	0.71470	0.77522	0.82919
70000.	0.70188	0.76168	0.81807

Table B.32 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
-----	-----	-----	-----
0.	1.446	1.386	1.370
100.	1.444	1.386	1.370
500.	1.440	1.381	1.368
1000.	1.435	1.375	1.366
1500.	1.430	1.369	1.363
2000.	1.424	1.361	1.358
2500.	1.418	1.353	1.352
3000.	1.411	1.346	1.346
3500.	1.405	1.338	1.340
4000.	1.398	1.329	1.333
4500.	1.391	1.321	1.326
5000.	1.384	1.313	1.319
5500.	1.377	1.308	1.311
6000.	1.370	1.302	1.304
6500.	1.363	1.297	1.296
7000.	1.355	1.292	1.288
7500.	1.348	1.286	1.280
8000.	1.340	1.281	1.272
8500.	1.332	1.275	1.264
9000.	1.324	1.269	1.257
9500.	1.316	1.264	1.250
10000.	1.307	1.258	1.243
10500.	1.299	1.252	1.237
11000.	1.291	1.246	1.230
11500.	1.282	1.240	1.223
12000.	1.273	1.234	1.216
12500.	1.265	1.228	1.209
13000.	1.256	1.222	1.203
13500.	1.247	1.216	1.196
14000.	1.237	1.210	1.189
14500.	1.228	1.203	1.182
15000.	1.220	1.197	1.175
15500.	1.213	1.190	1.168
16000.	1.206	1.183	1.160
16500.	1.199	1.176	1.156
17000.	1.192	1.170	1.152
17500.	1.185	1.163	1.149
18000.	1.179	1.157	1.145
18500.	1.173	1.152	1.141
19000.	1.168	1.148	1.137
19500.	1.163	1.145	1.133
20000.	1.158	1.141	1.129
20500.	1.154	1.138	1.126
21000.	1.150	1.135	1.123
21500.	1.146	1.133	1.121
22000.	1.143	1.130	1.119
22500.	1.140	1.128	1.117
23000.	1.137	1.126	1.115
23500.	1.135	1.124	1.113
24000.	1.132	1.122	1.112
24500.	1.129	1.121	1.111
25000.	1.127	1.119	1.110
25500.	1.125	1.118	1.109
26000.	1.122	1.117	1.108
26500.	1.120	1.115	1.108
27000.	1.117	1.114	1.107
27500.	1.115	1.113	1.107
28000.	1.113	1.112	1.106
28500.	1.110	1.110	1.106
30000.	1.103	1.106	1.104
32500.	1.091	1.100	1.102
35000.	1.080	1.093	1.100
37500.	1.078	1.087	1.097
40000.	1.081	1.081	1.095
42500.	1.084	1.075	1.092
45000.	1.086	1.069	1.089
47500.	1.087	1.065	1.087
50000.	1.086	1.065	1.084
52500.	1.084	1.065	1.082
55000.	1.080	1.065	1.080
57500.	1.074	1.063	1.078
60000.	1.066	1.061	1.076
62500.	1.058	1.057	1.074
65000.	1.049	1.052	1.073
67500.	1.051	1.054	1.073
70000.	1.057	1.056	1.083

Table B.33 [] Hot Uncontrolled k_∞

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.08014	1.06928	1.05428
100.	1.05403	1.04472	1.03208
500.	1.05258	1.04401	1.03204
1000.	1.05559	1.04751	1.03559
1500.	1.06028	1.05251	1.04024
2000.	1.06544	1.05785	1.04507
2500.	1.07078	1.06328	1.04981
3000.	1.07639	1.06881	1.05446
3500.	1.08234	1.07451	1.05909
4000.	1.08874	1.08050	1.06378
4500.	1.09565	1.08683	1.06860
5000.	1.10306	1.09351	1.07358
5500.	1.11096	1.10052	1.07873
6000.	1.11936	1.10784	1.08403
6500.	1.12832	1.11552	1.08950
7000.	1.13795	1.12361	1.09516
7500.	1.14835	1.13218	1.10103
8000.	1.15952	1.14122	1.10714
8500.	1.17141	1.15074	1.11348
9000.	1.18377	1.16069	1.12003
9500.	1.19611	1.17091	1.12673
10000.	1.20777	1.18108	1.13348
10500.	1.21808	1.19073	1.14015
11000.	1.22659	1.19940	1.14658
11500.	1.23309	1.20675	1.15258
12000.	1.23766	1.21254	1.15799
12500.	1.24051	1.21666	1.16264
13000.	1.24188	1.21916	1.16643
13500.	1.24194	1.22022	1.16928
14000.	1.24089	1.22008	1.17118
14500.	1.23890	1.21894	1.17215
15000.	1.23616	1.21702	1.17226
15500.	1.23280	1.21448	1.17158
16000.	1.22896	1.21143	1.17020
16500.	1.22475	1.20799	1.16825
17000.	1.22029	1.20423	1.16583
17500.	1.21566	1.20023	1.16304
18000.	1.21069	1.19607	1.15996
18500.	1.20573	1.19179	1.15665
19000.	1.20076	1.18742	1.15316
19500.	1.19580	1.18288	1.14955
20000.	1.19083	1.17834	1.14583
20500.	1.18587	1.17382	1.14204
21000.	1.18091	1.16930	1.13820
21500.	1.17595	1.16477	1.13433
22000.	1.17099	1.16025	1.13043
22500.	1.16603	1.15573	1.12648
25000.	1.14081	1.13331	1.10686
27500.	1.11510	1.11083	1.08769
30000.	1.08888	1.08826	1.06878
32500.	1.06211	1.06557	1.05012
35000.	1.03480	1.04277	1.03169
37500.	1.00700	1.01986	1.01351
40000.	0.97879	0.99689	0.99561
42500.	0.95032	0.97393	0.97802
45000.	0.92178	0.95108	0.96079
47500.	0.89346	0.92847	0.94396
50000.	0.86568	0.90622	0.92759
52500.	0.83879	0.88453	0.91172
55000.	0.81318	0.86357	0.89640
57500.	0.78925	0.84352	0.88169
60000.	0.76734	0.82457	0.86763
62500.	0.74767	0.80686	0.85426
65000.	0.73042	0.79054	0.84164
67500.	0.71558	0.77568	0.82979
70000.	0.70305	0.76234	0.81872

Table B.34 [] Hot Uncontrolled LPF

Exposure Mwd/MTU	0.00 Void History	0.40 Void History	0.80 Void History
0.	1.435	1.369	1.352
100.	1.433	1.369	1.348
500.	1.428	1.362	1.345
1000.	1.422	1.355	1.341
1500.	1.414	1.345	1.336
2000.	1.406	1.336	1.329
2500.	1.398	1.326	1.322
3000.	1.390	1.316	1.314
3500.	1.381	1.308	1.306
4000.	1.372	1.302	1.298
4500.	1.363	1.295	1.289
5000.	1.354	1.288	1.280
5500.	1.344	1.281	1.271
6000.	1.334	1.274	1.262
6500.	1.324	1.267	1.254
7000.	1.314	1.259	1.246
7500.	1.304	1.252	1.237
8000.	1.293	1.244	1.229
8500.	1.282	1.236	1.221
9000.	1.270	1.228	1.213
9500.	1.259	1.220	1.204
10000.	1.248	1.212	1.196
10500.	1.237	1.204	1.187
11000.	1.227	1.196	1.178
11500.	1.219	1.188	1.169
12000.	1.212	1.181	1.160
12500.	1.205	1.174	1.152
13000.	1.199	1.168	1.144
13500.	1.193	1.163	1.137
14000.	1.188	1.159	1.133
14500.	1.184	1.155	1.130
15000.	1.180	1.151	1.127
15500.	1.176	1.148	1.124
16000.	1.173	1.146	1.122
16500.	1.170	1.144	1.120
17000.	1.167	1.142	1.118
17500.	1.165	1.140	1.117
18000.	1.162	1.138	1.116
18500.	1.160	1.137	1.115
19000.	1.157	1.135	1.114
19500.	1.155	1.133	1.114
20000.	1.152	1.132	1.113
20500.	1.150	1.131	1.113
21000.	1.147	1.129	1.112
21500.	1.145	1.128	1.112
22000.	1.142	1.126	1.111
22500.	1.140	1.125	1.111
25000.	1.128	1.118	1.109
27500.	1.115	1.111	1.107
30000.	1.103	1.105	1.105
32500.	1.091	1.098	1.103
35000.	1.079	1.091	1.100
37500.	1.068	1.085	1.097
40000.	1.066	1.079	1.095
42500.	1.068	1.073	1.092
45000.	1.070	1.067	1.089
47500.	1.071	1.062	1.087
50000.	1.070	1.058	1.084
52500.	1.068	1.055	1.081
55000.	1.064	1.052	1.078
57500.	1.058	1.051	1.076
60000.	1.052	1.049	1.074
62500.	1.044	1.049	1.072
65000.	1.042	1.050	1.070
67500.	1.048	1.051	1.074
70000.	1.054	1.053	1.084

Appendix C Enriched Lattice Isotopic Data Tables

The results in this appendix are based on hot operating and equilibrium xenon conditions.

**Table C.1 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.347	45.869	0.000	953.784	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.347	45.749	0.023	953.730	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.345	45.271	0.115	953.511	0.002	0.000	0.195	0.001	0.000	0.000
1000.0	0.343	44.680	0.227	953.238	0.004	0.000	0.422	0.006	0.000	0.000
1500.0	0.341	44.099	0.338	952.966	0.006	0.000	0.638	0.015	0.001	0.000
2000.0	0.339	43.525	0.447	952.694	0.008	0.000	0.844	0.026	0.002	0.000
2500.0	0.337	42.958	0.554	952.423	0.011	0.000	1.041	0.039	0.004	0.000
3000.0	0.335	42.399	0.660	952.152	0.014	0.000	1.228	0.055	0.007	0.000
3500.0	0.333	41.846	0.764	951.882	0.017	0.001	1.407	0.073	0.011	0.000
4000.0	0.331	41.300	0.866	951.613	0.020	0.001	1.577	0.092	0.016	0.000
4500.0	0.330	40.761	0.967	951.345	0.023	0.001	1.739	0.113	0.022	0.001
5000.0	0.328	40.227	1.067	951.077	0.027	0.001	1.893	0.135	0.029	0.001
5500.0	0.326	39.699	1.165	950.809	0.030	0.001	2.040	0.158	0.036	0.001
6000.0	0.324	39.176	1.261	950.543	0.034	0.002	2.181	0.182	0.045	0.002
6500.0	0.322	38.659	1.357	950.276	0.038	0.002	2.315	0.207	0.054	0.002
7000.0	0.320	38.147	1.451	950.010	0.042	0.002	2.443	0.233	0.064	0.003
7500.0	0.319	37.640	1.543	949.743	0.046	0.003	2.565	0.259	0.075	0.004
8000.0	0.317	37.139	1.635	949.477	0.051	0.003	2.682	0.286	0.087	0.005
8500.0	0.315	36.642	1.725	949.212	0.055	0.004	2.794	0.314	0.099	0.006
9000.0	0.313	36.149	1.815	948.945	0.060	0.004	2.900	0.342	0.112	0.007
9500.0	0.311	35.662	1.903	948.680	0.064	0.005	3.002	0.371	0.126	0.008
10000.0	0.310	35.179	1.990	948.414	0.069	0.006	3.099	0.400	0.140	0.010
10500.0	0.308	34.700	2.076	948.148	0.074	0.006	3.191	0.430	0.155	0.011
11000.0	0.306	34.225	2.161	947.882	0.079	0.007	3.279	0.460	0.170	0.013
11500.0	0.304	33.755	2.244	947.616	0.084	0.008	3.362	0.490	0.186	0.015
12000.0	0.303	33.289	2.327	947.351	0.090	0.009	3.442	0.520	0.202	0.017
12500.0	0.301	32.827	2.409	947.085	0.095	0.009	3.518	0.551	0.218	0.019
13000.0	0.299	32.368	2.489	946.820	0.100	0.010	3.589	0.582	0.234	0.022
13500.0	0.298	31.914	2.569	946.555	0.106	0.011	3.657	0.613	0.251	0.024
14000.0	0.296	31.463	2.648	946.290	0.111	0.012	3.721	0.644	0.268	0.027
14500.0	0.294	31.016	2.726	946.026	0.117	0.013	3.782	0.676	0.285	0.030
15000.0	0.293	30.573	2.803	945.761	0.123	0.014	3.840	0.707	0.303	0.033
15500.0	0.291	30.132	2.879	945.497	0.128	0.015	3.894	0.739	0.320	0.037
16000.0	0.289	29.696	2.954	945.232	0.134	0.017	3.946	0.771	0.338	0.040
16500.0	0.288	29.262	3.028	944.967	0.140	0.018	3.994	0.802	0.355	0.044
17000.0	0.286	28.833	3.101	944.702	0.146	0.019	4.040	0.834	0.373	0.048
17500.0	0.284	28.406	3.174	944.437	0.152	0.021	4.084	0.866	0.391	0.052
18000.0	0.283	27.983	3.245	944.170	0.158	0.022	4.125	0.898	0.408	0.056
18500.0	0.281	27.563	3.316	943.903	0.164	0.024	4.164	0.929	0.426	0.061
19000.0	0.279	27.147	3.386	943.636	0.171	0.025	4.201	0.961	0.444	0.065
19500.0	0.278	26.734	3.456	943.367	0.177	0.027	4.236	0.992	0.462	0.070
20000.0	0.276	26.324	3.524	943.097	0.183	0.028	4.269	1.024	0.480	0.075
20500.0	0.275	25.918	3.592	942.826	0.189	0.030	4.301	1.055	0.498	0.081
21000.0	0.273	25.515	3.658	942.554	0.196	0.032	4.331	1.086	0.516	0.086
21500.0	0.271	25.116	3.724	942.281	0.202	0.034	4.359	1.117	0.534	0.092
22000.0	0.270	24.720	3.790	942.006	0.209	0.036	4.386	1.148	0.552	0.098
22500.0	0.268	24.327	3.854	941.730	0.216	0.038	4.411	1.179	0.569	0.104
25000.0	0.260	22.414	4.164	940.330	0.250	0.049	4.517	1.331	0.658	0.138
27500.0	0.252	20.586	4.454	938.894	0.285	0.061	4.592	1.478	0.744	0.177
30000.0	0.244	18.841	4.725	937.422	0.321	0.076	4.640	1.619	0.826	0.222
32500.0	0.236	17.180	4.976	935.911	0.358	0.092	4.664	1.756	0.902	0.273
35000.0	0.228	15.602	5.208	934.359	0.395	0.111	4.668	1.885	0.972	0.328
37500.0	0.221	14.108	5.420	932.765	0.433	0.131	4.656	2.008	1.035	0.389
40000.0	0.213	12.697	5.614	931.125	0.471	0.153	4.629	2.124	1.092	0.455
42500.0	0.205	11.371	5.788	929.439	0.508	0.176	4.590	2.232	1.141	0.525
45000.0	0.198	10.130	5.943	927.704	0.545	0.201	4.542	2.332	1.184	0.601
47500.0	0.190	8.974	6.079	925.918	0.581	0.228	4.486	2.423	1.220	0.680
50000.0	0.183	7.904	6.196	924.080	0.616	0.255	4.426	2.506	1.250	0.763
52500.0	0.175	6.919	6.295	922.187	0.650	0.283	4.362	2.581	1.274	0.850
55000.0	0.168	6.018	6.376	920.238	0.682	0.311	4.297	2.646	1.292	0.940
57500.0	0.161	5.201	6.438	918.234	0.712	0.340	4.231	2.704	1.305	1.033
60000.0	0.154	4.465	6.483	916.174	0.741	0.368	4.167	2.753	1.314	1.127
62500.0	0.147	3.808	6.512	914.058	0.768	0.395	4.105	2.795	1.318	1.224
65000.0	0.141	3.227	6.525	911.889	0.792	0.422	4.045	2.829	1.320	1.322
67500.0	0.134	2.717	6.523	909.667	0.814	0.447	3.990	2.856	1.319	1.420
70000.0	0.128	2.274	6.508	907.397	0.834	0.471	3.939	2.878	1.315	1.518

**Table C.2 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.347	45.869	0.000	953.784	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.347	45.749	0.024	953.722	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.345	45.272	0.119	953.475	0.002	0.000	0.219	0.002	0.000	0.000
1000.0	0.343	44.685	0.236	953.165	0.004	0.000	0.475	0.007	0.000	0.000
1500.0	0.340	44.108	0.351	952.856	0.007	0.000	0.719	0.017	0.001	0.000
2000.0	0.338	43.539	0.464	952.548	0.010	0.000	0.951	0.029	0.003	0.000
2500.0	0.336	42.978	0.575	952.240	0.013	0.000	1.173	0.044	0.006	0.000
3000.0	0.334	42.426	0.683	951.934	0.016	0.000	1.384	0.061	0.010	0.000
3500.0	0.332	41.881	0.790	951.627	0.020	0.001	1.585	0.081	0.014	0.000
4000.0	0.330	41.343	0.896	951.322	0.023	0.001	1.777	0.101	0.021	0.001
4500.0	0.327	40.812	0.999	951.018	0.027	0.001	1.961	0.124	0.028	0.001
5000.0	0.325	40.287	1.101	950.714	0.032	0.002	2.136	0.147	0.036	0.001
5500.0	0.323	39.769	1.201	950.410	0.036	0.002	2.303	0.172	0.045	0.002
6000.0	0.321	39.257	1.300	950.108	0.040	0.002	2.463	0.198	0.056	0.002
6500.0	0.319	38.751	1.397	949.805	0.045	0.003	2.616	0.225	0.067	0.003
7000.0	0.317	38.251	1.493	949.503	0.050	0.003	2.762	0.252	0.079	0.004
7500.0	0.315	37.756	1.587	949.202	0.055	0.004	2.902	0.280	0.093	0.005
8000.0	0.313	37.267	1.680	948.900	0.060	0.004	3.036	0.309	0.107	0.006
8500.0	0.311	36.782	1.772	948.599	0.065	0.005	3.164	0.339	0.121	0.007
9000.0	0.309	36.303	1.862	948.298	0.071	0.006	3.287	0.368	0.137	0.008
9500.0	0.307	35.829	1.951	947.997	0.077	0.007	3.404	0.399	0.153	0.010
10000.0	0.305	35.360	2.039	947.696	0.082	0.007	3.516	0.430	0.170	0.011
10500.0	0.303	34.895	2.126	947.395	0.088	0.008	3.624	0.461	0.187	0.013
11000.0	0.302	34.436	2.211	947.094	0.094	0.009	3.726	0.492	0.205	0.015
11500.0	0.300	33.980	2.295	946.793	0.100	0.010	3.824	0.524	0.223	0.017
12000.0	0.298	33.529	2.379	946.493	0.107	0.011	3.918	0.556	0.241	0.020
12500.0	0.296	33.083	2.461	946.192	0.113	0.012	4.007	0.589	0.260	0.022
13000.0	0.294	32.640	2.541	945.892	0.119	0.014	4.092	0.621	0.279	0.025
13500.0	0.292	32.202	2.621	945.592	0.126	0.015	4.174	0.654	0.299	0.028
14000.0	0.290	31.767	2.700	945.292	0.132	0.016	4.251	0.687	0.319	0.031
14500.0	0.289	31.337	2.778	944.992	0.139	0.017	4.325	0.720	0.338	0.034
15000.0	0.287	30.910	2.854	944.693	0.146	0.019	4.395	0.754	0.358	0.038
15500.0	0.285	30.487	2.930	944.393	0.152	0.020	4.461	0.787	0.378	0.042
16000.0	0.283	30.068	3.005	944.094	0.159	0.022	4.525	0.820	0.399	0.046
16500.0	0.281	29.653	3.079	943.794	0.166	0.024	4.585	0.854	0.419	0.050
17000.0	0.280	29.241	3.152	943.494	0.173	0.025	4.643	0.887	0.439	0.054
17500.0	0.278	28.832	3.224	943.194	0.180	0.027	4.697	0.921	0.460	0.058
18000.0	0.276	28.428	3.295	942.894	0.187	0.029	4.749	0.954	0.480	0.063
18500.0	0.274	28.026	3.365	942.593	0.194	0.031	4.799	0.988	0.500	0.068
19000.0	0.273	27.628	3.434	942.291	0.201	0.033	4.846	1.021	0.521	0.073
19500.0	0.271	27.234	3.503	941.989	0.208	0.035	4.892	1.055	0.541	0.078
20000.0	0.269	26.843	3.570	941.686	0.215	0.037	4.935	1.088	0.562	0.084
20500.0	0.267	26.455	3.637	941.382	0.222	0.039	4.976	1.121	0.582	0.089
21000.0	0.266	26.071	3.703	941.078	0.230	0.042	5.015	1.154	0.602	0.095
21500.0	0.264	25.690	3.768	940.772	0.237	0.044	5.052	1.187	0.623	0.101
22000.0	0.262	25.313	3.832	940.465	0.245	0.046	5.088	1.220	0.643	0.107
22500.0	0.261	24.939	3.895	940.156	0.252	0.049	5.122	1.252	0.663	0.114
23000.0	0.259	24.569	3.958	939.847	0.260	0.052	5.154	1.285	0.683	0.121
23500.0	0.257	24.202	4.019	939.537	0.268	0.054	5.185	1.317	0.703	0.127
24000.0	0.256	23.838	4.080	939.225	0.275	0.057	5.215	1.349	0.724	0.134
24500.0	0.254	23.478	4.140	938.912	0.283	0.060	5.243	1.381	0.743	0.142
25000.0	0.252	23.121	4.199	938.598	0.291	0.063	5.270	1.413	0.763	0.149
27500.0	0.244	21.386	4.482	937.006	0.331	0.079	5.385	1.569	0.861	0.189
30000.0	0.236	19.734	4.745	935.379	0.371	0.097	5.471	1.720	0.955	0.235
32500.0	0.228	18.163	4.989	933.719	0.412	0.117	5.532	1.864	1.044	0.285
35000.0	0.220	16.673	5.213	932.023	0.453	0.140	5.570	2.003	1.127	0.339
37500.0	0.212	15.261	5.418	930.290	0.494	0.165	5.590	2.136	1.204	0.398
40000.0	0.204	13.928	5.604	928.520	0.535	0.191	5.593	2.261	1.274	0.462
42500.0	0.197	12.672	5.772	926.711	0.575	0.220	5.582	2.379	1.337	0.529
45000.0	0.189	11.492	5.922	924.863	0.614	0.250	5.560	2.490	1.394	0.599
47500.0	0.182	10.388	6.054	922.975	0.652	0.281	5.528	2.593	1.444	0.673
50000.0	0.175	9.356	6.170	921.047	0.689	0.314	5.488	2.688	1.489	0.750
52500.0	0.168	8.398	6.268	919.078	0.725	0.348	5.442	2.775	1.527	0.829
55000.0	0.162	7.510	6.350	917.068	0.759	0.382	5.391	2.855	1.559	0.911
57500.0	0.155	6.692	6.417	915.017	0.792	0.417	5.338	2.927	1.586	0.995
60000.0	0.149	5.942	6.468	912.926	0.823	0.452	5.282	2.991	1.608	1.080
62500.0	0.143	5.256	6.505	910.794	0.851	0.486	5.226	3.049	1.625	1.167
65000.0	0.137	4.632	6.527	908.624	0.878	0.520	5.170	3.099	1.639	1.255
67500.0	0.131	4.069	6.537	906.416	0.903	0.553	5.115	3.143	1.648	1.343
70000.0	0.126	3.561	6.534	904.171	0.926	0.586	5.061	3.180	1.655	1.432

**Table C.3 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.347	45.869	0.000	953.784	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.346	45.750	0.025	953.713	0.000	0.000	0.024	0.000	0.000	0.000
500.0	0.344	45.276	0.125	953.428	0.002	0.000	0.249	0.002	0.000	0.000
1000.0	0.342	44.695	0.247	953.073	0.005	0.000	0.540	0.008	0.001	0.000
1500.0	0.339	44.123	0.367	952.718	0.008	0.000	0.818	0.018	0.002	0.000
2000.0	0.337	43.562	0.485	952.363	0.012	0.000	1.082	0.032	0.004	0.000
2500.0	0.334	43.009	0.600	952.010	0.016	0.000	1.335	0.048	0.008	0.000
3000.0	0.332	42.465	0.713	951.657	0.020	0.001	1.577	0.067	0.012	0.000
3500.0	0.329	41.930	0.824	951.305	0.024	0.001	1.808	0.087	0.019	0.000
4000.0	0.327	41.402	0.933	950.953	0.029	0.001	2.029	0.109	0.026	0.001
4500.0	0.325	40.882	1.040	950.602	0.033	0.002	2.241	0.133	0.035	0.001
5000.0	0.322	40.369	1.145	950.252	0.038	0.002	2.444	0.158	0.045	0.001
5500.0	0.320	39.862	1.249	949.903	0.044	0.003	2.639	0.184	0.056	0.002
6000.0	0.318	39.363	1.350	949.554	0.049	0.003	2.826	0.211	0.069	0.003
6500.0	0.315	38.869	1.450	949.205	0.055	0.004	3.005	0.239	0.082	0.003
7000.0	0.313	38.382	1.549	948.857	0.061	0.005	3.177	0.268	0.097	0.004
7500.0	0.311	37.901	1.646	948.509	0.067	0.005	3.343	0.298	0.112	0.005
8000.0	0.308	37.425	1.741	948.162	0.074	0.006	3.502	0.328	0.129	0.006
8500.0	0.306	36.956	1.835	947.814	0.080	0.007	3.654	0.359	0.146	0.008
9000.0	0.304	36.491	1.927	947.467	0.087	0.008	3.801	0.390	0.164	0.009
9500.0	0.302	36.032	2.018	947.120	0.094	0.009	3.943	0.422	0.182	0.011
10000.0	0.300	35.578	2.108	946.773	0.101	0.010	4.079	0.455	0.201	0.013
10500.0	0.298	35.130	2.196	946.426	0.108	0.012	4.209	0.488	0.221	0.015
11000.0	0.295	34.686	2.283	946.080	0.115	0.013	4.335	0.521	0.241	0.017
11500.0	0.293	34.247	2.369	945.733	0.122	0.014	4.456	0.555	0.261	0.019
12000.0	0.291	33.812	2.453	945.386	0.129	0.016	4.572	0.589	0.282	0.022
12500.0	0.289	33.382	2.537	945.040	0.137	0.017	4.684	0.623	0.304	0.025
13000.0	0.287	32.957	2.619	944.694	0.144	0.019	4.791	0.658	0.325	0.028
13500.0	0.285	32.536	2.700	944.347	0.152	0.021	4.894	0.693	0.347	0.031
14000.0	0.283	32.120	2.779	944.001	0.160	0.022	4.993	0.728	0.369	0.034
14500.0	0.281	31.707	2.858	943.655	0.168	0.024	5.089	0.763	0.392	0.037
15000.0	0.279	31.299	2.935	943.309	0.175	0.026	5.180	0.799	0.414	0.041
15500.0	0.277	30.895	3.012	942.963	0.183	0.028	5.268	0.834	0.436	0.045
16000.0	0.275	30.495	3.087	942.617	0.192	0.031	5.352	0.870	0.459	0.049
16500.0	0.273	30.098	3.161	942.271	0.200	0.033	5.433	0.906	0.482	0.053
17000.0	0.271	29.706	3.234	941.924	0.208	0.035	5.510	0.942	0.505	0.058
17500.0	0.269	29.317	3.306	941.578	0.216	0.038	5.585	0.978	0.527	0.062
18000.0	0.267	28.932	3.377	941.231	0.224	0.040	5.657	1.014	0.550	0.067
18500.0	0.265	28.551	3.448	940.884	0.233	0.043	5.726	1.050	0.573	0.072
19000.0	0.264	28.173	3.517	940.537	0.241	0.046	5.792	1.087	0.596	0.077
19500.0	0.262	27.799	3.585	940.189	0.249	0.048	5.856	1.123	0.619	0.082
20000.0	0.260	27.428	3.652	939.840	0.258	0.051	5.917	1.159	0.642	0.088
20500.0	0.258	27.061	3.719	939.491	0.266	0.054	5.976	1.195	0.665	0.093
21000.0	0.256	26.697	3.784	939.141	0.275	0.057	6.033	1.231	0.687	0.099
21500.0	0.254	26.337	3.849	938.791	0.283	0.061	6.088	1.267	0.710	0.105
22000.0	0.252	25.981	3.912	938.440	0.292	0.064	6.140	1.303	0.733	0.111
22500.0	0.251	25.627	3.975	938.088	0.300	0.067	6.191	1.339	0.755	0.118
23000.0	0.249	25.277	4.037	937.735	0.309	0.071	6.240	1.375	0.778	0.124
23500.0	0.247	24.931	4.098	937.381	0.317	0.074	6.287	1.410	0.800	0.131
24000.0	0.245	24.588	4.158	937.026	0.326	0.078	6.333	1.446	0.823	0.138
24500.0	0.243	24.248	4.217	936.669	0.335	0.082	6.377	1.481	0.845	0.145
25000.0	0.242	23.912	4.276	936.312	0.343	0.086	6.419	1.517	0.867	0.152
25500.0	0.240	23.579	4.333	935.954	0.352	0.090	6.460	1.552	0.890	0.159
26000.0	0.238	23.249	4.390	935.595	0.361	0.094	6.500	1.587	0.912	0.167
26500.0	0.236	22.922	4.446	935.234	0.370	0.098	6.538	1.622	0.934	0.174
27000.0	0.235	22.599	4.501	934.872	0.378	0.102	6.575	1.656	0.955	0.182
27500.0	0.233	22.279	4.555	934.510	0.387	0.107	6.610	1.691	0.977	0.190
28000.0	0.231	21.962	4.608	934.145	0.396	0.111	6.644	1.725	0.999	0.199
28500.0	0.230	21.649	4.661	933.780	0.405	0.116	6.677	1.759	1.020	0.207
29000.0	0.228	21.338	4.713	933.414	0.414	0.120	6.709	1.793	1.041	0.215
29500.0	0.226	21.031	4.764	933.046	0.423	0.125	6.739	1.827	1.063	0.224
30000.0	0.224	20.727	4.814	932.677	0.431	0.130	6.769	1.861	1.084	0.233
30500.0	0.223	20.426	4.863	932.307	0.440	0.135	6.797	1.894	1.105	0.242
32500.0	0.216	19.254	5.053	930.813	0.476	0.156	6.900	2.026	1.187	0.279
35000.0	0.208	17.857	5.272	928.918	0.520	0.185	7.007	2.184	1.285	0.329
37500.0	0.200	16.535	5.472	926.991	0.564	0.216	7.092	2.338	1.379	0.383
40000.0	0.193	15.286	5.654	925.033	0.607	0.249	7.158	2.485	1.467	0.439
42500.0	0.185	14.108	5.818	923.043	0.650	0.285	7.208	2.626	1.550	0.499
45000.0	0.178	12.999	5.964	921.023	0.691	0.322	7.243	2.760	1.627	0.561
47500.0	0.171	11.957	6.094	918.972	0.732	0.361	7.265	2.888	1.699	0.626
50000.0	0.165	10.980	6.207	916.890	0.771	0.402	7.276	3.009	1.765	0.693
52500.0	0.158	10.066	6.305	914.778	0.809	0.444	7.278	3.123	1.825	0.763
55000.0	0.152	9.212	6.387	912.636	0.845	0.487	7.272	3.231	1.881	0.834
57500.0	0.146	8.417	6.456	910.466	0.879	0.530	7.260	3.331	1.931	0.907
60000.0	0.141	7.678	6.511	908.267	0.912	0.574	7.242	3.426	1.977	0.981
62500.0	0.135	6.993	6.552	906.042	0.942	0.619	7.220	3.513	2.018	1.057
65000.0	0.130	6.359	6.582	903.790	0.971	0.663	7.195	3.594	2.055	1.134
67500.0	0.126	5.774	6.600	901.513	0.998	0.707	7.166	3.669	2.088	1.212
70000.0	0.121	5.235	6.607	899.212	1.022	0.751	7.136	3.738	2.118	1.292

**Table C.4 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.345	45.762	0.000	953.893	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.345	45.642	0.023	953.840	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.343	45.163	0.113	953.629	0.002	0.000	0.188	0.001	0.000	0.000
1000.0	0.342	44.573	0.225	953.365	0.003	0.000	0.408	0.006	0.000	0.000
1500.0	0.340	43.990	0.335	953.101	0.006	0.000	0.619	0.014	0.001	0.000
2000.0	0.338	43.415	0.444	952.836	0.008	0.000	0.820	0.025	0.002	0.000
2500.0	0.336	42.847	0.550	952.571	0.010	0.000	1.012	0.038	0.004	0.000
3000.0	0.334	42.287	0.655	952.306	0.013	0.000	1.196	0.053	0.007	0.000
3500.0	0.332	41.733	0.759	952.040	0.016	0.000	1.372	0.070	0.011	0.000
4000.0	0.330	41.186	0.861	951.775	0.019	0.001	1.541	0.089	0.015	0.000
4500.0	0.328	40.644	0.962	951.509	0.023	0.001	1.702	0.110	0.021	0.001
5000.0	0.326	40.109	1.061	951.244	0.026	0.001	1.856	0.131	0.027	0.001
5500.0	0.325	39.580	1.159	950.978	0.030	0.001	2.003	0.154	0.035	0.001
6000.0	0.323	39.056	1.256	950.712	0.033	0.002	2.145	0.178	0.043	0.002
6500.0	0.321	38.538	1.351	950.446	0.037	0.002	2.280	0.203	0.052	0.002
7000.0	0.319	38.026	1.445	950.179	0.041	0.002	2.409	0.228	0.062	0.003
7500.0	0.317	37.518	1.538	949.913	0.046	0.003	2.532	0.254	0.073	0.004
8000.0	0.316	37.015	1.630	949.647	0.050	0.003	2.650	0.281	0.085	0.004
8500.0	0.314	36.518	1.720	949.380	0.054	0.004	2.763	0.309	0.097	0.005
9000.0	0.312	36.025	1.810	949.114	0.059	0.004	2.870	0.337	0.110	0.007
9500.0	0.310	35.537	1.898	948.848	0.064	0.005	2.973	0.366	0.123	0.008
10000.0	0.308	35.053	1.985	948.581	0.068	0.005	3.071	0.395	0.138	0.009
10500.0	0.307	34.574	2.071	948.315	0.073	0.006	3.164	0.424	0.152	0.011
11000.0	0.305	34.099	2.156	948.049	0.078	0.007	3.253	0.454	0.167	0.013
11500.0	0.303	33.628	2.240	947.783	0.084	0.008	3.338	0.484	0.183	0.015
12000.0	0.302	33.161	2.322	947.517	0.089	0.008	3.418	0.515	0.199	0.017
12500.0	0.300	32.699	2.404	947.251	0.094	0.009	3.494	0.546	0.215	0.019
13000.0	0.298	32.240	2.485	946.985	0.100	0.010	3.567	0.577	0.231	0.021
13500.0	0.296	31.786	2.565	946.720	0.105	0.011	3.636	0.608	0.248	0.024
14000.0	0.295	31.335	2.643	946.455	0.111	0.012	3.701	0.639	0.265	0.027
14500.0	0.293	30.887	2.721	946.189	0.116	0.013	3.762	0.671	0.282	0.030
15000.0	0.291	30.443	2.798	945.925	0.122	0.014	3.820	0.702	0.300	0.033
15500.0	0.290	30.003	2.874	945.659	0.128	0.015	3.875	0.734	0.317	0.036
16000.0	0.288	29.566	2.949	945.394	0.134	0.017	3.927	0.766	0.335	0.040
16500.0	0.286	29.133	3.023	945.129	0.140	0.018	3.976	0.797	0.352	0.043
17000.0	0.285	28.703	3.096	944.864	0.145	0.019	4.023	0.829	0.370	0.047
17500.0	0.283	28.277	3.169	944.597	0.151	0.020	4.067	0.861	0.387	0.051
18000.0	0.282	27.854	3.241	944.331	0.158	0.022	4.108	0.893	0.405	0.056
18500.0	0.280	27.434	3.311	944.063	0.164	0.023	4.148	0.925	0.423	0.060
19000.0	0.278	27.018	3.381	943.795	0.170	0.025	4.185	0.956	0.441	0.065
19500.0	0.277	26.605	3.451	943.526	0.176	0.026	4.221	0.988	0.459	0.070
20000.0	0.275	26.195	3.519	943.256	0.182	0.028	4.254	1.019	0.477	0.075
20500.0	0.273	25.789	3.586	942.984	0.189	0.030	4.286	1.051	0.495	0.080
21000.0	0.272	25.387	3.653	942.712	0.195	0.032	4.316	1.082	0.513	0.086
21500.0	0.270	24.987	3.719	942.438	0.202	0.033	4.345	1.113	0.531	0.091
22000.0	0.269	24.592	3.784	942.163	0.208	0.035	4.372	1.144	0.549	0.097
22500.0	0.267	24.199	3.849	941.887	0.215	0.037	4.397	1.175	0.567	0.103
23000.0	0.265	23.810	3.912	941.609	0.222	0.039	4.421	1.206	0.584	0.110
25000.0	0.259	22.288	4.158	940.484	0.249	0.048	4.504	1.327	0.655	0.137
27500.0	0.251	20.461	4.448	939.046	0.284	0.061	4.580	1.475	0.741	0.177
30000.0	0.243	18.718	4.718	937.571	0.320	0.076	4.628	1.617	0.823	0.222
32500.0	0.235	17.060	4.969	936.056	0.357	0.092	4.653	1.754	0.899	0.272
35000.0	0.227	15.485	5.200	934.501	0.395	0.111	4.658	1.884	0.969	0.328
37500.0	0.220	13.994	5.411	932.903	0.432	0.131	4.645	2.007	1.033	0.389
40000.0	0.212	12.588	5.604	931.260	0.470	0.153	4.618	2.123	1.090	0.455
42500.0	0.204	11.267	5.777	929.570	0.508	0.176	4.579	2.231	1.139	0.526
45000.0	0.197	10.031	5.931	927.831	0.544	0.201	4.531	2.331	1.182	0.601
47500.0	0.189	8.881	6.066	926.040	0.580	0.228	4.476	2.423	1.218	0.681
50000.0	0.182	7.816	6.182	924.196	0.615	0.255	4.416	2.506	1.248	0.764
52500.0	0.174	6.837	6.280	922.298	0.649	0.283	4.353	2.580	1.272	0.851
55000.0	0.167	5.942	6.359	920.344	0.681	0.311	4.287	2.646	1.290	0.941
57500.0	0.160	5.131	6.420	918.334	0.712	0.340	4.222	2.703	1.303	1.034
60000.0	0.153	4.402	6.464	916.268	0.740	0.368	4.158	2.752	1.312	1.129
62500.0	0.146	3.751	6.492	914.147	0.767	0.395	4.096	2.793	1.316	1.226
65000.0	0.140	3.176	6.503	911.972	0.791	0.422	4.038	2.827	1.318	1.324
67500.0	0.133	2.673	6.501	909.745	0.813	0.447	3.983	2.855	1.316	1.423
70000.0	0.127	2.236	6.484	907.469	0.833	0.471	3.932	2.876	1.313	1.521

**Table C.5 [] Exposure-Dependent 40% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.345	45.762	0.000	953.893	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.345	45.642	0.024	953.833	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.343	45.165	0.118	953.594	0.002	0.000	0.212	0.002	0.000	0.000
1000.0	0.341	44.578	0.234	953.294	0.004	0.000	0.460	0.007	0.000	0.000
1500.0	0.339	43.999	0.348	952.993	0.007	0.000	0.697	0.016	0.001	0.000
2000.0	0.337	43.429	0.460	952.693	0.009	0.000	0.924	0.028	0.003	0.000
2500.0	0.335	42.868	0.570	952.392	0.012	0.000	1.141	0.042	0.005	0.000
3000.0	0.333	42.314	0.678	952.091	0.016	0.000	1.348	0.059	0.009	0.000
3500.0	0.330	41.767	0.785	951.791	0.019	0.001	1.547	0.078	0.014	0.000
4000.0	0.328	41.228	0.890	951.490	0.023	0.001	1.737	0.099	0.019	0.000
4500.0	0.326	40.695	0.993	951.189	0.027	0.001	1.919	0.120	0.026	0.001
5000.0	0.324	40.170	1.095	950.888	0.031	0.001	2.093	0.144	0.034	0.001
5500.0	0.322	39.650	1.195	950.586	0.035	0.002	2.260	0.168	0.043	0.001
6000.0	0.320	39.137	1.294	950.285	0.040	0.002	2.421	0.194	0.054	0.002
6500.0	0.318	38.630	1.391	949.984	0.044	0.003	2.574	0.220	0.065	0.003
7000.0	0.316	38.128	1.487	949.682	0.049	0.003	2.721	0.247	0.077	0.003
7500.0	0.314	37.632	1.581	949.381	0.054	0.004	2.862	0.275	0.090	0.004
8000.0	0.312	37.142	1.674	949.079	0.059	0.004	2.997	0.304	0.104	0.005
8500.0	0.310	36.657	1.766	948.778	0.064	0.005	3.126	0.333	0.118	0.007
9000.0	0.308	36.177	1.856	948.477	0.070	0.006	3.250	0.363	0.134	0.008
9500.0	0.306	35.702	1.945	948.175	0.076	0.006	3.369	0.393	0.150	0.009
10000.0	0.304	35.232	2.033	947.874	0.081	0.007	3.482	0.424	0.166	0.011
10500.0	0.302	34.767	2.120	947.573	0.087	0.008	3.590	0.455	0.184	0.013
11000.0	0.300	34.307	2.205	947.271	0.093	0.009	3.694	0.487	0.201	0.015
11500.0	0.299	33.851	2.290	946.970	0.099	0.010	3.793	0.518	0.219	0.017
12000.0	0.297	33.399	2.373	946.669	0.106	0.011	3.888	0.551	0.238	0.019
12500.0	0.295	32.952	2.455	946.369	0.112	0.012	3.978	0.583	0.257	0.022
13000.0	0.293	32.510	2.536	946.068	0.118	0.013	4.064	0.616	0.276	0.025
13500.0	0.291	32.071	2.616	945.768	0.125	0.015	4.146	0.648	0.295	0.028
14000.0	0.289	31.636	2.694	945.467	0.131	0.016	4.224	0.681	0.315	0.031
14500.0	0.287	31.205	2.772	945.167	0.138	0.017	4.299	0.715	0.335	0.034
15000.0	0.286	30.779	2.849	944.867	0.145	0.019	4.369	0.748	0.355	0.037
15500.0	0.284	30.356	2.925	944.567	0.151	0.020	4.437	0.781	0.375	0.041
16000.0	0.282	29.936	2.999	944.267	0.158	0.022	4.501	0.815	0.395	0.045
16500.0	0.280	29.521	3.073	943.967	0.165	0.023	4.562	0.848	0.415	0.049
17000.0	0.279	29.109	3.146	943.667	0.172	0.025	4.620	0.882	0.435	0.053
17500.0	0.277	28.700	3.218	943.366	0.179	0.027	4.675	0.915	0.456	0.058
18000.0	0.275	28.295	3.289	943.066	0.186	0.029	4.728	0.949	0.476	0.062
18500.0	0.273	27.894	3.359	942.764	0.193	0.031	4.778	0.982	0.497	0.067
19000.0	0.272	27.496	3.428	942.462	0.200	0.033	4.825	1.016	0.517	0.072
19500.0	0.270	27.101	3.497	942.160	0.207	0.035	4.871	1.049	0.537	0.077
20000.0	0.268	26.710	3.564	941.856	0.214	0.037	4.914	1.083	0.558	0.083
20500.0	0.266	26.323	3.631	941.552	0.222	0.039	4.956	1.116	0.578	0.089
21000.0	0.265	25.939	3.697	941.246	0.229	0.041	4.995	1.149	0.599	0.094
21500.0	0.263	25.558	3.762	940.940	0.236	0.044	5.033	1.182	0.619	0.100
22000.0	0.261	25.181	3.826	940.632	0.244	0.046	5.069	1.215	0.639	0.107
22500.0	0.260	24.807	3.889	940.324	0.251	0.049	5.104	1.247	0.660	0.113
23000.0	0.258	24.437	3.951	940.014	0.259	0.051	5.136	1.280	0.680	0.120
23500.0	0.256	24.070	4.013	939.703	0.267	0.054	5.168	1.313	0.700	0.127
24000.0	0.254	23.707	4.073	939.390	0.274	0.057	5.197	1.345	0.720	0.134
24500.0	0.253	23.347	4.133	939.077	0.282	0.060	5.226	1.377	0.740	0.141
25000.0	0.251	22.990	4.192	938.762	0.290	0.062	5.253	1.409	0.760	0.148
27500.0	0.243	21.257	4.475	937.168	0.330	0.078	5.369	1.565	0.858	0.189
30000.0	0.235	19.607	4.737	935.539	0.370	0.097	5.456	1.716	0.952	0.234
32500.0	0.227	18.039	4.980	933.875	0.411	0.117	5.517	1.861	1.041	0.284
35000.0	0.219	16.552	5.203	932.176	0.453	0.140	5.556	2.001	1.124	0.339
37500.0	0.211	15.144	5.407	930.440	0.494	0.164	5.576	2.133	1.201	0.398
40000.0	0.203	13.814	5.593	928.666	0.534	0.191	5.579	2.259	1.271	0.461
42500.0	0.196	12.562	5.760	926.853	0.574	0.220	5.568	2.377	1.334	0.529
45000.0	0.188	11.387	5.909	925.002	0.613	0.250	5.546	2.488	1.391	0.599
47500.0	0.181	10.287	6.040	923.110	0.652	0.281	5.514	2.591	1.442	0.673
50000.0	0.174	9.261	6.155	921.177	0.689	0.314	5.474	2.686	1.486	0.750
52500.0	0.167	8.307	6.252	919.204	0.724	0.348	5.429	2.774	1.524	0.830
55000.0	0.161	7.425	6.333	917.189	0.758	0.382	5.378	2.854	1.556	0.912
57500.0	0.154	6.613	6.398	915.133	0.791	0.417	5.325	2.925	1.583	0.996
60000.0	0.148	5.868	6.448	913.037	0.822	0.451	5.270	2.990	1.605	1.082
62500.0	0.142	5.187	6.484	910.901	0.850	0.486	5.214	3.047	1.622	1.169
65000.0	0.136	4.570	6.506	908.725	0.877	0.520	5.159	3.097	1.636	1.257
67500.0	0.131	4.011	6.514	906.512	0.902	0.553	5.104	3.141	1.645	1.346
70000.0	0.125	3.509	6.511	904.263	0.924	0.585	5.051	3.178	1.652	1.435

**Table C.6 [] Exposure-Dependent 80% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.345	45.762	0.000	953.893	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.345	45.643	0.025	953.824	0.000	0.000	0.024	0.000	0.000	0.000
500.0	0.343	45.169	0.124	953.548	0.002	0.000	0.242	0.002	0.000	0.000
1000.0	0.340	44.587	0.245	953.202	0.005	0.000	0.524	0.008	0.000	0.000
1500.0	0.338	44.015	0.364	952.856	0.008	0.000	0.794	0.018	0.002	0.000
2000.0	0.335	43.452	0.480	952.510	0.011	0.000	1.053	0.031	0.004	0.000
2500.0	0.333	42.899	0.595	952.164	0.015	0.000	1.301	0.047	0.007	0.000
3000.0	0.331	42.354	0.707	951.818	0.019	0.001	1.538	0.065	0.012	0.000
3500.0	0.328	41.817	0.818	951.472	0.023	0.001	1.766	0.085	0.018	0.000
4000.0	0.326	41.287	0.926	951.126	0.028	0.001	1.984	0.107	0.025	0.001
4500.0	0.323	40.766	1.033	950.779	0.033	0.002	2.194	0.130	0.033	0.001
5000.0	0.321	40.251	1.138	950.433	0.038	0.002	2.396	0.155	0.043	0.001
5500.0	0.319	39.743	1.242	950.086	0.043	0.003	2.590	0.180	0.054	0.002
6000.0	0.316	39.242	1.343	949.739	0.048	0.003	2.776	0.207	0.066	0.002
6500.0	0.314	38.748	1.443	949.393	0.054	0.004	2.956	0.235	0.080	0.003
7000.0	0.312	38.259	1.542	949.046	0.060	0.004	3.128	0.264	0.094	0.004
7500.0	0.310	37.777	1.638	948.699	0.066	0.005	3.294	0.293	0.109	0.005
8000.0	0.307	37.300	1.734	948.352	0.073	0.006	3.454	0.323	0.125	0.006
8500.0	0.305	36.830	1.828	948.005	0.079	0.007	3.608	0.354	0.142	0.008
9000.0	0.303	36.364	1.920	947.658	0.086	0.008	3.756	0.385	0.160	0.009
9500.0	0.301	35.904	2.011	947.311	0.092	0.009	3.898	0.417	0.178	0.011
10000.0	0.299	35.450	2.101	946.964	0.099	0.010	4.035	0.449	0.197	0.013
10500.0	0.297	35.000	2.189	946.617	0.106	0.011	4.167	0.482	0.217	0.015
11000.0	0.294	34.556	2.276	946.270	0.114	0.013	4.293	0.515	0.237	0.017
11500.0	0.292	34.116	2.362	945.923	0.121	0.014	4.415	0.549	0.257	0.019
12000.0	0.290	33.681	2.447	945.576	0.128	0.015	4.532	0.583	0.278	0.022
12500.0	0.288	33.251	2.530	945.230	0.136	0.017	4.645	0.617	0.300	0.024
13000.0	0.286	32.825	2.612	944.883	0.143	0.019	4.753	0.652	0.321	0.027
13500.0	0.284	32.404	2.693	944.536	0.151	0.020	4.857	0.687	0.343	0.030
14000.0	0.282	31.987	2.773	944.190	0.159	0.022	4.957	0.722	0.365	0.033
14500.0	0.280	31.574	2.851	943.843	0.166	0.024	5.053	0.757	0.387	0.037
15000.0	0.278	31.166	2.929	943.497	0.174	0.026	5.145	0.792	0.410	0.041
15500.0	0.276	30.761	3.005	943.150	0.182	0.028	5.233	0.828	0.432	0.044
16000.0	0.274	30.361	3.080	942.804	0.190	0.030	5.318	0.864	0.455	0.048
16500.0	0.272	29.964	3.154	942.457	0.199	0.033	5.399	0.900	0.478	0.053
17000.0	0.270	29.571	3.227	942.111	0.207	0.035	5.478	0.936	0.500	0.057
17500.0	0.268	29.182	3.300	941.764	0.215	0.037	5.553	0.972	0.523	0.061
18000.0	0.266	28.797	3.371	941.417	0.223	0.040	5.625	1.008	0.546	0.066
18500.0	0.264	28.416	3.441	941.069	0.231	0.042	5.695	1.044	0.569	0.071
19000.0	0.263	28.038	3.510	940.721	0.240	0.045	5.762	1.081	0.592	0.076
19500.0	0.261	27.664	3.578	940.373	0.248	0.048	5.826	1.117	0.615	0.081
20000.0	0.259	27.293	3.645	940.024	0.257	0.051	5.888	1.153	0.638	0.087
20500.0	0.257	26.926	3.712	939.675	0.265	0.054	5.947	1.189	0.660	0.093
21000.0	0.255	26.563	3.777	939.324	0.274	0.057	6.004	1.225	0.683	0.098
21500.0	0.253	26.203	3.841	938.973	0.282	0.060	6.059	1.262	0.706	0.104
22000.0	0.251	25.846	3.905	938.622	0.291	0.063	6.113	1.298	0.729	0.110
22500.0	0.250	25.493	3.968	938.269	0.299	0.067	6.164	1.334	0.751	0.117
23000.0	0.248	25.143	4.029	937.915	0.308	0.070	6.213	1.369	0.774	0.123
23500.0	0.246	24.797	4.090	937.561	0.316	0.074	6.261	1.405	0.796	0.130
24000.0	0.244	24.454	4.150	937.205	0.325	0.078	6.307	1.441	0.819	0.137
24500.0	0.242	24.114	4.210	936.849	0.334	0.081	6.351	1.476	0.841	0.144
25000.0	0.241	23.778	4.268	936.491	0.343	0.085	6.394	1.512	0.863	0.151
25500.0	0.239	23.445	4.325	936.132	0.351	0.089	6.435	1.547	0.886	0.158
26000.0	0.237	23.116	4.382	935.773	0.360	0.093	6.475	1.582	0.908	0.166
26500.0	0.235	22.789	4.438	935.412	0.369	0.097	6.513	1.617	0.930	0.174
27000.0	0.234	22.467	4.493	935.049	0.378	0.102	6.550	1.651	0.951	0.182
27500.0	0.232	22.147	4.547	934.686	0.386	0.106	6.586	1.686	0.973	0.190
28000.0	0.230	21.830	4.600	934.321	0.395	0.111	6.620	1.721	0.995	0.198
28500.0	0.229	21.517	4.653	933.955	0.404	0.115	6.653	1.755	1.016	0.206
29000.0	0.227	21.207	4.704	933.588	0.413	0.120	6.685	1.789	1.038	0.215
29500.0	0.225	20.900	4.755	933.220	0.422	0.125	6.716	1.823	1.059	0.223
30000.0	0.224	20.597	4.805	932.850	0.431	0.130	6.745	1.856	1.080	0.232
30500.0	0.222	20.296	4.854	932.480	0.439	0.135	6.774	1.890	1.101	0.241
32500.0	0.215	19.126	5.043	930.984	0.475	0.156	6.877	2.022	1.183	0.279
35000.0	0.207	17.732	5.262	929.085	0.519	0.184	6.985	2.181	1.282	0.329
37500.0	0.199	16.413	5.461	927.155	0.563	0.215	7.070	2.334	1.375	0.382
40000.0	0.192	15.168	5.642	925.194	0.606	0.249	7.137	2.482	1.464	0.439
42500.0	0.184	13.994	5.805	923.201	0.649	0.284	7.187	2.623	1.546	0.499
45000.0	0.177	12.888	5.951	921.177	0.691	0.322	7.222	2.758	1.623	0.561
47500.0	0.171	11.850	6.079	919.122	0.731	0.361	7.244	2.886	1.695	0.626
50000.0	0.164	10.878	6.191	917.036	0.770	0.401	7.256	3.007	1.761	0.694
52500.0	0.158	9.968	6.288	914.920	0.808	0.443	7.258	3.121	1.822	0.763
55000.0	0.151	9.119	6.370	912.775	0.844	0.486	7.252	3.229	1.877	0.835
57500.0	0.146	8.328	6.437	910.600	0.878	0.530	7.240	3.329	1.927	0.908
60000.0	0.140	7.594	6.491	908.398	0.911	0.574	7.223	3.423	1.973	0.982
62500.0	0.135	6.913	6.531	906.168	0.941	0.618	7.201	3.511	2.014	1.059
65000.0	0.130	6.284	6.560	903.913	0.970	0.662	7.176	3.592	2.051	1.136
67500.0	0.125	5.704	6.577	901.632	0.996	0.706	7.148	3.667	2.084	1.214
70000.0	0.120	5.170	6.583	899.327	1.021	0.750	7.118	3.736	2.114	1.294

**Table C.7 [Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.349	46.159	0.000	953.493	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.348	46.038	0.022	953.444	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.347	45.559	0.112	953.246	0.001	0.000	0.172	0.001	0.000	0.000
1000.0	0.345	44.966	0.222	952.999	0.003	0.000	0.379	0.006	0.000	0.000
1500.0	0.343	44.382	0.331	952.751	0.005	0.000	0.577	0.013	0.001	0.000
2000.0	0.341	43.804	0.438	952.503	0.007	0.000	0.766	0.023	0.002	0.000
2500.0	0.339	43.233	0.544	952.255	0.010	0.000	0.947	0.035	0.004	0.000
3000.0	0.338	42.668	0.648	952.006	0.012	0.000	1.120	0.049	0.006	0.000
3500.0	0.336	42.110	0.751	951.758	0.015	0.000	1.286	0.065	0.009	0.000
4000.0	0.334	41.558	0.852	951.510	0.018	0.001	1.444	0.083	0.013	0.000
4500.0	0.332	41.012	0.952	951.262	0.021	0.001	1.596	0.102	0.018	0.000
5000.0	0.331	40.472	1.051	951.013	0.024	0.001	1.741	0.122	0.024	0.001
5500.0	0.329	39.936	1.149	950.765	0.027	0.001	1.879	0.144	0.030	0.001
6000.0	0.327	39.407	1.245	950.517	0.031	0.001	2.011	0.167	0.038	0.001
6500.0	0.325	38.882	1.340	950.269	0.035	0.002	2.138	0.190	0.046	0.002
7000.0	0.324	38.362	1.434	950.021	0.038	0.002	2.258	0.215	0.055	0.002
7500.0	0.322	37.847	1.526	949.773	0.042	0.002	2.374	0.240	0.064	0.003
8000.0	0.320	37.337	1.618	949.525	0.046	0.003	2.483	0.265	0.075	0.004
8500.0	0.318	36.832	1.708	949.277	0.050	0.003	2.588	0.292	0.086	0.005
9000.0	0.317	36.331	1.798	949.030	0.054	0.004	2.688	0.319	0.097	0.006
9500.0	0.315	35.834	1.886	948.782	0.059	0.004	2.783	0.346	0.110	0.007
10000.0	0.313	35.342	1.973	948.535	0.063	0.005	2.873	0.374	0.122	0.008
10500.0	0.312	34.854	2.059	948.288	0.068	0.005	2.959	0.403	0.135	0.010
11000.0	0.310	34.370	2.144	948.042	0.072	0.006	3.041	0.431	0.149	0.011
11500.0	0.308	33.889	2.228	947.795	0.077	0.007	3.118	0.460	0.163	0.013
12000.0	0.307	33.413	2.311	947.549	0.082	0.007	3.191	0.490	0.177	0.015
12500.0	0.305	32.940	2.394	947.304	0.087	0.008	3.260	0.520	0.192	0.017
13000.0	0.303	32.471	2.475	947.059	0.091	0.009	3.325	0.549	0.207	0.019
13500.0	0.302	32.006	2.555	946.814	0.096	0.010	3.387	0.580	0.222	0.021
14000.0	0.300	31.544	2.634	946.569	0.102	0.010	3.445	0.610	0.237	0.024
14500.0	0.299	31.085	2.713	946.325	0.107	0.011	3.500	0.640	0.253	0.026
15000.0	0.297	30.630	2.790	946.081	0.112	0.012	3.551	0.671	0.268	0.029
15500.0	0.295	30.178	2.867	945.837	0.117	0.013	3.600	0.701	0.284	0.032
16000.0	0.294	29.729	2.943	945.593	0.122	0.014	3.646	0.732	0.300	0.035
16500.0	0.292	29.284	3.018	945.348	0.128	0.015	3.689	0.763	0.316	0.039
17000.0	0.291	28.841	3.092	945.103	0.133	0.016	3.730	0.794	0.332	0.042
17500.0	0.289	28.402	3.166	944.858	0.139	0.018	3.768	0.824	0.348	0.046
18000.0	0.288	27.967	3.238	944.611	0.144	0.019	3.805	0.855	0.364	0.050
18500.0	0.286	27.534	3.310	944.364	0.150	0.020	3.839	0.886	0.381	0.054
19000.0	0.284	27.105	3.381	944.116	0.155	0.021	3.872	0.916	0.397	0.058
19500.0	0.283	26.680	3.452	943.866	0.161	0.023	3.903	0.947	0.413	0.063
20000.0	0.281	26.257	3.521	943.616	0.167	0.024	3.932	0.978	0.430	0.067
20500.0	0.280	25.838	3.590	943.364	0.173	0.026	3.959	1.008	0.446	0.072
21000.0	0.278	25.422	3.658	943.111	0.179	0.027	3.985	1.039	0.463	0.077
21500.0	0.277	25.010	3.725	942.857	0.185	0.029	4.009	1.069	0.479	0.083
22000.0	0.275	24.600	3.792	942.602	0.191	0.030	4.032	1.099	0.496	0.088
22500.0	0.274	24.194	3.857	942.345	0.197	0.032	4.054	1.129	0.512	0.094
25000.0	0.266	22.214	4.175	941.040	0.228	0.042	4.142	1.277	0.594	0.126
27500.0	0.258	20.318	4.472	939.698	0.261	0.053	4.200	1.421	0.673	0.163
30000.0	0.250	18.505	4.751	938.317	0.295	0.065	4.231	1.560	0.748	0.206
32500.0	0.242	16.776	5.010	936.896	0.329	0.079	4.241	1.694	0.818	0.255
35000.0	0.234	15.132	5.250	935.431	0.365	0.095	4.232	1.822	0.882	0.309
37500.0	0.227	13.575	5.470	933.919	0.400	0.113	4.206	1.943	0.939	0.369
40000.0	0.219	12.106	5.671	932.358	0.436	0.132	4.168	2.056	0.989	0.435
42500.0	0.211	10.727	5.852	930.743	0.471	0.153	4.118	2.162	1.033	0.506
45000.0	0.203	9.439	6.013	929.073	0.507	0.175	4.061	2.259	1.070	0.582
47500.0	0.195	8.245	6.154	927.343	0.541	0.199	3.998	2.348	1.100	0.663
50000.0	0.187	7.145	6.274	925.551	0.574	0.223	3.932	2.427	1.124	0.749
52500.0	0.180	6.140	6.375	923.693	0.607	0.248	3.863	2.498	1.141	0.839
55000.0	0.172	5.231	6.455	921.770	0.637	0.273	3.795	2.559	1.154	0.933
57500.0	0.164	4.417	6.516	919.778	0.666	0.298	3.728	2.612	1.162	1.031
60000.0	0.157	3.696	6.558	917.718	0.693	0.322	3.664	2.656	1.166	1.131
62500.0	0.149	3.065	6.581	915.592	0.718	0.346	3.604	2.691	1.166	1.233
65000.0	0.142	2.520	6.587	913.400	0.741	0.369	3.548	2.719	1.164	1.337
67500.0	0.135	2.055	6.577	911.148	0.761	0.390	3.498	2.740	1.159	1.441
70000.0	0.128	1.663	6.553	908.839	0.779	0.410	3.453	2.756	1.154	1.546

**Table C.8 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.349	46.159	0.000	953.493	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.348	46.038	0.023	953.437	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.347	45.560	0.116	953.211	0.002	0.000	0.195	0.001	0.000	0.000
1000.0	0.344	44.971	0.231	952.928	0.004	0.000	0.430	0.006	0.000	0.000
1500.0	0.342	44.390	0.344	952.645	0.006	0.000	0.654	0.015	0.001	0.000
2000.0	0.340	43.817	0.455	952.362	0.009	0.000	0.869	0.026	0.002	0.000
2500.0	0.338	43.251	0.564	952.079	0.012	0.000	1.074	0.039	0.005	0.000
3000.0	0.336	42.693	0.671	951.796	0.015	0.000	1.270	0.055	0.008	0.000
3500.0	0.334	42.142	0.777	951.514	0.018	0.001	1.457	0.073	0.012	0.000
4000.0	0.332	41.598	0.881	951.231	0.021	0.001	1.637	0.092	0.017	0.000
4500.0	0.330	41.060	0.984	950.948	0.025	0.001	1.809	0.113	0.023	0.001
5000.0	0.328	40.528	1.085	950.666	0.029	0.001	1.973	0.135	0.030	0.001
5500.0	0.326	40.003	1.184	950.383	0.033	0.002	2.130	0.159	0.039	0.001
6000.0	0.324	39.483	1.283	950.101	0.037	0.002	2.281	0.183	0.048	0.002
6500.0	0.322	38.969	1.379	949.818	0.041	0.002	2.425	0.208	0.058	0.002
7000.0	0.321	38.461	1.475	949.536	0.046	0.003	2.562	0.234	0.069	0.003
7500.0	0.319	37.957	1.569	949.254	0.050	0.003	2.694	0.261	0.081	0.004
8000.0	0.317	37.459	1.662	948.973	0.055	0.004	2.820	0.289	0.093	0.005
8500.0	0.315	36.966	1.754	948.691	0.060	0.004	2.940	0.317	0.107	0.006
9000.0	0.313	36.478	1.844	948.410	0.065	0.005	3.055	0.346	0.121	0.007
9500.0	0.311	35.995	1.933	948.129	0.070	0.006	3.164	0.375	0.135	0.008
10000.0	0.309	35.516	2.021	947.848	0.075	0.006	3.269	0.405	0.151	0.010
10500.0	0.307	35.042	2.108	947.568	0.081	0.007	3.368	0.435	0.166	0.011
11000.0	0.306	34.573	2.193	947.287	0.086	0.008	3.463	0.465	0.183	0.013
11500.0	0.304	34.107	2.278	947.008	0.092	0.009	3.553	0.496	0.199	0.015
12000.0	0.302	33.646	2.361	946.728	0.098	0.010	3.639	0.527	0.216	0.017
12500.0	0.300	33.189	2.443	946.449	0.104	0.011	3.721	0.558	0.234	0.020
13000.0	0.298	32.736	2.525	946.171	0.110	0.012	3.798	0.590	0.251	0.022
13500.0	0.297	32.286	2.605	945.892	0.115	0.013	3.871	0.622	0.269	0.025
14000.0	0.295	31.841	2.684	945.614	0.121	0.014	3.941	0.654	0.287	0.028
14500.0	0.293	31.399	2.762	945.337	0.127	0.015	4.007	0.686	0.305	0.031
15000.0	0.291	30.961	2.840	945.060	0.134	0.016	4.069	0.719	0.323	0.034
15500.0	0.290	30.526	2.916	944.783	0.140	0.018	4.128	0.751	0.342	0.037
16000.0	0.288	30.095	2.991	944.506	0.146	0.019	4.184	0.783	0.360	0.041
16500.0	0.286	29.667	3.066	944.229	0.152	0.020	4.237	0.816	0.379	0.045
17000.0	0.285	29.243	3.140	943.951	0.159	0.022	4.287	0.848	0.398	0.049
17500.0	0.283	28.822	3.213	943.674	0.165	0.023	4.334	0.881	0.416	0.053
18000.0	0.281	28.405	3.284	943.395	0.171	0.025	4.380	0.913	0.435	0.057
18500.0	0.279	27.991	3.356	943.117	0.178	0.027	4.422	0.946	0.454	0.062
19000.0	0.278	27.580	3.426	942.837	0.184	0.028	4.463	0.978	0.473	0.066
19500.0	0.276	27.173	3.495	942.556	0.191	0.030	4.502	1.011	0.492	0.071
20000.0	0.274	26.769	3.564	942.275	0.198	0.032	4.539	1.043	0.510	0.076
20500.0	0.273	26.368	3.632	941.993	0.204	0.034	4.574	1.075	0.529	0.082
21000.0	0.271	25.971	3.698	941.709	0.211	0.036	4.607	1.107	0.548	0.087
21500.0	0.269	25.577	3.765	941.425	0.218	0.038	4.639	1.139	0.567	0.093
22000.0	0.268	25.187	3.830	941.139	0.225	0.040	4.669	1.171	0.586	0.099
22500.0	0.266	24.799	3.894	940.852	0.232	0.042	4.697	1.203	0.605	0.105
23000.0	0.265	24.416	3.958	940.564	0.239	0.044	4.724	1.234	0.624	0.111
23500.0	0.263	24.035	4.021	940.275	0.246	0.047	4.749	1.266	0.642	0.118
24000.0	0.261	23.658	4.083	939.984	0.253	0.049	4.773	1.297	0.661	0.125
25000.0	0.258	22.914	4.204	939.399	0.268	0.054	4.818	1.359	0.698	0.139
27500.0	0.250	21.112	4.494	937.911	0.305	0.068	4.907	1.511	0.789	0.178
30000.0	0.242	19.393	4.764	936.388	0.343	0.084	4.968	1.657	0.875	0.222
32500.0	0.234	17.756	5.015	934.828	0.382	0.102	5.005	1.798	0.957	0.271
35000.0	0.226	16.201	5.246	933.231	0.421	0.122	5.020	1.933	1.032	0.325
37500.0	0.218	14.727	5.458	931.593	0.460	0.143	5.018	2.062	1.101	0.384
40000.0	0.210	13.335	5.651	929.915	0.499	0.167	5.000	2.183	1.164	0.448
42500.0	0.203	12.024	5.825	928.193	0.537	0.192	4.969	2.296	1.219	0.516
45000.0	0.195	10.794	5.981	926.427	0.575	0.219	4.928	2.402	1.268	0.589
47500.0	0.188	9.645	6.118	924.615	0.611	0.247	4.879	2.500	1.310	0.665
50000.0	0.180	8.577	6.237	922.756	0.647	0.276	4.823	2.589	1.345	0.745
52500.0	0.173	7.588	6.339	920.848	0.681	0.306	4.763	2.670	1.374	0.828
55000.0	0.166	6.679	6.422	918.891	0.714	0.336	4.700	2.743	1.398	0.914
57500.0	0.159	5.847	6.489	916.884	0.745	0.366	4.635	2.807	1.416	1.002
60000.0	0.152	5.092	6.538	914.827	0.775	0.397	4.571	2.863	1.429	1.093
62500.0	0.146	4.410	6.572	912.721	0.802	0.427	4.507	2.911	1.438	1.185
65000.0	0.139	3.800	6.591	910.568	0.827	0.456	4.445	2.952	1.443	1.278
67500.0	0.133	3.257	6.595	908.367	0.850	0.484	4.387	2.986	1.445	1.373
70000.0	0.127	2.777	6.586	906.122	0.871	0.511	4.331	3.014	1.445	1.467

**Table C.9 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.349	46.159	0.000	953.493	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.348	46.039	0.025	953.428	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.346	45.564	0.122	953.165	0.002	0.000	0.225	0.002	0.000	0.000
1000.0	0.344	44.979	0.242	952.836	0.005	0.000	0.494	0.007	0.000	0.000
1500.0	0.341	44.404	0.360	952.507	0.008	0.000	0.752	0.017	0.001	0.000
2000.0	0.339	43.838	0.476	952.178	0.011	0.000	0.999	0.029	0.003	0.000
2500.0	0.337	43.281	0.590	951.849	0.014	0.000	1.235	0.044	0.006	0.000
3000.0	0.334	42.731	0.701	951.521	0.018	0.001	1.462	0.061	0.011	0.000
3500.0	0.332	42.189	0.811	951.192	0.022	0.001	1.679	0.080	0.016	0.000
4000.0	0.330	41.655	0.919	950.863	0.026	0.001	1.887	0.101	0.023	0.001
4500.0	0.327	41.128	1.026	950.535	0.031	0.001	2.086	0.124	0.030	0.001
5000.0	0.325	40.608	1.130	950.207	0.035	0.002	2.277	0.147	0.039	0.001
5500.0	0.323	40.094	1.233	949.879	0.040	0.002	2.461	0.172	0.050	0.002
6000.0	0.321	39.587	1.335	949.551	0.046	0.003	2.637	0.198	0.061	0.002
6500.0	0.318	39.085	1.434	949.223	0.051	0.003	2.807	0.225	0.073	0.003
7000.0	0.316	38.590	1.533	948.895	0.057	0.004	2.969	0.253	0.087	0.004
7500.0	0.314	38.101	1.629	948.568	0.062	0.005	3.125	0.281	0.101	0.005
8000.0	0.312	37.617	1.724	948.241	0.068	0.005	3.275	0.310	0.116	0.006
8500.0	0.310	37.139	1.818	947.914	0.074	0.006	3.418	0.340	0.132	0.007
9000.0	0.308	36.666	1.911	947.587	0.081	0.007	3.556	0.370	0.149	0.008
9500.0	0.306	36.198	2.002	947.260	0.087	0.008	3.688	0.401	0.166	0.010
10000.0	0.303	35.736	2.092	946.934	0.094	0.009	3.815	0.433	0.184	0.011
10500.0	0.301	35.278	2.180	946.607	0.100	0.010	3.937	0.465	0.203	0.013
11000.0	0.299	34.825	2.267	946.281	0.107	0.011	4.053	0.497	0.222	0.015
11500.0	0.297	34.377	2.353	945.956	0.114	0.013	4.165	0.530	0.241	0.018
12000.0	0.295	33.933	2.438	945.630	0.121	0.014	4.271	0.563	0.261	0.020
12500.0	0.293	33.494	2.522	945.306	0.128	0.015	4.374	0.596	0.281	0.022
13000.0	0.291	33.059	2.604	944.981	0.135	0.017	4.471	0.630	0.301	0.025
13500.0	0.289	32.628	2.685	944.657	0.142	0.018	4.565	0.664	0.322	0.028
14000.0	0.287	32.202	2.765	944.333	0.149	0.020	4.654	0.698	0.343	0.031
14500.0	0.285	31.779	2.844	944.009	0.157	0.022	4.740	0.733	0.364	0.034
15000.0	0.283	31.361	2.922	943.686	0.164	0.023	4.821	0.767	0.385	0.038
15500.0	0.282	30.946	2.999	943.362	0.171	0.025	4.899	0.802	0.406	0.041
16000.0	0.280	30.535	3.075	943.039	0.179	0.027	4.973	0.837	0.428	0.045
16500.0	0.278	30.128	3.149	942.716	0.187	0.029	5.045	0.872	0.449	0.049
17000.0	0.276	29.725	3.223	942.393	0.194	0.031	5.113	0.907	0.471	0.053
17500.0	0.274	29.325	3.296	942.070	0.202	0.033	5.178	0.942	0.492	0.058
18000.0	0.272	28.929	3.367	941.746	0.210	0.036	5.240	0.977	0.514	0.062
18500.0	0.270	28.536	3.438	941.422	0.218	0.038	5.299	1.013	0.535	0.067
19000.0	0.268	28.147	3.508	941.098	0.225	0.040	5.356	1.048	0.557	0.072
19500.0	0.267	27.761	3.577	940.773	0.233	0.043	5.410	1.083	0.578	0.077
20000.0	0.265	27.379	3.645	940.448	0.241	0.045	5.463	1.118	0.600	0.082
20500.0	0.263	27.001	3.712	940.122	0.249	0.048	5.513	1.153	0.621	0.088
21000.0	0.261	26.625	3.779	939.795	0.257	0.051	5.561	1.189	0.643	0.093
21500.0	0.259	26.253	3.844	939.468	0.265	0.054	5.607	1.224	0.664	0.099
22000.0	0.258	25.885	3.909	939.139	0.273	0.056	5.651	1.258	0.686	0.105
22500.0	0.256	25.520	3.972	938.810	0.281	0.059	5.693	1.293	0.707	0.111
23000.0	0.254	25.158	4.035	938.479	0.290	0.063	5.733	1.328	0.729	0.118
23500.0	0.252	24.800	4.097	938.148	0.298	0.066	5.772	1.363	0.750	0.124
24000.0	0.251	24.445	4.158	937.815	0.306	0.069	5.810	1.397	0.771	0.131
24500.0	0.249	24.093	4.218	937.481	0.314	0.072	5.846	1.431	0.792	0.138
25000.0	0.247	23.745	4.278	937.147	0.322	0.076	5.880	1.466	0.813	0.145
25500.0	0.245	23.400	4.336	936.810	0.331	0.079	5.913	1.500	0.834	0.152
26000.0	0.244	23.059	4.394	936.473	0.339	0.083	5.944	1.534	0.855	0.160
26500.0	0.242	22.720	4.451	936.135	0.347	0.087	5.975	1.567	0.876	0.167
27000.0	0.240	22.385	4.507	935.795	0.356	0.091	6.004	1.601	0.896	0.175
27500.0	0.239	22.053	4.562	935.454	0.364	0.094	6.031	1.634	0.917	0.183
28000.0	0.237	21.725	4.617	935.112	0.373	0.098	6.058	1.668	0.937	0.191
30000.0	0.230	20.443	4.827	933.730	0.406	0.116	6.152	1.798	1.017	0.225
32500.0	0.222	18.911	5.071	931.972	0.449	0.139	6.247	1.957	1.114	0.272
35000.0	0.214	17.458	5.296	930.182	0.491	0.165	6.317	2.110	1.206	0.323
37500.0	0.206	16.082	5.502	928.359	0.534	0.192	6.367	2.256	1.292	0.377
40000.0	0.198	14.781	5.688	926.502	0.576	0.222	6.399	2.397	1.373	0.435
42500.0	0.191	13.554	5.857	924.611	0.617	0.254	6.414	2.531	1.447	0.497
45000.0	0.183	12.399	6.007	922.685	0.658	0.288	6.417	2.658	1.515	0.562
47500.0	0.176	11.315	6.141	920.725	0.697	0.324	6.407	2.777	1.577	0.629
50000.0	0.169	10.300	6.257	918.729	0.736	0.360	6.388	2.889	1.634	0.700
52500.0	0.163	9.353	6.356	916.700	0.773	0.398	6.361	2.994	1.684	0.772
55000.0	0.156	8.472	6.440	914.635	0.808	0.437	6.327	3.091	1.729	0.847
57500.0	0.150	7.655	6.509	912.537	0.841	0.476	6.289	3.181	1.769	0.925
60000.0	0.144	6.898	6.563	910.406	0.873	0.516	6.246	3.264	1.804	1.003
62500.0	0.138	6.202	6.604	908.241	0.903	0.556	6.201	3.339	1.834	1.084
65000.0	0.133	5.561	6.631	906.045	0.930	0.595	6.154	3.407	1.859	1.166
67500.0	0.127	4.976	6.646	903.818	0.956	0.634	6.106	3.469	1.881	1.249
70000.0	0.122	4.441	6.649	901.562	0.980	0.672	6.058	3.524	1.899	1.333

**Table C.10 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.340	44.968	0.000	954.693	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.339	44.847	0.022	954.644	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.338	44.368	0.111	954.447	0.001	0.000	0.172	0.001	0.000	0.000
1000.0	0.336	43.777	0.221	954.200	0.003	0.000	0.378	0.006	0.000	0.000
1500.0	0.334	43.193	0.329	953.952	0.005	0.000	0.575	0.013	0.001	0.000
2000.0	0.332	42.616	0.435	953.705	0.007	0.000	0.763	0.023	0.002	0.000
2500.0	0.331	42.047	0.540	953.457	0.010	0.000	0.943	0.036	0.004	0.000
3000.0	0.329	41.483	0.643	953.210	0.012	0.000	1.115	0.050	0.006	0.000
3500.0	0.327	40.927	0.745	952.962	0.015	0.000	1.280	0.066	0.009	0.000
4000.0	0.325	40.376	0.845	952.714	0.018	0.001	1.437	0.084	0.013	0.000
4500.0	0.324	39.832	0.945	952.466	0.021	0.001	1.587	0.104	0.018	0.001
5000.0	0.322	39.293	1.042	952.217	0.024	0.001	1.731	0.124	0.024	0.001
5500.0	0.320	38.759	1.139	951.969	0.027	0.001	1.868	0.146	0.031	0.001
6000.0	0.318	38.231	1.234	951.720	0.031	0.001	1.999	0.169	0.038	0.001
6500.0	0.317	37.709	1.328	951.472	0.034	0.002	2.125	0.193	0.046	0.002
7000.0	0.315	37.191	1.421	951.223	0.038	0.002	2.244	0.218	0.055	0.003
7500.0	0.313	36.679	1.513	950.975	0.042	0.002	2.358	0.243	0.065	0.003
8000.0	0.312	36.171	1.604	950.727	0.046	0.003	2.467	0.269	0.076	0.004
8500.0	0.310	35.668	1.693	950.478	0.050	0.003	2.570	0.296	0.087	0.005
9000.0	0.308	35.169	1.782	950.230	0.054	0.004	2.669	0.323	0.098	0.006
9500.0	0.307	34.675	1.869	949.981	0.058	0.004	2.762	0.351	0.111	0.007
10000.0	0.305	34.186	1.955	949.733	0.063	0.005	2.851	0.380	0.124	0.009
10500.0	0.303	33.700	2.040	949.485	0.067	0.005	2.936	0.408	0.137	0.010
11000.0	0.302	33.219	2.124	949.237	0.072	0.006	3.016	0.438	0.151	0.012
11500.0	0.300	32.742	2.208	948.989	0.076	0.007	3.092	0.467	0.165	0.013
12000.0	0.298	32.268	2.290	948.742	0.081	0.007	3.164	0.497	0.179	0.015
12500.0	0.297	31.799	2.371	948.495	0.086	0.008	3.232	0.527	0.194	0.017
13000.0	0.295	31.333	2.451	948.248	0.091	0.009	3.296	0.557	0.209	0.020
13500.0	0.294	30.871	2.530	948.001	0.096	0.010	3.356	0.588	0.224	0.022
14000.0	0.292	30.413	2.609	947.755	0.101	0.011	3.413	0.619	0.240	0.025
14500.0	0.290	29.958	2.686	947.509	0.106	0.011	3.466	0.649	0.255	0.028
15000.0	0.289	29.507	2.763	947.263	0.111	0.012	3.516	0.680	0.271	0.031
15500.0	0.287	29.058	2.838	947.017	0.116	0.013	3.563	0.712	0.287	0.034
16000.0	0.286	28.614	2.913	946.772	0.122	0.014	3.606	0.743	0.302	0.037
16500.0	0.284	28.172	2.987	946.527	0.127	0.015	3.647	0.774	0.318	0.041
17000.0	0.283	27.733	3.060	946.281	0.132	0.017	3.685	0.805	0.334	0.044
17500.0	0.281	27.298	3.133	946.036	0.138	0.018	3.721	0.837	0.350	0.048
18000.0	0.280	26.866	3.204	945.789	0.143	0.019	3.755	0.868	0.366	0.052
18500.0	0.278	26.437	3.275	945.542	0.149	0.020	3.786	0.899	0.382	0.057
19000.0	0.277	26.012	3.345	945.294	0.154	0.021	3.816	0.930	0.398	0.061
19500.0	0.275	25.590	3.414	945.045	0.160	0.023	3.844	0.961	0.414	0.066
20000.0	0.273	25.171	3.483	944.794	0.165	0.024	3.870	0.992	0.430	0.071
20500.0	0.272	24.755	3.550	944.543	0.171	0.026	3.894	1.023	0.447	0.076
21000.0	0.270	24.343	3.617	944.290	0.177	0.027	3.918	1.054	0.463	0.081
22500.0	0.266	23.127	3.814	943.523	0.195	0.032	3.979	1.145	0.511	0.098
25000.0	0.258	21.167	4.125	942.215	0.225	0.041	4.054	1.294	0.592	0.131
27500.0	0.250	19.292	4.417	940.868	0.257	0.052	4.102	1.439	0.669	0.170
30000.0	0.243	17.502	4.690	939.481	0.290	0.065	4.124	1.578	0.742	0.215
32500.0	0.235	15.799	4.943	938.051	0.324	0.079	4.125	1.712	0.809	0.265
35000.0	0.227	14.184	5.176	936.574	0.359	0.095	4.108	1.839	0.870	0.321
37500.0	0.220	12.657	5.390	935.047	0.394	0.112	4.077	1.959	0.924	0.384
40000.0	0.212	11.222	5.584	933.467	0.428	0.131	4.033	2.071	0.972	0.452
42500.0	0.204	9.880	5.758	931.831	0.463	0.152	3.980	2.174	1.012	0.525
45000.0	0.196	8.633	5.911	930.134	0.497	0.173	3.920	2.269	1.046	0.604
47500.0	0.188	7.482	6.043	928.374	0.530	0.196	3.856	2.355	1.074	0.688
50000.0	0.181	6.429	6.155	926.548	0.563	0.220	3.788	2.432	1.095	0.777
52500.0	0.173	5.475	6.246	924.654	0.594	0.243	3.721	2.499	1.110	0.870
55000.0	0.165	4.619	6.317	922.689	0.623	0.268	3.654	2.556	1.120	0.967
57500.0	0.158	3.861	6.368	920.654	0.651	0.291	3.590	2.605	1.126	1.067
60000.0	0.150	3.196	6.401	918.548	0.676	0.315	3.529	2.645	1.128	1.170
62500.0	0.143	2.621	6.415	916.375	0.700	0.337	3.473	2.677	1.128	1.274
65000.0	0.135	2.131	6.412	914.136	0.721	0.358	3.422	2.702	1.125	1.380
67500.0	0.128	1.718	6.395	911.838	0.740	0.378	3.377	2.720	1.120	1.486
70000.0	0.122	1.375	6.364	909.485	0.756	0.396	3.337	2.732	1.114	1.592

**Table C.11 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.340	44.968	0.000	954.693	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.339	44.848	0.023	954.637	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.338	44.370	0.116	954.411	0.002	0.000	0.195	0.001	0.000	0.000
1000.0	0.335	43.782	0.229	954.127	0.004	0.000	0.430	0.006	0.000	0.000
1500.0	0.333	43.202	0.341	953.844	0.006	0.000	0.654	0.015	0.001	0.000
2000.0	0.331	42.630	0.451	953.561	0.009	0.000	0.868	0.026	0.003	0.000
2500.0	0.329	42.066	0.559	953.277	0.012	0.000	1.073	0.040	0.005	0.000
3000.0	0.327	41.510	0.666	952.994	0.015	0.000	1.268	0.056	0.008	0.000
3500.0	0.325	40.960	0.770	952.711	0.018	0.001	1.455	0.074	0.012	0.000
4000.0	0.324	40.418	0.874	952.427	0.021	0.001	1.634	0.094	0.017	0.000
4500.0	0.322	39.882	0.975	952.144	0.025	0.001	1.805	0.115	0.024	0.001
5000.0	0.320	39.353	1.075	951.861	0.029	0.001	1.969	0.138	0.031	0.001
5500.0	0.318	38.829	1.174	951.577	0.033	0.002	2.125	0.161	0.039	0.001
6000.0	0.316	38.312	1.271	951.294	0.037	0.002	2.275	0.186	0.049	0.002
6500.0	0.314	37.800	1.367	951.010	0.041	0.002	2.418	0.212	0.059	0.002
7000.0	0.312	37.294	1.462	950.727	0.046	0.003	2.554	0.238	0.070	0.003
7500.0	0.310	36.794	1.555	950.444	0.050	0.003	2.685	0.266	0.082	0.004
8000.0	0.308	36.299	1.647	950.161	0.055	0.004	2.810	0.294	0.095	0.005
8500.0	0.306	35.809	1.737	949.878	0.060	0.004	2.929	0.322	0.109	0.006
9000.0	0.305	35.324	1.826	949.595	0.065	0.005	3.042	0.351	0.123	0.007
9500.0	0.303	34.844	1.915	949.312	0.070	0.006	3.151	0.381	0.138	0.009
10000.0	0.301	34.368	2.001	949.030	0.075	0.006	3.254	0.411	0.153	0.010
10500.0	0.299	33.897	2.087	948.748	0.081	0.007	3.352	0.441	0.169	0.012
11000.0	0.297	33.431	2.172	948.466	0.086	0.008	3.446	0.472	0.186	0.014
11500.0	0.295	32.969	2.255	948.184	0.092	0.009	3.535	0.504	0.202	0.016
12000.0	0.294	32.512	2.337	947.903	0.098	0.010	3.619	0.535	0.220	0.018
12500.0	0.292	32.058	2.418	947.621	0.103	0.011	3.699	0.567	0.237	0.021
13000.0	0.290	31.609	2.499	947.341	0.109	0.012	3.775	0.599	0.255	0.023
13500.0	0.288	31.164	2.578	947.060	0.115	0.013	3.847	0.631	0.273	0.026
14000.0	0.287	30.722	2.656	946.780	0.121	0.014	3.915	0.664	0.291	0.029
14500.0	0.285	30.285	2.733	946.500	0.127	0.015	3.979	0.696	0.309	0.032
15000.0	0.283	29.851	2.809	946.221	0.133	0.016	4.040	0.729	0.328	0.036
15500.0	0.282	29.421	2.884	945.942	0.139	0.018	4.097	0.762	0.346	0.039
16000.0	0.280	28.994	2.959	945.663	0.146	0.019	4.150	0.795	0.365	0.043
16500.0	0.278	28.571	3.032	945.385	0.152	0.021	4.201	0.828	0.384	0.047
17000.0	0.277	28.151	3.104	945.106	0.158	0.022	4.249	0.861	0.402	0.051
17500.0	0.275	27.734	3.176	944.827	0.164	0.024	4.294	0.894	0.421	0.055
18000.0	0.273	27.321	3.247	944.548	0.171	0.025	4.336	0.927	0.439	0.060
18500.0	0.272	26.912	3.317	944.269	0.177	0.027	4.376	0.960	0.458	0.065
19000.0	0.270	26.505	3.386	943.989	0.184	0.029	4.413	0.993	0.477	0.069
19500.0	0.268	26.102	3.454	943.708	0.190	0.030	4.449	1.026	0.495	0.075
20000.0	0.267	25.703	3.521	943.427	0.197	0.032	4.483	1.058	0.514	0.080
20500.0	0.265	25.306	3.588	943.144	0.203	0.034	4.514	1.091	0.533	0.085
21000.0	0.263	24.913	3.653	942.861	0.210	0.036	4.544	1.123	0.551	0.091
21500.0	0.262	24.524	3.718	942.576	0.217	0.038	4.573	1.156	0.570	0.097
22000.0	0.260	24.138	3.782	942.290	0.224	0.040	4.600	1.188	0.588	0.103
22500.0	0.259	23.755	3.846	942.003	0.230	0.042	4.625	1.220	0.607	0.110
23000.0	0.257	23.376	3.908	941.715	0.237	0.045	4.649	1.252	0.625	0.116
25000.0	0.251	21.892	4.149	940.547	0.266	0.054	4.731	1.377	0.699	0.145
27500.0	0.243	20.114	4.433	939.056	0.302	0.068	4.807	1.529	0.788	0.185
30000.0	0.235	18.420	4.697	937.528	0.340	0.084	4.857	1.676	0.872	0.231
32500.0	0.227	16.809	4.941	935.962	0.378	0.102	4.883	1.816	0.951	0.282
35000.0	0.219	15.281	5.166	934.356	0.416	0.121	4.889	1.950	1.024	0.338
37500.0	0.211	13.836	5.371	932.708	0.454	0.143	4.878	2.077	1.090	0.399
40000.0	0.204	12.475	5.557	931.017	0.492	0.166	4.852	2.196	1.149	0.465
42500.0	0.196	11.197	5.724	929.280	0.529	0.190	4.816	2.307	1.201	0.535
45000.0	0.189	10.001	5.873	927.497	0.566	0.217	4.769	2.410	1.246	0.610
47500.0	0.181	8.889	6.003	925.666	0.602	0.244	4.716	2.505	1.285	0.689
50000.0	0.174	7.858	6.114	923.784	0.636	0.272	4.657	2.590	1.317	0.771
52500.0	0.167	6.910	6.208	921.852	0.669	0.301	4.595	2.668	1.343	0.856
55000.0	0.160	6.042	6.283	919.868	0.701	0.331	4.530	2.736	1.363	0.944
57500.0	0.153	5.253	6.342	917.833	0.731	0.360	4.466	2.797	1.379	1.035
60000.0	0.146	4.542	6.384	915.746	0.759	0.389	4.402	2.849	1.389	1.128
62500.0	0.140	3.904	6.410	913.609	0.785	0.418	4.340	2.893	1.396	1.222
65000.0	0.134	3.337	6.421	911.423	0.809	0.445	4.280	2.930	1.399	1.317
67500.0	0.127	2.838	6.418	909.189	0.830	0.472	4.224	2.960	1.400	1.413
70000.0	0.121	2.400	6.403	906.911	0.850	0.497	4.172	2.984	1.398	1.509

**Table C.12 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.340	44.968	0.000	954.693	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.339	44.848	0.024	954.627	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.337	44.374	0.122	954.362	0.002	0.000	0.226	0.002	0.000	0.000
1000.0	0.335	43.791	0.241	954.030	0.005	0.000	0.498	0.007	0.000	0.000
1500.0	0.332	43.217	0.358	953.699	0.008	0.000	0.758	0.017	0.001	0.000
2000.0	0.330	42.653	0.473	953.367	0.011	0.000	1.006	0.030	0.003	0.000
2500.0	0.328	42.097	0.586	953.035	0.014	0.000	1.243	0.045	0.007	0.000
3000.0	0.325	41.550	0.697	952.704	0.018	0.001	1.470	0.063	0.011	0.000
3500.0	0.323	41.011	0.806	952.373	0.022	0.001	1.688	0.082	0.016	0.000
4000.0	0.321	40.479	0.913	952.042	0.026	0.001	1.896	0.104	0.023	0.001
4500.0	0.319	39.955	1.018	951.710	0.031	0.001	2.096	0.127	0.031	0.001
5000.0	0.316	39.437	1.122	951.379	0.036	0.002	2.288	0.151	0.041	0.001
5500.0	0.314	38.926	1.224	951.048	0.041	0.002	2.472	0.176	0.051	0.002
6000.0	0.312	38.422	1.324	950.717	0.046	0.003	2.648	0.202	0.063	0.002
6500.0	0.310	37.924	1.423	950.386	0.051	0.003	2.817	0.230	0.076	0.003
7000.0	0.308	37.433	1.520	950.055	0.057	0.004	2.980	0.258	0.089	0.004
7500.0	0.305	36.947	1.616	949.724	0.063	0.005	3.136	0.287	0.104	0.005
8000.0	0.303	36.467	1.710	949.393	0.069	0.006	3.285	0.317	0.120	0.006
8500.0	0.301	35.993	1.802	949.063	0.075	0.006	3.428	0.347	0.136	0.007
9000.0	0.299	35.524	1.894	948.733	0.081	0.007	3.566	0.378	0.153	0.009
9500.0	0.297	35.060	1.984	948.402	0.088	0.008	3.698	0.409	0.171	0.010
10000.0	0.295	34.602	2.072	948.072	0.094	0.009	3.824	0.441	0.189	0.012
10500.0	0.293	34.148	2.160	947.743	0.101	0.010	3.945	0.473	0.208	0.014
11000.0	0.291	33.700	2.246	947.413	0.108	0.012	4.061	0.506	0.227	0.016
11500.0	0.289	33.256	2.331	947.084	0.114	0.013	4.171	0.539	0.247	0.019
12000.0	0.287	32.817	2.414	946.755	0.121	0.014	4.278	0.573	0.267	0.021
12500.0	0.285	32.382	2.496	946.426	0.128	0.016	4.379	0.607	0.288	0.024
13000.0	0.283	31.952	2.578	946.097	0.136	0.017	4.476	0.641	0.309	0.027
13500.0	0.281	31.527	2.658	945.769	0.143	0.019	4.568	0.676	0.330	0.030
14000.0	0.279	31.105	2.736	945.441	0.150	0.020	4.657	0.710	0.351	0.033
14500.0	0.277	30.688	2.814	945.114	0.157	0.022	4.741	0.745	0.372	0.036
15000.0	0.275	30.275	2.891	944.787	0.165	0.024	4.821	0.780	0.394	0.040
15500.0	0.273	29.865	2.966	944.460	0.172	0.026	4.898	0.816	0.415	0.044
16000.0	0.271	29.460	3.040	944.133	0.180	0.028	4.970	0.851	0.437	0.048
16500.0	0.270	29.058	3.114	943.807	0.187	0.030	5.040	0.887	0.459	0.052
17000.0	0.268	28.660	3.186	943.480	0.195	0.032	5.106	0.922	0.480	0.056
17500.0	0.266	28.266	3.258	943.154	0.203	0.034	5.169	0.958	0.502	0.061
18000.0	0.264	27.876	3.328	942.827	0.211	0.036	5.229	0.994	0.524	0.066
18500.0	0.262	27.489	3.397	942.501	0.218	0.039	5.286	1.029	0.546	0.071
19000.0	0.260	27.106	3.466	942.174	0.226	0.041	5.340	1.065	0.567	0.076
19500.0	0.259	26.726	3.533	941.846	0.234	0.044	5.392	1.101	0.589	0.081
20000.0	0.257	26.349	3.600	941.519	0.242	0.046	5.442	1.137	0.611	0.086
20500.0	0.255	25.976	3.666	941.191	0.250	0.049	5.489	1.172	0.632	0.092
21000.0	0.253	25.607	3.731	940.862	0.258	0.052	5.534	1.208	0.654	0.098
21500.0	0.252	25.241	3.794	940.532	0.266	0.054	5.577	1.243	0.675	0.104
22000.0	0.250	24.878	3.858	940.202	0.274	0.057	5.618	1.278	0.696	0.110
22500.0	0.248	24.519	3.920	939.871	0.282	0.060	5.657	1.314	0.718	0.117
23000.0	0.246	24.163	3.981	939.539	0.290	0.063	5.695	1.349	0.739	0.123
23500.0	0.245	23.810	4.042	939.206	0.298	0.067	5.730	1.384	0.760	0.130
24000.0	0.243	23.461	4.101	938.872	0.306	0.070	5.765	1.419	0.781	0.137
24500.0	0.241	23.115	4.160	938.537	0.314	0.073	5.797	1.453	0.802	0.144
25000.0	0.240	22.772	4.218	938.200	0.322	0.077	5.829	1.488	0.823	0.152
25500.0	0.238	22.433	4.275	937.862	0.330	0.080	5.859	1.522	0.844	0.159
26000.0	0.236	22.097	4.332	937.524	0.339	0.084	5.887	1.556	0.864	0.167
26500.0	0.234	21.764	4.387	937.183	0.347	0.088	5.914	1.590	0.885	0.175
27000.0	0.233	21.435	4.442	936.842	0.355	0.092	5.940	1.624	0.905	0.183
27500.0	0.231	21.109	4.496	936.499	0.363	0.096	5.965	1.658	0.925	0.191
30000.0	0.223	19.527	4.753	934.766	0.405	0.117	6.073	1.821	1.025	0.235
32500.0	0.215	18.026	4.990	932.999	0.447	0.140	6.155	1.979	1.120	0.283
35000.0	0.207	16.603	5.208	931.198	0.489	0.166	6.215	2.131	1.210	0.336
37500.0	0.199	15.258	5.406	929.363	0.531	0.193	6.254	2.277	1.294	0.392
40000.0	0.192	13.988	5.586	927.494	0.572	0.223	6.277	2.416	1.372	0.452
42500.0	0.184	12.793	5.747	925.589	0.613	0.255	6.284	2.547	1.444	0.515
45000.0	0.177	11.671	5.890	923.649	0.653	0.288	6.279	2.672	1.510	0.582
47500.0	0.170	10.620	6.016	921.674	0.691	0.323	6.264	2.788	1.569	0.651
50000.0	0.163	9.639	6.125	919.663	0.729	0.360	6.239	2.898	1.623	0.723
52500.0	0.157	8.725	6.218	917.616	0.764	0.397	6.207	2.999	1.670	0.798
55000.0	0.151	7.878	6.295	915.535	0.799	0.435	6.170	3.093	1.713	0.875
57500.0	0.145	7.093	6.357	913.419	0.831	0.474	6.128	3.179	1.749	0.953
60000.0	0.139	6.371	6.405	911.269	0.862	0.512	6.083	3.258	1.781	1.034
62500.0	0.133	5.707	6.439	909.086	0.890	0.551	6.036	3.329	1.809	1.116
65000.0	0.128	5.099	6.460	906.870	0.917	0.589	5.988	3.393	1.832	1.199
67500.0	0.122	4.545	6.470	904.625	0.942	0.627	5.940	3.451	1.851	1.284
70000.0	0.117	4.042	6.467	902.349	0.964	0.663	5.891	3.502	1.867	1.369

**Table C.13 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.337	44.567	0.000	955.096	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.336	44.447	0.022	955.049	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.335	43.968	0.110	954.856	0.001	0.000	0.164	0.001	0.000	0.000
1000.0	0.333	43.375	0.219	954.616	0.003	0.000	0.365	0.005	0.000	0.000
1500.0	0.332	42.791	0.326	954.375	0.005	0.000	0.558	0.013	0.001	0.000
2000.0	0.330	42.213	0.431	954.134	0.007	0.000	0.742	0.023	0.002	0.000
2500.0	0.328	41.642	0.535	953.893	0.009	0.000	0.917	0.035	0.003	0.000
3000.0	0.326	41.078	0.638	953.652	0.012	0.000	1.085	0.049	0.006	0.000
3500.0	0.325	40.520	0.739	953.411	0.014	0.000	1.245	0.065	0.009	0.000
4000.0	0.323	39.968	0.839	953.170	0.017	0.001	1.398	0.083	0.013	0.000
4500.0	0.321	39.422	0.937	952.929	0.020	0.001	1.544	0.102	0.017	0.000
5000.0	0.320	38.881	1.035	952.687	0.023	0.001	1.684	0.122	0.023	0.001
5500.0	0.318	38.346	1.131	952.446	0.026	0.001	1.817	0.144	0.029	0.001
6000.0	0.316	37.816	1.225	952.205	0.029	0.001	1.944	0.166	0.036	0.001
6500.0	0.315	37.292	1.319	951.964	0.033	0.002	2.065	0.190	0.044	0.002
7000.0	0.313	36.772	1.411	951.723	0.036	0.002	2.180	0.215	0.053	0.002
7500.0	0.311	36.257	1.502	951.481	0.040	0.002	2.290	0.240	0.062	0.003
8000.0	0.310	35.747	1.593	951.241	0.044	0.003	2.395	0.266	0.072	0.004
8500.0	0.308	35.242	1.682	951.000	0.048	0.003	2.494	0.292	0.083	0.005
9000.0	0.306	34.741	1.769	950.759	0.052	0.003	2.589	0.319	0.094	0.006
9500.0	0.305	34.244	1.856	950.519	0.056	0.004	2.678	0.347	0.106	0.007
10000.0	0.303	33.752	1.942	950.279	0.060	0.004	2.764	0.375	0.118	0.008
10500.0	0.302	33.264	2.027	950.039	0.064	0.005	2.844	0.404	0.131	0.010
11000.0	0.300	32.780	2.111	949.799	0.068	0.006	2.920	0.433	0.144	0.011
11500.0	0.298	32.299	2.194	949.560	0.073	0.006	2.992	0.462	0.158	0.013
12000.0	0.297	31.823	2.275	949.321	0.077	0.007	3.060	0.492	0.172	0.015
12500.0	0.295	31.351	2.356	949.082	0.082	0.008	3.124	0.521	0.186	0.017
13000.0	0.294	30.882	2.436	948.844	0.087	0.008	3.184	0.552	0.200	0.019
13500.0	0.292	30.416	2.515	948.606	0.091	0.009	3.240	0.582	0.215	0.021
14000.0	0.291	29.954	2.593	948.369	0.096	0.010	3.293	0.612	0.230	0.024
14500.0	0.289	29.495	2.671	948.132	0.101	0.011	3.342	0.643	0.244	0.027
15000.0	0.288	29.040	2.747	947.896	0.106	0.011	3.387	0.674	0.259	0.030
15500.0	0.286	28.588	2.822	947.660	0.111	0.012	3.430	0.705	0.274	0.033
16000.0	0.285	28.139	2.897	947.424	0.116	0.013	3.470	0.736	0.290	0.036
16500.0	0.283	27.693	2.971	947.189	0.121	0.014	3.507	0.767	0.305	0.039
17000.0	0.282	27.250	3.044	946.952	0.126	0.015	3.541	0.798	0.320	0.043
17500.0	0.280	26.810	3.117	946.715	0.131	0.016	3.574	0.829	0.335	0.047
18000.0	0.279	26.374	3.188	946.478	0.136	0.017	3.604	0.860	0.350	0.051
18500.0	0.277	25.941	3.259	946.239	0.141	0.019	3.633	0.891	0.366	0.055
19000.0	0.276	25.511	3.329	946.000	0.146	0.020	3.659	0.922	0.381	0.059
19500.0	0.274	25.085	3.399	945.759	0.152	0.021	3.684	0.952	0.397	0.064
20000.0	0.273	24.661	3.467	945.517	0.157	0.022	3.708	0.983	0.412	0.068
20500.0	0.271	24.241	3.535	945.274	0.163	0.024	3.730	1.014	0.428	0.073
21000.0	0.270	23.825	3.602	945.030	0.168	0.025	3.750	1.044	0.444	0.079
22500.0	0.265	22.595	3.799	944.287	0.185	0.030	3.803	1.135	0.490	0.096
25000.0	0.258	20.612	4.111	943.020	0.214	0.038	3.868	1.282	0.568	0.128
27500.0	0.250	18.715	4.404	941.713	0.245	0.048	3.904	1.425	0.642	0.167
30000.0	0.243	16.904	4.678	940.363	0.277	0.060	3.917	1.563	0.711	0.211
32500.0	0.235	15.180	4.933	938.967	0.309	0.073	3.909	1.695	0.775	0.262
35000.0	0.227	13.547	5.167	937.522	0.342	0.088	3.885	1.821	0.832	0.319
37500.0	0.219	12.005	5.382	936.024	0.376	0.104	3.847	1.938	0.883	0.382
40000.0	0.212	10.559	5.576	934.468	0.409	0.122	3.798	2.048	0.927	0.451
42500.0	0.204	9.210	5.749	932.850	0.443	0.141	3.741	2.150	0.964	0.526
45000.0	0.196	7.961	5.901	931.166	0.476	0.161	3.678	2.242	0.994	0.607
47500.0	0.188	6.816	6.031	929.412	0.508	0.182	3.611	2.325	1.018	0.694
50000.0	0.180	5.777	6.140	927.584	0.539	0.204	3.544	2.398	1.036	0.785
52500.0	0.172	4.843	6.227	925.679	0.569	0.227	3.477	2.462	1.048	0.882
55000.0	0.164	4.015	6.293	923.696	0.598	0.249	3.412	2.515	1.055	0.983
57500.0	0.156	3.292	6.337	921.634	0.624	0.271	3.351	2.560	1.059	1.087
60000.0	0.148	2.669	6.362	919.495	0.648	0.293	3.295	2.596	1.059	1.194
62500.0	0.141	2.142	6.368	917.283	0.670	0.313	3.244	2.623	1.057	1.303
65000.0	0.133	1.701	6.358	915.001	0.690	0.332	3.199	2.644	1.053	1.412
67500.0	0.126	1.340	6.332	912.656	0.707	0.350	3.160	2.658	1.048	1.523
70000.0	0.119	1.047	6.293	910.257	0.722	0.366	3.126	2.668	1.042	1.632

**Table C.14 [Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.337	44.567	0.000	955.096	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.336	44.447	0.023	955.041	0.000	0.000	0.017	0.000	0.000	0.000
500.0	0.335	43.969	0.115	954.820	0.002	0.000	0.187	0.001	0.000	0.000
1000.0	0.333	43.380	0.227	954.544	0.004	0.000	0.417	0.006	0.000	0.000
1500.0	0.331	42.799	0.338	954.267	0.006	0.000	0.637	0.015	0.001	0.000
2000.0	0.329	42.226	0.447	953.991	0.008	0.000	0.846	0.026	0.002	0.000
2500.0	0.327	41.661	0.555	953.714	0.011	0.000	1.046	0.039	0.005	0.000
3000.0	0.325	41.103	0.660	953.438	0.014	0.000	1.237	0.055	0.008	0.000
3500.0	0.323	40.552	0.764	953.162	0.017	0.001	1.420	0.073	0.012	0.000
4000.0	0.321	40.008	0.867	952.886	0.020	0.001	1.594	0.093	0.017	0.000
4500.0	0.319	39.471	0.968	952.610	0.024	0.001	1.761	0.114	0.023	0.001
5000.0	0.317	38.939	1.067	952.333	0.028	0.001	1.920	0.136	0.030	0.001
5500.0	0.316	38.414	1.165	952.058	0.031	0.002	2.072	0.159	0.038	0.001
6000.0	0.314	37.895	1.262	951.782	0.035	0.002	2.217	0.184	0.047	0.002
6500.0	0.312	37.382	1.357	951.506	0.039	0.002	2.356	0.209	0.057	0.002
7000.0	0.310	36.874	1.451	951.231	0.044	0.003	2.488	0.236	0.068	0.003
7500.0	0.308	36.371	1.543	950.956	0.048	0.003	2.614	0.263	0.079	0.004
8000.0	0.306	35.874	1.634	950.680	0.053	0.004	2.734	0.291	0.092	0.005
8500.0	0.305	35.381	1.724	950.406	0.057	0.004	2.848	0.319	0.105	0.006
9000.0	0.303	34.894	1.813	950.131	0.062	0.005	2.957	0.348	0.119	0.007
9500.0	0.301	34.411	1.901	949.857	0.067	0.005	3.061	0.378	0.133	0.008
10000.0	0.299	33.933	1.987	949.583	0.072	0.006	3.160	0.408	0.148	0.010
10500.0	0.297	33.460	2.072	949.310	0.077	0.007	3.253	0.438	0.163	0.012
11000.0	0.296	32.991	2.156	949.037	0.083	0.007	3.342	0.469	0.179	0.014
11500.0	0.294	32.526	2.239	948.764	0.088	0.008	3.426	0.500	0.196	0.016
12000.0	0.292	32.066	2.321	948.492	0.093	0.009	3.506	0.531	0.212	0.018
12500.0	0.291	31.609	2.402	948.220	0.099	0.010	3.581	0.563	0.229	0.020
13000.0	0.289	31.157	2.482	947.948	0.104	0.011	3.652	0.595	0.247	0.023
13500.0	0.287	30.708	2.560	947.678	0.110	0.012	3.719	0.627	0.264	0.025
14000.0	0.285	30.264	2.638	947.407	0.116	0.013	3.782	0.659	0.282	0.028
14500.0	0.284	29.823	2.715	947.138	0.122	0.014	3.841	0.692	0.299	0.031
15000.0	0.282	29.385	2.791	946.869	0.127	0.015	3.897	0.724	0.317	0.035
15500.0	0.281	28.951	2.866	946.600	0.133	0.017	3.949	0.757	0.335	0.038
16000.0	0.279	28.520	2.940	946.331	0.139	0.018	3.998	0.790	0.353	0.042
16500.0	0.277	28.093	3.013	946.063	0.145	0.019	4.043	0.822	0.371	0.046
17000.0	0.276	27.669	3.085	945.795	0.151	0.020	4.086	0.855	0.389	0.050
17500.0	0.274	27.248	3.157	945.527	0.157	0.022	4.126	0.888	0.407	0.054
18000.0	0.272	26.831	3.228	945.258	0.163	0.023	4.164	0.921	0.425	0.059
18500.0	0.271	26.417	3.297	944.989	0.169	0.025	4.199	0.953	0.443	0.063
19000.0	0.269	26.006	3.366	944.720	0.175	0.026	4.233	0.986	0.461	0.068
19500.0	0.268	25.599	3.434	944.449	0.181	0.028	4.264	1.018	0.479	0.073
20000.0	0.266	25.195	3.502	944.177	0.187	0.030	4.294	1.051	0.497	0.078
20500.0	0.264	24.794	3.568	943.904	0.194	0.032	4.322	1.083	0.515	0.084
21000.0	0.263	24.397	3.634	943.631	0.200	0.033	4.348	1.115	0.533	0.090
21500.0	0.261	24.003	3.699	943.355	0.207	0.035	4.373	1.147	0.551	0.096
22000.0	0.260	23.612	3.763	943.079	0.213	0.037	4.396	1.179	0.568	0.102
22500.0	0.258	23.225	3.826	942.801	0.220	0.039	4.418	1.210	0.586	0.108
25000.0	0.250	21.340	4.131	941.392	0.253	0.050	4.508	1.365	0.675	0.143
27500.0	0.242	19.539	4.415	939.945	0.289	0.063	4.568	1.515	0.761	0.183
30000.0	0.235	17.823	4.679	938.461	0.325	0.078	4.603	1.659	0.842	0.230
32500.0	0.227	16.192	4.924	936.938	0.361	0.094	4.615	1.796	0.917	0.281
35000.0	0.219	14.645	5.150	935.372	0.398	0.112	4.609	1.927	0.985	0.338
37500.0	0.211	13.183	5.355	933.761	0.435	0.132	4.586	2.051	1.047	0.401
40000.0	0.204	11.807	5.542	932.105	0.472	0.154	4.551	2.167	1.101	0.468
42500.0	0.196	10.518	5.709	930.399	0.508	0.177	4.505	2.274	1.149	0.540
45000.0	0.189	9.315	5.857	928.642	0.543	0.201	4.451	2.373	1.189	0.617
47500.0	0.181	8.200	5.985	926.831	0.578	0.227	4.391	2.463	1.222	0.698
50000.0	0.174	7.172	6.095	924.966	0.612	0.253	4.327	2.544	1.249	0.783
52500.0	0.167	6.232	6.185	923.044	0.644	0.280	4.260	2.616	1.270	0.872
55000.0	0.159	5.378	6.257	921.064	0.674	0.307	4.193	2.679	1.286	0.964
57500.0	0.152	4.608	6.311	919.025	0.703	0.335	4.127	2.733	1.296	1.058
60000.0	0.145	3.921	6.348	916.930	0.730	0.361	4.063	2.779	1.302	1.155
62500.0	0.139	3.314	6.368	914.778	0.755	0.387	4.002	2.817	1.305	1.253
65000.0	0.132	2.782	6.373	912.571	0.777	0.412	3.945	2.847	1.305	1.352
67500.0	0.126	2.320	6.363	910.312	0.797	0.436	3.892	2.871	1.302	1.452
70000.0	0.119	1.924	6.340	908.005	0.815	0.458	3.843	2.889	1.297	1.552

**Table C.15 [Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.337	44.567	0.000	955.096	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.336	44.448	0.024	955.032	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.334	43.973	0.121	954.771	0.002	0.000	0.218	0.002	0.000	0.000
1000.0	0.332	43.388	0.239	954.446	0.005	0.000	0.485	0.007	0.000	0.000
1500.0	0.330	42.813	0.356	954.121	0.007	0.000	0.741	0.017	0.001	0.000
2000.0	0.327	42.248	0.470	953.796	0.010	0.000	0.985	0.029	0.003	0.000
2500.0	0.325	41.690	0.582	953.471	0.014	0.000	1.218	0.045	0.006	0.000
3000.0	0.323	41.142	0.692	953.147	0.017	0.001	1.441	0.062	0.011	0.000
3500.0	0.321	40.601	0.800	952.822	0.021	0.001	1.654	0.082	0.016	0.000
4000.0	0.319	40.068	0.906	952.498	0.026	0.001	1.858	0.103	0.023	0.001
4500.0	0.316	39.542	1.011	952.174	0.030	0.001	2.053	0.126	0.031	0.001
5000.0	0.314	39.022	1.114	951.850	0.034	0.002	2.240	0.150	0.040	0.001
5500.0	0.312	38.510	1.215	951.527	0.039	0.002	2.419	0.175	0.050	0.002
6000.0	0.310	38.004	1.315	951.203	0.044	0.003	2.591	0.202	0.062	0.002
6500.0	0.308	37.505	1.413	950.880	0.050	0.003	2.755	0.229	0.074	0.003
7000.0	0.306	37.011	1.510	950.557	0.055	0.004	2.913	0.257	0.088	0.004
7500.0	0.304	36.524	1.604	950.234	0.061	0.004	3.063	0.286	0.102	0.005
8000.0	0.301	36.042	1.698	949.911	0.066	0.005	3.207	0.316	0.117	0.006
8500.0	0.299	35.566	1.790	949.589	0.072	0.006	3.346	0.346	0.134	0.007
9000.0	0.297	35.095	1.881	949.267	0.078	0.007	3.478	0.377	0.150	0.009
9500.0	0.295	34.629	1.970	948.945	0.085	0.008	3.604	0.408	0.168	0.010
10000.0	0.293	34.169	2.058	948.624	0.091	0.009	3.725	0.440	0.186	0.012
10500.0	0.291	33.713	2.145	948.303	0.097	0.010	3.840	0.472	0.205	0.014
11000.0	0.289	33.263	2.230	947.982	0.104	0.011	3.950	0.505	0.224	0.016
11500.0	0.287	32.817	2.315	947.662	0.110	0.012	4.055	0.538	0.243	0.018
12000.0	0.285	32.375	2.398	947.342	0.117	0.013	4.156	0.572	0.263	0.021
12500.0	0.283	31.939	2.480	947.022	0.124	0.015	4.251	0.605	0.283	0.024
13000.0	0.282	31.506	2.560	946.703	0.131	0.016	4.342	0.640	0.304	0.026
13500.0	0.280	31.078	2.640	946.385	0.138	0.018	4.429	0.674	0.325	0.029
14000.0	0.278	30.654	2.718	946.067	0.145	0.019	4.511	0.708	0.345	0.033
14500.0	0.276	30.234	2.795	945.750	0.152	0.021	4.589	0.743	0.366	0.036
15000.0	0.274	29.818	2.871	945.433	0.159	0.022	4.663	0.778	0.388	0.040
15500.0	0.272	29.406	2.946	945.116	0.166	0.024	4.733	0.813	0.409	0.044
16000.0	0.270	28.998	3.020	944.800	0.173	0.026	4.800	0.849	0.430	0.048
16500.0	0.269	28.594	3.093	944.484	0.181	0.028	4.863	0.884	0.451	0.052
17000.0	0.267	28.193	3.165	944.168	0.188	0.030	4.923	0.919	0.473	0.056
17500.0	0.265	27.796	3.236	943.853	0.195	0.032	4.979	0.955	0.494	0.061
18000.0	0.263	27.402	3.306	943.537	0.203	0.034	5.033	0.990	0.515	0.066
18500.0	0.261	27.012	3.375	943.221	0.210	0.036	5.084	1.026	0.536	0.071
19000.0	0.260	26.625	3.443	942.906	0.218	0.038	5.132	1.061	0.557	0.076
19500.0	0.258	26.242	3.511	942.589	0.225	0.041	5.178	1.097	0.578	0.081
20000.0	0.256	25.862	3.577	942.273	0.233	0.043	5.221	1.132	0.599	0.087
20500.0	0.254	25.486	3.642	941.956	0.241	0.046	5.263	1.167	0.620	0.092
21000.0	0.253	25.112	3.707	941.638	0.248	0.048	5.302	1.202	0.641	0.098
21500.0	0.251	24.743	3.771	941.319	0.256	0.051	5.339	1.237	0.662	0.105
22000.0	0.249	24.377	3.834	941.000	0.264	0.054	5.375	1.272	0.683	0.111
22500.0	0.248	24.014	3.896	940.679	0.271	0.057	5.408	1.307	0.704	0.117
23000.0	0.246	23.654	3.957	940.358	0.279	0.059	5.441	1.341	0.724	0.124
23500.0	0.244	23.298	4.017	940.035	0.287	0.062	5.471	1.376	0.745	0.131
24000.0	0.243	22.945	4.077	939.711	0.295	0.066	5.500	1.410	0.766	0.138
24500.0	0.241	22.596	4.135	939.386	0.303	0.069	5.528	1.444	0.786	0.145
25000.0	0.239	22.249	4.193	939.060	0.311	0.072	5.554	1.478	0.806	0.153
25500.0	0.238	21.907	4.250	938.732	0.318	0.075	5.579	1.512	0.827	0.161
26000.0	0.236	21.567	4.306	938.404	0.326	0.079	5.603	1.545	0.847	0.168
26500.0	0.234	21.231	4.362	938.074	0.334	0.082	5.626	1.578	0.867	0.176
27500.0	0.231	20.568	4.470	937.409	0.350	0.089	5.667	1.644	0.906	0.193
30000.0	0.223	18.969	4.727	935.725	0.391	0.109	5.753	1.804	1.003	0.238
32500.0	0.215	17.451	4.964	934.006	0.432	0.131	5.813	1.958	1.094	0.287
35000.0	0.207	16.013	5.181	932.252	0.473	0.155	5.852	2.105	1.180	0.341
37500.0	0.199	14.653	5.379	930.462	0.513	0.181	5.873	2.246	1.260	0.399
40000.0	0.192	13.371	5.558	928.635	0.554	0.209	5.877	2.379	1.333	0.461
42500.0	0.184	12.165	5.718	926.772	0.593	0.239	5.867	2.505	1.399	0.527
45000.0	0.177	11.035	5.860	924.870	0.632	0.271	5.846	2.623	1.459	0.596
47500.0	0.170	9.978	5.985	922.930	0.670	0.303	5.815	2.733	1.513	0.668
50000.0	0.163	8.994	6.092	920.952	0.707	0.337	5.777	2.835	1.560	0.743
52500.0	0.157	8.080	6.182	918.935	0.742	0.372	5.733	2.928	1.601	0.821
55000.0	0.150	7.235	6.257	916.879	0.775	0.408	5.684	3.014	1.636	0.901
57500.0	0.144	6.457	6.316	914.785	0.807	0.444	5.632	3.092	1.666	0.984
60000.0	0.138	5.744	6.360	912.654	0.837	0.480	5.578	3.162	1.691	1.068
62500.0	0.132	5.093	6.390	910.485	0.864	0.516	5.523	3.224	1.712	1.153
65000.0	0.127	4.501	6.407	908.281	0.890	0.551	5.469	3.279	1.728	1.240
67500.0	0.121	3.966	6.411	906.042	0.914	0.585	5.415	3.327	1.741	1.328
70000.0	0.116	3.484	6.404	903.771	0.935	0.619	5.362	3.369	1.750	1.416

**Table C.16 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.332	43.982	0.000	955.686	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.332	43.862	0.022	955.639	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.331	43.383	0.109	955.450	0.001	0.000	0.161	0.001	0.000	0.000
1000.0	0.329	42.791	0.217	955.214	0.003	0.000	0.358	0.005	0.000	0.000
1500.0	0.327	42.207	0.323	954.978	0.005	0.000	0.547	0.013	0.001	0.000
2000.0	0.326	41.629	0.428	954.741	0.007	0.000	0.727	0.022	0.002	0.000
2500.0	0.324	41.059	0.531	954.505	0.009	0.000	0.899	0.034	0.003	0.000
3000.0	0.322	40.494	0.633	954.268	0.012	0.000	1.063	0.049	0.006	0.000
3500.0	0.321	39.936	0.733	954.032	0.014	0.000	1.220	0.064	0.009	0.000
4000.0	0.319	39.384	0.832	953.795	0.017	0.001	1.369	0.082	0.012	0.000
4500.0	0.317	38.838	0.930	953.558	0.020	0.001	1.512	0.101	0.017	0.000
5000.0	0.316	38.298	1.027	953.321	0.023	0.001	1.648	0.121	0.022	0.001
5500.0	0.314	37.762	1.122	953.085	0.026	0.001	1.777	0.143	0.028	0.001
6000.0	0.312	37.232	1.216	952.848	0.029	0.001	1.901	0.166	0.035	0.001
6500.0	0.311	36.708	1.309	952.611	0.032	0.002	2.019	0.189	0.043	0.002
7000.0	0.309	36.188	1.400	952.375	0.036	0.002	2.131	0.213	0.051	0.002
7500.0	0.308	35.673	1.491	952.139	0.039	0.002	2.237	0.239	0.060	0.003
8000.0	0.306	35.162	1.581	951.902	0.043	0.003	2.339	0.264	0.070	0.004
8500.0	0.304	34.656	1.669	951.666	0.047	0.003	2.435	0.291	0.081	0.005
9000.0	0.303	34.155	1.756	951.431	0.050	0.003	2.526	0.318	0.092	0.006
9500.0	0.301	33.658	1.843	951.195	0.054	0.004	2.613	0.346	0.103	0.007
10000.0	0.300	33.165	1.928	950.960	0.058	0.004	2.694	0.374	0.115	0.008
10500.0	0.298	32.676	2.012	950.725	0.063	0.005	2.772	0.402	0.127	0.010
11000.0	0.297	32.191	2.096	950.490	0.067	0.005	2.845	0.431	0.140	0.011
11500.0	0.295	31.710	2.178	950.256	0.071	0.006	2.914	0.460	0.153	0.013
12000.0	0.294	31.233	2.259	950.022	0.075	0.007	2.979	0.490	0.167	0.015
12500.0	0.292	30.759	2.340	949.788	0.080	0.007	3.039	0.520	0.181	0.017
13000.0	0.290	30.289	2.419	949.555	0.084	0.008	3.096	0.550	0.194	0.019
13500.0	0.289	29.822	2.498	949.323	0.089	0.009	3.149	0.580	0.209	0.021
14000.0	0.287	29.359	2.575	949.091	0.093	0.009	3.199	0.610	0.223	0.024
14500.0	0.286	28.899	2.652	948.860	0.098	0.010	3.245	0.641	0.237	0.026
15000.0	0.284	28.442	2.728	948.629	0.103	0.011	3.288	0.672	0.251	0.029
15500.0	0.283	27.989	2.804	948.398	0.108	0.012	3.328	0.703	0.266	0.032
16000.0	0.282	27.538	2.878	948.167	0.112	0.013	3.366	0.733	0.281	0.035
16500.0	0.280	27.091	2.952	947.936	0.117	0.014	3.401	0.764	0.295	0.039
17000.0	0.279	26.647	3.024	947.703	0.122	0.015	3.434	0.795	0.310	0.042
17500.0	0.277	26.206	3.097	947.471	0.127	0.016	3.464	0.826	0.325	0.046
18000.0	0.276	25.768	3.168	947.237	0.132	0.017	3.493	0.857	0.340	0.050
18500.0	0.274	25.334	3.238	947.002	0.137	0.018	3.520	0.887	0.355	0.054
19000.0	0.273	24.903	3.308	946.766	0.142	0.019	3.545	0.918	0.370	0.059
19500.0	0.271	24.475	3.377	946.529	0.147	0.020	3.568	0.949	0.385	0.063
20000.0	0.270	24.051	3.446	946.291	0.153	0.022	3.590	0.979	0.400	0.068
20500.0	0.268	23.630	3.513	946.051	0.158	0.023	3.611	1.010	0.415	0.073
21000.0	0.267	23.212	3.580	945.811	0.163	0.024	3.630	1.040	0.430	0.078
22500.0	0.262	21.979	3.776	945.078	0.180	0.029	3.679	1.130	0.476	0.095
25000.0	0.255	19.993	4.087	943.826	0.208	0.037	3.737	1.277	0.551	0.128
27500.0	0.247	18.092	4.379	942.533	0.238	0.047	3.767	1.420	0.622	0.167
30000.0	0.240	16.279	4.652	941.196	0.269	0.058	3.775	1.557	0.689	0.212
32500.0	0.232	14.556	4.905	939.810	0.301	0.071	3.763	1.689	0.750	0.263
35000.0	0.225	12.925	5.138	938.372	0.333	0.085	3.734	1.814	0.805	0.320
37500.0	0.217	11.390	5.350	936.877	0.366	0.101	3.693	1.931	0.853	0.384
40000.0	0.209	9.953	5.542	935.320	0.399	0.118	3.642	2.040	0.895	0.455
42500.0	0.201	8.618	5.712	933.697	0.431	0.136	3.583	2.140	0.929	0.531
45000.0	0.193	7.388	5.860	932.004	0.463	0.156	3.519	2.231	0.957	0.614
47500.0	0.185	6.266	5.985	930.234	0.495	0.176	3.453	2.312	0.978	0.703
50000.0	0.177	5.254	6.089	928.386	0.525	0.198	3.387	2.384	0.994	0.797
52500.0	0.169	4.354	6.170	926.455	0.554	0.219	3.322	2.445	1.005	0.896
55000.0	0.161	3.564	6.229	924.441	0.581	0.240	3.260	2.496	1.011	0.999
57500.0	0.153	2.882	6.267	922.344	0.607	0.261	3.203	2.538	1.013	1.106
60000.0	0.145	2.304	6.284	920.167	0.630	0.282	3.151	2.572	1.012	1.216
62500.0	0.137	1.821	6.284	917.915	0.651	0.301	3.105	2.597	1.010	1.327
65000.0	0.130	1.425	6.266	915.593	0.669	0.318	3.065	2.615	1.006	1.440
67500.0	0.122	1.105	6.235	913.209	0.685	0.334	3.030	2.628	1.001	1.552
70000.0	0.115	0.851	6.191	910.774	0.699	0.349	3.001	2.636	0.996	1.663

**Table C.17 [Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.332	43.982	0.000	955.686	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.332	43.862	0.023	955.632	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.330	43.385	0.114	955.414	0.002	0.000	0.185	0.001	0.000	0.000
1000.0	0.328	42.796	0.226	955.141	0.004	0.000	0.411	0.006	0.000	0.000
1500.0	0.327	42.215	0.336	954.868	0.006	0.000	0.628	0.015	0.001	0.000
2000.0	0.325	41.643	0.444	954.595	0.008	0.000	0.834	0.026	0.002	0.000
2500.0	0.323	41.078	0.550	954.322	0.011	0.000	1.031	0.039	0.004	0.000
3000.0	0.321	40.521	0.655	954.049	0.014	0.000	1.219	0.055	0.008	0.000
3500.0	0.319	39.971	0.758	953.777	0.017	0.001	1.398	0.073	0.011	0.000
4000.0	0.317	39.427	0.860	953.504	0.020	0.001	1.569	0.092	0.016	0.000
4500.0	0.315	38.890	0.960	953.232	0.024	0.001	1.732	0.113	0.022	0.001
5000.0	0.313	38.359	1.059	952.960	0.027	0.001	1.888	0.136	0.029	0.001
5500.0	0.312	37.834	1.156	952.688	0.031	0.001	2.037	0.159	0.037	0.001
6000.0	0.310	37.316	1.252	952.416	0.035	0.002	2.178	0.184	0.046	0.002
6500.0	0.308	36.802	1.346	952.144	0.039	0.002	2.314	0.209	0.056	0.002
7000.0	0.306	36.295	1.439	951.873	0.043	0.003	2.442	0.236	0.067	0.003
7500.0	0.304	35.792	1.531	951.601	0.047	0.003	2.565	0.263	0.078	0.004
8000.0	0.303	35.295	1.622	951.331	0.052	0.003	2.682	0.291	0.090	0.005
8500.0	0.301	34.803	1.711	951.060	0.056	0.004	2.793	0.319	0.103	0.006
9000.0	0.299	34.315	1.799	950.790	0.061	0.005	2.899	0.348	0.117	0.007
9500.0	0.297	33.833	1.886	950.520	0.066	0.005	2.999	0.378	0.131	0.008
10000.0	0.296	33.355	1.972	950.250	0.071	0.006	3.094	0.408	0.146	0.010
10500.0	0.294	32.882	2.056	949.981	0.076	0.007	3.185	0.438	0.161	0.012
11000.0	0.292	32.412	2.140	949.712	0.081	0.007	3.270	0.469	0.176	0.014
11500.0	0.291	31.948	2.222	949.444	0.086	0.008	3.351	0.500	0.192	0.016
12000.0	0.289	31.487	2.303	949.177	0.092	0.009	3.427	0.531	0.209	0.018
12500.0	0.287	31.030	2.383	948.909	0.097	0.010	3.499	0.563	0.225	0.020
13000.0	0.285	30.578	2.463	948.643	0.102	0.011	3.567	0.595	0.242	0.023
13500.0	0.284	30.129	2.541	948.377	0.108	0.012	3.631	0.627	0.259	0.025
14000.0	0.282	29.683	2.618	948.112	0.113	0.013	3.690	0.659	0.276	0.028
14500.0	0.281	29.242	2.694	947.847	0.119	0.014	3.746	0.692	0.294	0.031
15000.0	0.279	28.804	2.770	947.583	0.125	0.015	3.799	0.724	0.311	0.035
15500.0	0.277	28.369	2.844	947.319	0.130	0.016	3.848	0.757	0.328	0.038
16000.0	0.276	27.937	2.918	947.055	0.136	0.017	3.893	0.789	0.346	0.042
16500.0	0.274	27.509	2.991	946.792	0.142	0.019	3.936	0.822	0.363	0.046
17000.0	0.273	27.085	3.062	946.528	0.147	0.020	3.976	0.855	0.381	0.050
17500.0	0.271	26.663	3.134	946.264	0.153	0.021	4.014	0.887	0.398	0.054
18000.0	0.269	26.245	3.204	946.000	0.159	0.023	4.049	0.920	0.416	0.059
18500.0	0.268	25.830	3.273	945.735	0.165	0.024	4.083	0.952	0.433	0.063
19000.0	0.266	25.419	3.342	945.469	0.171	0.026	4.114	0.985	0.451	0.068
19500.0	0.265	25.011	3.410	945.202	0.177	0.027	4.143	1.017	0.468	0.073
20000.0	0.263	24.606	3.477	944.933	0.183	0.029	4.171	1.049	0.486	0.079
20500.0	0.262	24.205	3.543	944.664	0.189	0.031	4.197	1.081	0.504	0.084
21000.0	0.260	23.808	3.608	944.394	0.196	0.032	4.222	1.113	0.521	0.090
21500.0	0.258	23.413	3.673	944.122	0.202	0.034	4.245	1.145	0.539	0.096
22000.0	0.257	23.022	3.736	943.849	0.208	0.036	4.266	1.176	0.556	0.102
22500.0	0.255	22.635	3.799	943.574	0.215	0.038	4.286	1.208	0.574	0.108
25000.0	0.248	20.748	4.102	942.180	0.248	0.049	4.368	1.362	0.660	0.144
27500.0	0.240	18.947	4.384	940.748	0.282	0.061	4.421	1.510	0.744	0.184
30000.0	0.232	17.231	4.647	939.277	0.318	0.075	4.448	1.653	0.822	0.231
32500.0	0.224	15.602	4.890	937.764	0.354	0.091	4.454	1.790	0.894	0.283
35000.0	0.217	14.058	5.113	936.207	0.390	0.109	4.442	1.919	0.960	0.341
37500.0	0.209	12.602	5.316	934.604	0.426	0.129	4.415	2.041	1.018	0.405
40000.0	0.201	11.234	5.500	932.952	0.462	0.150	4.375	2.155	1.070	0.473
42500.0	0.194	9.954	5.664	931.248	0.498	0.172	4.325	2.261	1.114	0.547
45000.0	0.186	8.765	5.809	929.490	0.532	0.196	4.268	2.357	1.151	0.626
47500.0	0.179	7.665	5.934	927.675	0.566	0.221	4.206	2.445	1.182	0.709
50000.0	0.171	6.657	6.039	925.801	0.599	0.246	4.140	2.523	1.206	0.796
52500.0	0.164	5.738	6.125	923.867	0.630	0.272	4.073	2.592	1.224	0.886
55000.0	0.157	4.909	6.192	921.872	0.660	0.298	4.006	2.652	1.237	0.980
57500.0	0.150	4.168	6.241	919.816	0.688	0.324	3.941	2.703	1.245	1.077
60000.0	0.143	3.512	6.272	917.699	0.714	0.350	3.879	2.745	1.249	1.176
62500.0	0.136	2.937	6.287	915.522	0.737	0.375	3.821	2.780	1.250	1.276
65000.0	0.129	2.438	6.286	913.289	0.759	0.398	3.766	2.807	1.248	1.377
67500.0	0.123	2.010	6.271	911.003	0.778	0.420	3.717	2.828	1.245	1.479
70000.0	0.117	1.648	6.243	908.668	0.795	0.441	3.672	2.843	1.239	1.580

**Table C.18 [Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.332	43.982	0.000	955.686	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.332	43.863	0.024	955.621	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.330	43.388	0.120	955.362	0.002	0.000	0.218	0.002	0.000	0.000
1000.0	0.328	42.805	0.238	955.037	0.005	0.000	0.484	0.007	0.000	0.000
1500.0	0.325	42.231	0.353	954.713	0.007	0.000	0.738	0.017	0.001	0.000
2000.0	0.323	41.666	0.467	954.389	0.011	0.000	0.980	0.030	0.003	0.000
2500.0	0.321	41.111	0.578	954.065	0.014	0.000	1.212	0.045	0.006	0.000
3000.0	0.319	40.563	0.688	953.741	0.018	0.001	1.433	0.063	0.011	0.000
3500.0	0.317	40.024	0.795	953.418	0.021	0.001	1.644	0.082	0.016	0.000
4000.0	0.314	39.492	0.901	953.094	0.026	0.001	1.846	0.104	0.023	0.001
4500.0	0.312	38.967	1.005	952.772	0.030	0.001	2.040	0.127	0.031	0.001
5000.0	0.310	38.450	1.107	952.449	0.035	0.002	2.225	0.151	0.040	0.001
5500.0	0.308	37.939	1.207	952.126	0.039	0.002	2.402	0.177	0.050	0.002
6000.0	0.306	37.434	1.306	951.804	0.044	0.003	2.571	0.203	0.062	0.002
6500.0	0.304	36.937	1.403	951.482	0.050	0.003	2.733	0.231	0.074	0.003
7000.0	0.302	36.444	1.499	951.160	0.055	0.004	2.888	0.259	0.088	0.004
7500.0	0.300	35.958	1.593	950.839	0.061	0.004	3.036	0.288	0.102	0.005
8000.0	0.298	35.478	1.686	950.518	0.066	0.005	3.178	0.318	0.118	0.006
8500.0	0.296	35.004	1.777	950.197	0.072	0.006	3.314	0.348	0.134	0.007
9000.0	0.294	34.534	1.867	949.876	0.078	0.007	3.443	0.379	0.151	0.009
9500.0	0.292	34.070	1.956	949.556	0.084	0.008	3.567	0.411	0.168	0.010
10000.0	0.290	33.611	2.043	949.236	0.091	0.009	3.685	0.443	0.186	0.012
10500.0	0.288	33.157	2.129	948.917	0.097	0.010	3.798	0.476	0.205	0.014
11000.0	0.286	32.708	2.214	948.599	0.103	0.011	3.905	0.509	0.224	0.016
11500.0	0.284	32.264	2.298	948.280	0.110	0.012	4.008	0.542	0.243	0.019
12000.0	0.282	31.824	2.380	947.962	0.117	0.013	4.105	0.575	0.263	0.021
12500.0	0.280	31.389	2.461	947.645	0.123	0.015	4.198	0.609	0.283	0.024
13000.0	0.278	30.958	2.541	947.328	0.130	0.016	4.286	0.644	0.304	0.027
13500.0	0.276	30.531	2.619	947.011	0.137	0.018	4.370	0.678	0.324	0.030
14000.0	0.274	30.109	2.697	946.696	0.144	0.019	4.449	0.713	0.345	0.033
14500.0	0.272	29.690	2.774	946.380	0.151	0.021	4.525	0.748	0.366	0.037
15000.0	0.271	29.276	2.849	946.066	0.158	0.022	4.596	0.783	0.387	0.040
15500.0	0.269	28.865	2.923	945.751	0.165	0.024	4.664	0.818	0.408	0.044
16000.0	0.267	28.458	2.997	945.437	0.172	0.026	4.727	0.853	0.429	0.048
16500.0	0.265	28.055	3.069	945.124	0.179	0.028	4.788	0.888	0.450	0.053
17000.0	0.263	27.655	3.140	944.810	0.187	0.030	4.845	0.924	0.471	0.057
17500.0	0.262	27.260	3.210	944.497	0.194	0.032	4.899	0.959	0.492	0.062
18000.0	0.260	26.867	3.280	944.183	0.201	0.034	4.951	0.995	0.513	0.067
18500.0	0.258	26.478	3.348	943.870	0.209	0.036	4.999	1.030	0.534	0.072
19000.0	0.256	26.093	3.416	943.556	0.216	0.038	5.045	1.066	0.555	0.077
19500.0	0.255	25.711	3.482	943.242	0.224	0.040	5.088	1.101	0.576	0.082
20000.0	0.253	25.332	3.548	942.927	0.231	0.043	5.130	1.136	0.597	0.088
20500.0	0.251	24.957	3.613	942.612	0.239	0.045	5.169	1.171	0.617	0.094
21000.0	0.250	24.585	3.677	942.295	0.246	0.048	5.206	1.206	0.638	0.100
21500.0	0.248	24.217	3.740	941.978	0.254	0.050	5.242	1.241	0.659	0.106
22000.0	0.246	23.852	3.802	941.660	0.262	0.053	5.275	1.276	0.679	0.113
22500.0	0.245	23.490	3.864	941.341	0.269	0.056	5.307	1.310	0.700	0.119
23000.0	0.243	23.132	3.924	941.021	0.277	0.059	5.338	1.345	0.720	0.126
23500.0	0.241	22.777	3.984	940.700	0.285	0.062	5.366	1.379	0.741	0.133
24000.0	0.240	22.426	4.043	940.377	0.292	0.065	5.394	1.413	0.761	0.140
24500.0	0.238	22.078	4.101	940.053	0.300	0.068	5.420	1.447	0.781	0.148
25000.0	0.236	21.733	4.158	939.728	0.308	0.071	5.445	1.480	0.801	0.155
25500.0	0.235	21.392	4.215	939.402	0.316	0.074	5.468	1.514	0.821	0.163
26000.0	0.233	21.054	4.270	939.074	0.324	0.078	5.490	1.547	0.841	0.171
27500.0	0.228	20.060	4.432	938.083	0.348	0.089	5.550	1.645	0.900	0.196
30000.0	0.220	18.470	4.686	936.402	0.388	0.108	5.628	1.804	0.995	0.242
32500.0	0.212	16.961	4.920	934.687	0.428	0.130	5.682	1.956	1.085	0.292
35000.0	0.204	15.533	5.134	932.936	0.469	0.153	5.715	2.102	1.169	0.347
37500.0	0.197	14.184	5.328	931.148	0.509	0.179	5.729	2.240	1.246	0.406
40000.0	0.189	12.914	5.504	929.323	0.549	0.207	5.728	2.372	1.317	0.469
42500.0	0.182	11.720	5.661	927.460	0.588	0.236	5.713	2.495	1.381	0.536
45000.0	0.175	10.603	5.800	925.557	0.627	0.267	5.688	2.610	1.439	0.606
47500.0	0.168	9.561	5.921	923.615	0.664	0.300	5.653	2.718	1.490	0.680
50000.0	0.161	8.591	6.024	921.634	0.700	0.333	5.612	2.817	1.534	0.756
52500.0	0.154	7.693	6.111	919.613	0.735	0.368	5.564	2.907	1.573	0.835
55000.0	0.148	6.865	6.182	917.552	0.768	0.402	5.513	2.990	1.606	0.917
57500.0	0.142	6.105	6.238	915.451	0.799	0.438	5.460	3.064	1.633	1.000
60000.0	0.136	5.409	6.278	913.312	0.828	0.473	5.405	3.131	1.656	1.085
62500.0	0.130	4.777	6.305	911.136	0.855	0.508	5.350	3.190	1.674	1.172
65000.0	0.124	4.204	6.318	908.922	0.880	0.542	5.295	3.242	1.688	1.260
67500.0	0.119	3.688	6.319	906.674	0.903	0.575	5.241	3.286	1.698	1.349
70000.0	0.114	3.225	6.308	904.391	0.924	0.607	5.189	3.325	1.706	1.438

**Table C.19 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.322	42.580	0.000	957.098	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.321	42.460	0.022	957.051	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.320	41.982	0.109	956.862	0.001	0.000	0.162	0.001	0.000	0.000
1000.0	0.318	41.390	0.216	956.626	0.003	0.000	0.359	0.006	0.000	0.000
1500.0	0.317	40.807	0.322	956.389	0.005	0.000	0.547	0.013	0.001	0.000
2000.0	0.315	40.230	0.426	956.153	0.007	0.000	0.727	0.023	0.002	0.000
2500.0	0.313	39.661	0.528	955.918	0.009	0.000	0.897	0.035	0.003	0.000
3000.0	0.312	39.097	0.629	955.682	0.011	0.000	1.060	0.050	0.006	0.000
3500.0	0.310	38.541	0.728	955.447	0.014	0.000	1.214	0.066	0.009	0.000
4000.0	0.308	37.990	0.827	955.212	0.017	0.001	1.361	0.084	0.012	0.000
4500.0	0.307	37.445	0.923	954.978	0.019	0.001	1.501	0.103	0.017	0.000
5000.0	0.305	36.905	1.019	954.745	0.022	0.001	1.633	0.124	0.022	0.001
5500.0	0.304	36.371	1.113	954.511	0.025	0.001	1.759	0.146	0.029	0.001
6000.0	0.302	35.842	1.206	954.279	0.028	0.001	1.878	0.169	0.035	0.001
6500.0	0.301	35.318	1.298	954.047	0.031	0.002	1.991	0.193	0.043	0.002
7000.0	0.299	34.799	1.389	953.816	0.035	0.002	2.098	0.217	0.051	0.002
7500.0	0.298	34.285	1.478	953.586	0.038	0.002	2.199	0.243	0.060	0.003
8000.0	0.296	33.774	1.567	953.357	0.042	0.003	2.294	0.269	0.070	0.004
8500.0	0.294	33.269	1.654	953.129	0.045	0.003	2.384	0.296	0.080	0.005
9000.0	0.293	32.767	1.740	952.902	0.049	0.003	2.468	0.323	0.090	0.006
9500.0	0.291	32.269	1.825	952.676	0.052	0.004	2.547	0.351	0.101	0.007
10000.0	0.290	31.775	1.910	952.450	0.056	0.004	2.622	0.379	0.112	0.008
10500.0	0.289	31.285	1.993	952.225	0.060	0.005	2.693	0.408	0.124	0.009
11000.0	0.287	30.799	2.075	952.001	0.064	0.005	2.759	0.437	0.136	0.011
11500.0	0.286	30.316	2.156	951.776	0.068	0.006	2.822	0.466	0.148	0.013
12000.0	0.284	29.837	2.237	951.551	0.072	0.006	2.881	0.496	0.161	0.014
12500.0	0.283	29.362	2.316	951.325	0.076	0.007	2.937	0.525	0.174	0.016
13000.0	0.281	28.891	2.395	951.099	0.080	0.007	2.991	0.555	0.188	0.018
13500.0	0.280	28.423	2.473	950.872	0.084	0.008	3.041	0.585	0.201	0.021
14000.0	0.278	27.958	2.550	950.644	0.089	0.009	3.089	0.615	0.215	0.023
14500.0	0.277	27.498	2.626	950.415	0.093	0.010	3.135	0.646	0.229	0.026
15000.0	0.275	27.041	2.702	950.185	0.098	0.010	3.178	0.676	0.244	0.029
15500.0	0.274	26.588	2.776	949.954	0.103	0.011	3.219	0.707	0.258	0.032
16000.0	0.273	26.138	2.850	949.721	0.107	0.012	3.257	0.737	0.273	0.035
16500.0	0.271	25.692	2.923	949.488	0.112	0.013	3.294	0.768	0.288	0.038
17500.0	0.268	24.811	3.066	949.016	0.122	0.015	3.362	0.829	0.318	0.046
20000.0	0.261	22.671	3.411	947.811	0.148	0.021	3.499	0.982	0.396	0.068
22500.0	0.254	20.622	3.735	946.569	0.175	0.028	3.597	1.133	0.473	0.096
25000.0	0.246	18.664	4.040	945.286	0.204	0.036	3.660	1.282	0.549	0.130
27500.0	0.239	16.797	4.324	943.959	0.234	0.046	3.694	1.427	0.620	0.170
30000.0	0.231	15.024	4.588	942.585	0.266	0.057	3.703	1.567	0.687	0.217
32500.0	0.223	13.346	4.832	941.159	0.297	0.070	3.691	1.700	0.747	0.271
35000.0	0.216	11.766	5.055	939.676	0.330	0.085	3.663	1.827	0.801	0.331
37500.0	0.208	10.287	5.256	938.133	0.363	0.101	3.622	1.945	0.849	0.398
40000.0	0.200	8.911	5.435	936.523	0.395	0.118	3.571	2.055	0.889	0.472
42500.0	0.192	7.644	5.592	934.843	0.428	0.137	3.512	2.156	0.922	0.552
45000.0	0.184	6.487	5.727	933.087	0.459	0.157	3.450	2.246	0.948	0.638
47500.0	0.176	5.442	5.838	931.251	0.490	0.177	3.386	2.326	0.969	0.730
50000.0	0.168	4.511	5.927	929.333	0.520	0.198	3.322	2.396	0.983	0.828
52500.0	0.160	3.694	5.994	927.330	0.548	0.220	3.261	2.455	0.993	0.931
55000.0	0.152	2.987	6.038	925.242	0.574	0.241	3.204	2.504	0.998	1.038
57500.0	0.144	2.387	6.062	923.073	0.598	0.261	3.152	2.544	1.000	1.147
60000.0	0.137	1.886	6.067	920.826	0.620	0.280	3.105	2.575	1.000	1.259
62500.0	0.129	1.475	6.055	918.508	0.639	0.299	3.065	2.598	0.998	1.373
65000.0	0.122	1.143	6.028	916.127	0.656	0.315	3.030	2.614	0.995	1.486
67500.0	0.115	0.879	5.988	913.691	0.671	0.330	3.001	2.625	0.991	1.599
70000.0	0.108	0.672	5.938	911.211	0.683	0.344	2.976	2.632	0.987	1.710

**Table C.20 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.322	42.580	0.000	957.098	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.321	42.460	0.023	957.044	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.320	41.983	0.113	956.826	0.002	0.000	0.185	0.001	0.000	0.000
1000.0	0.318	41.395	0.224	956.553	0.004	0.000	0.412	0.006	0.000	0.000
1500.0	0.316	40.816	0.333	956.281	0.006	0.000	0.627	0.015	0.001	0.000
2000.0	0.314	40.245	0.441	956.009	0.008	0.000	0.832	0.026	0.002	0.000
2500.0	0.312	39.681	0.546	955.737	0.011	0.000	1.027	0.040	0.005	0.000
3000.0	0.310	39.125	0.650	955.466	0.014	0.000	1.212	0.056	0.008	0.000
3500.0	0.309	38.576	0.752	955.196	0.017	0.001	1.388	0.075	0.012	0.000
4000.0	0.307	38.034	0.853	954.926	0.020	0.001	1.556	0.095	0.017	0.000
4500.0	0.305	37.499	0.952	954.658	0.023	0.001	1.715	0.116	0.023	0.001
5000.0	0.303	36.969	1.049	954.389	0.027	0.001	1.866	0.139	0.030	0.001
5500.0	0.301	36.446	1.145	954.122	0.030	0.001	2.010	0.163	0.038	0.001
6000.0	0.300	35.928	1.240	953.855	0.034	0.002	2.146	0.188	0.046	0.002
6500.0	0.298	35.416	1.333	953.589	0.038	0.002	2.276	0.214	0.056	0.002
7000.0	0.296	34.910	1.425	953.324	0.042	0.003	2.398	0.241	0.067	0.003
7500.0	0.294	34.408	1.515	953.060	0.046	0.003	2.514	0.268	0.078	0.004
8000.0	0.293	33.912	1.605	952.797	0.050	0.003	2.624	0.296	0.090	0.005
8500.0	0.291	33.420	1.692	952.535	0.055	0.004	2.727	0.325	0.102	0.006
9000.0	0.289	32.933	1.779	952.274	0.059	0.004	2.825	0.355	0.115	0.007
9500.0	0.288	32.450	1.865	952.014	0.064	0.005	2.917	0.384	0.129	0.008
10000.0	0.286	31.972	1.949	951.756	0.068	0.006	3.004	0.415	0.143	0.010
10500.0	0.285	31.497	2.032	951.498	0.073	0.006	3.086	0.445	0.157	0.012
11000.0	0.283	31.027	2.115	951.241	0.078	0.007	3.164	0.476	0.172	0.014
11500.0	0.281	30.561	2.196	950.984	0.083	0.008	3.237	0.507	0.187	0.015
12000.0	0.280	30.099	2.276	950.727	0.088	0.008	3.306	0.539	0.203	0.018
12500.0	0.278	29.640	2.355	950.470	0.093	0.009	3.372	0.570	0.218	0.020
13000.0	0.277	29.186	2.433	950.213	0.098	0.010	3.434	0.602	0.234	0.023
13500.0	0.275	28.735	2.511	949.955	0.103	0.011	3.493	0.634	0.251	0.025
14000.0	0.273	28.288	2.587	949.696	0.108	0.012	3.549	0.666	0.267	0.028
14500.0	0.272	27.845	2.663	949.437	0.113	0.013	3.603	0.698	0.284	0.031
15000.0	0.270	27.406	2.737	949.176	0.119	0.014	3.654	0.730	0.301	0.034
15500.0	0.269	26.971	2.811	948.915	0.124	0.015	3.702	0.762	0.318	0.038
16000.0	0.267	26.540	2.884	948.652	0.130	0.016	3.748	0.794	0.336	0.042
16500.0	0.266	26.112	2.956	948.388	0.136	0.018	3.792	0.827	0.353	0.045
17000.0	0.264	25.688	3.027	948.123	0.141	0.019	3.834	0.859	0.371	0.050
17500.0	0.262	25.268	3.097	947.857	0.147	0.020	3.874	0.891	0.389	0.054
18000.0	0.261	24.851	3.167	947.589	0.153	0.022	3.911	0.923	0.407	0.058
20000.0	0.255	23.223	3.435	946.505	0.177	0.028	4.044	1.051	0.479	0.079
22500.0	0.247	21.271	3.752	945.117	0.209	0.037	4.171	1.209	0.569	0.109
25000.0	0.239	19.410	4.048	943.692	0.243	0.048	4.261	1.363	0.656	0.146
27500.0	0.231	17.640	4.323	942.228	0.277	0.060	4.319	1.513	0.739	0.188
30000.0	0.224	15.960	4.577	940.722	0.313	0.074	4.351	1.657	0.817	0.236
32500.0	0.216	14.371	4.811	939.173	0.349	0.091	4.359	1.795	0.888	0.291
35000.0	0.208	12.873	5.025	937.576	0.385	0.109	4.348	1.926	0.953	0.351
37500.0	0.201	11.467	5.218	935.931	0.421	0.128	4.321	2.049	1.010	0.417
40000.0	0.193	10.153	5.390	934.233	0.457	0.149	4.282	2.164	1.061	0.488
42500.0	0.186	8.931	5.543	932.480	0.492	0.172	4.233	2.270	1.103	0.564
45000.0	0.178	7.803	5.675	930.670	0.527	0.196	4.177	2.366	1.139	0.646
47500.0	0.171	6.769	5.787	928.801	0.560	0.221	4.116	2.453	1.168	0.732
50000.0	0.163	5.827	5.880	926.870	0.592	0.246	4.053	2.530	1.191	0.822
52500.0	0.156	4.979	5.953	924.877	0.623	0.272	3.989	2.597	1.208	0.915
55000.0	0.149	4.221	6.007	922.821	0.651	0.298	3.926	2.655	1.219	1.012
57500.0	0.142	3.550	6.043	920.704	0.678	0.324	3.865	2.704	1.227	1.111
60000.0	0.135	2.963	6.061	918.525	0.703	0.348	3.807	2.745	1.231	1.212
62500.0	0.128	2.455	6.064	916.289	0.725	0.372	3.754	2.777	1.231	1.314
65000.0	0.122	2.020	6.053	913.999	0.745	0.395	3.705	2.802	1.230	1.416
67500.0	0.116	1.652	6.028	911.659	0.763	0.416	3.661	2.822	1.226	1.519
70000.0	0.110	1.343	5.992	909.273	0.778	0.435	3.622	2.835	1.222	1.620

**Table C.21 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
0.0	0.322	42.580	0.000	957.098	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.321	42.461	0.024	957.034	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.319	41.987	0.119	956.775	0.002	0.000	0.218	0.002	0.000	0.000
1000.0	0.317	41.404	0.236	956.451	0.005	0.000	0.483	0.008	0.000	0.000
1500.0	0.315	40.832	0.351	956.127	0.007	0.000	0.735	0.017	0.001	0.000
2000.0	0.313	40.269	0.463	955.805	0.010	0.000	0.976	0.030	0.003	0.000
2500.0	0.310	39.714	0.573	955.483	0.014	0.000	1.204	0.046	0.007	0.000
3000.0	0.308	39.169	0.682	955.162	0.017	0.001	1.422	0.064	0.011	0.000
3500.0	0.306	38.631	0.788	954.842	0.021	0.001	1.629	0.085	0.016	0.000
4000.0	0.304	38.101	0.892	954.522	0.025	0.001	1.827	0.107	0.023	0.001
4500.0	0.302	37.578	0.995	954.203	0.030	0.001	2.015	0.130	0.031	0.001
5000.0	0.300	37.062	1.096	953.885	0.034	0.002	2.194	0.155	0.041	0.001
5500.0	0.298	36.553	1.195	953.568	0.039	0.002	2.365	0.181	0.051	0.002
6000.0	0.296	36.051	1.292	953.251	0.043	0.003	2.528	0.208	0.063	0.002
6500.0	0.294	35.555	1.388	952.935	0.049	0.003	2.683	0.236	0.075	0.003
7000.0	0.292	35.065	1.482	952.620	0.054	0.004	2.831	0.265	0.089	0.004
7500.0	0.290	34.580	1.575	952.306	0.059	0.004	2.971	0.295	0.103	0.005
8000.0	0.288	34.102	1.666	951.993	0.065	0.005	3.105	0.325	0.118	0.006
8500.0	0.286	33.628	1.756	951.681	0.070	0.006	3.232	0.356	0.134	0.007
9000.0	0.284	33.160	1.844	951.370	0.076	0.007	3.352	0.388	0.150	0.009
9500.0	0.282	32.697	1.931	951.060	0.082	0.008	3.467	0.420	0.167	0.011
10000.0	0.280	32.239	2.017	950.751	0.088	0.008	3.576	0.453	0.185	0.012
10500.0	0.278	31.785	2.101	950.443	0.094	0.009	3.679	0.486	0.203	0.014
11000.0	0.277	31.337	2.184	950.135	0.100	0.011	3.777	0.519	0.221	0.017
11500.0	0.275	30.892	2.266	949.828	0.106	0.012	3.870	0.553	0.240	0.019
12000.0	0.273	30.452	2.347	949.522	0.112	0.013	3.958	0.587	0.259	0.021
12500.0	0.271	30.016	2.427	949.216	0.119	0.014	4.043	0.621	0.278	0.024
13000.0	0.269	29.584	2.505	948.911	0.125	0.015	4.123	0.655	0.297	0.027
13500.0	0.268	29.157	2.583	948.605	0.132	0.017	4.199	0.689	0.317	0.030
14000.0	0.266	28.733	2.659	948.299	0.138	0.018	4.272	0.724	0.337	0.033
14500.0	0.264	28.314	2.734	947.992	0.145	0.020	4.342	0.759	0.357	0.037
15000.0	0.262	27.899	2.809	947.685	0.152	0.021	4.409	0.794	0.377	0.041
15500.0	0.260	27.487	2.882	947.378	0.158	0.023	4.472	0.828	0.398	0.045
16000.0	0.259	27.080	2.954	947.069	0.165	0.025	4.533	0.863	0.418	0.049
16500.0	0.257	26.676	3.025	946.759	0.172	0.026	4.592	0.898	0.439	0.053
17000.0	0.255	26.277	3.096	946.449	0.179	0.028	4.648	0.933	0.460	0.057
17500.0	0.254	25.881	3.165	946.137	0.187	0.030	4.702	0.968	0.481	0.062
18000.0	0.252	25.489	3.233	945.824	0.194	0.032	4.753	1.003	0.502	0.067
18500.0	0.250	25.101	3.301	945.510	0.201	0.034	4.803	1.038	0.523	0.072
19000.0	0.248	24.717	3.367	945.195	0.209	0.036	4.850	1.072	0.544	0.077
19500.0	0.247	24.336	3.433	944.879	0.216	0.039	4.895	1.107	0.565	0.083
20000.0	0.245	23.960	3.498	944.561	0.224	0.041	4.939	1.142	0.586	0.089
20500.0	0.243	23.587	3.562	944.242	0.231	0.044	4.980	1.176	0.607	0.095
21000.0	0.242	23.218	3.624	943.921	0.239	0.046	5.020	1.211	0.628	0.101
22500.0	0.237	22.133	3.808	942.952	0.262	0.054	5.129	1.313	0.691	0.120
25000.0	0.228	20.397	4.096	941.310	0.301	0.069	5.280	1.481	0.794	0.157
27500.0	0.220	18.751	4.362	939.632	0.341	0.087	5.396	1.645	0.894	0.200
30000.0	0.212	17.192	4.608	937.919	0.381	0.106	5.481	1.803	0.989	0.247
32500.0	0.204	15.719	4.833	936.170	0.422	0.128	5.541	1.956	1.078	0.299
35000.0	0.197	14.330	5.037	934.384	0.462	0.152	5.577	2.102	1.161	0.355
37500.0	0.189	13.024	5.222	932.559	0.503	0.178	5.595	2.242	1.237	0.416
40000.0	0.182	11.799	5.387	930.695	0.542	0.206	5.596	2.373	1.306	0.481
42500.0	0.175	10.654	5.533	928.791	0.581	0.236	5.583	2.497	1.369	0.550
45000.0	0.168	9.588	5.661	926.847	0.619	0.267	5.560	2.612	1.424	0.623
47500.0	0.161	8.598	5.771	924.862	0.656	0.299	5.527	2.719	1.474	0.698
50000.0	0.154	7.682	5.863	922.836	0.692	0.333	5.487	2.817	1.517	0.777
52500.0	0.147	6.840	5.939	920.770	0.725	0.367	5.442	2.907	1.554	0.858
55000.0	0.141	6.067	5.998	918.663	0.757	0.401	5.394	2.988	1.585	0.941
57500.0	0.135	5.363	6.043	916.516	0.787	0.436	5.344	3.061	1.611	1.026
60000.0	0.129	4.723	6.072	914.331	0.815	0.470	5.292	3.126	1.632	1.113
62500.0	0.123	4.146	6.089	912.107	0.841	0.504	5.240	3.183	1.649	1.202
65000.0	0.118	3.627	6.092	909.848	0.865	0.538	5.190	3.233	1.663	1.291
67500.0	0.113	3.163	6.083	907.555	0.886	0.570	5.141	3.276	1.672	1.381
70000.0	0.108	2.750	6.064	905.229	0.906	0.601	5.094	3.312	1.680	1.472

**Table C.22 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.198	0.000	952.446	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	47.078	0.023	952.394	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.354	46.599	0.114	952.188	0.002	0.000	0.184	0.001	0.000	0.000
1000.0	0.352	46.007	0.226	951.928	0.003	0.000	0.401	0.006	0.000	0.000
1500.0	0.350	45.422	0.337	951.668	0.005	0.000	0.608	0.013	0.001	0.000
2000.0	0.348	44.845	0.446	951.408	0.008	0.000	0.806	0.024	0.002	0.000
2500.0	0.346	44.275	0.554	951.148	0.010	0.000	0.996	0.036	0.004	0.000
3000.0	0.345	43.711	0.660	950.888	0.013	0.000	1.178	0.051	0.006	0.000
3500.0	0.343	43.154	0.764	950.627	0.016	0.000	1.353	0.067	0.010	0.000
4000.0	0.341	42.604	0.867	950.367	0.019	0.001	1.520	0.085	0.014	0.000
4500.0	0.339	42.059	0.969	950.105	0.022	0.001	1.681	0.105	0.019	0.001
5000.0	0.337	41.520	1.069	949.844	0.026	0.001	1.834	0.125	0.026	0.001
5500.0	0.335	40.986	1.168	949.583	0.029	0.001	1.982	0.147	0.033	0.001
6000.0	0.333	40.458	1.266	949.321	0.033	0.002	2.123	0.170	0.041	0.001
6500.0	0.331	39.936	1.363	949.060	0.037	0.002	2.258	0.194	0.049	0.002
7000.0	0.330	39.418	1.458	948.798	0.041	0.002	2.388	0.218	0.059	0.003
7500.0	0.328	38.906	1.552	948.536	0.045	0.003	2.512	0.244	0.069	0.003
8000.0	0.326	38.398	1.645	948.274	0.050	0.003	2.630	0.270	0.080	0.004
8500.0	0.324	37.896	1.737	948.012	0.054	0.004	2.744	0.297	0.092	0.005
9000.0	0.322	37.397	1.827	947.750	0.059	0.004	2.853	0.324	0.105	0.006
9500.0	0.320	36.904	1.917	947.488	0.063	0.005	2.957	0.352	0.118	0.007
10000.0	0.319	36.415	2.005	947.226	0.068	0.005	3.056	0.380	0.132	0.008
10500.0	0.317	35.930	2.092	946.964	0.073	0.006	3.151	0.408	0.146	0.010
11000.0	0.315	35.450	2.179	946.702	0.078	0.007	3.241	0.437	0.160	0.012
11500.0	0.313	34.973	2.264	946.440	0.083	0.007	3.328	0.467	0.176	0.013
12000.0	0.312	34.501	2.348	946.178	0.088	0.008	3.410	0.496	0.191	0.015
12500.0	0.310	34.032	2.431	945.916	0.094	0.009	3.488	0.526	0.207	0.017
13000.0	0.308	33.568	2.513	945.654	0.099	0.010	3.563	0.556	0.223	0.020
13500.0	0.306	33.107	2.594	945.392	0.105	0.011	3.633	0.587	0.240	0.022
14000.0	0.305	32.650	2.675	945.130	0.110	0.012	3.700	0.617	0.256	0.025
14500.0	0.303	32.197	2.754	944.869	0.116	0.013	3.764	0.648	0.273	0.027
15000.0	0.301	31.747	2.832	944.608	0.122	0.014	3.824	0.679	0.290	0.030
15500.0	0.300	31.300	2.910	944.346	0.128	0.015	3.881	0.710	0.307	0.033
16000.0	0.298	30.857	2.986	944.085	0.133	0.016	3.935	0.741	0.325	0.037
16500.0	0.296	30.418	3.062	943.824	0.139	0.017	3.986	0.772	0.342	0.040
17000.0	0.295	29.981	3.137	943.563	0.145	0.019	4.034	0.803	0.359	0.044
17500.0	0.293	29.548	3.211	943.301	0.151	0.020	4.080	0.835	0.377	0.048
18000.0	0.291	29.119	3.284	943.038	0.157	0.021	4.124	0.866	0.395	0.052
18500.0	0.290	28.692	3.356	942.775	0.164	0.023	4.165	0.897	0.412	0.056
19000.0	0.288	28.269	3.428	942.512	0.170	0.024	4.204	0.928	0.430	0.060
19500.0	0.286	27.850	3.498	942.247	0.176	0.026	4.241	0.959	0.448	0.065
20000.0	0.285	27.433	3.568	941.982	0.182	0.028	4.276	0.990	0.465	0.070
20500.0	0.283	27.020	3.637	941.715	0.189	0.029	4.309	1.021	0.483	0.075
21000.0	0.281	26.610	3.706	941.448	0.195	0.031	4.341	1.052	0.501	0.080
21500.0	0.280	26.204	3.773	941.179	0.202	0.033	4.371	1.083	0.519	0.085
22000.0	0.278	25.801	3.840	940.909	0.208	0.035	4.399	1.114	0.537	0.091
22500.0	0.277	25.401	3.906	940.638	0.215	0.037	4.426	1.144	0.555	0.097
23000.0	0.275	25.004	3.971	940.366	0.222	0.039	4.451	1.175	0.572	0.103
25000.0	0.268	23.451	4.223	939.263	0.249	0.047	4.539	1.295	0.643	0.129
27500.0	0.260	21.584	4.521	937.853	0.284	0.060	4.621	1.441	0.729	0.166
30000.0	0.252	19.799	4.800	936.408	0.321	0.074	4.676	1.583	0.812	0.209
32500.0	0.244	18.096	5.059	934.926	0.358	0.091	4.706	1.719	0.889	0.257
35000.0	0.236	16.475	5.300	933.404	0.396	0.109	4.715	1.850	0.961	0.310
37500.0	0.228	14.937	5.521	931.841	0.434	0.129	4.706	1.974	1.026	0.368
40000.0	0.221	13.481	5.723	930.234	0.472	0.151	4.682	2.091	1.084	0.432
42500.0	0.213	12.108	5.906	928.582	0.510	0.174	4.646	2.201	1.136	0.500
45000.0	0.205	10.820	6.070	926.883	0.548	0.199	4.600	2.303	1.181	0.573
47500.0	0.197	9.616	6.215	925.133	0.585	0.225	4.545	2.397	1.219	0.650
50000.0	0.190	8.497	6.341	923.331	0.620	0.253	4.485	2.483	1.251	0.731
52500.0	0.182	7.463	6.448	921.476	0.655	0.281	4.421	2.560	1.276	0.816
55000.0	0.175	6.514	6.537	919.566	0.688	0.310	4.354	2.629	1.296	0.904
57500.0	0.168	5.649	6.608	917.600	0.719	0.339	4.286	2.689	1.311	0.995
60000.0	0.161	4.867	6.661	915.577	0.749	0.368	4.219	2.741	1.321	1.088
62500.0	0.154	4.165	6.697	913.499	0.777	0.396	4.154	2.786	1.327	1.184
65000.0	0.147	3.541	6.716	911.366	0.803	0.423	4.092	2.823	1.329	1.281
67500.0	0.140	2.991	6.721	909.179	0.826	0.450	4.033	2.853	1.328	1.378
70000.0	0.134	2.511	6.710	906.941	0.847	0.474	3.978	2.876	1.325	1.477

**Table C.23 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.198	0.000	952.446	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	47.078	0.024	952.387	0.000	0.000	0.020	0.000	0.000	0.000
500.0	0.354	46.600	0.119	952.152	0.002	0.000	0.208	0.001	0.000	0.000
1000.0	0.352	46.011	0.235	951.857	0.004	0.000	0.452	0.007	0.000	0.000
1500.0	0.350	45.431	0.350	951.562	0.006	0.000	0.686	0.015	0.001	0.000
2000.0	0.347	44.858	0.463	951.267	0.009	0.000	0.909	0.026	0.003	0.000
2500.0	0.345	44.294	0.574	950.972	0.012	0.000	1.123	0.040	0.005	0.000
3000.0	0.343	43.737	0.683	950.677	0.015	0.000	1.329	0.056	0.008	0.000
3500.0	0.341	43.186	0.791	950.381	0.019	0.001	1.526	0.074	0.013	0.000
4000.0	0.339	42.643	0.897	950.085	0.023	0.001	1.715	0.094	0.018	0.000
4500.0	0.337	42.107	1.001	949.789	0.026	0.001	1.896	0.115	0.025	0.001
5000.0	0.335	41.577	1.104	949.493	0.031	0.001	2.070	0.137	0.032	0.001
5500.0	0.333	41.053	1.206	949.197	0.035	0.002	2.237	0.161	0.041	0.001
6000.0	0.331	40.535	1.305	948.900	0.039	0.002	2.397	0.185	0.051	0.002
6500.0	0.328	40.022	1.404	948.604	0.044	0.003	2.551	0.211	0.061	0.002
7000.0	0.326	39.516	1.501	948.307	0.049	0.003	2.699	0.237	0.073	0.003
7500.0	0.324	39.015	1.597	948.010	0.054	0.004	2.840	0.264	0.085	0.004
8000.0	0.322	38.519	1.691	947.714	0.059	0.004	2.976	0.292	0.099	0.005
8500.0	0.320	38.028	1.785	947.417	0.064	0.005	3.107	0.320	0.113	0.006
9000.0	0.318	37.543	1.876	947.120	0.070	0.005	3.232	0.349	0.128	0.007
9500.0	0.316	37.062	1.967	946.823	0.075	0.006	3.352	0.378	0.143	0.009
10000.0	0.314	36.586	2.056	946.526	0.081	0.007	3.467	0.408	0.159	0.010
10500.0	0.313	36.115	2.144	946.229	0.087	0.008	3.577	0.438	0.176	0.012
11000.0	0.311	35.649	2.231	945.932	0.093	0.009	3.682	0.469	0.193	0.014
11500.0	0.309	35.187	2.317	945.635	0.099	0.010	3.783	0.500	0.211	0.016
12000.0	0.307	34.729	2.402	945.338	0.105	0.011	3.880	0.531	0.229	0.018
12500.0	0.305	34.276	2.485	945.041	0.112	0.012	3.972	0.563	0.247	0.020
13000.0	0.303	33.826	2.568	944.745	0.118	0.013	4.061	0.595	0.266	0.023
13500.0	0.301	33.381	2.649	944.448	0.124	0.014	4.145	0.627	0.285	0.025
14000.0	0.299	32.940	2.730	944.151	0.131	0.016	4.225	0.659	0.305	0.028
14500.0	0.297	32.503	2.809	943.855	0.138	0.017	4.302	0.691	0.324	0.031
15000.0	0.295	32.070	2.887	943.559	0.144	0.018	4.375	0.724	0.344	0.035
15500.0	0.294	31.640	2.965	943.263	0.151	0.020	4.445	0.757	0.364	0.038
16000.0	0.292	31.214	3.041	942.967	0.158	0.021	4.511	0.789	0.384	0.042
16500.0	0.290	30.792	3.117	942.671	0.165	0.023	4.574	0.822	0.404	0.045
17000.0	0.288	30.373	3.191	942.374	0.172	0.025	4.634	0.855	0.424	0.049
17500.0	0.286	29.958	3.265	942.078	0.179	0.026	4.691	0.888	0.444	0.054
18000.0	0.285	29.546	3.337	941.781	0.186	0.028	4.746	0.921	0.464	0.058
18500.0	0.283	29.138	3.409	941.485	0.193	0.030	4.798	0.954	0.484	0.063
19000.0	0.281	28.733	3.480	941.187	0.200	0.032	4.848	0.987	0.505	0.067
19500.0	0.279	28.331	3.550	940.889	0.207	0.034	4.895	1.020	0.525	0.072
20000.0	0.278	27.933	3.619	940.590	0.215	0.036	4.940	1.053	0.545	0.077
20500.0	0.276	27.538	3.687	940.291	0.222	0.038	4.983	1.086	0.565	0.083
21000.0	0.274	27.147	3.755	939.990	0.229	0.041	5.024	1.118	0.586	0.088
21500.0	0.272	26.759	3.821	939.688	0.237	0.043	5.064	1.151	0.606	0.094
22000.0	0.271	26.374	3.887	939.386	0.244	0.045	5.101	1.183	0.626	0.100
22500.0	0.269	25.993	3.952	939.083	0.252	0.048	5.137	1.216	0.646	0.106
23000.0	0.267	25.615	4.016	938.778	0.260	0.050	5.172	1.248	0.667	0.112
23500.0	0.265	25.241	4.079	938.472	0.267	0.053	5.204	1.280	0.687	0.119
24000.0	0.264	24.869	4.141	938.165	0.275	0.056	5.236	1.312	0.707	0.126
24500.0	0.262	24.502	4.203	937.857	0.283	0.059	5.265	1.344	0.727	0.132
25000.0	0.260	24.137	4.264	937.548	0.291	0.061	5.294	1.376	0.746	0.140
25500.0	0.259	23.776	4.323	937.237	0.299	0.064	5.321	1.407	0.766	0.147
27500.0	0.252	22.364	4.555	935.981	0.331	0.077	5.416	1.531	0.844	0.178
30000.0	0.244	20.672	4.826	934.381	0.372	0.095	5.510	1.682	0.939	0.221
32500.0	0.235	19.060	5.078	932.747	0.413	0.115	5.577	1.827	1.029	0.269
35000.0	0.227	17.528	5.311	931.078	0.454	0.138	5.621	1.967	1.113	0.322
37500.0	0.219	16.075	5.524	929.374	0.496	0.162	5.645	2.100	1.192	0.379
40000.0	0.211	14.699	5.719	927.633	0.537	0.189	5.652	2.227	1.264	0.440
42500.0	0.204	13.400	5.895	925.854	0.578	0.217	5.645	2.347	1.329	0.505
45000.0	0.196	12.177	6.054	924.036	0.618	0.247	5.625	2.460	1.388	0.573
47500.0	0.189	11.029	6.194	922.179	0.657	0.279	5.594	2.565	1.441	0.645
50000.0	0.182	9.955	6.318	920.282	0.695	0.312	5.555	2.663	1.487	0.720
52500.0	0.175	8.954	6.424	918.344	0.731	0.346	5.510	2.753	1.527	0.798
55000.0	0.168	8.025	6.514	916.365	0.766	0.381	5.459	2.835	1.561	0.879
57500.0	0.161	7.166	6.587	914.345	0.800	0.416	5.404	2.910	1.590	0.961
60000.0	0.155	6.376	6.645	912.284	0.832	0.451	5.348	2.978	1.614	1.045
62500.0	0.149	5.651	6.688	910.183	0.862	0.487	5.290	3.038	1.632	1.131
65000.0	0.143	4.991	6.717	908.042	0.890	0.521	5.231	3.091	1.647	1.218
67500.0	0.137	4.392	6.732	905.862	0.916	0.556	5.174	3.137	1.658	1.306
70000.0	0.131	3.852	6.734	903.645	0.939	0.589	5.118	3.177	1.665	1.394

**Table C.24 [] Exposure-Dependent 80% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.198	0.000	952.446	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	47.079	0.025	952.378	0.000	0.000	0.023	0.000	0.000	0.000
500.0	0.354	46.604	0.124	952.107	0.002	0.000	0.237	0.002	0.000	0.000
1000.0	0.351	46.021	0.246	951.767	0.005	0.000	0.515	0.007	0.000	0.000
1500.0	0.349	45.446	0.366	951.427	0.008	0.000	0.781	0.017	0.002	0.000
2000.0	0.346	44.881	0.483	951.087	0.011	0.000	1.037	0.029	0.004	0.000
2500.0	0.344	44.324	0.599	950.747	0.015	0.000	1.282	0.044	0.007	0.000
3000.0	0.341	43.775	0.712	950.407	0.019	0.001	1.517	0.062	0.011	0.000
3500.0	0.339	43.234	0.824	950.066	0.023	0.001	1.743	0.081	0.016	0.000
4000.0	0.336	42.701	0.934	949.726	0.028	0.001	1.960	0.102	0.023	0.001
4500.0	0.334	42.175	1.042	949.385	0.032	0.002	2.169	0.124	0.031	0.001
5000.0	0.332	41.655	1.148	949.044	0.037	0.002	2.370	0.148	0.041	0.001
5500.0	0.329	41.143	1.253	948.703	0.042	0.002	2.564	0.173	0.051	0.002
6000.0	0.327	40.636	1.356	948.361	0.048	0.003	2.750	0.199	0.063	0.002
6500.0	0.325	40.136	1.457	948.020	0.054	0.004	2.930	0.225	0.075	0.003
7000.0	0.322	39.642	1.557	947.678	0.060	0.004	3.103	0.253	0.089	0.004
7500.0	0.320	39.154	1.656	947.336	0.066	0.005	3.270	0.281	0.104	0.005
8000.0	0.318	38.672	1.752	946.994	0.072	0.006	3.431	0.310	0.119	0.006
8500.0	0.315	38.195	1.848	946.652	0.079	0.007	3.586	0.340	0.136	0.007
9000.0	0.313	37.723	1.942	946.310	0.085	0.008	3.735	0.370	0.153	0.008
9500.0	0.311	37.257	2.035	945.968	0.092	0.009	3.879	0.401	0.171	0.010
10000.0	0.309	36.796	2.126	945.626	0.099	0.010	4.017	0.433	0.189	0.011
10500.0	0.307	36.340	2.216	945.283	0.106	0.011	4.151	0.465	0.208	0.013
11000.0	0.304	35.889	2.305	944.941	0.113	0.012	4.279	0.497	0.228	0.015
11500.0	0.302	35.443	2.393	944.598	0.120	0.014	4.403	0.530	0.248	0.017
12000.0	0.300	35.001	2.479	944.256	0.128	0.015	4.523	0.563	0.268	0.020
12500.0	0.298	34.564	2.564	943.914	0.135	0.017	4.637	0.596	0.289	0.022
13000.0	0.296	34.131	2.648	943.571	0.143	0.018	4.748	0.630	0.310	0.025
13500.0	0.294	33.703	2.730	943.229	0.151	0.020	4.854	0.664	0.331	0.028
14000.0	0.292	33.279	2.812	942.886	0.158	0.022	4.956	0.698	0.353	0.031
14500.0	0.290	32.859	2.892	942.544	0.166	0.024	5.055	0.733	0.375	0.034
15000.0	0.288	32.444	2.971	942.202	0.174	0.026	5.149	0.767	0.397	0.038
15500.0	0.286	32.032	3.049	941.859	0.182	0.028	5.240	0.802	0.419	0.041
16000.0	0.284	31.625	3.126	941.517	0.190	0.030	5.328	0.837	0.442	0.045
16500.0	0.282	31.221	3.202	941.174	0.199	0.032	5.412	0.873	0.464	0.049
17000.0	0.280	30.821	3.277	940.832	0.207	0.034	5.492	0.908	0.487	0.053
17500.0	0.278	30.425	3.351	940.489	0.215	0.037	5.570	0.943	0.509	0.057
18000.0	0.276	30.032	3.424	940.146	0.223	0.039	5.645	0.979	0.532	0.062
18500.0	0.274	29.643	3.496	939.803	0.232	0.042	5.716	1.015	0.555	0.066
19000.0	0.272	29.258	3.567	939.460	0.240	0.044	5.785	1.050	0.577	0.071
19500.0	0.270	28.877	3.637	939.116	0.249	0.047	5.852	1.086	0.600	0.076
20000.0	0.268	28.499	3.706	938.771	0.257	0.050	5.916	1.122	0.623	0.081
20500.0	0.266	28.124	3.774	938.426	0.266	0.053	5.977	1.157	0.645	0.087
21000.0	0.264	27.753	3.841	938.081	0.274	0.056	6.036	1.193	0.668	0.092
21500.0	0.262	27.385	3.907	937.735	0.283	0.059	6.093	1.229	0.691	0.098
22000.0	0.261	27.021	3.973	937.388	0.291	0.062	6.148	1.264	0.713	0.104
22500.0	0.259	26.660	4.037	937.040	0.300	0.066	6.201	1.300	0.736	0.110
23000.0	0.257	26.303	4.101	936.691	0.309	0.069	6.253	1.335	0.758	0.116
23500.0	0.255	25.949	4.164	936.342	0.317	0.073	6.302	1.371	0.781	0.122
24000.0	0.253	25.598	4.226	935.991	0.326	0.076	6.350	1.406	0.803	0.129
24500.0	0.251	25.251	4.287	935.640	0.335	0.080	6.395	1.441	0.825	0.136
25000.0	0.250	24.906	4.347	935.287	0.343	0.084	6.440	1.476	0.848	0.142
25500.0	0.248	24.566	4.406	934.934	0.352	0.088	6.483	1.511	0.870	0.149
26000.0	0.246	24.228	4.464	934.579	0.361	0.092	6.524	1.546	0.892	0.157
26500.0	0.244	23.894	4.522	934.223	0.370	0.096	6.564	1.581	0.914	0.164
27000.0	0.242	23.563	4.579	933.866	0.379	0.100	6.602	1.615	0.936	0.172
27500.0	0.241	23.235	4.635	933.509	0.388	0.105	6.639	1.650	0.957	0.179
28000.0	0.239	22.910	4.690	933.149	0.397	0.109	6.675	1.684	0.979	0.187
28500.0	0.237	22.589	4.744	932.789	0.406	0.114	6.710	1.718	1.001	0.195
29000.0	0.235	22.270	4.798	932.427	0.414	0.118	6.743	1.752	1.022	0.203
29500.0	0.234	21.955	4.850	932.065	0.423	0.123	6.775	1.786	1.043	0.212
30000.0	0.232	21.643	4.902	931.701	0.432	0.128	6.806	1.819	1.064	0.220
30500.0	0.230	21.335	4.953	931.335	0.441	0.133	6.836	1.853	1.085	0.229
31000.0	0.229	21.029	5.004	930.969	0.450	0.138	6.865	1.886	1.106	0.237
32500.0	0.224	20.130	5.150	929.862	0.477	0.154	6.945	1.985	1.168	0.265
35000.0	0.215	18.694	5.377	927.992	0.522	0.182	7.058	2.144	1.268	0.313
37500.0	0.207	17.332	5.586	926.091	0.567	0.213	7.149	2.298	1.363	0.365
40000.0	0.200	16.043	5.776	924.158	0.611	0.246	7.220	2.447	1.452	0.419
42500.0	0.192	14.825	5.948	922.195	0.655	0.282	7.274	2.589	1.537	0.477
45000.0	0.185	13.676	6.102	920.201	0.697	0.319	7.312	2.726	1.616	0.538
47500.0	0.178	12.595	6.239	918.175	0.739	0.359	7.337	2.856	1.689	0.602
50000.0	0.171	11.580	6.359	916.119	0.779	0.400	7.351	2.979	1.757	0.667
52500.0	0.164	10.628	6.464	914.033	0.818	0.442	7.354	3.096	1.819	0.735
55000.0	0.158	9.738	6.553	911.916	0.855	0.485	7.350	3.206	1.876	0.805
57500.0	0.152	8.907	6.627	909.770	0.891	0.530	7.338	3.309	1.929	0.877
60000.0	0.146	8.134	6.688	907.596	0.924	0.575	7.320	3.406	1.976	0.950
62500.0	0.141	7.416	6.735	905.394	0.956	0.620	7.297	3.496	2.019	1.025
65000.0	0.135	6.750	6.770	903.165	0.986	0.665	7.271	3.580	2.058	1.101
67500.0	0.130	6.135	6.792	900.911	1.014	0.710	7.242	3.658	2.092	1.179
70000.0	0.126	5.568	6.804	898.631	1.039	0.755	7.210	3.729	2.123	1.258

**Table C.25 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.108	0.000	952.535	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	46.988	0.023	952.482	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.354	46.509	0.115	952.265	0.002	0.000	0.193	0.001	0.000	0.000
1000.0	0.352	45.918	0.229	951.994	0.004	0.000	0.418	0.006	0.000	0.000
1500.0	0.350	45.335	0.340	951.723	0.006	0.000	0.634	0.014	0.001	0.000
2000.0	0.348	44.759	0.450	951.452	0.008	0.000	0.841	0.025	0.002	0.000
2500.0	0.346	44.191	0.558	951.181	0.011	0.000	1.039	0.038	0.004	0.000
3000.0	0.344	43.629	0.665	950.910	0.014	0.000	1.228	0.053	0.007	0.000
3500.0	0.342	43.075	0.770	950.639	0.017	0.001	1.409	0.070	0.011	0.000
4000.0	0.340	42.526	0.874	950.368	0.020	0.001	1.582	0.089	0.016	0.000
4500.0	0.338	41.984	0.976	950.097	0.024	0.001	1.748	0.109	0.021	0.001
5000.0	0.336	41.448	1.077	949.826	0.027	0.001	1.907	0.130	0.028	0.001
5500.0	0.335	40.918	1.176	949.555	0.031	0.001	2.059	0.153	0.035	0.001
6000.0	0.333	40.394	1.274	949.285	0.035	0.002	2.205	0.177	0.044	0.002
6500.0	0.331	39.875	1.371	949.014	0.039	0.002	2.344	0.201	0.053	0.002
7000.0	0.329	39.361	1.466	948.744	0.043	0.002	2.477	0.226	0.063	0.003
7500.0	0.327	38.852	1.560	948.474	0.047	0.003	2.604	0.253	0.075	0.004
8000.0	0.325	38.348	1.653	948.204	0.052	0.003	2.726	0.279	0.086	0.004
8500.0	0.323	37.850	1.745	947.934	0.057	0.004	2.842	0.307	0.099	0.005
9000.0	0.321	37.355	1.835	947.664	0.061	0.004	2.952	0.335	0.112	0.007
9500.0	0.320	36.866	1.925	947.395	0.066	0.005	3.058	0.363	0.126	0.008
10000.0	0.318	36.381	2.013	947.126	0.071	0.006	3.159	0.392	0.140	0.009
10500.0	0.316	35.900	2.100	946.857	0.076	0.006	3.255	0.421	0.155	0.011
11000.0	0.314	35.424	2.186	946.589	0.081	0.007	3.346	0.451	0.170	0.013
11500.0	0.312	34.952	2.271	946.321	0.087	0.008	3.433	0.480	0.186	0.014
12000.0	0.311	34.484	2.355	946.053	0.092	0.009	3.516	0.511	0.202	0.016
12500.0	0.309	34.020	2.438	945.786	0.098	0.010	3.594	0.541	0.219	0.019
13000.0	0.307	33.559	2.519	945.520	0.103	0.011	3.668	0.572	0.235	0.021
13500.0	0.305	33.103	2.600	945.254	0.109	0.012	3.738	0.603	0.252	0.024
14000.0	0.304	32.649	2.680	944.988	0.114	0.013	3.804	0.634	0.269	0.026
14500.0	0.302	32.200	2.759	944.723	0.120	0.014	3.867	0.665	0.287	0.029
15000.0	0.300	31.754	2.837	944.459	0.126	0.015	3.926	0.697	0.304	0.032
15500.0	0.298	31.311	2.914	944.195	0.132	0.016	3.981	0.728	0.321	0.036
16000.0	0.297	30.872	2.990	943.932	0.138	0.017	4.033	0.760	0.339	0.039
16500.0	0.295	30.436	3.065	943.669	0.144	0.018	4.082	0.791	0.357	0.043
17000.0	0.293	30.003	3.140	943.406	0.150	0.020	4.128	0.823	0.374	0.046
17500.0	0.292	29.573	3.213	943.143	0.156	0.021	4.172	0.855	0.392	0.050
18000.0	0.290	29.146	3.286	942.880	0.162	0.023	4.212	0.886	0.409	0.055
18500.0	0.289	28.723	3.358	942.617	0.168	0.024	4.251	0.918	0.427	0.059
19000.0	0.287	28.302	3.429	942.353	0.174	0.026	4.287	0.949	0.445	0.063
19500.0	0.285	27.885	3.499	942.089	0.180	0.027	4.321	0.981	0.462	0.068
20000.0	0.284	27.471	3.569	941.824	0.186	0.029	4.354	1.012	0.480	0.073
20500.0	0.282	27.060	3.637	941.558	0.193	0.030	4.384	1.043	0.498	0.078
21000.0	0.280	26.653	3.705	941.291	0.199	0.032	4.414	1.075	0.516	0.083
21500.0	0.279	26.249	3.772	941.022	0.206	0.034	4.441	1.106	0.533	0.089
22000.0	0.277	25.847	3.839	940.753	0.212	0.036	4.467	1.136	0.551	0.095
22500.0	0.276	25.450	3.904	940.482	0.219	0.038	4.491	1.167	0.569	0.101
25000.0	0.267	23.509	4.221	939.108	0.253	0.049	4.595	1.318	0.658	0.133
27500.0	0.259	21.649	4.518	937.701	0.288	0.061	4.669	1.464	0.744	0.171
30000.0	0.251	19.871	4.796	936.258	0.324	0.076	4.716	1.605	0.825	0.214
32500.0	0.244	18.172	5.055	934.778	0.361	0.092	4.740	1.740	0.902	0.263
35000.0	0.236	16.555	5.294	933.259	0.399	0.111	4.744	1.870	0.973	0.316
37500.0	0.228	15.019	5.515	931.700	0.436	0.131	4.732	1.992	1.037	0.375
40000.0	0.220	13.564	5.718	930.097	0.474	0.152	4.704	2.108	1.095	0.439
42500.0	0.212	12.192	5.901	928.448	0.512	0.176	4.666	2.217	1.146	0.507
45000.0	0.205	10.903	6.065	926.753	0.549	0.201	4.617	2.318	1.191	0.580
47500.0	0.197	9.697	6.211	925.008	0.586	0.227	4.561	2.410	1.228	0.657
50000.0	0.189	8.576	6.338	923.211	0.621	0.254	4.499	2.495	1.259	0.738
52500.0	0.182	7.539	6.446	921.361	0.656	0.283	4.433	2.571	1.284	0.823
55000.0	0.175	6.586	6.536	919.457	0.689	0.311	4.365	2.639	1.304	0.911
57500.0	0.167	5.716	6.608	917.497	0.720	0.340	4.297	2.698	1.318	1.002
60000.0	0.160	4.929	6.662	915.481	0.750	0.369	4.229	2.750	1.327	1.095
62500.0	0.153	4.222	6.699	913.409	0.778	0.397	4.163	2.793	1.332	1.190
65000.0	0.147	3.593	6.720	911.282	0.803	0.424	4.100	2.829	1.334	1.287
67500.0	0.140	3.038	6.725	909.101	0.827	0.450	4.040	2.858	1.333	1.384
70000.0	0.134	2.552	6.716	906.870	0.848	0.475	3.985	2.881	1.329	1.482

**Table C.26 [Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.108	0.000	952.535	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	46.988	0.024	952.474	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.354	46.511	0.120	952.229	0.002	0.000	0.217	0.002	0.000	0.000
1000.0	0.352	45.923	0.238	951.921	0.004	0.000	0.472	0.007	0.000	0.000
1500.0	0.349	45.343	0.354	951.613	0.007	0.000	0.716	0.016	0.001	0.000
2000.0	0.347	44.772	0.468	951.306	0.010	0.000	0.949	0.028	0.003	0.000
2500.0	0.345	44.209	0.579	950.998	0.013	0.000	1.172	0.042	0.006	0.000
3000.0	0.343	43.654	0.690	950.691	0.016	0.000	1.385	0.059	0.009	0.000
3500.0	0.341	43.107	0.798	950.383	0.020	0.001	1.590	0.077	0.014	0.000
4000.0	0.338	42.566	0.905	950.076	0.024	0.001	1.786	0.098	0.020	0.000
4500.0	0.336	42.033	1.009	949.769	0.028	0.001	1.974	0.119	0.027	0.001
5000.0	0.334	41.506	1.113	949.462	0.032	0.002	2.154	0.142	0.035	0.001
5500.0	0.332	40.985	1.215	949.155	0.037	0.002	2.326	0.167	0.044	0.001
6000.0	0.330	40.470	1.315	948.848	0.041	0.002	2.492	0.192	0.055	0.002
6500.0	0.328	39.962	1.414	948.542	0.046	0.003	2.650	0.218	0.066	0.003
7000.0	0.326	39.459	1.511	948.236	0.051	0.003	2.802	0.245	0.078	0.003
7500.0	0.324	38.962	1.607	947.929	0.056	0.004	2.948	0.273	0.091	0.004
8000.0	0.321	38.470	1.701	947.623	0.062	0.004	3.087	0.301	0.105	0.005
8500.0	0.319	37.983	1.795	947.318	0.067	0.005	3.221	0.330	0.120	0.006
9000.0	0.317	37.502	1.886	947.012	0.073	0.006	3.349	0.359	0.136	0.008
9500.0	0.315	37.025	1.977	946.707	0.079	0.007	3.471	0.389	0.152	0.009
10000.0	0.313	36.554	2.066	946.402	0.085	0.008	3.589	0.420	0.169	0.011
10500.0	0.311	36.087	2.154	946.098	0.091	0.008	3.701	0.451	0.186	0.013
11000.0	0.309	35.625	2.241	945.794	0.097	0.009	3.808	0.482	0.204	0.015
11500.0	0.307	35.167	2.326	945.490	0.103	0.010	3.910	0.513	0.223	0.017
12000.0	0.305	34.714	2.411	945.186	0.109	0.012	4.007	0.545	0.241	0.019
12500.0	0.304	34.265	2.494	944.884	0.116	0.013	4.100	0.577	0.260	0.022
13000.0	0.302	33.820	2.576	944.581	0.122	0.014	4.189	0.610	0.280	0.024
13500.0	0.300	33.380	2.657	944.279	0.129	0.015	4.273	0.642	0.300	0.027
14000.0	0.298	32.943	2.737	943.978	0.136	0.017	4.353	0.675	0.319	0.030
14500.0	0.296	32.510	2.816	943.677	0.142	0.018	4.429	0.708	0.339	0.033
15000.0	0.294	32.081	2.894	943.376	0.149	0.019	4.502	0.741	0.360	0.037
15500.0	0.292	31.655	2.971	943.076	0.156	0.021	4.570	0.775	0.380	0.040
16000.0	0.290	31.233	3.047	942.777	0.163	0.023	4.635	0.808	0.400	0.044
16500.0	0.289	30.815	3.122	942.478	0.170	0.024	4.697	0.841	0.421	0.048
17000.0	0.287	30.400	3.196	942.179	0.177	0.026	4.755	0.875	0.441	0.052
17500.0	0.285	29.989	3.269	941.881	0.184	0.028	4.810	0.908	0.461	0.057
18000.0	0.283	29.580	3.341	941.583	0.191	0.030	4.863	0.942	0.482	0.061
18500.0	0.281	29.175	3.413	941.284	0.198	0.032	4.912	0.975	0.502	0.066
19000.0	0.280	28.774	3.483	940.986	0.205	0.034	4.959	1.009	0.522	0.071
19500.0	0.278	28.375	3.553	940.688	0.212	0.036	5.004	1.042	0.543	0.076
20000.0	0.276	27.980	3.621	940.389	0.219	0.038	5.046	1.075	0.563	0.081
20500.0	0.274	27.588	3.689	940.089	0.227	0.040	5.086	1.108	0.583	0.086
21000.0	0.273	27.199	3.756	939.789	0.234	0.042	5.125	1.142	0.603	0.092
21500.0	0.271	26.814	3.822	939.488	0.242	0.045	5.161	1.174	0.624	0.098
22000.0	0.269	26.432	3.888	939.186	0.249	0.047	5.196	1.207	0.644	0.104
22500.0	0.268	26.053	3.952	938.882	0.257	0.050	5.229	1.240	0.664	0.110
23000.0	0.266	25.677	4.016	938.578	0.264	0.052	5.261	1.272	0.684	0.117
23500.0	0.264	25.305	4.079	938.273	0.272	0.055	5.291	1.305	0.704	0.123
24000.0	0.263	24.936	4.141	937.967	0.280	0.058	5.320	1.337	0.724	0.130
24500.0	0.261	24.570	4.202	937.659	0.287	0.061	5.347	1.369	0.744	0.137
25000.0	0.259	24.207	4.262	937.350	0.295	0.063	5.373	1.401	0.763	0.144
27500.0	0.251	22.442	4.553	935.786	0.335	0.079	5.485	1.556	0.861	0.183
30000.0	0.243	20.757	4.823	934.189	0.375	0.097	5.570	1.706	0.956	0.227
32500.0	0.234	19.151	5.074	932.558	0.416	0.118	5.629	1.851	1.045	0.275
35000.0	0.226	17.623	5.307	930.893	0.458	0.140	5.667	1.990	1.129	0.328
37500.0	0.218	16.173	5.520	929.192	0.499	0.165	5.686	2.122	1.207	0.385
40000.0	0.211	14.799	5.715	927.455	0.540	0.191	5.689	2.248	1.278	0.446
42500.0	0.203	13.501	5.891	925.680	0.580	0.220	5.678	2.367	1.343	0.512
45000.0	0.196	12.278	6.050	923.867	0.620	0.250	5.654	2.478	1.402	0.580
47500.0	0.188	11.128	6.192	922.015	0.659	0.281	5.621	2.582	1.453	0.652
50000.0	0.181	10.053	6.316	920.123	0.696	0.314	5.580	2.679	1.499	0.727
52500.0	0.174	9.049	6.423	918.191	0.733	0.348	5.532	2.768	1.539	0.805
55000.0	0.168	8.116	6.513	916.218	0.768	0.383	5.480	2.849	1.572	0.886
57500.0	0.161	7.253	6.588	914.204	0.801	0.418	5.424	2.923	1.600	0.968
60000.0	0.155	6.458	6.647	912.150	0.833	0.453	5.366	2.989	1.623	1.052
62500.0	0.148	5.729	6.691	910.055	0.863	0.488	5.306	3.048	1.642	1.138
65000.0	0.142	5.064	6.721	907.920	0.891	0.523	5.247	3.101	1.656	1.225
67500.0	0.137	4.460	6.738	905.747	0.917	0.557	5.188	3.146	1.666	1.312
70000.0	0.131	3.914	6.741	903.537	0.940	0.590	5.131	3.185	1.673	1.400

**Table C.27 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.356	47.108	0.000	952.535	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.356	46.989	0.025	952.465	0.000	0.000	0.024	0.000	0.000	0.000
500.0	0.354	46.515	0.126	952.182	0.002	0.000	0.248	0.002	0.000	0.000
1000.0	0.351	45.932	0.249	951.828	0.005	0.000	0.538	0.008	0.000	0.000
1500.0	0.348	45.358	0.370	951.474	0.008	0.000	0.815	0.018	0.002	0.000
2000.0	0.346	44.794	0.489	951.120	0.012	0.000	1.081	0.030	0.004	0.000
2500.0	0.343	44.239	0.605	950.767	0.016	0.000	1.336	0.046	0.007	0.000
3000.0	0.341	43.693	0.720	950.413	0.020	0.001	1.581	0.064	0.012	0.000
3500.0	0.338	43.154	0.832	950.060	0.024	0.001	1.815	0.084	0.018	0.000
4000.0	0.336	42.623	0.943	949.707	0.029	0.001	2.041	0.105	0.025	0.001
4500.0	0.333	42.100	1.051	949.353	0.034	0.002	2.258	0.128	0.034	0.001
5000.0	0.331	41.583	1.158	949.001	0.039	0.002	2.466	0.152	0.043	0.001
5500.0	0.328	41.074	1.264	948.648	0.044	0.003	2.667	0.178	0.055	0.002
6000.0	0.326	40.571	1.367	948.295	0.050	0.003	2.860	0.204	0.067	0.002
6500.0	0.324	40.074	1.469	947.942	0.056	0.004	3.045	0.231	0.080	0.003
7000.0	0.321	39.583	1.569	947.590	0.062	0.005	3.224	0.260	0.095	0.004
7500.0	0.319	39.099	1.667	947.238	0.069	0.005	3.396	0.289	0.110	0.005
8000.0	0.317	38.620	1.765	946.886	0.075	0.006	3.561	0.318	0.126	0.006
8500.0	0.314	38.147	1.860	946.534	0.082	0.007	3.721	0.348	0.143	0.007
9000.0	0.312	37.680	1.954	946.182	0.089	0.008	3.874	0.379	0.161	0.009
9500.0	0.310	37.218	2.047	945.830	0.096	0.009	4.022	0.411	0.180	0.010
10000.0	0.308	36.761	2.138	945.479	0.103	0.010	4.164	0.443	0.199	0.012
10500.0	0.305	36.309	2.228	945.128	0.110	0.012	4.300	0.475	0.219	0.014
11000.0	0.303	35.862	2.317	944.778	0.117	0.013	4.432	0.508	0.239	0.016
11500.0	0.301	35.420	2.404	944.427	0.125	0.015	4.558	0.541	0.260	0.019
12000.0	0.299	34.982	2.490	944.077	0.132	0.016	4.679	0.575	0.281	0.021
12500.0	0.297	34.550	2.575	943.727	0.140	0.018	4.796	0.609	0.302	0.024
13000.0	0.295	34.121	2.659	943.378	0.148	0.019	4.908	0.643	0.324	0.026
13500.0	0.292	33.697	2.741	943.029	0.156	0.021	5.015	0.678	0.346	0.029
14000.0	0.290	33.278	2.822	942.680	0.164	0.023	5.119	0.713	0.369	0.033
14500.0	0.288	32.862	2.902	942.332	0.172	0.025	5.218	0.748	0.391	0.036
15000.0	0.286	32.451	2.981	941.984	0.180	0.027	5.312	0.783	0.414	0.040
15500.0	0.284	32.044	3.059	941.636	0.188	0.029	5.403	0.818	0.436	0.043
16000.0	0.282	31.640	3.135	941.289	0.196	0.031	5.490	0.854	0.459	0.047
16500.0	0.280	31.241	3.211	940.942	0.204	0.034	5.574	0.890	0.482	0.051
17000.0	0.278	30.845	3.286	940.596	0.213	0.036	5.654	0.926	0.505	0.055
17500.0	0.276	30.453	3.359	940.249	0.221	0.039	5.730	0.962	0.528	0.060
18000.0	0.274	30.064	3.431	939.903	0.229	0.041	5.804	0.998	0.551	0.064
18500.0	0.272	29.679	3.503	939.557	0.238	0.044	5.874	1.034	0.574	0.069
19000.0	0.270	29.298	3.573	939.212	0.246	0.047	5.941	1.071	0.597	0.074
19500.0	0.268	28.920	3.643	938.866	0.255	0.049	6.005	1.107	0.620	0.079
20000.0	0.267	28.545	3.711	938.520	0.263	0.052	6.066	1.143	0.643	0.085
20500.0	0.265	28.174	3.779	938.174	0.271	0.055	6.125	1.179	0.666	0.090
21000.0	0.263	27.806	3.846	937.828	0.280	0.058	6.182	1.216	0.688	0.096
21500.0	0.261	27.441	3.912	937.481	0.288	0.062	6.236	1.252	0.711	0.101
22000.0	0.259	27.080	3.977	937.134	0.297	0.065	6.289	1.288	0.733	0.107
22500.0	0.257	26.722	4.041	936.786	0.306	0.068	6.339	1.324	0.756	0.113
23000.0	0.255	26.367	4.104	936.437	0.314	0.072	6.387	1.360	0.778	0.120
23500.0	0.254	26.016	4.166	936.088	0.323	0.075	6.433	1.396	0.801	0.126
24000.0	0.252	25.667	4.228	935.738	0.331	0.079	6.478	1.431	0.823	0.133
24500.0	0.250	25.322	4.288	935.387	0.340	0.083	6.521	1.467	0.845	0.140
25000.0	0.248	24.980	4.348	935.035	0.349	0.087	6.563	1.502	0.868	0.147
25500.0	0.246	24.641	4.407	934.682	0.358	0.091	6.603	1.537	0.890	0.154
26000.0	0.245	24.306	4.465	934.328	0.366	0.095	6.641	1.572	0.912	0.161
26500.0	0.243	23.974	4.523	933.973	0.375	0.099	6.679	1.607	0.934	0.168
27000.0	0.241	23.645	4.579	933.617	0.384	0.103	6.715	1.642	0.955	0.176
27500.0	0.239	23.319	4.635	933.259	0.393	0.108	6.749	1.677	0.977	0.184
28000.0	0.238	22.996	4.690	932.901	0.402	0.112	6.783	1.711	0.999	0.192
28500.0	0.236	22.676	4.744	932.541	0.410	0.117	6.815	1.745	1.020	0.200
29000.0	0.234	22.359	4.797	932.180	0.419	0.121	6.846	1.780	1.041	0.208
29500.0	0.233	22.046	4.849	931.818	0.428	0.126	6.876	1.813	1.063	0.216
30000.0	0.231	21.735	4.901	931.455	0.437	0.131	6.905	1.847	1.084	0.225
30500.0	0.229	21.428	4.952	931.090	0.446	0.136	6.933	1.881	1.105	0.234
32500.0	0.222	20.229	5.148	929.620	0.482	0.157	7.034	2.012	1.187	0.270
35000.0	0.214	18.797	5.375	927.753	0.526	0.186	7.139	2.171	1.287	0.318
37500.0	0.206	17.439	5.583	925.856	0.570	0.217	7.223	2.325	1.381	0.370
40000.0	0.199	16.153	5.773	923.928	0.614	0.250	7.288	2.473	1.471	0.425
42500.0	0.191	14.937	5.945	921.969	0.657	0.285	7.336	2.614	1.555	0.483
45000.0	0.184	13.789	6.100	919.980	0.700	0.323	7.370	2.750	1.633	0.544
47500.0	0.177	12.708	6.237	917.959	0.741	0.362	7.391	2.879	1.706	0.608
50000.0	0.170	11.691	6.358	915.908	0.781	0.403	7.401	3.001	1.774	0.673
52500.0	0.164	10.738	6.464	913.827	0.820	0.445	7.401	3.117	1.836	0.741
55000.0	0.158	9.845	6.554	911.717	0.857	0.488	7.394	3.226	1.893	0.811
57500.0	0.152	9.012	6.629	909.577	0.892	0.533	7.379	3.328	1.945	0.883
60000.0	0.146	8.235	6.691	907.409	0.925	0.577	7.359	3.424	1.992	0.956
62500.0	0.140	7.513	6.740	905.213	0.957	0.623	7.334	3.513	2.034	1.031
65000.0	0.135	6.844	6.775	902.990	0.987	0.668	7.306	3.596	2.072	1.107
67500.0	0.130	6.224	6.799	900.742	1.015	0.713	7.275	3.673	2.106	1.185
70000.0	0.125	5.652	6.812	898.468	1.040	0.757	7.242	3.744	2.137	1.263

**Table C.28 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.407	0.000	952.235	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.286	0.023	952.182	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.357	46.807	0.115	951.968	0.002	0.000	0.190	0.001	0.000	0.000
1000.0	0.354	46.215	0.229	951.701	0.004	0.000	0.413	0.006	0.000	0.000
1500.0	0.353	45.631	0.340	951.435	0.006	0.000	0.626	0.014	0.001	0.000
2000.0	0.351	45.055	0.450	951.168	0.008	0.000	0.829	0.024	0.002	0.000
2500.0	0.349	44.485	0.558	950.902	0.011	0.000	1.023	0.037	0.004	0.000
3000.0	0.347	43.923	0.665	950.637	0.013	0.000	1.208	0.052	0.007	0.000
3500.0	0.345	43.367	0.770	950.372	0.016	0.000	1.385	0.069	0.010	0.000
4000.0	0.343	42.817	0.873	950.108	0.020	0.001	1.554	0.087	0.015	0.000
4500.0	0.341	42.273	0.975	949.845	0.023	0.001	1.715	0.107	0.020	0.001
5000.0	0.339	41.735	1.075	949.582	0.026	0.001	1.869	0.128	0.027	0.001
5500.0	0.337	41.202	1.175	949.320	0.030	0.001	2.016	0.150	0.034	0.001
6000.0	0.335	40.675	1.272	949.058	0.034	0.002	2.157	0.173	0.042	0.002
6500.0	0.333	40.153	1.369	948.796	0.038	0.002	2.291	0.197	0.051	0.002
7000.0	0.331	39.636	1.464	948.534	0.042	0.002	2.420	0.222	0.061	0.003
7500.0	0.330	39.124	1.558	948.273	0.046	0.003	2.543	0.247	0.071	0.003
8000.0	0.328	38.617	1.651	948.012	0.050	0.003	2.661	0.274	0.082	0.004
8500.0	0.326	38.114	1.743	947.750	0.055	0.004	2.773	0.300	0.094	0.005
9000.0	0.324	37.616	1.834	947.489	0.059	0.004	2.881	0.327	0.107	0.006
9500.0	0.322	37.123	1.923	947.228	0.064	0.005	2.984	0.355	0.120	0.007
10000.0	0.321	36.634	2.012	946.966	0.069	0.005	3.083	0.383	0.134	0.009
10500.0	0.319	36.149	2.099	946.705	0.074	0.006	3.177	0.412	0.148	0.010
11000.0	0.317	35.668	2.185	946.443	0.079	0.007	3.266	0.441	0.163	0.012
11500.0	0.315	35.192	2.271	946.182	0.084	0.007	3.352	0.470	0.178	0.014
12000.0	0.314	34.719	2.355	945.921	0.089	0.008	3.433	0.500	0.193	0.015
12500.0	0.312	34.251	2.438	945.659	0.095	0.009	3.511	0.530	0.209	0.018
13000.0	0.310	33.786	2.520	945.398	0.100	0.010	3.585	0.560	0.225	0.020
13500.0	0.308	33.325	2.602	945.137	0.106	0.011	3.655	0.590	0.242	0.022
14000.0	0.307	32.868	2.682	944.877	0.111	0.012	3.722	0.620	0.258	0.025
14500.0	0.305	32.414	2.761	944.616	0.117	0.013	3.785	0.651	0.275	0.028
15000.0	0.303	31.963	2.840	944.355	0.122	0.014	3.844	0.682	0.292	0.030
15500.0	0.301	31.517	2.918	944.095	0.128	0.015	3.901	0.713	0.310	0.034
16000.0	0.300	31.073	2.994	943.835	0.134	0.016	3.954	0.744	0.327	0.037
16500.0	0.298	30.633	3.070	943.574	0.140	0.018	4.005	0.775	0.344	0.040
17000.0	0.296	30.196	3.145	943.314	0.146	0.019	4.053	0.806	0.362	0.044
17500.0	0.295	29.763	3.219	943.053	0.152	0.020	4.099	0.837	0.379	0.048
18000.0	0.293	29.333	3.292	942.791	0.158	0.022	4.142	0.868	0.397	0.052
18500.0	0.291	28.906	3.365	942.529	0.164	0.023	4.182	0.899	0.414	0.056
19000.0	0.290	28.482	3.436	942.266	0.170	0.024	4.221	0.930	0.432	0.060
19500.0	0.288	28.062	3.507	942.003	0.177	0.026	4.258	0.961	0.450	0.065
20000.0	0.287	27.645	3.577	941.738	0.183	0.028	4.293	0.992	0.468	0.070
20500.0	0.285	27.231	3.647	941.473	0.189	0.029	4.326	1.023	0.485	0.075
21000.0	0.283	26.820	3.715	941.206	0.196	0.031	4.357	1.054	0.503	0.080
21500.0	0.282	26.413	3.783	940.938	0.202	0.033	4.387	1.084	0.521	0.085
22000.0	0.280	26.009	3.850	940.669	0.209	0.035	4.415	1.115	0.539	0.091
22500.0	0.278	25.609	3.916	940.399	0.216	0.037	4.442	1.145	0.556	0.097
23000.0	0.277	25.211	3.981	940.128	0.222	0.039	4.467	1.176	0.574	0.103
25000.0	0.270	23.655	4.234	939.028	0.250	0.047	4.555	1.295	0.645	0.129
27500.0	0.262	21.783	4.534	937.624	0.285	0.060	4.637	1.441	0.731	0.166
30000.0	0.254	19.992	4.814	936.184	0.322	0.074	4.691	1.582	0.813	0.208
32500.0	0.246	18.283	5.074	934.707	0.359	0.091	4.721	1.718	0.891	0.256
35000.0	0.238	16.655	5.316	933.191	0.397	0.109	4.730	1.849	0.962	0.309
37500.0	0.230	15.109	5.538	931.634	0.435	0.129	4.721	1.972	1.027	0.367
40000.0	0.222	13.645	5.742	930.035	0.473	0.151	4.697	2.090	1.086	0.430
42500.0	0.214	12.265	5.927	928.389	0.511	0.174	4.661	2.199	1.138	0.498
45000.0	0.207	10.967	6.092	926.697	0.549	0.199	4.615	2.301	1.183	0.570
47500.0	0.199	9.754	6.239	924.955	0.585	0.225	4.560	2.396	1.221	0.647
50000.0	0.191	8.626	6.367	923.161	0.621	0.253	4.499	2.482	1.253	0.727
52500.0	0.184	7.583	6.476	921.314	0.656	0.281	4.435	2.559	1.279	0.812
55000.0	0.176	6.624	6.567	919.412	0.689	0.310	4.368	2.628	1.299	0.899
57500.0	0.169	5.749	6.639	917.454	0.721	0.339	4.299	2.689	1.314	0.990
60000.0	0.162	4.957	6.694	915.440	0.751	0.368	4.232	2.742	1.324	1.083
62500.0	0.155	4.246	6.732	913.370	0.779	0.396	4.166	2.787	1.329	1.178
65000.0	0.148	3.613	6.753	911.245	0.804	0.424	4.103	2.824	1.332	1.275
67500.0	0.141	3.054	6.759	909.066	0.828	0.450	4.044	2.854	1.331	1.372
70000.0	0.135	2.566	6.750	906.835	0.849	0.475	3.988	2.878	1.328	1.470

**Table C.29 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.407	0.000	952.235	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.286	0.024	952.175	0.000	0.000	0.021	0.000	0.000	0.000
500.0	0.356	46.809	0.120	951.932	0.002	0.000	0.215	0.002	0.000	0.000
1000.0	0.354	46.220	0.238	951.629	0.004	0.000	0.465	0.007	0.000	0.000
1500.0	0.352	45.639	0.353	951.327	0.007	0.000	0.705	0.016	0.001	0.000
2000.0	0.350	45.068	0.467	951.024	0.010	0.000	0.934	0.027	0.003	0.000
2500.0	0.347	44.504	0.579	950.723	0.013	0.000	1.153	0.042	0.005	0.000
3000.0	0.345	43.948	0.689	950.422	0.016	0.000	1.362	0.058	0.009	0.000
3500.0	0.343	43.398	0.797	950.122	0.019	0.001	1.561	0.076	0.013	0.000
4000.0	0.341	42.856	0.904	949.822	0.023	0.001	1.752	0.096	0.019	0.000
4500.0	0.339	42.321	1.008	949.523	0.027	0.001	1.935	0.117	0.026	0.001
5000.0	0.337	41.791	1.111	949.224	0.031	0.001	2.110	0.140	0.034	0.001
5500.0	0.334	41.268	1.213	948.926	0.036	0.002	2.277	0.164	0.042	0.001
6000.0	0.332	40.751	1.313	948.629	0.040	0.002	2.437	0.189	0.052	0.002
6500.0	0.330	40.240	1.412	948.332	0.045	0.003	2.591	0.214	0.063	0.002
7000.0	0.328	39.734	1.509	948.035	0.050	0.003	2.738	0.241	0.075	0.003
7500.0	0.326	39.233	1.605	947.738	0.055	0.004	2.878	0.268	0.088	0.004
8000.0	0.324	38.737	1.699	947.441	0.060	0.004	3.013	0.296	0.101	0.005
8500.0	0.322	38.247	1.793	947.145	0.065	0.005	3.143	0.324	0.115	0.006
9000.0	0.320	37.762	1.884	946.849	0.071	0.006	3.267	0.353	0.130	0.007
9500.0	0.318	37.282	1.975	946.552	0.076	0.006	3.386	0.382	0.146	0.009
10000.0	0.316	36.806	2.064	946.256	0.082	0.007	3.500	0.412	0.162	0.010
10500.0	0.314	36.335	2.153	945.960	0.088	0.008	3.609	0.442	0.179	0.012
11000.0	0.312	35.868	2.240	945.663	0.094	0.009	3.714	0.473	0.196	0.014
11500.0	0.310	35.406	2.326	945.367	0.100	0.010	3.814	0.504	0.213	0.016
12000.0	0.308	34.949	2.410	945.071	0.106	0.011	3.910	0.535	0.232	0.018
12500.0	0.307	34.495	2.494	944.775	0.113	0.012	4.002	0.567	0.250	0.020
13000.0	0.305	34.046	2.577	944.479	0.119	0.013	4.089	0.598	0.269	0.023
13500.0	0.303	33.600	2.658	944.183	0.125	0.014	4.173	0.630	0.288	0.026
14000.0	0.301	33.159	2.739	943.887	0.132	0.016	4.253	0.662	0.307	0.029
14500.0	0.299	32.722	2.818	943.592	0.139	0.017	4.329	0.695	0.327	0.032
15000.0	0.297	32.288	2.897	943.297	0.145	0.018	4.402	0.727	0.347	0.035
15500.0	0.295	31.858	2.974	943.001	0.152	0.020	4.471	0.760	0.366	0.038
16000.0	0.294	31.432	3.051	942.706	0.159	0.022	4.537	0.793	0.386	0.042
16500.0	0.292	31.009	3.126	942.410	0.166	0.023	4.599	0.825	0.406	0.046
17000.0	0.290	30.590	3.201	942.115	0.173	0.025	4.659	0.858	0.427	0.050
17500.0	0.288	30.174	3.274	941.820	0.180	0.027	4.716	0.891	0.447	0.054
18000.0	0.286	29.761	3.347	941.524	0.187	0.028	4.770	0.924	0.467	0.058
18500.0	0.285	29.353	3.419	941.228	0.194	0.030	4.822	0.957	0.487	0.063
19000.0	0.283	28.947	3.490	940.931	0.201	0.032	4.871	0.990	0.507	0.068
19500.0	0.281	28.545	3.560	940.634	0.208	0.034	4.918	1.022	0.528	0.072
20000.0	0.279	28.146	3.630	940.336	0.215	0.036	4.963	1.055	0.548	0.078
20500.0	0.277	27.751	3.698	940.037	0.223	0.039	5.006	1.088	0.568	0.083
21000.0	0.276	27.359	3.766	939.737	0.230	0.041	5.047	1.120	0.588	0.088
21500.0	0.274	26.970	3.832	939.437	0.238	0.043	5.086	1.153	0.609	0.094
22000.0	0.272	26.585	3.898	939.135	0.245	0.046	5.124	1.185	0.629	0.100
22500.0	0.271	26.203	3.963	938.833	0.253	0.048	5.159	1.218	0.649	0.106
23000.0	0.269	25.824	4.028	938.529	0.260	0.051	5.193	1.250	0.669	0.112
23500.0	0.267	25.449	4.091	938.224	0.268	0.053	5.226	1.282	0.689	0.119
24000.0	0.265	25.076	4.154	937.918	0.276	0.056	5.257	1.314	0.709	0.126
24500.0	0.264	24.708	4.215	937.611	0.284	0.059	5.287	1.345	0.729	0.132
25000.0	0.262	24.342	4.276	937.302	0.292	0.062	5.315	1.377	0.749	0.139
25500.0	0.260	23.980	4.336	936.993	0.300	0.065	5.342	1.408	0.769	0.147
27500.0	0.253	22.564	4.569	935.741	0.332	0.077	5.437	1.532	0.847	0.178
30000.0	0.245	20.866	4.842	934.146	0.372	0.095	5.530	1.682	0.941	0.221
32500.0	0.237	19.249	5.095	932.517	0.414	0.116	5.597	1.827	1.031	0.268
35000.0	0.229	17.711	5.329	930.854	0.455	0.138	5.641	1.966	1.116	0.321
37500.0	0.221	16.251	5.544	929.156	0.497	0.163	5.665	2.100	1.194	0.377
40000.0	0.213	14.868	5.740	927.421	0.538	0.189	5.672	2.226	1.266	0.438
42500.0	0.205	13.561	5.918	925.648	0.579	0.217	5.665	2.346	1.332	0.503
45000.0	0.198	12.330	6.078	923.837	0.619	0.248	5.644	2.459	1.391	0.571
47500.0	0.190	11.174	6.220	921.986	0.658	0.279	5.614	2.564	1.444	0.643
50000.0	0.183	10.092	6.345	920.096	0.696	0.312	5.575	2.662	1.490	0.717
52500.0	0.176	9.083	6.453	918.165	0.733	0.346	5.529	2.753	1.530	0.795
55000.0	0.169	8.145	6.545	916.193	0.768	0.381	5.478	2.836	1.564	0.875
57500.0	0.163	7.278	6.620	914.180	0.802	0.416	5.423	2.911	1.593	0.957
60000.0	0.156	6.479	6.679	912.127	0.834	0.452	5.365	2.979	1.617	1.041
62500.0	0.150	5.746	6.724	910.032	0.864	0.487	5.307	3.039	1.636	1.126
65000.0	0.144	5.078	6.754	907.898	0.892	0.522	5.248	3.092	1.651	1.213
67500.0	0.138	4.471	6.770	905.725	0.918	0.556	5.190	3.139	1.662	1.301
70000.0	0.132	3.923	6.774	903.515	0.942	0.590	5.133	3.179	1.669	1.389

**Table C.30 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.407	0.000	952.235	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.287	0.025	952.166	0.000	0.000	0.024	0.000	0.000	0.000
500.0	0.356	46.813	0.126	951.887	0.002	0.000	0.244	0.002	0.000	0.000
1000.0	0.353	46.229	0.249	951.538	0.005	0.000	0.529	0.008	0.000	0.000
1500.0	0.351	45.655	0.369	951.190	0.008	0.000	0.802	0.017	0.002	0.000
2000.0	0.348	45.090	0.488	950.843	0.012	0.000	1.063	0.030	0.004	0.000
2500.0	0.346	44.534	0.604	950.496	0.015	0.000	1.313	0.045	0.007	0.000
3000.0	0.343	43.986	0.719	950.150	0.019	0.001	1.552	0.063	0.011	0.000
3500.0	0.341	43.446	0.831	949.804	0.024	0.001	1.782	0.083	0.017	0.000
4000.0	0.338	42.913	0.941	949.459	0.028	0.001	2.002	0.104	0.024	0.001
4500.0	0.336	42.388	1.050	949.114	0.033	0.002	2.213	0.127	0.033	0.001
5000.0	0.333	41.869	1.156	948.770	0.038	0.002	2.415	0.150	0.042	0.001
5500.0	0.331	41.358	1.261	948.426	0.043	0.003	2.610	0.175	0.053	0.002
6000.0	0.329	40.852	1.365	948.083	0.049	0.003	2.797	0.202	0.065	0.002
6500.0	0.326	40.353	1.466	947.740	0.055	0.004	2.977	0.228	0.078	0.003
7000.0	0.324	39.860	1.566	947.397	0.061	0.004	3.150	0.256	0.091	0.004
7500.0	0.322	39.372	1.665	947.055	0.067	0.005	3.316	0.285	0.106	0.005
8000.0	0.319	38.890	1.762	946.712	0.073	0.006	3.477	0.314	0.122	0.006
8500.0	0.317	38.414	1.857	946.370	0.080	0.007	3.631	0.344	0.138	0.007
9000.0	0.315	37.943	1.951	946.028	0.086	0.008	3.779	0.374	0.156	0.008
9500.0	0.313	37.476	2.044	945.686	0.093	0.009	3.922	0.405	0.173	0.010
10000.0	0.310	37.016	2.136	945.345	0.100	0.010	4.060	0.437	0.192	0.012
10500.0	0.308	36.560	2.226	945.003	0.107	0.011	4.193	0.468	0.211	0.014
11000.0	0.306	36.109	2.315	944.661	0.114	0.013	4.321	0.501	0.231	0.016
11500.0	0.304	35.662	2.402	944.319	0.122	0.014	4.444	0.533	0.251	0.018
12000.0	0.302	35.220	2.489	943.977	0.129	0.015	4.563	0.566	0.271	0.020
12500.0	0.300	34.783	2.574	943.635	0.136	0.017	4.677	0.600	0.292	0.023
13000.0	0.298	34.351	2.658	943.294	0.144	0.018	4.787	0.633	0.313	0.025
13500.0	0.295	33.922	2.741	942.952	0.152	0.020	4.892	0.667	0.335	0.028
14000.0	0.293	33.498	2.822	942.610	0.160	0.022	4.994	0.702	0.356	0.031
14500.0	0.291	33.078	2.903	942.269	0.167	0.024	5.092	0.736	0.378	0.034
15000.0	0.289	32.662	2.982	941.927	0.175	0.026	5.186	0.771	0.400	0.038
15500.0	0.287	32.250	3.060	941.585	0.183	0.028	5.277	0.806	0.422	0.041
16000.0	0.285	31.842	3.137	941.243	0.192	0.030	5.364	0.841	0.445	0.045
16500.0	0.283	31.438	3.214	940.902	0.200	0.032	5.447	0.876	0.467	0.049
17000.0	0.281	31.038	3.289	940.560	0.208	0.035	5.528	0.911	0.490	0.053
17500.0	0.279	30.641	3.363	940.218	0.216	0.037	5.605	0.946	0.513	0.058
18000.0	0.277	30.248	3.436	939.876	0.225	0.039	5.679	0.982	0.535	0.062
18500.0	0.275	29.859	3.508	939.533	0.233	0.042	5.751	1.017	0.558	0.067
19000.0	0.273	29.473	3.579	939.190	0.241	0.045	5.819	1.053	0.581	0.071
19500.0	0.272	29.091	3.649	938.847	0.250	0.048	5.885	1.089	0.603	0.076
20000.0	0.270	28.712	3.718	938.504	0.258	0.050	5.949	1.124	0.626	0.082
20500.0	0.268	28.337	3.787	938.159	0.267	0.053	6.010	1.160	0.649	0.087
21000.0	0.266	27.965	3.854	937.815	0.275	0.056	6.069	1.195	0.671	0.092
21500.0	0.264	27.597	3.920	937.469	0.284	0.060	6.126	1.231	0.694	0.098
22000.0	0.262	27.232	3.986	937.123	0.292	0.063	6.181	1.266	0.716	0.104
22500.0	0.260	26.871	4.051	936.776	0.301	0.066	6.234	1.302	0.739	0.110
23000.0	0.258	26.512	4.114	936.429	0.310	0.070	6.285	1.337	0.761	0.116
23500.0	0.257	26.157	4.177	936.080	0.318	0.073	6.334	1.373	0.784	0.122
24000.0	0.255	25.806	4.239	935.731	0.327	0.077	6.381	1.408	0.806	0.129
24500.0	0.253	25.457	4.301	935.380	0.336	0.081	6.427	1.443	0.828	0.136
25000.0	0.251	25.112	4.361	935.029	0.345	0.084	6.471	1.478	0.851	0.142
25500.0	0.249	24.771	4.421	934.676	0.353	0.088	6.514	1.513	0.873	0.149
26000.0	0.247	24.432	4.479	934.322	0.362	0.092	6.555	1.548	0.895	0.157
26500.0	0.246	24.097	4.537	933.967	0.371	0.096	6.595	1.582	0.917	0.164
27000.0	0.244	23.765	4.594	933.611	0.380	0.101	6.633	1.617	0.939	0.171
27500.0	0.242	23.436	4.650	933.254	0.389	0.105	6.670	1.651	0.960	0.179
28000.0	0.240	23.111	4.706	932.896	0.398	0.110	6.706	1.685	0.982	0.187
28500.0	0.239	22.788	4.760	932.537	0.407	0.114	6.740	1.719	1.003	0.195
29000.0	0.237	22.469	4.814	932.176	0.416	0.119	6.773	1.753	1.025	0.203
29500.0	0.235	22.153	4.867	931.814	0.425	0.124	6.805	1.787	1.046	0.211
30000.0	0.233	21.840	4.919	931.451	0.434	0.128	6.836	1.820	1.067	0.220
30500.0	0.232	21.530	4.970	931.087	0.442	0.133	6.866	1.854	1.088	0.228
31000.0	0.230	21.223	5.021	930.722	0.451	0.138	6.894	1.887	1.109	0.237
32500.0	0.225	20.321	5.168	929.618	0.478	0.154	6.974	1.985	1.171	0.264
35000.0	0.217	18.878	5.397	927.753	0.523	0.183	7.087	2.144	1.270	0.312
37500.0	0.209	17.510	5.607	925.857	0.568	0.214	7.178	2.298	1.365	0.363
40000.0	0.201	16.215	5.798	923.930	0.612	0.247	7.249	2.447	1.455	0.418
42500.0	0.193	14.990	5.972	921.973	0.656	0.282	7.303	2.589	1.540	0.476
45000.0	0.186	13.834	6.127	919.984	0.699	0.320	7.341	2.725	1.619	0.536
47500.0	0.179	12.746	6.266	917.964	0.740	0.359	7.366	2.855	1.692	0.599
50000.0	0.172	11.724	6.388	915.914	0.781	0.400	7.380	2.979	1.760	0.665
52500.0	0.166	10.765	6.494	913.833	0.820	0.443	7.383	3.096	1.823	0.732
55000.0	0.159	9.867	6.584	911.723	0.857	0.486	7.378	3.206	1.880	0.802
57500.0	0.153	9.029	6.660	909.583	0.893	0.530	7.366	3.310	1.933	0.873
60000.0	0.147	8.249	6.722	907.415	0.927	0.575	7.347	3.407	1.980	0.946
62500.0	0.142	7.523	6.771	905.218	0.959	0.621	7.324	3.497	2.023	1.021
65000.0	0.136	6.851	6.807	902.995	0.989	0.666	7.298	3.582	2.062	1.097
67500.0	0.131	6.229	6.830	900.746	1.017	0.711	7.268	3.660	2.097	1.174
70000.0	0.127	5.655	6.843	898.472	1.043	0.756	7.236	3.732	2.128	1.252

**Table C.31 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.496	0.000	952.145	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.376	0.023	952.094	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.356	46.896	0.114	951.888	0.002	0.000	0.184	0.001	0.000	0.000
1000.0	0.354	46.304	0.227	951.630	0.003	0.000	0.399	0.006	0.000	0.000
1500.0	0.353	45.719	0.337	951.371	0.005	0.000	0.606	0.013	0.001	0.000
2000.0	0.351	45.142	0.447	951.112	0.008	0.000	0.804	0.023	0.002	0.000
2500.0	0.349	44.571	0.554	950.853	0.010	0.000	0.993	0.036	0.004	0.000
3000.0	0.347	44.007	0.660	950.593	0.013	0.000	1.175	0.050	0.006	0.000
3500.0	0.345	43.450	0.765	950.334	0.016	0.000	1.349	0.066	0.010	0.000
4000.0	0.343	42.898	0.868	950.074	0.019	0.001	1.516	0.084	0.014	0.000
4500.0	0.341	42.353	0.970	949.814	0.022	0.001	1.676	0.104	0.019	0.001
5000.0	0.339	41.813	1.071	949.554	0.026	0.001	1.830	0.124	0.025	0.001
5500.0	0.337	41.279	1.170	949.293	0.029	0.001	1.977	0.146	0.032	0.001
6000.0	0.335	40.750	1.268	949.033	0.033	0.002	2.118	0.168	0.040	0.001
6500.0	0.334	40.226	1.365	948.772	0.037	0.002	2.254	0.192	0.049	0.002
7000.0	0.332	39.708	1.460	948.511	0.041	0.002	2.383	0.217	0.058	0.002
7500.0	0.330	39.195	1.555	948.250	0.045	0.003	2.507	0.242	0.069	0.003
8000.0	0.328	38.686	1.648	947.989	0.049	0.003	2.626	0.268	0.080	0.004
8500.0	0.326	38.182	1.740	947.728	0.054	0.004	2.740	0.294	0.091	0.005
9000.0	0.324	37.683	1.831	947.467	0.058	0.004	2.849	0.321	0.104	0.006
9500.0	0.323	37.188	1.920	947.205	0.063	0.005	2.953	0.349	0.117	0.007
10000.0	0.321	36.698	2.009	946.944	0.068	0.005	3.053	0.377	0.130	0.008
10500.0	0.319	36.212	2.097	946.683	0.073	0.006	3.148	0.405	0.144	0.010
11000.0	0.317	35.731	2.183	946.421	0.078	0.007	3.239	0.434	0.159	0.011
11500.0	0.316	35.253	2.269	946.160	0.083	0.007	3.326	0.463	0.174	0.013
12000.0	0.314	34.780	2.353	945.899	0.088	0.008	3.408	0.493	0.190	0.015
12500.0	0.312	34.310	2.437	945.637	0.094	0.009	3.487	0.522	0.205	0.017
13000.0	0.310	33.844	2.519	945.376	0.099	0.010	3.562	0.552	0.221	0.019
13500.0	0.309	33.382	2.600	945.115	0.105	0.011	3.633	0.583	0.238	0.022
14000.0	0.307	32.924	2.681	944.855	0.110	0.012	3.700	0.613	0.254	0.024
14500.0	0.305	32.469	2.761	944.594	0.116	0.013	3.764	0.644	0.271	0.027
15000.0	0.303	32.018	2.839	944.333	0.122	0.014	3.825	0.674	0.288	0.030
15500.0	0.302	31.571	2.917	944.073	0.128	0.015	3.882	0.705	0.305	0.033
16000.0	0.300	31.126	2.994	943.812	0.133	0.016	3.937	0.736	0.323	0.036
16500.0	0.298	30.686	3.070	943.552	0.139	0.017	3.988	0.767	0.340	0.039
17000.0	0.297	30.248	3.145	943.291	0.145	0.019	4.037	0.798	0.357	0.043
17500.0	0.295	29.814	3.219	943.030	0.151	0.020	4.083	0.829	0.375	0.047
18000.0	0.293	29.383	3.293	942.769	0.157	0.021	4.127	0.860	0.392	0.051
18500.0	0.292	28.955	3.365	942.507	0.164	0.023	4.168	0.891	0.410	0.055
19000.0	0.290	28.531	3.437	942.244	0.170	0.024	4.207	0.922	0.428	0.059
19500.0	0.288	28.110	3.508	941.981	0.176	0.026	4.245	0.953	0.445	0.064
20000.0	0.287	27.692	3.578	941.716	0.182	0.027	4.280	0.984	0.463	0.069
20500.0	0.285	27.277	3.647	941.451	0.189	0.029	4.314	1.015	0.481	0.074
21000.0	0.283	26.866	3.716	941.184	0.195	0.031	4.346	1.046	0.499	0.079
21500.0	0.282	26.458	3.784	940.916	0.202	0.033	4.376	1.077	0.517	0.084
22000.0	0.280	26.054	3.851	940.647	0.208	0.035	4.405	1.107	0.534	0.089
22500.0	0.279	25.652	3.917	940.377	0.215	0.036	4.432	1.138	0.552	0.095
23000.0	0.277	25.254	3.983	940.106	0.222	0.038	4.457	1.168	0.570	0.101
25000.0	0.270	23.695	4.236	939.007	0.249	0.047	4.547	1.288	0.641	0.127
27500.0	0.262	21.820	4.536	937.603	0.285	0.060	4.630	1.434	0.727	0.164
30000.0	0.254	20.026	4.817	936.164	0.321	0.074	4.686	1.576	0.809	0.206
32500.0	0.246	18.314	5.078	934.688	0.358	0.090	4.717	1.712	0.887	0.254
35000.0	0.238	16.684	5.320	933.173	0.396	0.108	4.727	1.842	0.959	0.306
37500.0	0.230	15.136	5.543	931.617	0.435	0.128	4.719	1.967	1.024	0.364
40000.0	0.222	13.670	5.747	930.018	0.473	0.150	4.696	2.084	1.083	0.427
42500.0	0.215	12.287	5.932	928.374	0.511	0.174	4.660	2.194	1.135	0.495
45000.0	0.207	10.987	6.098	926.682	0.548	0.199	4.614	2.297	1.180	0.567
47500.0	0.199	9.772	6.245	924.941	0.585	0.225	4.560	2.391	1.219	0.643
50000.0	0.192	8.642	6.373	923.148	0.621	0.252	4.499	2.478	1.251	0.724
52500.0	0.184	7.597	6.483	921.302	0.656	0.281	4.435	2.556	1.277	0.808
55000.0	0.177	6.636	6.574	919.401	0.689	0.310	4.368	2.625	1.298	0.896
57500.0	0.169	5.760	6.646	917.444	0.721	0.339	4.300	2.686	1.313	0.987
60000.0	0.162	4.967	6.701	915.430	0.751	0.367	4.233	2.739	1.323	1.080
62500.0	0.155	4.254	6.739	913.361	0.779	0.396	4.167	2.784	1.329	1.175
65000.0	0.148	3.620	6.760	911.236	0.805	0.424	4.104	2.822	1.331	1.271
67500.0	0.142	3.061	6.766	909.058	0.828	0.450	4.044	2.852	1.331	1.369
70000.0	0.135	2.572	6.758	906.828	0.850	0.475	3.989	2.876	1.328	1.467

**Table C.32 [] Exposure-Dependent 40% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.496	0.000	952.145	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.376	0.024	952.087	0.000	0.000	0.020	0.000	0.000	0.000
500.0	0.356	46.898	0.119	951.853	0.002	0.000	0.207	0.001	0.000	0.000
1000.0	0.354	46.309	0.236	951.559	0.004	0.000	0.450	0.007	0.000	0.000
1500.0	0.352	45.728	0.350	951.265	0.006	0.000	0.683	0.015	0.001	0.000
2000.0	0.350	45.155	0.463	950.971	0.009	0.000	0.906	0.026	0.003	0.000
2500.0	0.347	44.590	0.575	950.677	0.012	0.000	1.120	0.040	0.005	0.000
3000.0	0.345	44.032	0.684	950.383	0.015	0.000	1.325	0.056	0.008	0.000
3500.0	0.343	43.481	0.792	950.088	0.019	0.001	1.522	0.074	0.013	0.000
4000.0	0.341	42.937	0.898	949.793	0.023	0.001	1.710	0.093	0.018	0.000
4500.0	0.339	42.400	1.003	949.498	0.026	0.001	1.891	0.114	0.024	0.001
5000.0	0.337	41.869	1.106	949.203	0.030	0.001	2.065	0.136	0.032	0.001
5500.0	0.335	41.344	1.208	948.908	0.035	0.002	2.232	0.159	0.040	0.001
6000.0	0.333	40.825	1.308	948.612	0.039	0.002	2.392	0.184	0.050	0.002
6500.0	0.331	40.312	1.407	948.317	0.044	0.003	2.546	0.209	0.061	0.002
7000.0	0.329	39.804	1.504	948.021	0.049	0.003	2.694	0.235	0.072	0.003
7500.0	0.327	39.302	1.600	947.725	0.054	0.004	2.836	0.262	0.085	0.004
8000.0	0.325	38.805	1.695	947.430	0.059	0.004	2.972	0.289	0.098	0.005
8500.0	0.323	38.313	1.788	947.133	0.064	0.005	3.103	0.318	0.112	0.006
9000.0	0.321	37.827	1.880	946.837	0.070	0.005	3.228	0.346	0.126	0.007
9500.0	0.319	37.345	1.971	946.541	0.075	0.006	3.348	0.375	0.142	0.008
10000.0	0.317	36.868	2.061	946.245	0.081	0.007	3.464	0.405	0.158	0.010
10500.0	0.315	36.396	2.149	945.949	0.087	0.008	3.574	0.435	0.174	0.012
11000.0	0.313	35.928	2.237	945.653	0.093	0.009	3.680	0.466	0.192	0.013
11500.0	0.311	35.465	2.323	945.357	0.099	0.010	3.781	0.496	0.209	0.015
12000.0	0.309	35.006	2.408	945.061	0.105	0.011	3.878	0.527	0.227	0.017
12500.0	0.307	34.551	2.492	944.765	0.112	0.012	3.971	0.559	0.246	0.020
13000.0	0.305	34.101	2.574	944.469	0.118	0.013	4.060	0.590	0.264	0.022
13500.0	0.303	33.654	2.656	944.173	0.124	0.014	4.144	0.622	0.283	0.025
14000.0	0.301	33.212	2.737	943.877	0.131	0.015	4.225	0.654	0.303	0.028
14500.0	0.299	32.773	2.817	943.582	0.138	0.017	4.302	0.687	0.322	0.031
15000.0	0.297	32.339	2.895	943.286	0.144	0.018	4.376	0.719	0.342	0.034
15500.0	0.296	31.908	2.973	942.991	0.151	0.020	4.446	0.752	0.362	0.037
16000.0	0.294	31.481	3.050	942.696	0.158	0.021	4.513	0.784	0.381	0.041
16500.0	0.292	31.057	3.125	942.400	0.165	0.023	4.576	0.817	0.401	0.045
17000.0	0.290	30.637	3.200	942.105	0.172	0.024	4.637	0.850	0.421	0.049
17500.0	0.288	30.220	3.274	941.809	0.179	0.026	4.695	0.883	0.442	0.053
18000.0	0.287	29.807	3.347	941.514	0.186	0.028	4.750	0.915	0.462	0.057
18500.0	0.285	29.397	3.419	941.218	0.193	0.030	4.802	0.948	0.482	0.062
19000.0	0.283	28.991	3.490	940.921	0.200	0.032	4.852	0.981	0.502	0.066
19500.0	0.281	28.588	3.561	940.624	0.207	0.034	4.900	1.014	0.522	0.071
20000.0	0.279	28.188	3.630	940.326	0.215	0.036	4.945	1.047	0.543	0.076
20500.0	0.278	27.792	3.699	940.027	0.222	0.038	4.989	1.079	0.563	0.082
21000.0	0.276	27.399	3.766	939.728	0.229	0.040	5.030	1.112	0.583	0.087
21500.0	0.274	27.010	3.833	939.427	0.237	0.043	5.070	1.145	0.603	0.093
22000.0	0.273	26.624	3.899	939.126	0.244	0.045	5.108	1.177	0.624	0.099
22500.0	0.271	26.241	3.965	938.823	0.252	0.048	5.144	1.209	0.644	0.105
23000.0	0.269	25.862	4.029	938.520	0.260	0.050	5.179	1.241	0.664	0.111
23500.0	0.267	25.486	4.092	938.215	0.267	0.053	5.212	1.274	0.684	0.117
24000.0	0.266	25.113	4.155	937.909	0.275	0.056	5.244	1.305	0.704	0.124
24500.0	0.264	24.743	4.217	937.602	0.283	0.058	5.274	1.337	0.724	0.131
25000.0	0.262	24.377	4.278	937.294	0.291	0.061	5.302	1.369	0.744	0.138
25500.0	0.260	24.014	4.338	936.984	0.299	0.064	5.330	1.400	0.763	0.145
26000.0	0.259	23.655	4.398	936.673	0.307	0.067	5.356	1.432	0.783	0.152
27500.0	0.254	22.596	4.571	935.733	0.331	0.077	5.426	1.524	0.841	0.176
30000.0	0.245	20.895	4.845	934.139	0.372	0.095	5.521	1.675	0.936	0.219
32500.0	0.237	19.275	5.098	932.511	0.413	0.115	5.589	1.820	1.026	0.266
35000.0	0.229	17.734	5.333	930.848	0.455	0.137	5.634	1.960	1.111	0.318
37500.0	0.221	16.271	5.548	929.150	0.496	0.162	5.660	2.093	1.190	0.375
40000.0	0.213	14.886	5.745	927.416	0.538	0.188	5.668	2.220	1.262	0.435
42500.0	0.205	13.577	5.923	925.644	0.578	0.217	5.661	2.341	1.328	0.500
45000.0	0.198	12.344	6.084	923.833	0.619	0.247	5.641	2.454	1.388	0.568
47500.0	0.191	11.187	6.226	921.983	0.658	0.279	5.611	2.559	1.440	0.639
50000.0	0.183	10.103	6.351	920.093	0.696	0.312	5.572	2.658	1.487	0.714
52500.0	0.176	9.092	6.460	918.163	0.733	0.346	5.527	2.749	1.528	0.792
55000.0	0.169	8.153	6.551	916.191	0.768	0.381	5.476	2.832	1.562	0.872
57500.0	0.163	7.284	6.626	914.178	0.802	0.416	5.421	2.907	1.591	0.954
60000.0	0.156	6.484	6.686	912.125	0.834	0.451	5.364	2.975	1.615	1.038
62500.0	0.150	5.751	6.731	910.031	0.864	0.487	5.306	3.036	1.635	1.123
65000.0	0.144	5.082	6.761	907.897	0.892	0.522	5.247	3.089	1.649	1.210
67500.0	0.138	4.474	6.777	905.724	0.918	0.556	5.189	3.136	1.661	1.298
70000.0	0.132	3.926	6.781	903.514	0.943	0.589	5.132	3.177	1.668	1.386

**Table C.33 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.496	0.000	952.145	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.377	0.025	952.078	0.000	0.000	0.023	0.000	0.000	0.000
500.0	0.356	46.902	0.124	951.808	0.002	0.000	0.236	0.002	0.000	0.000
1000.0	0.353	46.318	0.246	951.469	0.005	0.000	0.513	0.007	0.000	0.000
1500.0	0.351	45.743	0.366	951.131	0.008	0.000	0.779	0.017	0.001	0.000
2000.0	0.348	45.177	0.484	950.792	0.011	0.000	1.033	0.029	0.003	0.000
2500.0	0.346	44.620	0.600	950.453	0.015	0.000	1.278	0.044	0.006	0.000
3000.0	0.343	44.071	0.713	950.114	0.019	0.001	1.512	0.061	0.011	0.000
3500.0	0.341	43.529	0.825	949.774	0.023	0.001	1.738	0.080	0.016	0.000
4000.0	0.338	42.994	0.935	949.435	0.027	0.001	1.955	0.101	0.023	0.001
4500.0	0.336	42.467	1.044	949.095	0.032	0.002	2.164	0.123	0.031	0.001
5000.0	0.334	41.947	1.150	948.755	0.037	0.002	2.365	0.147	0.040	0.001
5500.0	0.331	41.433	1.255	948.415	0.042	0.002	2.559	0.171	0.051	0.002
6000.0	0.329	40.926	1.358	948.075	0.048	0.003	2.745	0.197	0.062	0.002
6500.0	0.327	40.425	1.460	947.734	0.054	0.004	2.925	0.223	0.075	0.003
7000.0	0.324	39.930	1.560	947.394	0.060	0.004	3.098	0.251	0.088	0.004
7500.0	0.322	39.441	1.659	947.053	0.066	0.005	3.265	0.279	0.103	0.005
8000.0	0.320	38.957	1.756	946.712	0.072	0.006	3.426	0.308	0.118	0.006
8500.0	0.318	38.479	1.852	946.371	0.079	0.007	3.581	0.337	0.134	0.007
9000.0	0.315	38.006	1.946	946.030	0.085	0.008	3.731	0.368	0.151	0.008
9500.0	0.313	37.539	2.040	945.689	0.092	0.009	3.875	0.398	0.169	0.010
10000.0	0.311	37.076	2.131	945.347	0.099	0.010	4.014	0.429	0.187	0.011
10500.0	0.309	36.619	2.222	945.006	0.106	0.011	4.147	0.461	0.206	0.013
11000.0	0.306	36.167	2.311	944.664	0.113	0.012	4.276	0.493	0.226	0.015
11500.0	0.304	35.719	2.399	944.323	0.120	0.014	4.401	0.526	0.246	0.017
12000.0	0.302	35.276	2.485	943.981	0.128	0.015	4.520	0.559	0.266	0.020
12500.0	0.300	34.837	2.571	943.640	0.135	0.017	4.636	0.592	0.287	0.022
13000.0	0.298	34.403	2.655	943.298	0.143	0.018	4.747	0.625	0.308	0.025
13500.0	0.296	33.974	2.738	942.957	0.151	0.020	4.854	0.659	0.329	0.027
14000.0	0.294	33.548	2.820	942.615	0.158	0.022	4.956	0.693	0.351	0.030
14500.0	0.292	33.127	2.900	942.274	0.166	0.023	5.055	0.728	0.373	0.034
15000.0	0.290	32.710	2.980	941.932	0.174	0.025	5.150	0.762	0.395	0.037
15500.0	0.288	32.297	3.058	941.591	0.182	0.027	5.242	0.797	0.417	0.041
16000.0	0.286	31.888	3.136	941.249	0.190	0.030	5.330	0.832	0.439	0.044
16500.0	0.284	31.483	3.212	940.907	0.199	0.032	5.414	0.867	0.462	0.048
17000.0	0.282	31.081	3.287	940.566	0.207	0.034	5.495	0.902	0.484	0.052
17500.0	0.280	30.684	3.362	940.224	0.215	0.036	5.573	0.937	0.507	0.056
18000.0	0.278	30.290	3.435	939.882	0.223	0.039	5.649	0.973	0.529	0.061
18500.0	0.276	29.900	3.507	939.539	0.232	0.042	5.721	1.008	0.552	0.065
19000.0	0.274	29.513	3.579	939.196	0.240	0.044	5.790	1.044	0.575	0.070
19500.0	0.272	29.130	3.649	938.853	0.249	0.047	5.857	1.080	0.597	0.075
20000.0	0.270	28.750	3.718	938.510	0.257	0.050	5.921	1.115	0.620	0.080
20500.0	0.268	28.374	3.787	938.166	0.266	0.053	5.983	1.151	0.642	0.086
21000.0	0.266	28.002	3.854	937.821	0.274	0.056	6.043	1.186	0.665	0.091
21500.0	0.264	27.633	3.921	937.476	0.283	0.059	6.101	1.222	0.688	0.097
22000.0	0.262	27.267	3.987	937.130	0.291	0.062	6.156	1.257	0.710	0.102
22500.0	0.261	26.904	4.052	936.783	0.300	0.066	6.209	1.293	0.733	0.108
23000.0	0.259	26.545	4.115	936.436	0.309	0.069	6.261	1.328	0.755	0.115
23500.0	0.257	26.190	4.179	936.087	0.317	0.073	6.311	1.363	0.778	0.121
24000.0	0.255	25.837	4.241	935.738	0.326	0.076	6.359	1.399	0.800	0.127
24500.0	0.253	25.488	4.302	935.387	0.335	0.080	6.405	1.434	0.822	0.134
25000.0	0.251	25.143	4.363	935.036	0.344	0.084	6.450	1.469	0.844	0.141
25500.0	0.250	24.800	4.422	934.683	0.353	0.088	6.493	1.504	0.867	0.148
26000.0	0.248	24.461	4.481	934.330	0.361	0.092	6.534	1.538	0.889	0.155
26500.0	0.246	24.125	4.539	933.975	0.370	0.096	6.575	1.573	0.911	0.162
27000.0	0.244	23.792	4.596	933.619	0.379	0.100	6.613	1.608	0.932	0.170
27500.0	0.242	23.463	4.653	933.262	0.388	0.104	6.651	1.642	0.954	0.177
28000.0	0.241	23.136	4.708	932.904	0.397	0.109	6.687	1.676	0.976	0.185
28500.0	0.239	22.813	4.763	932.545	0.406	0.113	6.722	1.710	0.997	0.193
29000.0	0.237	22.493	4.817	932.184	0.415	0.118	6.755	1.744	1.019	0.201
29500.0	0.235	22.177	4.870	931.823	0.424	0.123	6.788	1.778	1.040	0.209
30000.0	0.234	21.863	4.922	931.460	0.433	0.128	6.819	1.812	1.061	0.218
30500.0	0.232	21.552	4.974	931.096	0.442	0.133	6.849	1.845	1.082	0.226
31000.0	0.230	21.245	5.024	930.730	0.451	0.138	6.878	1.878	1.103	0.235
32500.0	0.225	20.341	5.171	929.627	0.478	0.154	6.959	1.977	1.165	0.262
35000.0	0.217	18.896	5.401	927.762	0.523	0.182	7.074	2.136	1.265	0.310
37500.0	0.209	17.525	5.611	925.867	0.568	0.213	7.166	2.290	1.360	0.361
40000.0	0.201	16.227	5.803	923.941	0.612	0.246	7.238	2.439	1.450	0.416
42500.0	0.194	15.000	5.977	921.983	0.656	0.281	7.293	2.582	1.535	0.473
45000.0	0.186	13.843	6.133	919.995	0.699	0.319	7.332	2.719	1.614	0.534
47500.0	0.179	12.753	6.271	917.976	0.741	0.358	7.357	2.849	1.687	0.596
50000.0	0.172	11.729	6.394	915.926	0.781	0.399	7.371	2.973	1.756	0.662
52500.0	0.166	10.768	6.500	913.845	0.820	0.442	7.375	3.090	1.819	0.729
55000.0	0.159	9.870	6.590	911.735	0.858	0.485	7.370	3.201	1.876	0.799
57500.0	0.153	9.031	6.667	909.595	0.893	0.530	7.359	3.305	1.929	0.870
60000.0	0.147	8.249	6.729	907.426	0.927	0.575	7.341	3.402	1.977	0.944
62500.0	0.142	7.523	6.777	905.230	0.959	0.620	7.318	3.493	2.020	1.018
65000.0	0.137	6.850	6.813	903.007	0.989	0.666	7.292	3.578	2.059	1.094
67500.0	0.131	6.227	6.837	900.758	1.017	0.711	7.262	3.656	2.094	1.172
70000.0	0.127	5.653	6.849	898.484	1.043	0.756	7.230	3.728	2.125	1.250

**Table C.34 [Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.983	0.023	951.485	0.000	0.000	0.015	0.000	0.000	0.000
500.0	0.361	47.503	0.113	951.293	0.001	0.000	0.167	0.001	0.000	0.000
1000.0	0.359	46.909	0.224	951.052	0.003	0.000	0.369	0.005	0.000	0.000
1500.0	0.358	46.322	0.333	950.810	0.005	0.000	0.563	0.012	0.001	0.000
2000.0	0.356	45.741	0.442	950.568	0.007	0.000	0.748	0.021	0.002	0.000
2500.0	0.354	45.167	0.548	950.327	0.010	0.000	0.926	0.033	0.003	0.000
3000.0	0.352	44.599	0.653	950.085	0.012	0.000	1.097	0.046	0.005	0.000
3500.0	0.350	44.037	0.757	949.843	0.015	0.000	1.260	0.061	0.008	0.000
4000.0	0.348	43.480	0.860	949.601	0.018	0.001	1.417	0.077	0.012	0.000
4500.0	0.347	42.930	0.961	949.358	0.021	0.001	1.568	0.095	0.017	0.000
5000.0	0.345	42.384	1.061	949.116	0.024	0.001	1.712	0.115	0.022	0.001
5500.0	0.343	41.844	1.160	948.874	0.027	0.001	1.850	0.135	0.028	0.001
6000.0	0.341	41.308	1.258	948.631	0.031	0.001	1.982	0.156	0.035	0.001
6500.0	0.339	40.778	1.354	948.389	0.034	0.002	2.109	0.179	0.042	0.002
7000.0	0.338	40.252	1.449	948.147	0.038	0.002	2.230	0.202	0.051	0.002
7500.0	0.336	39.731	1.544	947.905	0.042	0.002	2.346	0.226	0.060	0.003
8000.0	0.334	39.215	1.637	947.662	0.046	0.003	2.457	0.250	0.070	0.003
8500.0	0.332	38.703	1.729	947.420	0.050	0.003	2.563	0.276	0.080	0.004
9000.0	0.331	38.195	1.820	947.178	0.054	0.004	2.664	0.301	0.091	0.005
9500.0	0.329	37.692	1.910	946.936	0.058	0.004	2.760	0.328	0.103	0.006
10000.0	0.327	37.193	1.998	946.694	0.063	0.005	2.853	0.354	0.115	0.007
10500.0	0.326	36.697	2.086	946.453	0.067	0.005	2.940	0.382	0.127	0.008
11000.0	0.324	36.206	2.173	946.211	0.072	0.006	3.024	0.409	0.141	0.010
11500.0	0.322	35.719	2.259	945.970	0.076	0.006	3.103	0.437	0.154	0.011
12000.0	0.321	35.235	2.344	945.729	0.081	0.007	3.179	0.465	0.168	0.013
12500.0	0.319	34.755	2.428	945.488	0.086	0.008	3.251	0.494	0.182	0.015
13000.0	0.317	34.278	2.511	945.247	0.091	0.009	3.319	0.523	0.197	0.017
13500.0	0.316	33.805	2.593	945.007	0.096	0.009	3.383	0.552	0.211	0.019
14000.0	0.314	33.335	2.674	944.768	0.101	0.010	3.444	0.581	0.226	0.021
14500.0	0.312	32.869	2.754	944.528	0.106	0.011	3.501	0.610	0.241	0.023
15000.0	0.311	32.406	2.833	944.289	0.112	0.012	3.555	0.640	0.257	0.026
15500.0	0.309	31.946	2.912	944.050	0.117	0.013	3.606	0.670	0.272	0.029
16000.0	0.307	31.490	2.990	943.811	0.122	0.014	3.655	0.700	0.288	0.032
16500.0	0.306	31.036	3.067	943.571	0.128	0.015	3.700	0.729	0.303	0.035
17000.0	0.304	30.586	3.143	943.332	0.133	0.016	3.743	0.759	0.319	0.038
17500.0	0.303	30.139	3.218	943.092	0.138	0.017	3.784	0.789	0.335	0.041
18000.0	0.301	29.694	3.293	942.851	0.144	0.018	3.823	0.819	0.351	0.045
18500.0	0.299	29.253	3.366	942.610	0.150	0.020	3.859	0.849	0.367	0.049
19000.0	0.298	28.816	3.439	942.368	0.155	0.021	3.894	0.879	0.383	0.053
19500.0	0.296	28.381	3.512	942.124	0.161	0.022	3.926	0.909	0.399	0.057
20000.0	0.295	27.950	3.583	941.880	0.167	0.024	3.957	0.939	0.415	0.061
20500.0	0.293	27.521	3.654	941.635	0.173	0.025	3.987	0.969	0.432	0.066
21000.0	0.291	27.096	3.724	941.389	0.179	0.026	4.014	0.999	0.448	0.070
21500.0	0.290	26.674	3.793	941.142	0.185	0.028	4.041	1.028	0.464	0.075
22000.0	0.288	26.256	3.862	940.893	0.191	0.030	4.065	1.058	0.481	0.080
22500.0	0.287	25.840	3.930	940.643	0.197	0.031	4.088	1.087	0.497	0.085
25000.0	0.279	23.810	4.257	939.374	0.228	0.040	4.185	1.233	0.579	0.115
27500.0	0.271	21.861	4.566	938.070	0.261	0.051	4.251	1.375	0.658	0.149
30000.0	0.263	19.991	4.855	936.731	0.295	0.063	4.291	1.513	0.734	0.189
32500.0	0.255	18.203	5.126	935.353	0.330	0.078	4.307	1.647	0.805	0.235
35000.0	0.247	16.496	5.378	933.934	0.366	0.093	4.304	1.775	0.870	0.286
37500.0	0.239	14.873	5.612	932.471	0.402	0.111	4.283	1.897	0.929	0.342
40000.0	0.231	13.335	5.826	930.962	0.438	0.130	4.248	2.012	0.982	0.404
42500.0	0.223	11.884	6.020	929.402	0.474	0.150	4.202	2.120	1.029	0.471
45000.0	0.215	10.522	6.195	927.789	0.510	0.172	4.147	2.220	1.068	0.543
47500.0	0.207	9.250	6.350	926.120	0.545	0.196	4.084	2.312	1.101	0.620
50000.0	0.199	8.071	6.485	924.390	0.580	0.220	4.017	2.395	1.127	0.702
52500.0	0.191	6.985	6.600	922.598	0.613	0.245	3.946	2.470	1.148	0.789
55000.0	0.183	5.995	6.695	920.741	0.645	0.271	3.875	2.536	1.163	0.880
57500.0	0.175	5.100	6.769	918.817	0.675	0.296	3.804	2.593	1.172	0.974
60000.0	0.167	4.300	6.824	916.824	0.704	0.322	3.736	2.641	1.177	1.071
62500.0	0.160	3.592	6.860	914.763	0.731	0.347	3.671	2.681	1.179	1.172
65000.0	0.152	2.974	6.878	912.635	0.755	0.371	3.610	2.713	1.177	1.274
67500.0	0.144	2.441	6.879	910.442	0.777	0.394	3.553	2.738	1.173	1.377
70000.0	0.137	1.987	6.864	908.188	0.797	0.415	3.503	2.756	1.168	1.481

**Table C.35 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.983	0.024	951.478	0.000	0.000	0.018	0.000	0.000	0.000
500.0	0.361	47.505	0.117	951.258	0.002	0.000	0.190	0.001	0.000	0.000
1000.0	0.359	46.913	0.233	950.983	0.004	0.000	0.419	0.006	0.000	0.000
1500.0	0.357	46.329	0.346	950.707	0.006	0.000	0.639	0.014	0.001	0.000
2000.0	0.355	45.753	0.458	950.431	0.009	0.000	0.849	0.024	0.002	0.000
2500.0	0.353	45.184	0.569	950.155	0.011	0.000	1.051	0.037	0.004	0.000
3000.0	0.351	44.622	0.677	949.879	0.014	0.000	1.244	0.051	0.007	0.000
3500.0	0.349	44.066	0.784	949.603	0.018	0.001	1.430	0.068	0.011	0.000
4000.0	0.347	43.517	0.890	949.326	0.021	0.001	1.608	0.086	0.016	0.000
4500.0	0.345	42.973	0.994	949.050	0.025	0.001	1.778	0.106	0.021	0.001
5000.0	0.343	42.436	1.097	948.774	0.028	0.001	1.942	0.127	0.028	0.001
5500.0	0.341	41.905	1.198	948.498	0.032	0.002	2.099	0.149	0.036	0.001
6000.0	0.339	41.379	1.298	948.222	0.036	0.002	2.250	0.172	0.044	0.002
6500.0	0.337	40.859	1.396	947.946	0.041	0.002	2.394	0.196	0.054	0.002
7000.0	0.335	40.344	1.493	947.670	0.045	0.003	2.532	0.221	0.064	0.003
7500.0	0.333	39.834	1.589	947.394	0.050	0.003	2.665	0.247	0.075	0.003
8000.0	0.331	39.329	1.684	947.118	0.055	0.004	2.792	0.273	0.087	0.004
8500.0	0.329	38.829	1.777	946.842	0.059	0.004	2.914	0.300	0.100	0.005
9000.0	0.327	38.333	1.869	946.567	0.064	0.005	3.030	0.327	0.113	0.006
9500.0	0.325	37.843	1.960	946.291	0.070	0.005	3.142	0.355	0.127	0.007
10000.0	0.323	37.357	2.050	946.016	0.075	0.006	3.248	0.384	0.142	0.009
10500.0	0.321	36.875	2.139	945.741	0.080	0.007	3.350	0.413	0.157	0.010
11000.0	0.319	36.397	2.226	945.466	0.086	0.008	3.448	0.442	0.173	0.012
11500.0	0.317	35.924	2.313	945.191	0.092	0.008	3.540	0.472	0.189	0.013
12000.0	0.316	35.455	2.398	944.917	0.097	0.009	3.629	0.502	0.205	0.015
12500.0	0.314	34.990	2.482	944.643	0.103	0.010	3.713	0.532	0.222	0.018
13000.0	0.312	34.529	2.566	944.369	0.109	0.011	3.794	0.562	0.239	0.020
13500.0	0.310	34.071	2.648	944.095	0.115	0.012	3.870	0.593	0.257	0.022
14000.0	0.308	33.618	2.729	943.822	0.121	0.014	3.942	0.624	0.274	0.025
14500.0	0.307	33.168	2.809	943.549	0.127	0.015	4.011	0.655	0.292	0.028
15000.0	0.305	32.721	2.889	943.277	0.133	0.016	4.077	0.687	0.310	0.030
15500.0	0.303	32.278	2.967	943.005	0.140	0.017	4.139	0.718	0.328	0.034
16000.0	0.301	31.839	3.045	942.733	0.146	0.018	4.197	0.750	0.346	0.037
16500.0	0.299	31.402	3.121	942.461	0.152	0.020	4.253	0.781	0.365	0.040
17000.0	0.298	30.969	3.197	942.189	0.158	0.021	4.306	0.813	0.383	0.044
17500.0	0.296	30.540	3.272	941.917	0.165	0.023	4.356	0.845	0.401	0.048
18000.0	0.294	30.114	3.346	941.644	0.171	0.024	4.404	0.877	0.420	0.052
18500.0	0.293	29.691	3.419	941.371	0.178	0.026	4.449	0.908	0.439	0.056
19000.0	0.291	29.271	3.491	941.097	0.184	0.028	4.492	0.940	0.457	0.060
19500.0	0.289	28.854	3.563	940.823	0.191	0.029	4.533	0.972	0.476	0.065
20000.0	0.287	28.441	3.633	940.548	0.198	0.031	4.572	1.003	0.494	0.069
20500.0	0.286	28.031	3.703	940.272	0.205	0.033	4.609	1.035	0.513	0.074
21000.0	0.284	27.625	3.772	939.995	0.212	0.035	4.644	1.067	0.532	0.079
21500.0	0.282	27.221	3.840	939.717	0.218	0.037	4.678	1.098	0.551	0.085
22000.0	0.281	26.821	3.908	939.438	0.225	0.039	4.710	1.129	0.569	0.090
22500.0	0.279	26.424	3.974	939.158	0.233	0.041	4.740	1.161	0.588	0.096
23000.0	0.277	26.031	4.040	938.876	0.240	0.043	4.769	1.192	0.607	0.102
23500.0	0.276	25.640	4.105	938.594	0.247	0.046	4.796	1.223	0.625	0.108
24000.0	0.274	25.253	4.169	938.310	0.254	0.048	4.822	1.254	0.644	0.114
24500.0	0.272	24.869	4.233	938.025	0.261	0.050	4.847	1.284	0.662	0.121
25000.0	0.271	24.488	4.295	937.739	0.269	0.053	4.870	1.315	0.681	0.127
27500.0	0.262	22.633	4.597	936.288	0.306	0.067	4.968	1.465	0.772	0.163
30000.0	0.254	20.858	4.878	934.804	0.345	0.082	5.038	1.611	0.860	0.205
32500.0	0.246	19.163	5.141	933.285	0.384	0.100	5.082	1.752	0.942	0.251
35000.0	0.238	17.548	5.385	931.729	0.423	0.119	5.104	1.887	1.020	0.302
37500.0	0.230	16.012	5.609	930.136	0.463	0.141	5.107	2.016	1.091	0.358
40000.0	0.222	14.556	5.815	928.504	0.502	0.164	5.094	2.139	1.156	0.418
42500.0	0.214	13.179	6.002	926.830	0.541	0.189	5.067	2.255	1.214	0.483
45000.0	0.206	11.882	6.171	925.113	0.580	0.216	5.029	2.363	1.265	0.552
47500.0	0.198	10.665	6.321	923.352	0.617	0.244	4.981	2.464	1.310	0.625
50000.0	0.191	9.527	6.453	921.545	0.654	0.273	4.926	2.557	1.348	0.702
52500.0	0.183	8.469	6.567	919.690	0.690	0.303	4.865	2.642	1.380	0.782
55000.0	0.176	7.490	6.664	917.787	0.724	0.334	4.801	2.719	1.406	0.865
57500.0	0.169	6.590	6.742	915.835	0.756	0.365	4.734	2.787	1.427	0.951
60000.0	0.162	5.767	6.804	913.833	0.787	0.397	4.666	2.848	1.442	1.040
62500.0	0.155	5.020	6.849	911.781	0.816	0.428	4.598	2.900	1.453	1.130
65000.0	0.148	4.345	6.878	909.680	0.843	0.458	4.532	2.945	1.460	1.222
67500.0	0.142	3.742	6.892	907.531	0.868	0.488	4.469	2.983	1.463	1.315
70000.0	0.136	3.205	6.891	905.335	0.890	0.516	4.408	3.014	1.463	1.409

**Table C.36 [] Exposure-Dependent 80% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.984	0.025	951.469	0.000	0.000	0.020	0.000	0.000	0.000
500.0	0.361	47.508	0.123	951.213	0.002	0.000	0.219	0.001	0.000	0.000
1000.0	0.358	46.921	0.244	950.892	0.005	0.000	0.482	0.007	0.000	0.000
1500.0	0.356	46.343	0.363	950.571	0.007	0.000	0.735	0.015	0.001	0.000
2000.0	0.353	45.773	0.480	950.249	0.011	0.000	0.978	0.027	0.003	0.000
2500.0	0.351	45.212	0.595	949.928	0.014	0.000	1.210	0.041	0.006	0.000
3000.0	0.349	44.658	0.708	949.607	0.018	0.001	1.434	0.057	0.010	0.000
3500.0	0.346	44.111	0.819	949.286	0.022	0.001	1.648	0.075	0.014	0.000
4000.0	0.344	43.571	0.929	948.965	0.026	0.001	1.855	0.095	0.021	0.000
4500.0	0.342	43.038	1.037	948.644	0.030	0.001	2.053	0.116	0.028	0.001
5000.0	0.339	42.512	1.143	948.323	0.035	0.002	2.244	0.139	0.036	0.001
5500.0	0.337	41.992	1.248	948.002	0.040	0.002	2.427	0.162	0.046	0.001
6000.0	0.335	41.478	1.351	947.681	0.045	0.003	2.603	0.187	0.056	0.002
6500.0	0.332	40.970	1.453	947.359	0.051	0.003	2.773	0.212	0.068	0.002
7000.0	0.330	40.467	1.553	947.038	0.056	0.004	2.936	0.239	0.081	0.003
7500.0	0.328	39.971	1.651	946.717	0.062	0.004	3.093	0.266	0.094	0.004
8000.0	0.326	39.479	1.749	946.396	0.068	0.005	3.244	0.294	0.109	0.005
8500.0	0.324	38.993	1.844	946.076	0.074	0.006	3.390	0.322	0.124	0.006
9000.0	0.321	38.512	1.939	945.755	0.080	0.007	3.529	0.351	0.140	0.007
9500.0	0.319	38.037	2.032	945.434	0.087	0.008	3.664	0.381	0.156	0.009
10000.0	0.317	37.566	2.124	945.114	0.093	0.009	3.793	0.411	0.174	0.010
10500.0	0.315	37.099	2.215	944.793	0.100	0.010	3.917	0.442	0.191	0.012
11000.0	0.313	36.638	2.304	944.473	0.106	0.011	4.036	0.473	0.210	0.014
11500.0	0.311	36.181	2.392	944.153	0.113	0.012	4.150	0.504	0.229	0.016
12000.0	0.309	35.729	2.479	943.833	0.120	0.013	4.260	0.536	0.248	0.018
12500.0	0.307	35.281	2.565	943.513	0.127	0.015	4.365	0.568	0.267	0.020
13000.0	0.305	34.837	2.650	943.194	0.134	0.016	4.466	0.601	0.287	0.023
13500.0	0.303	34.397	2.733	942.875	0.142	0.018	4.563	0.634	0.307	0.025
14000.0	0.301	33.962	2.816	942.556	0.149	0.019	4.656	0.667	0.328	0.028
14500.0	0.299	33.530	2.897	942.237	0.156	0.021	4.745	0.700	0.348	0.031
15000.0	0.297	33.103	2.977	941.919	0.164	0.023	4.830	0.734	0.369	0.034
15500.0	0.295	32.679	3.056	941.601	0.171	0.025	4.911	0.768	0.390	0.037
16000.0	0.293	32.259	3.134	941.282	0.179	0.026	4.989	0.802	0.411	0.041
16500.0	0.291	31.843	3.211	940.964	0.187	0.028	5.063	0.836	0.432	0.045
17000.0	0.289	31.430	3.287	940.646	0.194	0.030	5.135	0.870	0.453	0.048
17500.0	0.287	31.021	3.362	940.328	0.202	0.033	5.203	0.904	0.475	0.052
18000.0	0.285	30.615	3.436	940.010	0.210	0.035	5.268	0.939	0.496	0.057
18500.0	0.283	30.213	3.509	939.692	0.218	0.037	5.330	0.973	0.517	0.061
19000.0	0.281	29.815	3.582	939.373	0.226	0.039	5.390	1.008	0.539	0.066
19500.0	0.279	29.420	3.653	939.054	0.234	0.042	5.447	1.042	0.560	0.070
20000.0	0.277	29.028	3.723	938.735	0.242	0.044	5.502	1.077	0.581	0.075
20500.0	0.276	28.639	3.793	938.415	0.250	0.047	5.555	1.111	0.603	0.080
21000.0	0.274	28.254	3.861	938.094	0.258	0.050	5.605	1.146	0.624	0.085
21500.0	0.272	27.873	3.929	937.773	0.266	0.052	5.654	1.180	0.645	0.091
22000.0	0.270	27.494	3.996	937.451	0.274	0.055	5.700	1.214	0.667	0.096
22500.0	0.268	27.119	4.062	937.128	0.282	0.058	5.745	1.249	0.688	0.102
23000.0	0.266	26.748	4.127	936.804	0.290	0.061	5.788	1.283	0.709	0.108
23500.0	0.265	26.379	4.191	936.479	0.299	0.064	5.829	1.317	0.730	0.114
24000.0	0.263	26.014	4.255	936.153	0.307	0.068	5.868	1.351	0.752	0.121
24500.0	0.261	25.652	4.317	935.826	0.315	0.071	5.906	1.385	0.773	0.127
25000.0	0.259	25.293	4.379	935.498	0.324	0.074	5.943	1.419	0.794	0.134
25500.0	0.257	24.938	4.440	935.168	0.332	0.078	5.978	1.453	0.815	0.140
26000.0	0.256	24.586	4.500	934.838	0.340	0.081	6.012	1.486	0.835	0.147
26500.0	0.254	24.236	4.560	934.507	0.349	0.085	6.044	1.520	0.856	0.155
27000.0	0.252	23.891	4.618	934.174	0.357	0.089	6.075	1.553	0.877	0.162
27500.0	0.250	23.548	4.676	933.840	0.366	0.093	6.104	1.586	0.897	0.169
28000.0	0.249	23.209	4.733	933.505	0.374	0.097	6.133	1.619	0.918	0.177
28500.0	0.247	22.872	4.789	933.169	0.383	0.101	6.160	1.652	0.938	0.185
29000.0	0.245	22.539	4.844	932.831	0.391	0.105	6.186	1.685	0.958	0.193
30000.0	0.242	21.882	4.952	932.153	0.409	0.113	6.234	1.750	0.998	0.209
32500.0	0.233	20.295	5.209	930.433	0.452	0.137	6.337	1.908	1.096	0.253
35000.0	0.225	18.784	5.446	928.681	0.495	0.162	6.416	2.061	1.189	0.301
37500.0	0.217	17.349	5.664	926.897	0.539	0.190	6.472	2.209	1.277	0.353
40000.0	0.209	15.989	5.863	925.081	0.582	0.220	6.510	2.351	1.360	0.408
42500.0	0.201	14.701	6.044	923.230	0.624	0.252	6.531	2.487	1.437	0.467
45000.0	0.194	13.486	6.206	921.346	0.666	0.286	6.537	2.616	1.508	0.529
47500.0	0.186	12.342	6.351	919.428	0.707	0.321	6.531	2.738	1.572	0.594
50000.0	0.179	11.267	6.479	917.475	0.747	0.358	6.514	2.854	1.632	0.662
52500.0	0.172	10.261	6.590	915.488	0.785	0.397	6.488	2.962	1.685	0.733
55000.0	0.165	9.320	6.684	913.467	0.822	0.436	6.455	3.063	1.733	0.806
57500.0	0.159	8.445	6.764	911.411	0.857	0.476	6.416	3.157	1.775	0.881
60000.0	0.153	7.632	6.828	909.321	0.891	0.517	6.372	3.243	1.812	0.958
62500.0	0.147	6.880	6.878	907.198	0.922	0.558	6.325	3.323	1.844	1.036
65000.0	0.141	6.187	6.914	905.043	0.951	0.599	6.276	3.395	1.872	1.117
67500.0	0.135	5.549	6.937	902.856	0.979	0.639	6.225	3.461	1.896	1.198
70000.0	0.130	4.966	6.947	900.638	1.004	0.679	6.174	3.520	1.916	1.281

**Table C.37 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.983	0.022	951.486	0.000	0.000	0.015	0.000	0.000	0.000
500.0	0.361	47.503	0.112	951.297	0.001	0.000	0.165	0.001	0.000	0.000
1000.0	0.360	46.909	0.223	951.059	0.003	0.000	0.363	0.005	0.000	0.000
1500.0	0.358	46.322	0.332	950.822	0.005	0.000	0.553	0.012	0.001	0.000
2000.0	0.356	45.741	0.440	950.584	0.007	0.000	0.736	0.021	0.002	0.000
2500.0	0.354	45.166	0.546	950.346	0.009	0.000	0.911	0.032	0.003	0.000
3000.0	0.352	44.598	0.651	950.108	0.012	0.000	1.078	0.045	0.005	0.000
3500.0	0.350	44.035	0.755	949.870	0.015	0.000	1.239	0.060	0.008	0.000
4000.0	0.349	43.478	0.857	949.632	0.017	0.001	1.393	0.076	0.012	0.000
4500.0	0.347	42.926	0.958	949.394	0.020	0.001	1.541	0.094	0.016	0.000
5000.0	0.345	42.380	1.058	949.156	0.023	0.001	1.683	0.113	0.021	0.001
5500.0	0.343	41.839	1.156	948.917	0.027	0.001	1.818	0.133	0.027	0.001
6000.0	0.342	41.302	1.254	948.679	0.030	0.001	1.948	0.155	0.034	0.001
6500.0	0.340	40.771	1.350	948.440	0.034	0.002	2.072	0.177	0.041	0.002
7000.0	0.338	40.244	1.445	948.202	0.037	0.002	2.192	0.199	0.049	0.002
7500.0	0.336	39.722	1.539	947.963	0.041	0.002	2.305	0.223	0.058	0.003
8000.0	0.335	39.205	1.632	947.725	0.045	0.003	2.414	0.247	0.068	0.003
8500.0	0.333	38.692	1.724	947.487	0.049	0.003	2.518	0.272	0.078	0.004
9000.0	0.331	38.183	1.814	947.249	0.053	0.003	2.618	0.298	0.089	0.005
9500.0	0.329	37.678	1.904	947.010	0.057	0.004	2.712	0.324	0.100	0.006
10000.0	0.328	37.178	1.993	946.772	0.061	0.004	2.803	0.350	0.112	0.007
10500.0	0.326	36.681	2.081	946.535	0.066	0.005	2.889	0.377	0.124	0.008
11000.0	0.324	36.188	2.167	946.297	0.070	0.006	2.971	0.405	0.137	0.010
11500.0	0.323	35.699	2.253	946.059	0.075	0.006	3.049	0.432	0.150	0.011
12000.0	0.321	35.214	2.338	945.822	0.080	0.007	3.123	0.460	0.164	0.013
12500.0	0.319	34.732	2.422	945.585	0.085	0.008	3.193	0.489	0.177	0.015
13000.0	0.318	34.254	2.505	945.349	0.089	0.008	3.259	0.517	0.191	0.016
13500.0	0.316	33.779	2.587	945.113	0.094	0.009	3.322	0.546	0.206	0.019
14000.0	0.314	33.308	2.668	944.877	0.099	0.010	3.381	0.575	0.220	0.021
14500.0	0.313	32.840	2.748	944.641	0.104	0.011	3.437	0.604	0.235	0.023
15000.0	0.311	32.375	2.828	944.406	0.109	0.012	3.490	0.634	0.250	0.026
15500.0	0.310	31.913	2.906	944.170	0.115	0.012	3.540	0.663	0.265	0.028
16000.0	0.308	31.454	2.984	943.935	0.120	0.013	3.587	0.693	0.280	0.031
16500.0	0.306	30.999	3.061	943.700	0.125	0.014	3.632	0.722	0.295	0.034
17000.0	0.305	30.547	3.137	943.464	0.130	0.016	3.673	0.752	0.311	0.037
17500.0	0.303	30.097	3.213	943.227	0.136	0.017	3.713	0.782	0.326	0.041
18000.0	0.302	29.651	3.287	942.991	0.141	0.018	3.751	0.812	0.342	0.044
18500.0	0.300	29.208	3.361	942.753	0.147	0.019	3.786	0.841	0.357	0.048
19000.0	0.298	28.769	3.434	942.514	0.152	0.020	3.820	0.871	0.373	0.052
19500.0	0.297	28.332	3.507	942.275	0.158	0.022	3.852	0.901	0.389	0.056
20000.0	0.295	27.899	3.578	942.034	0.164	0.023	3.882	0.930	0.405	0.060
20500.0	0.294	27.468	3.649	941.792	0.169	0.024	3.911	0.960	0.421	0.065
21000.0	0.292	27.041	3.719	941.549	0.175	0.026	3.937	0.990	0.437	0.069
21500.0	0.291	26.617	3.789	941.305	0.181	0.027	3.963	1.019	0.453	0.074
22000.0	0.289	26.196	3.857	941.060	0.187	0.029	3.987	1.049	0.469	0.079
22500.0	0.287	25.779	3.925	940.814	0.193	0.030	4.009	1.078	0.485	0.084
25000.0	0.279	23.738	4.254	939.561	0.224	0.039	4.103	1.222	0.565	0.114
27500.0	0.272	21.778	4.563	938.273	0.256	0.050	4.166	1.364	0.642	0.148
30000.0	0.264	19.898	4.854	936.949	0.290	0.062	4.203	1.501	0.716	0.188
32500.0	0.256	18.100	5.126	935.586	0.324	0.075	4.217	1.634	0.786	0.233
35000.0	0.248	16.384	5.379	934.180	0.360	0.091	4.212	1.761	0.850	0.284
37500.0	0.240	14.752	5.613	932.730	0.395	0.108	4.190	1.882	0.908	0.340
40000.0	0.232	13.206	5.828	931.233	0.431	0.126	4.154	1.997	0.959	0.402
42500.0	0.224	11.748	6.024	929.683	0.467	0.147	4.106	2.104	1.004	0.469
45000.0	0.216	10.380	6.199	928.079	0.502	0.168	4.050	2.204	1.042	0.541
47500.0	0.208	9.103	6.355	926.417	0.537	0.191	3.987	2.295	1.074	0.619
50000.0	0.199	7.922	6.490	924.693	0.571	0.215	3.919	2.378	1.099	0.701
52500.0	0.191	6.836	6.605	922.904	0.604	0.239	3.849	2.452	1.119	0.788
55000.0	0.183	5.847	6.699	921.048	0.635	0.264	3.778	2.517	1.133	0.879
57500.0	0.175	4.955	6.774	919.122	0.665	0.289	3.708	2.574	1.142	0.975
60000.0	0.168	4.160	6.828	917.127	0.694	0.314	3.640	2.621	1.146	1.073
62500.0	0.160	3.460	6.863	915.060	0.720	0.338	3.576	2.660	1.147	1.174
65000.0	0.152	2.850	6.879	912.925	0.744	0.361	3.516	2.691	1.146	1.277
67500.0	0.144	2.327	6.878	910.724	0.765	0.383	3.462	2.715	1.141	1.381
70000.0	0.137	1.884	6.862	908.461	0.785	0.404	3.413	2.733	1.136	1.486

**Table C.38 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.983	0.023	951.479	0.000	0.000	0.017	0.000	0.000	0.000
500.0	0.361	47.505	0.117	951.262	0.002	0.000	0.188	0.001	0.000	0.000
1000.0	0.359	46.913	0.232	950.990	0.004	0.000	0.413	0.006	0.000	0.000
1500.0	0.357	46.329	0.345	950.717	0.006	0.000	0.630	0.013	0.001	0.000
2000.0	0.355	45.753	0.457	950.445	0.009	0.000	0.838	0.024	0.002	0.000
2500.0	0.353	45.183	0.567	950.172	0.011	0.000	1.037	0.036	0.004	0.000
3000.0	0.351	44.620	0.675	949.900	0.014	0.000	1.227	0.051	0.007	0.000
3500.0	0.349	44.064	0.782	949.628	0.017	0.001	1.410	0.067	0.011	0.000
4000.0	0.347	43.515	0.887	949.355	0.021	0.001	1.586	0.085	0.015	0.000
4500.0	0.345	42.971	0.991	949.083	0.024	0.001	1.754	0.105	0.021	0.001
5000.0	0.343	42.433	1.093	948.810	0.028	0.001	1.915	0.126	0.027	0.001
5500.0	0.341	41.901	1.194	948.538	0.032	0.001	2.070	0.148	0.035	0.001
6000.0	0.339	41.375	1.294	948.265	0.036	0.002	2.218	0.171	0.043	0.002
6500.0	0.337	40.854	1.392	947.992	0.040	0.002	2.360	0.194	0.053	0.002
7000.0	0.335	40.338	1.489	947.720	0.045	0.003	2.497	0.219	0.063	0.003
7500.0	0.333	39.827	1.585	947.448	0.049	0.003	2.627	0.244	0.074	0.003
8000.0	0.331	39.321	1.679	947.175	0.054	0.004	2.752	0.271	0.085	0.004
8500.0	0.329	38.820	1.772	946.903	0.059	0.004	2.872	0.297	0.098	0.005
9000.0	0.327	38.324	1.864	946.631	0.064	0.005	2.987	0.325	0.111	0.006
9500.0	0.325	37.832	1.955	946.359	0.069	0.005	3.096	0.352	0.125	0.007
10000.0	0.323	37.345	2.045	946.087	0.074	0.006	3.201	0.381	0.139	0.009
10500.0	0.322	36.862	2.133	945.816	0.079	0.007	3.301	0.409	0.154	0.010
11000.0	0.320	36.383	2.221	945.545	0.085	0.007	3.397	0.438	0.169	0.012
11500.0	0.318	35.909	2.307	945.274	0.090	0.008	3.488	0.468	0.185	0.013
12000.0	0.316	35.438	2.392	945.003	0.096	0.009	3.575	0.498	0.201	0.015
12500.0	0.314	34.972	2.477	944.732	0.102	0.010	3.657	0.528	0.218	0.017
13000.0	0.312	34.509	2.560	944.462	0.108	0.011	3.736	0.558	0.235	0.020
13500.0	0.311	34.050	2.642	944.192	0.114	0.012	3.811	0.589	0.252	0.022
14000.0	0.309	33.595	2.723	943.923	0.119	0.013	3.882	0.619	0.269	0.025
14500.0	0.307	33.144	2.803	943.654	0.125	0.014	3.949	0.650	0.286	0.027
15000.0	0.305	32.696	2.883	943.385	0.132	0.016	4.013	0.682	0.304	0.030
15500.0	0.304	32.251	2.961	943.117	0.138	0.017	4.073	0.713	0.322	0.033
16000.0	0.302	31.810	3.039	942.848	0.144	0.018	4.130	0.744	0.340	0.036
16500.0	0.300	31.372	3.115	942.580	0.150	0.019	4.185	0.776	0.358	0.040
17000.0	0.298	30.938	3.191	942.311	0.156	0.021	4.236	0.807	0.376	0.043
17500.0	0.297	30.506	3.266	942.043	0.163	0.022	4.285	0.839	0.394	0.047
18000.0	0.295	30.078	3.340	941.774	0.169	0.024	4.332	0.870	0.412	0.051
18500.0	0.293	29.654	3.413	941.504	0.175	0.025	4.376	0.902	0.430	0.055
19000.0	0.291	29.232	3.485	941.234	0.182	0.027	4.418	0.933	0.448	0.060
19500.0	0.290	28.814	3.557	940.963	0.188	0.029	4.457	0.965	0.467	0.064
20000.0	0.288	28.399	3.628	940.692	0.195	0.030	4.495	0.996	0.485	0.069
20500.0	0.286	27.988	3.697	940.419	0.202	0.032	4.531	1.027	0.503	0.074
21000.0	0.285	27.579	3.767	940.145	0.209	0.034	4.566	1.059	0.522	0.079
21500.0	0.283	27.174	3.835	939.871	0.215	0.036	4.598	1.090	0.540	0.084
22000.0	0.281	26.772	3.902	939.595	0.222	0.038	4.629	1.121	0.559	0.090
22500.0	0.280	26.374	3.969	939.318	0.229	0.040	4.659	1.152	0.577	0.095
23000.0	0.278	25.978	4.035	939.040	0.236	0.042	4.687	1.183	0.595	0.101
23500.0	0.276	25.586	4.100	938.761	0.243	0.045	4.713	1.214	0.614	0.107
24000.0	0.275	25.197	4.164	938.480	0.251	0.047	4.738	1.244	0.632	0.113
25000.0	0.271	24.429	4.291	937.915	0.265	0.052	4.785	1.305	0.668	0.126
27500.0	0.263	22.565	4.593	936.480	0.302	0.065	4.879	1.454	0.758	0.162
30000.0	0.255	20.781	4.875	935.011	0.340	0.080	4.945	1.599	0.844	0.204
32500.0	0.247	19.078	5.138	933.506	0.379	0.098	4.986	1.739	0.925	0.250
35000.0	0.239	17.454	5.383	931.965	0.418	0.117	5.005	1.873	1.001	0.301
37500.0	0.230	15.911	5.608	930.385	0.457	0.138	5.005	2.001	1.070	0.357
40000.0	0.223	14.447	5.815	928.766	0.496	0.161	4.989	2.123	1.133	0.417
42500.0	0.215	13.064	6.003	927.104	0.535	0.185	4.960	2.238	1.190	0.483
45000.0	0.207	11.761	6.172	925.398	0.573	0.211	4.919	2.345	1.240	0.552
47500.0	0.199	10.539	6.323	923.647	0.610	0.239	4.870	2.445	1.283	0.625
50000.0	0.192	9.397	6.455	921.848	0.646	0.268	4.813	2.537	1.320	0.702
52500.0	0.184	8.336	6.569	920.001	0.682	0.297	4.750	2.621	1.350	0.783
55000.0	0.177	7.356	6.666	918.104	0.715	0.327	4.685	2.696	1.375	0.867
57500.0	0.169	6.456	6.744	916.156	0.748	0.358	4.617	2.763	1.394	0.953
60000.0	0.162	5.634	6.805	914.157	0.778	0.388	4.549	2.822	1.408	1.042
62500.0	0.155	4.889	6.850	912.107	0.807	0.419	4.481	2.874	1.418	1.133
65000.0	0.149	4.218	6.878	910.006	0.833	0.448	4.415	2.917	1.424	1.226
67500.0	0.142	3.619	6.891	907.856	0.858	0.477	4.351	2.954	1.426	1.320
70000.0	0.136	3.088	6.890	905.658	0.880	0.504	4.291	2.983	1.426	1.414

**Table C.39 [] Exposure-Dependent 80% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.363	48.104	0.000	951.533	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.363	47.984	0.025	951.470	0.000	0.000	0.020	0.000	0.000	0.000
500.0	0.361	47.508	0.123	951.215	0.002	0.000	0.217	0.001	0.000	0.000
1000.0	0.358	46.921	0.244	950.896	0.005	0.000	0.479	0.007	0.000	0.000
1500.0	0.356	46.343	0.362	950.577	0.007	0.000	0.730	0.015	0.001	0.000
2000.0	0.353	45.774	0.479	950.257	0.011	0.000	0.971	0.027	0.003	0.000
2500.0	0.351	45.212	0.594	949.939	0.014	0.000	1.202	0.041	0.006	0.000
3000.0	0.349	44.658	0.707	949.619	0.018	0.001	1.424	0.057	0.009	0.000
3500.0	0.346	44.111	0.818	949.300	0.022	0.001	1.636	0.075	0.014	0.000
4000.0	0.344	43.571	0.927	948.981	0.026	0.001	1.841	0.095	0.020	0.000
4500.0	0.342	43.038	1.035	948.662	0.030	0.001	2.038	0.116	0.028	0.001
5000.0	0.339	42.512	1.141	948.343	0.035	0.002	2.227	0.138	0.036	0.001
5500.0	0.337	41.991	1.245	948.024	0.040	0.002	2.409	0.162	0.045	0.001
6000.0	0.335	41.477	1.348	947.705	0.045	0.003	2.584	0.186	0.056	0.002
6500.0	0.333	40.969	1.450	947.386	0.050	0.003	2.752	0.212	0.068	0.002
7000.0	0.330	40.466	1.550	947.067	0.056	0.004	2.914	0.238	0.080	0.003
7500.0	0.328	39.969	1.648	946.748	0.062	0.004	3.069	0.265	0.094	0.004
8000.0	0.326	39.478	1.745	946.429	0.068	0.005	3.219	0.293	0.108	0.005
8500.0	0.324	38.991	1.841	946.111	0.074	0.006	3.363	0.321	0.123	0.006
9000.0	0.322	38.510	1.935	945.792	0.080	0.007	3.501	0.350	0.139	0.007
9500.0	0.319	38.034	2.029	945.473	0.086	0.008	3.634	0.380	0.155	0.009
10000.0	0.317	37.562	2.120	945.155	0.093	0.009	3.762	0.410	0.172	0.010
10500.0	0.315	37.096	2.211	944.837	0.099	0.010	3.885	0.440	0.190	0.012
11000.0	0.313	36.634	2.300	944.519	0.106	0.011	4.003	0.471	0.208	0.014
11500.0	0.311	36.176	2.388	944.201	0.113	0.012	4.116	0.503	0.227	0.016
12000.0	0.309	35.724	2.475	943.883	0.120	0.013	4.224	0.534	0.246	0.018
12500.0	0.307	35.275	2.561	943.565	0.127	0.015	4.328	0.566	0.265	0.020
13000.0	0.305	34.831	2.645	943.248	0.134	0.016	4.428	0.599	0.285	0.022
13500.0	0.303	34.391	2.729	942.931	0.141	0.018	4.524	0.632	0.305	0.025
14000.0	0.301	33.955	2.811	942.614	0.148	0.019	4.615	0.665	0.325	0.028
14500.0	0.299	33.522	2.892	942.298	0.156	0.021	4.703	0.698	0.346	0.031
15000.0	0.297	33.094	2.972	941.982	0.163	0.023	4.787	0.731	0.366	0.034
15500.0	0.295	32.670	3.052	941.665	0.171	0.024	4.867	0.765	0.387	0.037
16000.0	0.293	32.249	3.129	941.349	0.178	0.026	4.943	0.799	0.408	0.041
16500.0	0.291	31.832	3.206	941.034	0.186	0.028	5.017	0.833	0.429	0.045
17000.0	0.289	31.419	3.282	940.718	0.193	0.030	5.087	0.867	0.450	0.048
17500.0	0.287	31.009	3.357	940.402	0.201	0.032	5.154	0.901	0.471	0.052
18000.0	0.285	30.603	3.431	940.086	0.209	0.034	5.218	0.935	0.492	0.057
18500.0	0.283	30.200	3.505	939.770	0.217	0.037	5.279	0.969	0.513	0.061
19000.0	0.282	29.801	3.577	939.454	0.225	0.039	5.338	1.004	0.534	0.066
19500.0	0.280	29.405	3.648	939.137	0.233	0.041	5.394	1.038	0.556	0.070
20000.0	0.278	29.012	3.718	938.820	0.240	0.044	5.448	1.072	0.577	0.075
20500.0	0.276	28.623	3.788	938.502	0.248	0.046	5.500	1.107	0.598	0.080
21000.0	0.274	28.237	3.856	938.184	0.256	0.049	5.549	1.141	0.619	0.085
21500.0	0.272	27.855	3.924	937.864	0.265	0.052	5.597	1.175	0.640	0.091
22000.0	0.270	27.476	3.991	937.544	0.273	0.055	5.642	1.209	0.661	0.096
22500.0	0.269	27.100	4.057	937.223	0.281	0.058	5.686	1.244	0.682	0.102
23000.0	0.267	26.728	4.122	936.901	0.289	0.061	5.728	1.278	0.703	0.108
23500.0	0.265	26.358	4.186	936.579	0.297	0.064	5.768	1.312	0.724	0.114
24000.0	0.263	25.992	4.250	936.255	0.305	0.067	5.807	1.345	0.745	0.121
24500.0	0.261	25.629	4.313	935.930	0.314	0.070	5.844	1.379	0.766	0.127
25000.0	0.260	25.270	4.374	935.604	0.322	0.074	5.880	1.413	0.787	0.134
25500.0	0.258	24.914	4.435	935.277	0.330	0.077	5.914	1.446	0.808	0.140
26000.0	0.256	24.560	4.496	934.948	0.339	0.081	5.947	1.480	0.829	0.147
26500.0	0.254	24.211	4.555	934.619	0.347	0.084	5.978	1.513	0.849	0.155
27000.0	0.253	23.864	4.614	934.288	0.355	0.088	6.009	1.546	0.870	0.162
27500.0	0.251	23.521	4.671	933.956	0.364	0.092	6.037	1.579	0.890	0.169
28000.0	0.249	23.180	4.728	933.623	0.372	0.096	6.065	1.612	0.910	0.177
28500.0	0.247	22.843	4.784	933.289	0.381	0.100	6.091	1.644	0.930	0.185
30000.0	0.242	21.851	4.948	932.278	0.407	0.112	6.164	1.741	0.990	0.209
32500.0	0.234	20.259	5.205	930.568	0.450	0.135	6.264	1.898	1.087	0.253
35000.0	0.225	18.745	5.442	928.826	0.493	0.160	6.339	2.050	1.179	0.302
37500.0	0.217	17.306	5.660	927.051	0.536	0.188	6.393	2.197	1.266	0.353
40000.0	0.209	15.942	5.860	925.243	0.579	0.217	6.428	2.338	1.348	0.409
42500.0	0.202	14.651	6.040	923.401	0.621	0.249	6.446	2.472	1.423	0.468
45000.0	0.194	13.433	6.203	921.525	0.663	0.283	6.449	2.601	1.493	0.530
47500.0	0.187	12.286	6.348	919.615	0.704	0.318	6.441	2.722	1.557	0.596
50000.0	0.180	11.209	6.476	917.670	0.744	0.355	6.422	2.836	1.615	0.664
52500.0	0.173	10.200	6.587	915.689	0.782	0.393	6.394	2.943	1.667	0.735
55000.0	0.166	9.258	6.682	913.674	0.818	0.432	6.358	3.043	1.714	0.808
57500.0	0.159	8.381	6.761	911.625	0.853	0.472	6.318	3.135	1.755	0.883
60000.0	0.153	7.567	6.825	909.540	0.887	0.512	6.272	3.220	1.791	0.960
62500.0	0.147	6.814	6.875	907.423	0.918	0.552	6.224	3.298	1.822	1.039
65000.0	0.141	6.121	6.911	905.272	0.947	0.593	6.173	3.369	1.849	1.120
67500.0	0.135	5.484	6.934	903.088	0.975	0.632	6.121	3.433	1.871	1.202
70000.0	0.130	4.901	6.944	900.874	1.000	0.671	6.068	3.491	1.890	1.285

**Table C.40 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.568	0.000	952.073	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.359	47.447	0.022	952.026	0.000	0.000	0.015	0.000	0.000	0.000
500.0	0.357	46.967	0.112	951.835	0.001	0.000	0.166	0.001	0.000	0.000
1000.0	0.355	46.373	0.223	951.596	0.003	0.000	0.365	0.005	0.000	0.000
1500.0	0.353	45.786	0.332	951.357	0.005	0.000	0.557	0.012	0.001	0.000
2000.0	0.352	45.206	0.439	951.117	0.007	0.000	0.741	0.021	0.002	0.000
2500.0	0.350	44.632	0.545	950.878	0.009	0.000	0.918	0.032	0.003	0.000
3000.0	0.348	44.064	0.650	950.637	0.012	0.000	1.087	0.046	0.005	0.000
3500.0	0.346	43.503	0.753	950.397	0.015	0.000	1.249	0.061	0.008	0.000
4000.0	0.344	42.946	0.855	950.156	0.017	0.001	1.405	0.077	0.012	0.000
4500.0	0.343	42.396	0.956	949.915	0.020	0.001	1.554	0.095	0.016	0.000
5000.0	0.341	41.851	1.056	949.674	0.024	0.001	1.697	0.114	0.022	0.001
5500.0	0.339	41.310	1.154	949.433	0.027	0.001	1.834	0.135	0.028	0.001
6000.0	0.337	40.775	1.251	949.191	0.030	0.001	1.966	0.156	0.034	0.001
6500.0	0.336	40.245	1.347	948.950	0.034	0.002	2.092	0.178	0.042	0.002
7000.0	0.334	39.720	1.442	948.708	0.038	0.002	2.213	0.201	0.050	0.002
7500.0	0.332	39.200	1.536	948.465	0.041	0.002	2.329	0.225	0.059	0.003
8000.0	0.330	38.684	1.629	948.223	0.045	0.003	2.439	0.250	0.069	0.003
8500.0	0.329	38.173	1.720	947.981	0.049	0.003	2.545	0.275	0.080	0.004
9000.0	0.327	37.666	1.811	947.739	0.054	0.004	2.646	0.301	0.091	0.005
9500.0	0.325	37.163	1.900	947.496	0.058	0.004	2.743	0.327	0.102	0.006
10000.0	0.323	36.665	1.989	947.253	0.062	0.005	2.835	0.354	0.114	0.007
10500.0	0.322	36.170	2.076	947.011	0.067	0.005	2.923	0.381	0.127	0.009
11000.0	0.320	35.680	2.163	946.768	0.071	0.006	3.007	0.409	0.140	0.010
11500.0	0.318	35.194	2.248	946.526	0.076	0.006	3.087	0.437	0.154	0.012
12000.0	0.317	34.711	2.333	946.283	0.081	0.007	3.163	0.465	0.168	0.013
12500.0	0.315	34.233	2.416	946.040	0.086	0.008	3.235	0.494	0.182	0.015
13000.0	0.313	33.758	2.499	945.798	0.091	0.009	3.304	0.522	0.197	0.017
13500.0	0.312	33.286	2.580	945.555	0.096	0.009	3.369	0.552	0.211	0.019
14000.0	0.310	32.819	2.661	945.313	0.101	0.010	3.430	0.581	0.227	0.022
14500.0	0.308	32.355	2.741	945.071	0.106	0.011	3.488	0.611	0.242	0.024
15000.0	0.307	31.894	2.820	944.829	0.112	0.012	3.542	0.641	0.257	0.027
15500.0	0.305	31.436	2.898	944.587	0.117	0.013	3.594	0.670	0.273	0.030
16000.0	0.304	30.982	2.975	944.346	0.122	0.014	3.642	0.701	0.289	0.033
16500.0	0.302	30.531	3.052	944.105	0.128	0.015	3.687	0.731	0.304	0.036
17000.0	0.300	30.083	3.127	943.864	0.133	0.016	3.729	0.761	0.320	0.039
17500.0	0.299	29.639	3.202	943.623	0.139	0.017	3.768	0.792	0.336	0.043
18000.0	0.297	29.197	3.276	943.382	0.144	0.018	3.805	0.822	0.352	0.046
18500.0	0.296	28.758	3.349	943.140	0.150	0.020	3.840	0.852	0.368	0.050
19000.0	0.294	28.323	3.422	942.898	0.155	0.021	3.872	0.883	0.383	0.054
19500.0	0.292	27.890	3.493	942.656	0.161	0.022	3.903	0.913	0.399	0.058
20000.0	0.291	27.461	3.564	942.413	0.167	0.024	3.931	0.943	0.415	0.063
20500.0	0.289	27.034	3.634	942.169	0.172	0.025	3.958	0.974	0.431	0.067
21000.0	0.288	26.611	3.704	941.924	0.178	0.027	3.983	1.004	0.447	0.072
21500.0	0.286	26.191	3.772	941.679	0.184	0.028	4.006	1.034	0.463	0.077
22000.0	0.285	25.774	3.840	941.432	0.190	0.030	4.028	1.064	0.479	0.082
22500.0	0.283	25.360	3.908	941.184	0.196	0.031	4.048	1.094	0.495	0.088
23000.0	0.281	24.949	3.974	940.935	0.202	0.033	4.067	1.124	0.511	0.093
23500.0	0.280	24.542	4.040	940.684	0.208	0.035	4.085	1.153	0.526	0.099
24000.0	0.278	24.137	4.105	940.433	0.214	0.037	4.101	1.183	0.542	0.105
25000.0	0.275	23.337	4.232	939.925	0.227	0.040	4.131	1.241	0.574	0.118
27500.0	0.267	21.394	4.539	938.631	0.259	0.051	4.185	1.384	0.651	0.153
30000.0	0.259	19.531	4.826	937.299	0.292	0.063	4.215	1.522	0.725	0.193
32500.0	0.252	17.750	5.095	935.928	0.326	0.077	4.223	1.655	0.794	0.240
35000.0	0.244	16.051	5.345	934.514	0.361	0.092	4.212	1.783	0.858	0.291
37500.0	0.236	14.436	5.576	933.054	0.396	0.109	4.185	1.903	0.915	0.349
40000.0	0.228	12.907	5.788	931.546	0.432	0.128	4.146	2.017	0.966	0.411
42500.0	0.220	11.467	5.980	929.986	0.467	0.148	4.095	2.123	1.010	0.480
45000.0	0.212	10.116	6.153	928.371	0.502	0.170	4.037	2.222	1.047	0.553
47500.0	0.204	8.859	6.305	926.696	0.537	0.192	3.972	2.312	1.078	0.632
50000.0	0.196	7.696	6.437	924.959	0.570	0.216	3.903	2.393	1.102	0.715
52500.0	0.188	6.629	6.549	923.157	0.603	0.240	3.832	2.465	1.121	0.803
55000.0	0.180	5.659	6.640	921.287	0.634	0.265	3.761	2.529	1.134	0.896
57500.0	0.172	4.787	6.711	919.347	0.663	0.290	3.691	2.583	1.142	0.992
60000.0	0.164	4.011	6.762	917.337	0.691	0.314	3.624	2.629	1.146	1.091
62500.0	0.157	3.329	6.794	915.256	0.716	0.338	3.561	2.666	1.146	1.192
65000.0	0.149	2.737	6.808	913.107	0.740	0.361	3.502	2.696	1.144	1.296
67500.0	0.141	2.230	6.804	910.892	0.761	0.383	3.448	2.718	1.139	1.401
70000.0	0.134	1.802	6.786	908.616	0.780	0.403	3.400	2.735	1.133	1.506

**Table C.41 [] Exposure-Dependent 40% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.568	0.000	952.073	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.448	0.023	952.019	0.000	0.000	0.017	0.000	0.000	0.000
500.0	0.357	46.969	0.117	951.800	0.002	0.000	0.189	0.001	0.000	0.000
1000.0	0.355	46.378	0.231	951.525	0.004	0.000	0.417	0.006	0.000	0.000
1500.0	0.353	45.794	0.345	951.251	0.006	0.000	0.635	0.014	0.001	0.000
2000.0	0.351	45.219	0.456	950.976	0.009	0.000	0.845	0.024	0.002	0.000
2500.0	0.349	44.650	0.566	950.701	0.011	0.000	1.046	0.037	0.004	0.000
3000.0	0.347	44.088	0.674	950.426	0.014	0.000	1.238	0.051	0.007	0.000
3500.0	0.344	43.533	0.780	950.150	0.018	0.001	1.423	0.068	0.011	0.000
4000.0	0.342	42.984	0.885	949.875	0.021	0.001	1.600	0.086	0.016	0.000
4500.0	0.340	42.442	0.989	949.599	0.025	0.001	1.770	0.106	0.021	0.001
5000.0	0.338	41.905	1.091	949.323	0.028	0.001	1.934	0.127	0.028	0.001
5500.0	0.337	41.374	1.192	949.047	0.032	0.002	2.090	0.149	0.036	0.001
6000.0	0.335	40.849	1.291	948.771	0.036	0.002	2.241	0.172	0.044	0.002
6500.0	0.333	40.329	1.390	948.495	0.041	0.002	2.385	0.196	0.054	0.002
7000.0	0.331	39.815	1.486	948.218	0.045	0.003	2.524	0.221	0.064	0.003
7500.0	0.329	39.306	1.582	947.942	0.050	0.003	2.656	0.247	0.075	0.003
8000.0	0.327	38.802	1.676	947.665	0.054	0.004	2.784	0.273	0.087	0.004
8500.0	0.325	38.303	1.769	947.388	0.059	0.004	2.906	0.300	0.100	0.005
9000.0	0.323	37.808	1.861	947.112	0.064	0.005	3.022	0.327	0.113	0.006
9500.0	0.321	37.319	1.951	946.835	0.070	0.005	3.134	0.355	0.127	0.007
10000.0	0.319	36.834	2.041	946.558	0.075	0.006	3.241	0.384	0.142	0.009
10500.0	0.317	36.354	2.129	946.281	0.081	0.007	3.344	0.413	0.157	0.010
11000.0	0.315	35.878	2.216	946.004	0.086	0.008	3.441	0.442	0.173	0.012
11500.0	0.314	35.406	2.302	945.728	0.092	0.009	3.535	0.472	0.189	0.014
12000.0	0.312	34.939	2.387	945.451	0.098	0.009	3.624	0.502	0.206	0.016
12500.0	0.310	34.475	2.471	945.175	0.103	0.010	3.709	0.532	0.223	0.018
13000.0	0.308	34.016	2.553	944.898	0.109	0.011	3.790	0.563	0.240	0.020
13500.0	0.306	33.561	2.635	944.622	0.115	0.012	3.867	0.594	0.258	0.023
14000.0	0.304	33.109	2.716	944.346	0.121	0.014	3.940	0.625	0.276	0.025
14500.0	0.303	32.662	2.796	944.070	0.128	0.015	4.009	0.656	0.294	0.028
15000.0	0.301	32.218	2.875	943.795	0.134	0.016	4.075	0.688	0.312	0.031
15500.0	0.299	31.777	2.952	943.519	0.140	0.017	4.138	0.720	0.331	0.034
16000.0	0.297	31.341	3.029	943.244	0.146	0.019	4.196	0.751	0.349	0.038
16500.0	0.296	30.907	3.105	942.969	0.153	0.020	4.252	0.783	0.368	0.041
17000.0	0.294	30.478	3.181	942.695	0.159	0.022	4.304	0.815	0.386	0.045
17500.0	0.292	30.051	3.255	942.420	0.165	0.023	4.354	0.848	0.405	0.049
18000.0	0.290	29.628	3.328	942.146	0.172	0.025	4.400	0.880	0.423	0.053
18500.0	0.289	29.208	3.401	941.871	0.178	0.026	4.444	0.912	0.442	0.057
19000.0	0.287	28.791	3.472	941.597	0.185	0.028	4.485	0.944	0.460	0.062
19500.0	0.285	28.377	3.543	941.322	0.192	0.030	4.524	0.976	0.479	0.067
20000.0	0.284	27.967	3.613	941.047	0.198	0.031	4.560	1.008	0.497	0.071
20500.0	0.282	27.560	3.682	940.772	0.205	0.033	4.595	1.040	0.516	0.076
21000.0	0.280	27.156	3.750	940.496	0.212	0.035	4.627	1.072	0.534	0.082
21500.0	0.279	26.755	3.818	940.219	0.219	0.037	4.658	1.104	0.553	0.087
22000.0	0.277	26.357	3.885	939.941	0.226	0.039	4.687	1.136	0.571	0.093
22500.0	0.275	25.962	3.951	939.662	0.232	0.041	4.714	1.168	0.589	0.099
23000.0	0.274	25.571	4.016	939.382	0.239	0.044	4.740	1.199	0.608	0.105
23500.0	0.272	25.183	4.080	939.101	0.247	0.046	4.764	1.230	0.626	0.111
24000.0	0.270	24.798	4.144	938.820	0.254	0.048	4.787	1.262	0.644	0.117
24500.0	0.269	24.416	4.206	938.536	0.261	0.051	4.808	1.293	0.662	0.124
25000.0	0.267	24.037	4.268	938.252	0.268	0.053	4.828	1.324	0.680	0.131
25500.0	0.265	23.662	4.330	937.967	0.275	0.056	4.847	1.354	0.698	0.138
26000.0	0.264	23.289	4.390	937.680	0.283	0.058	4.865	1.385	0.716	0.145
27500.0	0.259	22.192	4.567	936.811	0.305	0.067	4.911	1.475	0.769	0.168
30000.0	0.251	20.425	4.846	935.336	0.343	0.082	4.968	1.621	0.854	0.210
32500.0	0.243	18.739	5.106	933.824	0.381	0.099	5.001	1.762	0.935	0.257
35000.0	0.235	17.132	5.347	932.276	0.419	0.119	5.013	1.896	1.010	0.309
37500.0	0.227	15.606	5.569	930.688	0.458	0.140	5.008	2.024	1.079	0.365
40000.0	0.219	14.159	5.773	929.060	0.497	0.163	4.987	2.145	1.142	0.427
42500.0	0.211	12.792	5.958	927.390	0.535	0.187	4.954	2.259	1.198	0.493
45000.0	0.203	11.505	6.124	925.675	0.573	0.213	4.910	2.365	1.247	0.563
47500.0	0.196	10.300	6.272	923.915	0.610	0.241	4.857	2.464	1.289	0.637
50000.0	0.188	9.174	6.401	922.106	0.645	0.269	4.798	2.554	1.325	0.715
52500.0	0.181	8.130	6.513	920.250	0.680	0.299	4.734	2.636	1.355	0.797
55000.0	0.174	7.166	6.606	918.342	0.714	0.329	4.668	2.710	1.378	0.881
57500.0	0.166	6.281	6.682	916.384	0.745	0.359	4.599	2.775	1.397	0.969
60000.0	0.159	5.475	6.740	914.375	0.775	0.389	4.530	2.833	1.410	1.058
62500.0	0.153	4.745	6.782	912.314	0.804	0.419	4.463	2.882	1.419	1.150
65000.0	0.146	4.089	6.809	910.203	0.830	0.448	4.397	2.924	1.424	1.243
67500.0	0.139	3.504	6.819	908.042	0.854	0.477	4.334	2.959	1.425	1.337
70000.0	0.133	2.986	6.816	905.834	0.876	0.504	4.274	2.987	1.424	1.432

**Table C.42 [] Exposure-Dependent 80% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.359	47.568	0.000	952.073	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.358	47.448	0.025	952.010	0.000	0.000	0.020	0.000	0.000	0.000
500.0	0.356	46.972	0.123	951.752	0.002	0.000	0.219	0.001	0.000	0.000
1000.0	0.354	46.386	0.243	951.430	0.005	0.000	0.483	0.007	0.000	0.000
1500.0	0.352	45.809	0.362	951.108	0.007	0.000	0.737	0.015	0.001	0.000
2000.0	0.349	45.240	0.478	950.786	0.011	0.000	0.980	0.027	0.003	0.000
2500.0	0.347	44.679	0.593	950.463	0.014	0.000	1.214	0.041	0.006	0.000
3000.0	0.344	44.126	0.706	950.141	0.018	0.001	1.438	0.058	0.010	0.000
3500.0	0.342	43.580	0.816	949.818	0.022	0.001	1.653	0.076	0.015	0.000
4000.0	0.340	43.042	0.926	949.495	0.026	0.001	1.860	0.095	0.021	0.000
4500.0	0.337	42.510	1.033	949.173	0.031	0.001	2.059	0.117	0.028	0.001
5000.0	0.335	41.984	1.139	948.850	0.035	0.002	2.251	0.139	0.037	0.001
5500.0	0.333	41.465	1.243	948.526	0.040	0.002	2.435	0.163	0.046	0.001
6000.0	0.331	40.953	1.346	948.203	0.045	0.003	2.613	0.188	0.057	0.002
6500.0	0.328	40.446	1.447	947.880	0.051	0.003	2.783	0.213	0.069	0.003
7000.0	0.326	39.945	1.547	947.556	0.056	0.004	2.948	0.240	0.082	0.003
7500.0	0.324	39.450	1.645	947.232	0.062	0.005	3.106	0.267	0.095	0.004
8000.0	0.322	38.960	1.742	946.909	0.068	0.005	3.258	0.295	0.110	0.005
8500.0	0.320	38.476	1.837	946.585	0.074	0.006	3.405	0.324	0.125	0.006
9000.0	0.317	37.997	1.931	946.261	0.081	0.007	3.546	0.353	0.141	0.007
9500.0	0.315	37.523	2.024	945.937	0.087	0.008	3.682	0.383	0.158	0.009
10000.0	0.313	37.054	2.116	945.613	0.094	0.009	3.812	0.413	0.176	0.010
10500.0	0.311	36.590	2.206	945.289	0.100	0.010	3.937	0.444	0.194	0.012
11000.0	0.309	36.131	2.295	944.966	0.107	0.011	4.058	0.475	0.212	0.014
11500.0	0.307	35.676	2.383	944.642	0.114	0.012	4.174	0.506	0.231	0.016
12000.0	0.305	35.226	2.469	944.318	0.121	0.014	4.285	0.538	0.251	0.018
12500.0	0.303	34.780	2.555	943.994	0.128	0.015	4.392	0.571	0.271	0.021
13000.0	0.301	34.339	2.639	943.671	0.136	0.017	4.494	0.603	0.291	0.023
13500.0	0.298	33.902	2.722	943.347	0.143	0.018	4.592	0.636	0.312	0.026
14000.0	0.296	33.470	2.804	943.024	0.150	0.020	4.686	0.670	0.332	0.029
14500.0	0.294	33.041	2.884	942.701	0.158	0.021	4.776	0.703	0.353	0.032
15000.0	0.292	32.617	2.964	942.377	0.165	0.023	4.862	0.737	0.375	0.035
15500.0	0.290	32.196	3.042	942.055	0.173	0.025	4.945	0.771	0.396	0.039
16000.0	0.289	31.780	3.120	941.732	0.181	0.027	5.024	0.805	0.417	0.042
16500.0	0.287	31.367	3.196	941.409	0.189	0.029	5.099	0.839	0.439	0.046
17000.0	0.285	30.958	3.272	941.087	0.196	0.031	5.171	0.874	0.461	0.050
17500.0	0.283	30.553	3.346	940.764	0.204	0.033	5.239	0.909	0.482	0.054
18000.0	0.281	30.151	3.419	940.442	0.212	0.035	5.304	0.943	0.504	0.058
18500.0	0.279	29.753	3.492	940.120	0.220	0.038	5.366	0.978	0.525	0.063
19000.0	0.277	29.358	3.563	939.798	0.228	0.040	5.426	1.013	0.547	0.068
19500.0	0.275	28.967	3.634	939.476	0.236	0.043	5.482	1.048	0.569	0.072
20000.0	0.273	28.579	3.703	939.153	0.244	0.045	5.536	1.083	0.590	0.077
20500.0	0.271	28.195	3.772	938.831	0.252	0.048	5.587	1.118	0.612	0.083
21000.0	0.270	27.814	3.840	938.508	0.260	0.051	5.636	1.153	0.633	0.088
21500.0	0.268	27.436	3.907	938.185	0.268	0.053	5.682	1.188	0.655	0.094
22000.0	0.266	27.061	3.973	937.861	0.276	0.056	5.727	1.223	0.676	0.099
22500.0	0.264	26.690	4.038	937.537	0.284	0.059	5.769	1.257	0.697	0.105
23000.0	0.262	26.322	4.102	937.213	0.293	0.062	5.809	1.292	0.718	0.111
23500.0	0.261	25.957	4.166	936.887	0.301	0.066	5.848	1.327	0.739	0.118
24000.0	0.259	25.596	4.229	936.561	0.309	0.069	5.884	1.361	0.760	0.124
24500.0	0.257	25.237	4.290	936.234	0.317	0.072	5.919	1.396	0.781	0.131
25000.0	0.255	24.882	4.352	935.906	0.325	0.075	5.953	1.430	0.802	0.137
25500.0	0.254	24.530	4.412	935.577	0.334	0.079	5.985	1.464	0.823	0.144
26000.0	0.252	24.181	4.471	935.247	0.342	0.083	6.015	1.498	0.843	0.152
26500.0	0.250	23.835	4.530	934.916	0.350	0.086	6.044	1.532	0.864	0.159
27000.0	0.248	23.492	4.587	934.584	0.359	0.090	6.072	1.565	0.884	0.166
27500.0	0.247	23.153	4.644	934.250	0.367	0.094	6.099	1.599	0.904	0.174
28000.0	0.245	22.816	4.701	933.916	0.375	0.098	6.124	1.632	0.925	0.182
28500.0	0.243	22.483	4.756	933.581	0.384	0.102	6.148	1.665	0.945	0.190
29000.0	0.242	22.153	4.811	933.244	0.392	0.106	6.171	1.698	0.965	0.198
29500.0	0.240	21.826	4.864	932.906	0.401	0.110	6.193	1.731	0.984	0.206
30000.0	0.238	21.502	4.917	932.567	0.409	0.115	6.214	1.763	1.004	0.215
30500.0	0.236	21.181	4.970	932.226	0.418	0.119	6.233	1.796	1.023	0.223
32500.0	0.230	19.928	5.171	930.851	0.452	0.138	6.303	1.923	1.100	0.260
35000.0	0.222	18.431	5.404	929.103	0.495	0.163	6.369	2.075	1.192	0.308
37500.0	0.214	17.009	5.619	927.322	0.538	0.190	6.415	2.222	1.279	0.361
40000.0	0.206	15.661	5.815	925.507	0.580	0.220	6.442	2.363	1.360	0.418
42500.0	0.198	14.387	5.993	923.659	0.622	0.252	6.455	2.497	1.435	0.477
45000.0	0.191	13.184	6.153	921.776	0.664	0.285	6.453	2.625	1.504	0.540
47500.0	0.183	12.052	6.295	919.859	0.704	0.321	6.440	2.745	1.567	0.606
50000.0	0.176	10.990	6.420	917.907	0.743	0.357	6.417	2.858	1.624	0.675
52500.0	0.170	9.995	6.528	915.920	0.781	0.395	6.386	2.964	1.676	0.747
55000.0	0.163	9.067	6.621	913.898	0.817	0.434	6.348	3.062	1.722	0.820
57500.0	0.156	8.203	6.698	911.841	0.851	0.474	6.305	3.153	1.762	0.896
60000.0	0.150	7.403	6.760	909.750	0.884	0.514	6.258	3.236	1.797	0.974
62500.0	0.144	6.663	6.808	907.626	0.915	0.554	6.208	3.313	1.827	1.054
65000.0	0.139	5.981	6.842	905.468	0.943	0.594	6.156	3.382	1.853	1.135
67500.0	0.133	5.356	6.863	903.278	0.970	0.633	6.103	3.445	1.875	1.218
70000.0	0.128	4.784	6.871	901.057	0.995	0.672	6.050	3.501	1.893	1.301

**Table C.43 [] Exposure-Dependent 0% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.397	0.000	952.245	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.357	47.276	0.022	952.199	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.356	46.796	0.111	952.014	0.001	0.000	0.158	0.001	0.000	0.000
1000.0	0.354	46.201	0.221	951.782	0.003	0.000	0.352	0.005	0.000	0.000
1500.0	0.352	45.613	0.329	951.550	0.005	0.000	0.539	0.011	0.001	0.000
2000.0	0.351	45.032	0.436	951.318	0.007	0.000	0.718	0.020	0.002	0.000
2500.0	0.349	44.457	0.541	951.085	0.009	0.000	0.889	0.031	0.003	0.000
3000.0	0.347	43.887	0.645	950.852	0.011	0.000	1.054	0.044	0.005	0.000
3500.0	0.345	43.324	0.748	950.619	0.014	0.000	1.212	0.059	0.008	0.000
4000.0	0.344	42.766	0.849	950.386	0.017	0.001	1.363	0.075	0.011	0.000
4500.0	0.342	42.213	0.950	950.153	0.020	0.001	1.508	0.093	0.015	0.000
5000.0	0.340	41.666	1.049	949.919	0.023	0.001	1.647	0.111	0.020	0.001
5500.0	0.339	41.124	1.146	949.685	0.026	0.001	1.780	0.131	0.026	0.001
6000.0	0.337	40.587	1.243	949.451	0.029	0.001	1.907	0.152	0.032	0.001
6500.0	0.335	40.054	1.339	949.217	0.032	0.002	2.029	0.174	0.040	0.002
7000.0	0.333	39.527	1.433	948.983	0.036	0.002	2.146	0.197	0.048	0.002
7500.0	0.332	39.004	1.527	948.749	0.040	0.002	2.258	0.221	0.056	0.003
8000.0	0.330	38.485	1.619	948.514	0.043	0.003	2.365	0.245	0.065	0.003
8500.0	0.328	37.971	1.710	948.280	0.047	0.003	2.467	0.270	0.075	0.004
9000.0	0.327	37.461	1.800	948.046	0.051	0.003	2.564	0.295	0.086	0.005
9500.0	0.325	36.955	1.889	947.812	0.055	0.004	2.657	0.321	0.097	0.006
10000.0	0.323	36.454	1.978	947.578	0.059	0.004	2.745	0.347	0.109	0.007
10500.0	0.322	35.956	2.065	947.343	0.064	0.005	2.829	0.374	0.121	0.008
11000.0	0.320	35.463	2.151	947.109	0.068	0.005	2.910	0.402	0.133	0.009
11500.0	0.318	34.973	2.236	946.875	0.073	0.006	2.986	0.429	0.146	0.011
12000.0	0.317	34.487	2.320	946.641	0.077	0.007	3.058	0.457	0.160	0.013
12500.0	0.315	34.005	2.404	946.408	0.082	0.007	3.126	0.486	0.173	0.014
13000.0	0.314	33.526	2.486	946.174	0.087	0.008	3.191	0.514	0.187	0.016
13500.0	0.312	33.051	2.568	945.941	0.091	0.009	3.252	0.543	0.201	0.018
14000.0	0.310	32.579	2.648	945.708	0.096	0.009	3.309	0.572	0.216	0.021
14500.0	0.309	32.110	2.728	945.475	0.101	0.010	3.363	0.602	0.231	0.023
15000.0	0.307	31.645	2.807	945.243	0.106	0.011	3.414	0.631	0.245	0.026
15500.0	0.306	31.183	2.885	945.011	0.111	0.012	3.462	0.661	0.260	0.028
16000.0	0.304	30.724	2.962	944.779	0.116	0.013	3.506	0.691	0.275	0.031
16500.0	0.302	30.269	3.039	944.548	0.121	0.014	3.547	0.720	0.290	0.034
17000.0	0.301	29.816	3.115	944.316	0.126	0.015	3.586	0.750	0.305	0.037
17500.0	0.299	29.367	3.189	944.085	0.132	0.016	3.622	0.780	0.320	0.041
18000.0	0.298	28.920	3.264	943.853	0.137	0.017	3.656	0.810	0.335	0.044
18500.0	0.296	28.476	3.337	943.621	0.142	0.018	3.688	0.841	0.351	0.048
19000.0	0.295	28.036	3.410	943.389	0.147	0.019	3.717	0.871	0.366	0.052
19500.0	0.293	27.598	3.481	943.155	0.153	0.021	3.745	0.901	0.381	0.056
20000.0	0.292	27.163	3.553	942.921	0.158	0.022	3.770	0.930	0.396	0.060
20500.0	0.290	26.732	3.623	942.687	0.164	0.023	3.794	0.960	0.412	0.065
21000.0	0.289	26.303	3.693	942.451	0.169	0.024	3.817	0.990	0.427	0.069
21500.0	0.287	25.878	3.762	942.214	0.175	0.026	3.838	1.020	0.442	0.074
22000.0	0.286	25.456	3.830	941.976	0.180	0.027	3.857	1.049	0.458	0.079
22500.0	0.284	25.036	3.898	941.737	0.186	0.029	3.875	1.079	0.473	0.085
23000.0	0.282	24.620	3.964	941.497	0.192	0.030	3.892	1.108	0.488	0.090
23500.0	0.281	24.207	4.031	941.256	0.198	0.032	3.907	1.138	0.503	0.096
24000.0	0.279	23.797	4.096	941.013	0.203	0.034	3.921	1.167	0.518	0.102
25000.0	0.276	22.986	4.224	940.523	0.215	0.037	3.946	1.225	0.548	0.114
27500.0	0.269	21.014	4.533	939.273	0.246	0.047	3.991	1.366	0.623	0.149
30000.0	0.261	19.123	4.823	937.985	0.278	0.058	4.011	1.502	0.693	0.189
32500.0	0.253	17.313	5.095	936.655	0.311	0.071	4.010	1.633	0.759	0.234
35000.0	0.245	15.587	5.347	935.281	0.344	0.085	3.992	1.759	0.820	0.286
37500.0	0.237	13.946	5.581	933.859	0.378	0.101	3.959	1.878	0.874	0.343
40000.0	0.229	12.394	5.795	932.386	0.413	0.118	3.914	1.990	0.921	0.407
42500.0	0.221	10.933	5.989	930.856	0.447	0.137	3.860	2.094	0.962	0.476
45000.0	0.213	9.567	6.163	929.267	0.481	0.157	3.797	2.190	0.996	0.550
47500.0	0.205	8.298	6.316	927.612	0.514	0.178	3.730	2.277	1.023	0.630
50000.0	0.197	7.130	6.448	925.890	0.547	0.200	3.660	2.356	1.044	0.716
52500.0	0.189	6.065	6.559	924.094	0.578	0.223	3.589	2.425	1.060	0.807
55000.0	0.181	5.104	6.648	922.223	0.608	0.246	3.518	2.486	1.070	0.902
57500.0	0.172	4.248	6.715	920.275	0.637	0.269	3.450	2.537	1.075	1.001
60000.0	0.164	3.497	6.762	918.247	0.663	0.292	3.386	2.579	1.077	1.104
62500.0	0.156	2.846	6.788	916.142	0.688	0.314	3.326	2.612	1.076	1.209
65000.0	0.148	2.291	6.795	913.962	0.710	0.335	3.272	2.638	1.072	1.317
67500.0	0.140	1.826	6.785	911.711	0.730	0.355	3.224	2.657	1.066	1.425
70000.0	0.133	1.442	6.759	909.396	0.747	0.372	3.182	2.670	1.060	1.534

**Table C.44 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.397	0.000	952.245	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.357	47.276	0.023	952.193	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.356	46.797	0.116	951.979	0.002	0.000	0.181	0.001	0.000	0.000
1000.0	0.354	46.205	0.230	951.712	0.004	0.000	0.403	0.006	0.000	0.000
1500.0	0.352	45.620	0.342	951.445	0.006	0.000	0.616	0.013	0.001	0.000
2000.0	0.350	45.043	0.453	951.177	0.008	0.000	0.821	0.023	0.002	0.000
2500.0	0.348	44.473	0.562	950.910	0.011	0.000	1.017	0.036	0.004	0.000
3000.0	0.346	43.910	0.669	950.642	0.014	0.000	1.205	0.050	0.007	0.000
3500.0	0.344	43.353	0.775	950.375	0.017	0.001	1.385	0.066	0.010	0.000
4000.0	0.342	42.802	0.879	950.107	0.020	0.001	1.557	0.084	0.015	0.000
4500.0	0.340	42.257	0.982	949.839	0.024	0.001	1.723	0.104	0.020	0.001
5000.0	0.338	41.719	1.084	949.571	0.027	0.001	1.882	0.124	0.027	0.001
5500.0	0.336	41.185	1.184	949.303	0.031	0.001	2.034	0.146	0.034	0.001
6000.0	0.334	40.658	1.283	949.035	0.035	0.002	2.180	0.169	0.042	0.001
6500.0	0.332	40.136	1.380	948.767	0.039	0.002	2.320	0.193	0.051	0.002
7000.0	0.330	39.619	1.477	948.499	0.043	0.002	2.454	0.217	0.061	0.003
7500.0	0.328	39.107	1.572	948.231	0.048	0.003	2.582	0.243	0.072	0.003
8000.0	0.327	38.600	1.665	947.962	0.052	0.003	2.705	0.269	0.083	0.004
8500.0	0.325	38.099	1.758	947.694	0.057	0.004	2.823	0.295	0.096	0.005
9000.0	0.323	37.601	1.849	947.426	0.062	0.004	2.935	0.323	0.109	0.006
9500.0	0.321	37.109	1.939	947.158	0.067	0.005	3.043	0.350	0.122	0.007
10000.0	0.319	36.621	2.028	946.890	0.072	0.006	3.145	0.379	0.136	0.008
10500.0	0.317	36.137	2.116	946.623	0.077	0.006	3.243	0.407	0.151	0.010
11000.0	0.315	35.658	2.203	946.355	0.082	0.007	3.336	0.436	0.166	0.012
11500.0	0.314	35.183	2.289	946.088	0.088	0.008	3.425	0.466	0.182	0.013
12000.0	0.312	34.712	2.373	945.820	0.093	0.009	3.510	0.496	0.198	0.015
12500.0	0.310	34.245	2.457	945.553	0.099	0.010	3.591	0.526	0.215	0.017
13000.0	0.308	33.782	2.539	945.287	0.105	0.011	3.667	0.556	0.231	0.020
13500.0	0.307	33.323	2.621	945.020	0.110	0.012	3.739	0.587	0.248	0.022
14000.0	0.305	32.868	2.702	944.754	0.116	0.013	3.808	0.618	0.266	0.025
14500.0	0.303	32.416	2.781	944.488	0.122	0.014	3.873	0.649	0.283	0.027
15000.0	0.301	31.968	2.860	944.223	0.128	0.015	3.934	0.680	0.301	0.030
15500.0	0.300	31.523	2.938	943.958	0.134	0.016	3.992	0.711	0.319	0.033
16000.0	0.298	31.082	3.015	943.693	0.140	0.017	4.046	0.743	0.336	0.037
16500.0	0.296	30.644	3.091	943.429	0.146	0.019	4.097	0.775	0.354	0.040
17000.0	0.295	30.210	3.166	943.165	0.152	0.020	4.145	0.806	0.372	0.044
17500.0	0.293	29.779	3.240	942.901	0.158	0.021	4.190	0.838	0.390	0.048
18000.0	0.291	29.351	3.313	942.638	0.164	0.023	4.232	0.870	0.408	0.052
18500.0	0.290	28.925	3.386	942.374	0.170	0.024	4.271	0.902	0.426	0.056
19000.0	0.288	28.504	3.458	942.110	0.176	0.026	4.308	0.934	0.444	0.060
19500.0	0.286	28.085	3.528	941.846	0.183	0.027	4.343	0.965	0.461	0.065
20000.0	0.285	27.669	3.599	941.582	0.189	0.029	4.375	0.997	0.479	0.069
20500.0	0.283	27.257	3.668	941.317	0.195	0.031	4.406	1.029	0.497	0.074
21000.0	0.281	26.848	3.736	941.051	0.202	0.033	4.435	1.060	0.515	0.080
21500.0	0.280	26.441	3.804	940.784	0.208	0.034	4.462	1.092	0.533	0.085
22000.0	0.278	26.038	3.871	940.517	0.215	0.036	4.487	1.123	0.550	0.090
22500.0	0.276	25.639	3.937	940.248	0.222	0.038	4.511	1.154	0.568	0.096
23000.0	0.275	25.242	4.003	939.978	0.228	0.040	4.533	1.185	0.586	0.102
23500.0	0.273	24.848	4.067	939.708	0.235	0.042	4.554	1.216	0.603	0.108
24000.0	0.272	24.458	4.131	939.436	0.242	0.045	4.573	1.247	0.621	0.115
24500.0	0.270	24.070	4.194	939.163	0.249	0.047	4.591	1.277	0.638	0.121
25000.0	0.268	23.686	4.257	938.889	0.256	0.049	4.608	1.308	0.655	0.128
25500.0	0.267	23.305	4.318	938.613	0.263	0.051	4.624	1.338	0.673	0.135
26000.0	0.265	22.927	4.379	938.337	0.270	0.054	4.639	1.368	0.690	0.142
27500.0	0.260	21.812	4.557	937.498	0.291	0.061	4.676	1.457	0.741	0.165
30000.0	0.252	20.018	4.838	936.072	0.327	0.076	4.719	1.600	0.823	0.207
32500.0	0.244	18.304	5.100	934.608	0.364	0.092	4.738	1.738	0.900	0.254
35000.0	0.236	16.670	5.343	933.107	0.402	0.110	4.739	1.869	0.972	0.306
37500.0	0.228	15.116	5.568	931.564	0.439	0.129	4.722	1.994	1.037	0.363
40000.0	0.221	13.644	5.773	929.979	0.476	0.150	4.691	2.112	1.095	0.426
42500.0	0.213	12.255	5.960	928.349	0.514	0.173	4.649	2.222	1.147	0.493
45000.0	0.205	10.949	6.128	926.671	0.550	0.198	4.597	2.325	1.191	0.565
47500.0	0.197	9.727	6.277	924.943	0.586	0.223	4.537	2.419	1.229	0.641
50000.0	0.190	8.590	6.407	923.164	0.621	0.250	4.472	2.505	1.260	0.721
52500.0	0.182	7.538	6.518	921.330	0.655	0.277	4.403	2.582	1.284	0.805
55000.0	0.175	6.572	6.611	919.441	0.687	0.305	4.332	2.651	1.303	0.892
57500.0	0.167	5.691	6.685	917.494	0.718	0.333	4.261	2.711	1.317	0.983
60000.0	0.160	4.894	6.740	915.490	0.747	0.361	4.191	2.763	1.325	1.076
62500.0	0.153	4.179	6.779	913.428	0.774	0.389	4.123	2.807	1.330	1.171
65000.0	0.146	3.544	6.800	911.310	0.800	0.416	4.058	2.843	1.331	1.268
67500.0	0.139	2.985	6.806	909.136	0.822	0.441	3.996	2.872	1.329	1.366
70000.0	0.132	2.497	6.797	906.910	0.843	0.466	3.939	2.894	1.324	1.464

**Table C.45 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.358	47.397	0.000	952.245	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.357	47.277	0.024	952.183	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.355	46.800	0.122	951.931	0.002	0.000	0.211	0.001	0.000	0.000
1000.0	0.353	46.213	0.242	951.616	0.004	0.000	0.470	0.007	0.000	0.000
1500.0	0.351	45.634	0.359	951.301	0.007	0.000	0.719	0.015	0.001	0.000
2000.0	0.348	45.063	0.475	950.986	0.010	0.000	0.957	0.027	0.003	0.000
2500.0	0.346	44.501	0.589	950.672	0.014	0.000	1.186	0.040	0.006	0.000
3000.0	0.344	43.946	0.701	950.357	0.017	0.001	1.405	0.057	0.009	0.000
3500.0	0.341	43.398	0.811	950.042	0.021	0.001	1.616	0.075	0.014	0.000
4000.0	0.339	42.857	0.920	949.726	0.025	0.001	1.819	0.094	0.020	0.000
4500.0	0.337	42.323	1.027	949.411	0.029	0.001	2.013	0.115	0.027	0.001
5000.0	0.335	41.796	1.132	949.096	0.034	0.002	2.200	0.138	0.035	0.001
5500.0	0.332	41.275	1.236	948.781	0.039	0.002	2.380	0.161	0.045	0.001
6000.0	0.330	40.760	1.338	948.466	0.044	0.003	2.552	0.186	0.055	0.002
6500.0	0.328	40.251	1.439	948.151	0.049	0.003	2.718	0.211	0.067	0.002
7000.0	0.326	39.747	1.538	947.835	0.054	0.004	2.878	0.238	0.079	0.003
7500.0	0.324	39.250	1.636	947.520	0.060	0.004	3.031	0.265	0.093	0.004
8000.0	0.321	38.757	1.732	947.205	0.066	0.005	3.178	0.292	0.107	0.005
8500.0	0.319	38.271	1.827	946.890	0.072	0.006	3.320	0.321	0.122	0.006
9000.0	0.317	37.789	1.921	946.575	0.078	0.007	3.456	0.350	0.138	0.007
9500.0	0.315	37.312	2.013	946.260	0.084	0.007	3.586	0.380	0.154	0.009
10000.0	0.313	36.841	2.104	945.945	0.090	0.008	3.712	0.410	0.172	0.010
10500.0	0.311	36.374	2.194	945.630	0.097	0.009	3.832	0.440	0.189	0.012
11000.0	0.309	35.912	2.283	945.315	0.103	0.010	3.947	0.471	0.208	0.014
11500.0	0.307	35.454	2.370	945.001	0.110	0.012	4.058	0.503	0.226	0.016
12000.0	0.305	35.001	2.456	944.687	0.117	0.013	4.163	0.534	0.246	0.018
12500.0	0.303	34.553	2.541	944.372	0.124	0.014	4.265	0.567	0.265	0.020
13000.0	0.301	34.109	2.625	944.058	0.131	0.016	4.362	0.599	0.285	0.023
13500.0	0.299	33.669	2.708	943.745	0.138	0.017	4.454	0.632	0.305	0.026
14000.0	0.297	33.233	2.789	943.431	0.145	0.019	4.543	0.665	0.326	0.028
14500.0	0.295	32.801	2.870	943.118	0.152	0.020	4.627	0.698	0.347	0.031
15000.0	0.293	32.373	2.949	942.805	0.159	0.022	4.708	0.732	0.367	0.035
15500.0	0.291	31.950	3.027	942.492	0.167	0.023	4.785	0.765	0.388	0.038
16000.0	0.289	31.530	3.105	942.180	0.174	0.025	4.858	0.799	0.409	0.042
16500.0	0.287	31.113	3.181	941.868	0.182	0.027	4.927	0.833	0.431	0.045
17000.0	0.285	30.701	3.256	941.556	0.189	0.029	4.993	0.868	0.452	0.049
17500.0	0.283	30.292	3.330	941.245	0.197	0.031	5.056	0.902	0.473	0.054
18000.0	0.281	29.886	3.403	940.934	0.205	0.033	5.115	0.936	0.494	0.058
18500.0	0.280	29.484	3.476	940.623	0.212	0.035	5.171	0.971	0.515	0.062
19000.0	0.278	29.086	3.547	940.312	0.220	0.038	5.225	1.005	0.536	0.067
19500.0	0.276	28.690	3.617	940.001	0.228	0.040	5.275	1.040	0.558	0.072
20000.0	0.274	28.298	3.687	939.690	0.235	0.042	5.323	1.075	0.579	0.077
20500.0	0.272	27.910	3.756	939.379	0.243	0.045	5.369	1.109	0.600	0.082
21000.0	0.271	27.524	3.823	939.068	0.251	0.047	5.412	1.144	0.620	0.088
21500.0	0.269	27.142	3.890	938.756	0.259	0.050	5.453	1.178	0.641	0.093
22000.0	0.267	26.763	3.956	938.444	0.266	0.053	5.491	1.212	0.662	0.099
22500.0	0.265	26.387	4.021	938.131	0.274	0.055	5.528	1.247	0.683	0.105
23000.0	0.263	26.015	4.086	937.818	0.282	0.058	5.563	1.281	0.703	0.111
23500.0	0.262	25.646	4.149	937.503	0.290	0.061	5.596	1.315	0.724	0.117
24000.0	0.260	25.279	4.212	937.188	0.298	0.064	5.628	1.349	0.744	0.124
24500.0	0.258	24.916	4.274	936.872	0.306	0.067	5.658	1.383	0.765	0.131
25000.0	0.257	24.556	4.335	936.555	0.314	0.071	5.686	1.416	0.785	0.137
25500.0	0.255	24.200	4.395	936.238	0.322	0.074	5.714	1.450	0.805	0.144
26000.0	0.253	23.846	4.455	935.919	0.330	0.077	5.739	1.483	0.825	0.152
26500.0	0.251	23.496	4.514	935.599	0.338	0.081	5.764	1.516	0.845	0.159
27000.0	0.250	23.148	4.572	935.277	0.346	0.084	5.787	1.549	0.865	0.167
27500.0	0.248	22.804	4.629	934.955	0.354	0.088	5.809	1.582	0.885	0.174
28000.0	0.246	22.463	4.685	934.631	0.362	0.091	5.829	1.615	0.904	0.182
28500.0	0.245	22.125	4.741	934.306	0.370	0.095	5.849	1.647	0.924	0.190
29000.0	0.243	21.790	4.795	933.980	0.379	0.099	5.867	1.679	0.943	0.199
29500.0	0.241	21.458	4.849	933.653	0.387	0.103	5.885	1.711	0.962	0.207
30000.0	0.240	21.130	4.902	933.325	0.395	0.107	5.901	1.743	0.981	0.216
32500.0	0.231	19.533	5.157	931.662	0.437	0.129	5.970	1.897	1.074	0.261
35000.0	0.223	18.013	5.392	929.966	0.478	0.152	6.016	2.046	1.163	0.311
37500.0	0.215	16.569	5.608	928.235	0.520	0.178	6.042	2.188	1.245	0.365
40000.0	0.207	15.200	5.805	926.470	0.562	0.206	6.052	2.323	1.322	0.423
42500.0	0.200	13.905	5.983	924.670	0.603	0.236	6.047	2.452	1.392	0.485
45000.0	0.192	12.684	6.144	922.833	0.644	0.267	6.029	2.574	1.456	0.550
47500.0	0.185	11.536	6.286	920.960	0.683	0.300	6.001	2.688	1.514	0.618
50000.0	0.178	10.460	6.411	919.049	0.722	0.335	5.964	2.794	1.565	0.689
52500.0	0.171	9.454	6.520	917.101	0.759	0.371	5.920	2.893	1.611	0.763
55000.0	0.164	8.517	6.612	915.114	0.794	0.407	5.870	2.984	1.650	0.840
57500.0	0.157	7.649	6.687	913.089	0.828	0.444	5.815	3.067	1.684	0.919
60000.0	0.151	6.846	6.748	911.027	0.860	0.481	5.758	3.142	1.712	1.000
62500.0	0.145	6.107	6.793	908.927	0.890	0.519	5.699	3.210	1.736	1.083
65000.0	0.139	5.430	6.825	906.790	0.918	0.556	5.640	3.271	1.755	1.167
67500.0	0.133	4.813	6.843	904.618	0.944	0.592	5.580	3.325	1.770	1.253
70000.0	0.127	4.252	6.848	902.410	0.968	0.628	5.521	3.372	1.781	1.340

**Table C.46 [Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.343	45.363	0.000	954.295	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.242	0.022	954.249	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.341	44.763	0.110	954.064	0.001	0.000	0.158	0.001	0.000	0.000
1000.0	0.339	44.170	0.218	953.832	0.003	0.000	0.351	0.005	0.000	0.000
1500.0	0.337	43.583	0.325	953.600	0.005	0.000	0.537	0.012	0.001	0.000
2000.0	0.336	43.004	0.430	953.368	0.007	0.000	0.715	0.021	0.002	0.000
2500.0	0.334	42.431	0.534	953.136	0.009	0.000	0.885	0.033	0.003	0.000
3000.0	0.332	41.865	0.637	952.903	0.011	0.000	1.048	0.046	0.005	0.000
3500.0	0.331	41.304	0.738	952.670	0.014	0.000	1.203	0.061	0.008	0.000
4000.0	0.329	40.749	0.838	952.438	0.017	0.001	1.352	0.078	0.012	0.000
4500.0	0.327	40.199	0.936	952.205	0.019	0.001	1.494	0.096	0.016	0.000
5000.0	0.326	39.655	1.034	951.971	0.022	0.001	1.630	0.116	0.021	0.001
5500.0	0.324	39.116	1.130	951.738	0.025	0.001	1.760	0.136	0.027	0.001
6000.0	0.322	38.583	1.225	951.505	0.029	0.001	1.885	0.158	0.033	0.001
6500.0	0.321	38.054	1.319	951.271	0.032	0.002	2.003	0.181	0.041	0.002
7000.0	0.319	37.530	1.412	951.038	0.035	0.002	2.116	0.204	0.049	0.002
7500.0	0.317	37.011	1.503	950.805	0.039	0.002	2.224	0.228	0.058	0.003
8000.0	0.316	36.496	1.594	950.571	0.043	0.003	2.327	0.253	0.067	0.003
8500.0	0.314	35.986	1.683	950.338	0.046	0.003	2.425	0.279	0.077	0.004
9000.0	0.313	35.480	1.772	950.104	0.050	0.003	2.519	0.305	0.088	0.005
9500.0	0.311	34.978	1.859	949.871	0.054	0.004	2.607	0.332	0.099	0.006
10000.0	0.309	34.481	1.946	949.638	0.058	0.004	2.691	0.359	0.110	0.007
10500.0	0.308	33.987	2.031	949.405	0.063	0.005	2.771	0.387	0.123	0.009
11000.0	0.306	33.498	2.116	949.172	0.067	0.005	2.847	0.415	0.135	0.010
11500.0	0.305	33.012	2.199	948.940	0.071	0.006	2.918	0.443	0.148	0.012
12000.0	0.303	32.531	2.282	948.707	0.076	0.006	2.986	0.472	0.161	0.014
12500.0	0.302	32.052	2.364	948.475	0.080	0.007	3.049	0.501	0.175	0.015
13000.0	0.300	31.578	2.444	948.243	0.085	0.008	3.109	0.530	0.189	0.017
13500.0	0.298	31.107	2.524	948.012	0.089	0.009	3.166	0.560	0.203	0.020
14000.0	0.297	30.639	2.603	947.781	0.094	0.009	3.218	0.590	0.217	0.022
14500.0	0.295	30.175	2.681	947.551	0.099	0.010	3.267	0.620	0.231	0.025
15000.0	0.294	29.714	2.758	947.320	0.103	0.011	3.313	0.650	0.246	0.027
15500.0	0.292	29.256	2.835	947.091	0.108	0.012	3.356	0.680	0.260	0.030
16000.0	0.291	28.801	2.910	946.861	0.113	0.013	3.396	0.710	0.275	0.033
16500.0	0.289	28.349	2.985	946.631	0.118	0.014	3.433	0.741	0.290	0.036
17000.0	0.288	27.901	3.059	946.401	0.123	0.015	3.468	0.771	0.304	0.040
17500.0	0.286	27.456	3.133	946.170	0.128	0.016	3.500	0.802	0.319	0.043
18000.0	0.285	27.013	3.205	945.939	0.133	0.017	3.530	0.832	0.334	0.047
18500.0	0.283	26.574	3.277	945.707	0.138	0.018	3.559	0.862	0.349	0.051
19000.0	0.282	26.138	3.348	945.475	0.143	0.019	3.585	0.893	0.364	0.055
19500.0	0.280	25.705	3.418	945.242	0.148	0.020	3.609	0.923	0.379	0.060
20000.0	0.279	25.275	3.488	945.007	0.154	0.021	3.632	0.953	0.394	0.064
20500.0	0.277	24.849	3.557	944.772	0.159	0.023	3.653	0.984	0.409	0.069
21000.0	0.276	24.425	3.625	944.536	0.164	0.024	3.673	1.014	0.424	0.074
21500.0	0.274	24.005	3.692	944.298	0.170	0.025	3.691	1.044	0.439	0.079
22000.0	0.273	23.588	3.759	944.059	0.175	0.027	3.707	1.074	0.453	0.084
22500.0	0.271	23.174	3.825	943.819	0.181	0.028	3.723	1.103	0.468	0.090
23000.0	0.270	22.763	3.890	943.578	0.186	0.030	3.737	1.133	0.483	0.096
25000.0	0.264	21.153	4.143	942.596	0.209	0.036	3.782	1.250	0.542	0.121
27500.0	0.256	19.215	4.443	941.334	0.239	0.046	3.815	1.392	0.614	0.157
30000.0	0.249	17.360	4.724	940.029	0.270	0.057	3.825	1.528	0.681	0.200
32500.0	0.241	15.592	4.985	938.679	0.302	0.070	3.815	1.660	0.744	0.249
35000.0	0.233	13.913	5.228	937.280	0.334	0.084	3.789	1.784	0.800	0.304
37500.0	0.226	12.325	5.450	935.826	0.367	0.099	3.749	1.902	0.850	0.365
40000.0	0.218	10.832	5.652	934.315	0.400	0.116	3.699	2.012	0.893	0.432
42500.0	0.210	9.437	5.833	932.741	0.433	0.134	3.641	2.114	0.929	0.505
45000.0	0.202	8.145	5.992	931.099	0.466	0.154	3.577	2.207	0.959	0.585
47500.0	0.194	6.957	6.130	929.384	0.498	0.175	3.509	2.290	0.982	0.670
50000.0	0.185	5.878	6.246	927.592	0.529	0.196	3.441	2.364	0.999	0.761
52500.0	0.177	4.908	6.339	925.720	0.559	0.218	3.373	2.429	1.011	0.857
55000.0	0.169	4.050	6.410	923.766	0.587	0.239	3.307	2.483	1.018	0.958
57500.0	0.161	3.301	6.459	921.728	0.613	0.261	3.246	2.528	1.021	1.062
60000.0	0.153	2.658	6.487	919.607	0.638	0.282	3.190	2.564	1.021	1.170
62500.0	0.145	2.115	6.496	917.407	0.660	0.302	3.139	2.592	1.018	1.280
65000.0	0.137	1.665	6.487	915.134	0.679	0.320	3.094	2.613	1.014	1.391
67500.0	0.129	1.298	6.462	912.794	0.697	0.337	3.056	2.628	1.009	1.503
70000.0	0.122	1.004	6.423	910.396	0.712	0.353	3.023	2.637	1.003	1.614

**Table C.47 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.343	45.363	0.000	954.295	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.242	0.023	954.242	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.341	44.764	0.114	954.028	0.002	0.000	0.181	0.001	0.000	0.000
1000.0	0.339	44.174	0.227	953.759	0.004	0.000	0.404	0.006	0.000	0.000
1500.0	0.337	43.592	0.337	953.491	0.006	0.000	0.618	0.014	0.001	0.000
2000.0	0.335	43.017	0.446	953.222	0.008	0.000	0.822	0.024	0.002	0.000
2500.0	0.333	42.450	0.554	952.954	0.011	0.000	1.017	0.037	0.004	0.000
3000.0	0.331	41.890	0.659	952.685	0.014	0.000	1.203	0.052	0.007	0.000
3500.0	0.329	41.336	0.763	952.417	0.017	0.001	1.381	0.069	0.011	0.000
4000.0	0.327	40.789	0.866	952.148	0.020	0.001	1.552	0.088	0.015	0.000
4500.0	0.325	40.249	0.967	951.880	0.023	0.001	1.715	0.108	0.021	0.001
5000.0	0.323	39.714	1.067	951.611	0.027	0.001	1.871	0.130	0.028	0.001
5500.0	0.322	39.185	1.165	951.342	0.031	0.001	2.021	0.152	0.035	0.001
6000.0	0.320	38.662	1.262	951.074	0.035	0.002	2.163	0.176	0.044	0.002
6500.0	0.318	38.145	1.358	950.805	0.039	0.002	2.300	0.201	0.053	0.002
7000.0	0.316	37.633	1.452	950.537	0.043	0.003	2.430	0.226	0.063	0.003
7500.0	0.314	37.126	1.545	950.268	0.047	0.003	2.555	0.252	0.074	0.004
8000.0	0.312	36.624	1.637	950.000	0.052	0.003	2.674	0.279	0.086	0.004
8500.0	0.311	36.127	1.728	949.732	0.056	0.004	2.787	0.307	0.099	0.005
9000.0	0.309	35.635	1.817	949.464	0.061	0.004	2.895	0.335	0.112	0.007
9500.0	0.307	35.147	1.905	949.197	0.066	0.005	2.998	0.363	0.126	0.008
10000.0	0.305	34.665	1.993	948.929	0.071	0.006	3.096	0.393	0.140	0.009
10500.0	0.303	34.186	2.078	948.662	0.076	0.006	3.189	0.422	0.155	0.011
11000.0	0.302	33.712	2.163	948.395	0.081	0.007	3.277	0.452	0.170	0.013
11500.0	0.300	33.243	2.247	948.128	0.087	0.008	3.361	0.482	0.186	0.014
12000.0	0.298	32.777	2.330	947.862	0.092	0.009	3.441	0.513	0.202	0.016
12500.0	0.297	32.316	2.411	947.596	0.097	0.010	3.516	0.544	0.219	0.019
13000.0	0.295	31.858	2.492	947.330	0.103	0.011	3.587	0.575	0.235	0.021
13500.0	0.293	31.404	2.571	947.065	0.108	0.012	3.654	0.606	0.252	0.024
14000.0	0.291	30.954	2.650	946.800	0.114	0.013	3.718	0.638	0.270	0.026
14500.0	0.290	30.508	2.728	946.536	0.120	0.014	3.777	0.670	0.287	0.029
15000.0	0.288	30.065	2.804	946.272	0.126	0.015	3.833	0.702	0.304	0.033
15500.0	0.286	29.626	2.880	946.009	0.131	0.016	3.885	0.734	0.322	0.036
16000.0	0.285	29.190	2.955	945.746	0.137	0.017	3.934	0.766	0.339	0.039
16500.0	0.283	28.757	3.029	945.483	0.143	0.018	3.979	0.798	0.357	0.043
17000.0	0.282	28.328	3.102	945.221	0.149	0.020	4.022	0.830	0.374	0.047
17500.0	0.280	27.902	3.175	944.959	0.155	0.021	4.062	0.863	0.392	0.051
18000.0	0.278	27.479	3.246	944.696	0.161	0.023	4.099	0.895	0.409	0.055
18500.0	0.277	27.060	3.317	944.434	0.167	0.024	4.134	0.927	0.427	0.060
19000.0	0.275	26.643	3.387	944.170	0.173	0.026	4.167	0.959	0.444	0.064
19500.0	0.274	26.230	3.456	943.906	0.179	0.027	4.198	0.991	0.462	0.069
20000.0	0.272	25.820	3.524	943.642	0.185	0.029	4.226	1.023	0.479	0.074
20500.0	0.270	25.413	3.592	943.376	0.191	0.030	4.253	1.055	0.497	0.080
21000.0	0.269	25.010	3.658	943.110	0.197	0.032	4.279	1.087	0.514	0.085
21500.0	0.267	24.610	3.724	942.843	0.204	0.034	4.302	1.118	0.532	0.091
22000.0	0.266	24.213	3.789	942.574	0.210	0.036	4.324	1.150	0.549	0.097
22500.0	0.264	23.819	3.854	942.304	0.216	0.038	4.345	1.181	0.567	0.103
23000.0	0.263	23.428	3.917	942.034	0.223	0.040	4.364	1.212	0.584	0.109
23500.0	0.261	23.041	3.980	941.761	0.230	0.042	4.382	1.243	0.601	0.115
24000.0	0.259	22.657	4.042	941.488	0.236	0.044	4.398	1.274	0.618	0.122
24500.0	0.258	22.277	4.103	941.214	0.243	0.046	4.414	1.305	0.635	0.129
25000.0	0.256	21.899	4.164	940.937	0.250	0.048	4.428	1.335	0.652	0.136
27500.0	0.248	20.061	4.454	939.535	0.284	0.061	4.483	1.484	0.735	0.175
30000.0	0.241	18.306	4.725	938.094	0.320	0.075	4.512	1.626	0.814	0.220
32500.0	0.233	16.634	4.976	936.614	0.356	0.090	4.520	1.763	0.888	0.270
35000.0	0.225	15.046	5.209	935.092	0.392	0.108	4.510	1.893	0.955	0.325
37500.0	0.217	13.542	5.422	933.526	0.428	0.127	4.484	2.016	1.015	0.386
40000.0	0.210	12.124	5.616	931.912	0.465	0.148	4.446	2.131	1.069	0.452
42500.0	0.202	10.792	5.790	930.249	0.501	0.171	4.397	2.237	1.115	0.523
45000.0	0.194	9.548	5.945	928.534	0.536	0.194	4.340	2.336	1.154	0.599
47500.0	0.187	8.393	6.080	926.764	0.571	0.219	4.277	2.426	1.187	0.679
50000.0	0.179	7.326	6.196	924.937	0.604	0.245	4.210	2.506	1.213	0.764
52500.0	0.172	6.350	6.293	923.051	0.636	0.271	4.141	2.578	1.232	0.852
55000.0	0.164	5.463	6.371	921.104	0.667	0.298	4.072	2.641	1.247	0.944
57500.0	0.157	4.664	6.429	919.097	0.696	0.324	4.003	2.694	1.256	1.039
60000.0	0.150	3.951	6.470	917.027	0.723	0.350	3.937	2.740	1.261	1.136
62500.0	0.143	3.322	6.494	914.898	0.748	0.376	3.875	2.777	1.263	1.235
65000.0	0.136	2.772	6.501	912.710	0.770	0.400	3.816	2.807	1.261	1.335
67500.0	0.129	2.297	6.493	910.467	0.791	0.423	3.762	2.830	1.258	1.436
70000.0	0.123	1.890	6.472	908.171	0.809	0.445	3.713	2.847	1.252	1.537

**Table C.48 [] Exposure-Dependent 80% Void
Isotopes (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.343	45.363	0.000	954.295	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.243	0.024	954.232	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.340	44.768	0.121	953.976	0.002	0.000	0.214	0.001	0.000	0.000
1000.0	0.338	44.183	0.239	953.657	0.005	0.000	0.476	0.007	0.000	0.000
1500.0	0.336	43.607	0.355	953.337	0.007	0.000	0.727	0.016	0.001	0.000
2000.0	0.333	43.040	0.470	953.018	0.010	0.000	0.967	0.028	0.003	0.000
2500.0	0.331	42.481	0.582	952.698	0.014	0.000	1.197	0.043	0.006	0.000
3000.0	0.329	41.931	0.692	952.379	0.017	0.001	1.417	0.060	0.010	0.000
3500.0	0.327	41.388	0.801	952.060	0.021	0.001	1.628	0.079	0.015	0.000
4000.0	0.324	40.852	0.908	951.741	0.025	0.001	1.830	0.099	0.021	0.000
4500.0	0.322	40.324	1.013	951.422	0.030	0.001	2.023	0.121	0.029	0.001
5000.0	0.320	39.802	1.116	951.103	0.034	0.002	2.209	0.145	0.038	0.001
5500.0	0.318	39.286	1.218	950.784	0.039	0.002	2.386	0.169	0.048	0.002
6000.0	0.316	38.778	1.318	950.465	0.044	0.003	2.557	0.195	0.059	0.002
6500.0	0.314	38.275	1.417	950.146	0.049	0.003	2.721	0.222	0.071	0.003
7000.0	0.311	37.778	1.514	949.827	0.055	0.004	2.878	0.249	0.084	0.004
7500.0	0.309	37.287	1.609	949.509	0.060	0.004	3.028	0.277	0.098	0.004
8000.0	0.307	36.802	1.703	949.191	0.066	0.005	3.172	0.306	0.113	0.006
8500.0	0.305	36.322	1.796	948.872	0.072	0.006	3.310	0.336	0.128	0.007
9000.0	0.303	35.847	1.888	948.554	0.078	0.007	3.442	0.366	0.145	0.008
9500.0	0.301	35.378	1.978	948.236	0.084	0.008	3.569	0.396	0.162	0.010
10000.0	0.299	34.914	2.067	947.919	0.091	0.009	3.690	0.427	0.179	0.011
10500.0	0.297	34.455	2.154	947.601	0.097	0.010	3.806	0.459	0.198	0.013
11000.0	0.295	34.000	2.240	947.284	0.104	0.011	3.917	0.491	0.216	0.015
11500.0	0.293	33.550	2.325	946.967	0.110	0.012	4.023	0.524	0.236	0.017
12000.0	0.291	33.105	2.409	946.651	0.117	0.013	4.124	0.556	0.255	0.020
12500.0	0.289	32.664	2.492	946.335	0.124	0.014	4.221	0.589	0.275	0.022
13000.0	0.287	32.228	2.573	946.019	0.131	0.016	4.313	0.623	0.295	0.025
13500.0	0.285	31.796	2.654	945.703	0.138	0.017	4.401	0.657	0.316	0.028
14000.0	0.283	31.368	2.733	945.388	0.145	0.019	4.484	0.690	0.337	0.031
14500.0	0.281	30.944	2.811	945.074	0.152	0.020	4.563	0.725	0.357	0.034
15000.0	0.280	30.524	2.888	944.759	0.159	0.022	4.638	0.759	0.378	0.038
15500.0	0.278	30.108	2.964	944.445	0.166	0.024	4.710	0.794	0.399	0.042
16000.0	0.276	29.696	3.039	944.132	0.173	0.026	4.778	0.828	0.421	0.045
16500.0	0.274	29.288	3.113	943.819	0.181	0.027	4.842	0.863	0.442	0.049
17000.0	0.272	28.883	3.186	943.506	0.188	0.029	4.902	0.898	0.463	0.054
17500.0	0.270	28.482	3.257	943.194	0.196	0.031	4.959	0.933	0.484	0.058
18000.0	0.269	28.084	3.328	942.882	0.203	0.034	5.014	0.968	0.505	0.063
18500.0	0.267	27.690	3.398	942.570	0.210	0.036	5.065	1.003	0.526	0.068
19000.0	0.265	27.299	3.467	942.257	0.218	0.038	5.113	1.038	0.547	0.073
19500.0	0.263	26.912	3.535	941.945	0.226	0.040	5.159	1.073	0.568	0.078
20000.0	0.262	26.528	3.603	941.633	0.233	0.043	5.202	1.108	0.589	0.083
20500.0	0.260	26.147	3.669	941.320	0.241	0.045	5.243	1.143	0.610	0.089
21000.0	0.258	25.770	3.734	941.007	0.248	0.048	5.282	1.178	0.631	0.095
21500.0	0.256	25.395	3.799	940.693	0.256	0.050	5.319	1.213	0.651	0.101
22000.0	0.255	25.025	3.863	940.379	0.264	0.053	5.354	1.247	0.672	0.107
22500.0	0.253	24.657	3.926	940.063	0.271	0.056	5.387	1.282	0.692	0.113
23000.0	0.251	24.293	3.988	939.747	0.279	0.059	5.418	1.316	0.713	0.120
23500.0	0.250	23.932	4.049	939.430	0.287	0.062	5.448	1.350	0.733	0.126
24000.0	0.248	23.574	4.110	939.112	0.295	0.065	5.476	1.384	0.753	0.133
24500.0	0.246	23.220	4.169	938.793	0.303	0.068	5.503	1.418	0.773	0.140
25000.0	0.244	22.868	4.228	938.473	0.310	0.071	5.528	1.452	0.793	0.148
25500.0	0.243	22.520	4.286	938.151	0.318	0.074	5.552	1.485	0.813	0.155
26000.0	0.241	22.176	4.343	937.829	0.326	0.077	5.574	1.519	0.833	0.163
26500.0	0.240	21.834	4.400	937.505	0.334	0.081	5.596	1.552	0.853	0.171
27000.0	0.238	21.496	4.455	937.180	0.342	0.084	5.616	1.585	0.872	0.179
27500.0	0.236	21.161	4.510	936.854	0.350	0.088	5.635	1.617	0.892	0.187
28000.0	0.235	20.829	4.564	936.526	0.358	0.092	5.653	1.650	0.911	0.195
28500.0	0.233	20.500	4.617	936.197	0.366	0.095	5.670	1.682	0.930	0.204
30000.0	0.228	19.533	4.772	935.202	0.390	0.107	5.714	1.777	0.987	0.231
32500.0	0.220	17.985	5.015	933.517	0.431	0.129	5.770	1.930	1.077	0.279
35000.0	0.212	16.516	5.238	931.796	0.472	0.152	5.804	2.076	1.163	0.332
37500.0	0.204	15.124	5.441	930.040	0.513	0.178	5.820	2.216	1.242	0.389
40000.0	0.197	13.810	5.626	928.248	0.553	0.206	5.820	2.348	1.315	0.450
42500.0	0.189	12.571	5.793	926.418	0.593	0.235	5.807	2.473	1.381	0.515
45000.0	0.182	11.408	5.941	924.550	0.632	0.266	5.782	2.590	1.440	0.583
47500.0	0.175	10.319	6.071	922.643	0.670	0.299	5.748	2.699	1.493	0.654
50000.0	0.168	9.302	6.184	920.698	0.707	0.332	5.706	2.800	1.540	0.729
52500.0	0.161	8.357	6.280	918.712	0.743	0.367	5.658	2.893	1.580	0.806
55000.0	0.155	7.482	6.360	916.688	0.777	0.402	5.606	2.978	1.615	0.886
57500.0	0.148	6.675	6.424	914.624	0.809	0.438	5.550	3.055	1.644	0.968
60000.0	0.142	5.934	6.473	912.521	0.839	0.474	5.493	3.125	1.668	1.052
62500.0	0.136	5.257	6.507	910.380	0.867	0.509	5.435	3.186	1.688	1.137
65000.0	0.130	4.641	6.528	908.202	0.894	0.544	5.377	3.241	1.703	1.224
67500.0	0.125	4.084	6.536	905.988	0.918	0.579	5.320	3.288	1.715	1.312
70000.0	0.119	3.582	6.531	903.738	0.940	0.612	5.264	3.329	1.723	1.401

**Table C.49 [] Exposure-Dependent 0% Void Isotopics
(kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.342	45.328	0.000	954.329	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.208	0.022	954.284	0.000	0.000	0.014	0.000	0.000	0.000
500.0	0.341	44.728	0.110	954.101	0.001	0.000	0.157	0.001	0.000	0.000
1000.0	0.339	44.135	0.218	953.871	0.003	0.000	0.348	0.005	0.000	0.000
1500.0	0.337	43.548	0.324	953.642	0.005	0.000	0.532	0.012	0.001	0.000
2000.0	0.336	42.969	0.430	953.413	0.007	0.000	0.707	0.021	0.002	0.000
2500.0	0.334	42.395	0.533	953.184	0.009	0.000	0.874	0.033	0.003	0.000
3000.0	0.332	41.828	0.636	952.956	0.011	0.000	1.034	0.046	0.005	0.000
3500.0	0.331	41.267	0.737	952.728	0.014	0.000	1.186	0.061	0.008	0.000
4000.0	0.329	40.711	0.836	952.500	0.016	0.001	1.331	0.078	0.011	0.000
4500.0	0.327	40.161	0.935	952.272	0.019	0.001	1.469	0.096	0.015	0.000
5000.0	0.326	39.616	1.032	952.045	0.022	0.001	1.601	0.115	0.020	0.001
5500.0	0.324	39.076	1.128	951.818	0.025	0.001	1.726	0.136	0.026	0.001
6000.0	0.322	38.541	1.222	951.592	0.028	0.001	1.846	0.157	0.032	0.001
6500.0	0.321	38.010	1.316	951.367	0.031	0.001	1.959	0.180	0.039	0.002
7000.0	0.319	37.484	1.409	951.142	0.034	0.002	2.067	0.203	0.047	0.002
7500.0	0.318	36.963	1.500	950.917	0.038	0.002	2.169	0.227	0.055	0.003
8000.0	0.316	36.445	1.590	950.694	0.041	0.002	2.266	0.252	0.064	0.003
8500.0	0.315	35.932	1.680	950.471	0.045	0.003	2.357	0.277	0.074	0.004
9000.0	0.313	35.423	1.768	950.249	0.048	0.003	2.444	0.303	0.084	0.005
9500.0	0.311	34.917	1.855	950.029	0.052	0.004	2.526	0.330	0.094	0.006
10000.0	0.310	34.416	1.941	949.808	0.056	0.004	2.603	0.356	0.105	0.007
10500.0	0.308	33.918	2.027	949.589	0.060	0.004	2.676	0.384	0.116	0.008
11000.0	0.307	33.423	2.111	949.370	0.063	0.005	2.745	0.411	0.127	0.010
11500.0	0.305	32.932	2.194	949.151	0.067	0.005	2.811	0.439	0.139	0.011
12000.0	0.304	32.445	2.277	948.932	0.071	0.006	2.873	0.467	0.152	0.013
12500.0	0.302	31.960	2.359	948.713	0.076	0.007	2.931	0.495	0.164	0.014
13000.0	0.301	31.480	2.440	948.493	0.080	0.007	2.987	0.524	0.177	0.016
13500.0	0.299	31.002	2.520	948.273	0.084	0.008	3.040	0.552	0.190	0.018
14000.0	0.298	30.528	2.599	948.052	0.089	0.009	3.090	0.581	0.203	0.020
14500.0	0.296	30.058	2.677	947.831	0.093	0.009	3.138	0.610	0.217	0.023
15000.0	0.295	29.591	2.755	947.608	0.098	0.010	3.183	0.639	0.231	0.025
15500.0	0.294	29.127	2.832	947.385	0.102	0.011	3.227	0.668	0.245	0.028
16000.0	0.292	28.667	2.908	947.161	0.107	0.012	3.268	0.698	0.259	0.031
16500.0	0.291	28.210	2.983	946.935	0.112	0.013	3.307	0.727	0.273	0.034
17000.0	0.289	27.757	3.058	946.708	0.117	0.013	3.344	0.757	0.288	0.037
17500.0	0.288	27.307	3.132	946.480	0.122	0.014	3.379	0.786	0.303	0.040
20000.0	0.280	25.107	3.489	945.321	0.148	0.020	3.529	0.933	0.378	0.060
22500.0	0.273	22.992	3.828	944.127	0.175	0.027	3.638	1.080	0.455	0.085
25000.0	0.265	20.962	4.147	942.897	0.204	0.035	3.713	1.224	0.529	0.116
27500.0	0.257	19.018	4.447	941.628	0.234	0.044	3.759	1.366	0.601	0.152
30000.0	0.250	17.160	4.728	940.316	0.266	0.055	3.778	1.503	0.669	0.194
32500.0	0.242	15.391	4.990	938.958	0.298	0.068	3.776	1.636	0.732	0.243
35000.0	0.234	13.713	5.231	937.550	0.331	0.082	3.756	1.762	0.788	0.297
37500.0	0.226	12.128	5.452	936.088	0.364	0.097	3.721	1.882	0.839	0.358
40000.0	0.218	10.640	5.653	934.567	0.397	0.114	3.675	1.994	0.882	0.425
42500.0	0.210	9.253	5.832	932.981	0.431	0.133	3.619	2.098	0.919	0.499
45000.0	0.202	7.969	5.990	931.327	0.464	0.152	3.557	2.192	0.949	0.579
47500.0	0.194	6.792	6.125	929.599	0.496	0.173	3.492	2.278	0.973	0.664
50000.0	0.185	5.725	6.238	927.794	0.527	0.195	3.425	2.354	0.991	0.755
52500.0	0.177	4.769	6.328	925.907	0.557	0.216	3.358	2.419	1.003	0.852
55000.0	0.169	3.924	6.396	923.937	0.586	0.238	3.295	2.475	1.011	0.953
57500.0	0.161	3.190	6.443	921.883	0.612	0.260	3.235	2.522	1.015	1.058
60000.0	0.152	2.562	6.468	919.747	0.636	0.281	3.180	2.559	1.015	1.166
62500.0	0.144	2.034	6.474	917.533	0.658	0.301	3.130	2.588	1.013	1.277
65000.0	0.137	1.598	6.462	915.245	0.678	0.320	3.087	2.609	1.010	1.388
67500.0	0.129	1.243	6.435	912.893	0.695	0.337	3.050	2.624	1.005	1.500
70000.0	0.121	0.960	6.395	910.483	0.710	0.352	3.018	2.634	1.000	1.612

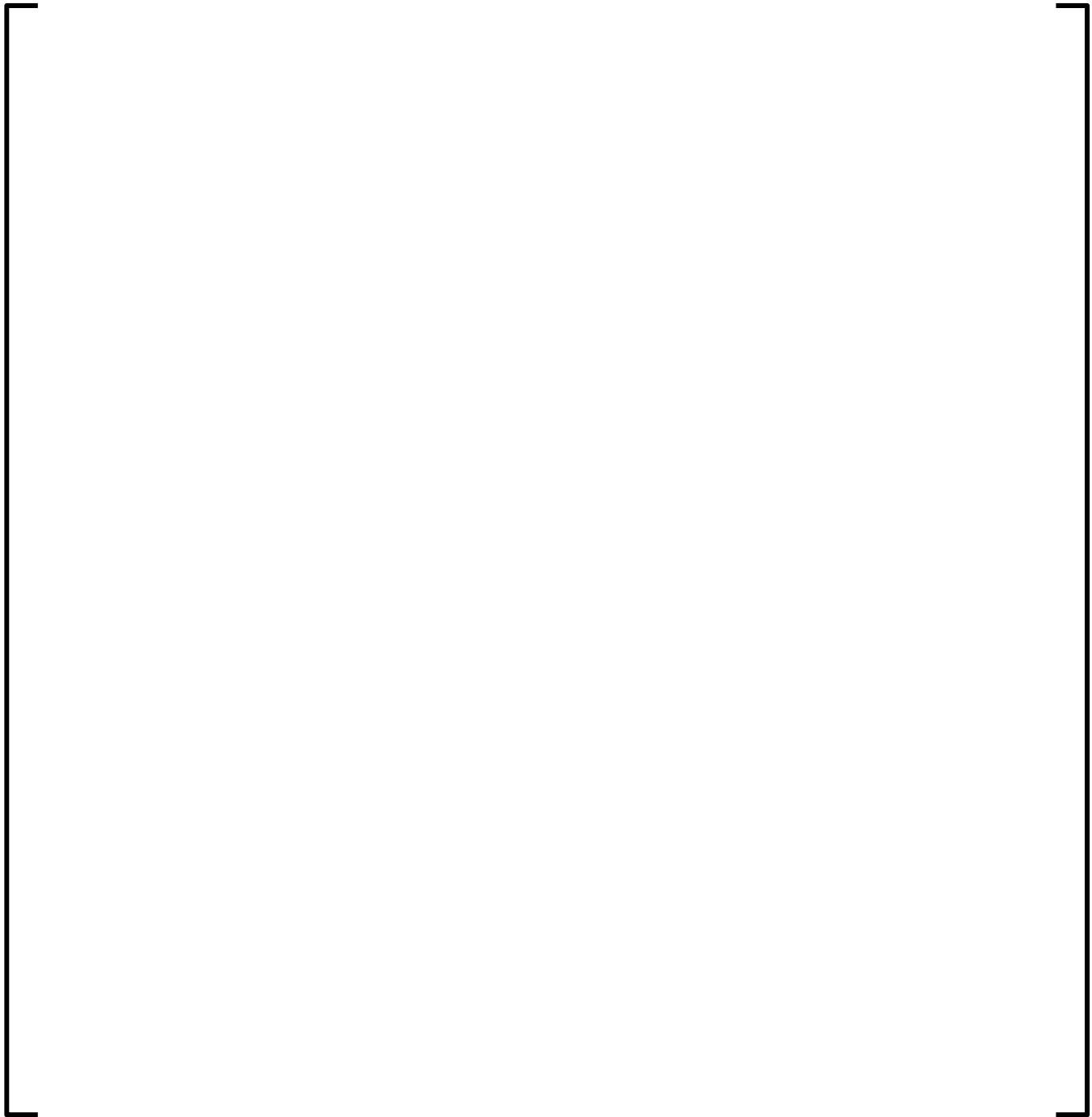
**Table C.50 [] Exposure-Dependent 40% Void
Isotopics (kg/MTU Initial)**

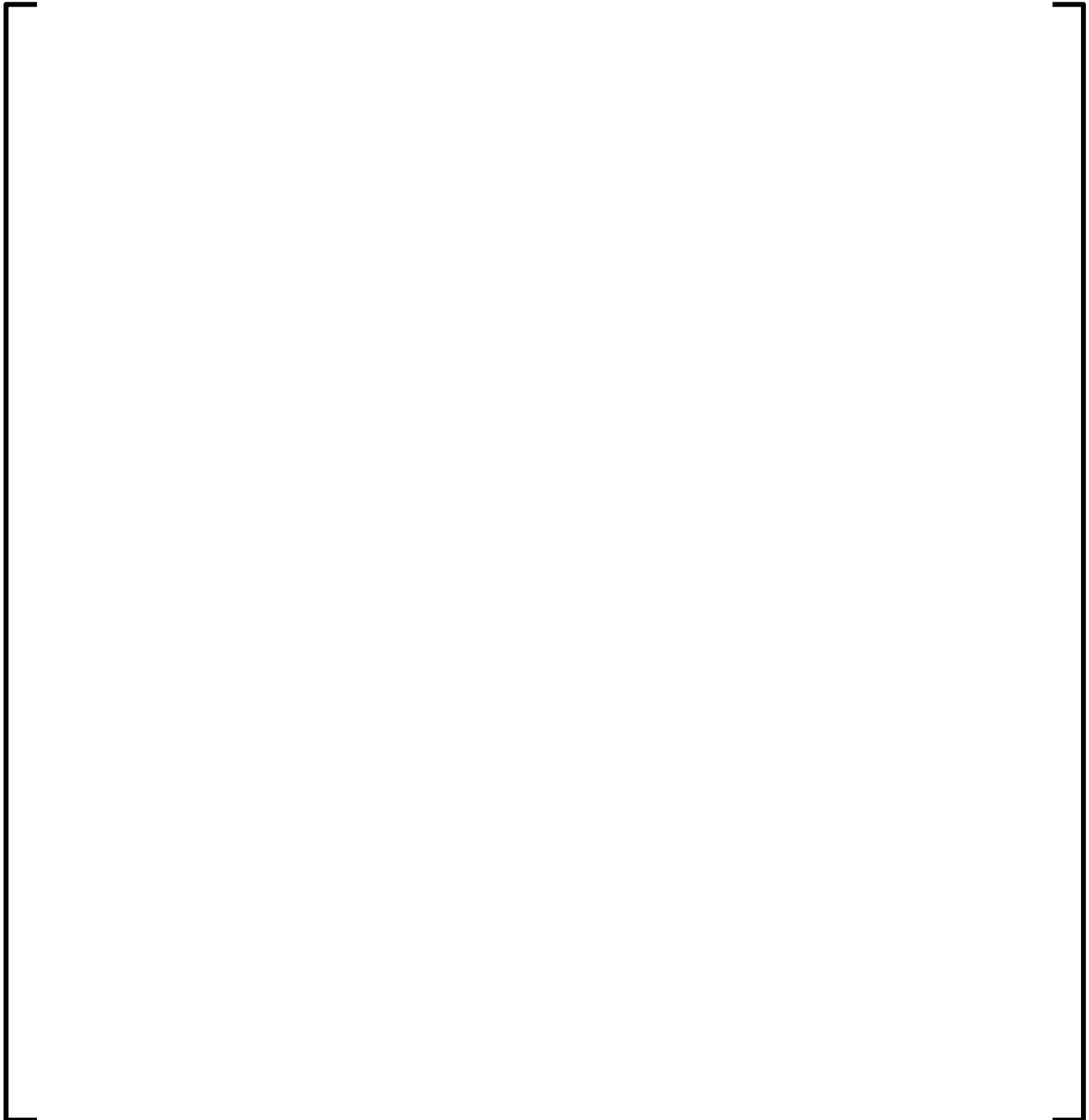
Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.342	45.328	0.000	954.329	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.208	0.023	954.277	0.000	0.000	0.016	0.000	0.000	0.000
500.0	0.340	44.730	0.114	954.065	0.002	0.000	0.180	0.001	0.000	0.000
1000.0	0.339	44.139	0.226	953.800	0.004	0.000	0.400	0.006	0.000	0.000
1500.0	0.337	43.557	0.337	953.536	0.006	0.000	0.610	0.014	0.001	0.000
2000.0	0.335	42.982	0.446	953.271	0.008	0.000	0.810	0.024	0.002	0.000
2500.0	0.333	42.414	0.553	953.008	0.011	0.000	1.001	0.037	0.004	0.000
3000.0	0.331	41.853	0.658	952.744	0.013	0.000	1.184	0.052	0.007	0.000
3500.0	0.329	41.299	0.762	952.482	0.016	0.001	1.357	0.069	0.011	0.000
4000.0	0.327	40.752	0.864	952.219	0.020	0.001	1.523	0.088	0.015	0.000
4500.0	0.325	40.210	0.965	951.957	0.023	0.001	1.681	0.108	0.021	0.001
5000.0	0.324	39.674	1.064	951.696	0.026	0.001	1.832	0.129	0.027	0.001
5500.0	0.322	39.144	1.162	951.435	0.030	0.001	1.976	0.152	0.034	0.001
6000.0	0.320	38.620	1.259	951.175	0.034	0.002	2.112	0.176	0.043	0.002
6500.0	0.318	38.101	1.354	950.916	0.038	0.002	2.242	0.200	0.052	0.002
7000.0	0.316	37.586	1.448	950.657	0.042	0.002	2.366	0.225	0.061	0.003
7500.0	0.315	37.077	1.541	950.399	0.046	0.003	2.484	0.252	0.072	0.003
8000.0	0.313	36.573	1.632	950.142	0.050	0.003	2.595	0.278	0.083	0.004
8500.0	0.311	36.073	1.722	949.886	0.054	0.004	2.701	0.306	0.095	0.005
9000.0	0.309	35.578	1.811	949.631	0.059	0.004	2.802	0.333	0.107	0.006
9500.0	0.308	35.087	1.899	949.376	0.063	0.005	2.897	0.362	0.120	0.007
10000.0	0.306	34.600	1.986	949.123	0.068	0.005	2.987	0.391	0.134	0.009
10500.0	0.304	34.117	2.072	948.870	0.073	0.006	3.072	0.420	0.148	0.010
11000.0	0.303	33.638	2.156	948.619	0.077	0.007	3.152	0.449	0.162	0.012
11500.0	0.301	33.162	2.240	948.367	0.082	0.007	3.229	0.479	0.176	0.014
12000.0	0.299	32.691	2.322	948.116	0.087	0.008	3.301	0.509	0.191	0.016
12500.0	0.298	32.223	2.404	947.865	0.092	0.009	3.370	0.539	0.206	0.018
13000.0	0.296	31.759	2.484	947.615	0.097	0.010	3.435	0.570	0.222	0.020
13500.0	0.294	31.299	2.564	947.363	0.103	0.011	3.497	0.600	0.237	0.022
14000.0	0.293	30.842	2.643	947.112	0.108	0.012	3.556	0.631	0.253	0.025
14500.0	0.291	30.389	2.721	946.860	0.113	0.013	3.612	0.662	0.270	0.028
15000.0	0.290	29.939	2.798	946.606	0.119	0.014	3.666	0.693	0.286	0.031
15500.0	0.288	29.493	2.874	946.353	0.124	0.015	3.717	0.724	0.303	0.034
16000.0	0.286	29.051	2.950	946.098	0.130	0.016	3.766	0.755	0.320	0.037
16500.0	0.285	28.612	3.024	945.842	0.136	0.017	3.812	0.786	0.337	0.040
17000.0	0.283	28.177	3.098	945.585	0.141	0.018	3.857	0.817	0.354	0.044
17500.0	0.281	27.745	3.171	945.327	0.147	0.019	3.899	0.848	0.371	0.048
18000.0	0.280	27.317	3.243	945.068	0.153	0.021	3.939	0.879	0.389	0.052
18500.0	0.278	26.892	3.314	944.807	0.159	0.022	3.977	0.910	0.406	0.056
19000.0	0.277	26.471	3.385	944.546	0.165	0.024	4.014	0.941	0.424	0.061
20000.0	0.273	25.639	3.523	944.019	0.177	0.027	4.082	1.003	0.459	0.070
22500.0	0.265	23.620	3.855	942.678	0.209	0.036	4.222	1.156	0.548	0.098
25000.0	0.257	21.688	4.166	941.303	0.243	0.046	4.325	1.307	0.635	0.131
27500.0	0.250	19.842	4.457	939.892	0.278	0.058	4.396	1.454	0.719	0.169
30000.0	0.242	18.081	4.729	938.444	0.314	0.072	4.439	1.597	0.798	0.213
32500.0	0.234	16.406	4.980	936.955	0.350	0.088	4.458	1.734	0.872	0.263
35000.0	0.226	14.817	5.212	935.425	0.387	0.105	4.456	1.865	0.939	0.318
37500.0	0.218	13.315	5.424	933.848	0.424	0.125	4.438	1.990	1.000	0.379
40000.0	0.210	11.901	5.616	932.225	0.461	0.146	4.405	2.106	1.054	0.445
42500.0	0.202	10.575	5.789	930.551	0.497	0.168	4.360	2.215	1.100	0.516
45000.0	0.195	9.338	5.942	928.824	0.533	0.192	4.307	2.316	1.140	0.592
47500.0	0.187	8.191	6.075	927.041	0.568	0.217	4.247	2.407	1.173	0.672
50000.0	0.179	7.136	6.189	925.201	0.602	0.243	4.183	2.490	1.200	0.757
52500.0	0.172	6.171	6.283	923.300	0.634	0.269	4.116	2.563	1.220	0.846
55000.0	0.164	5.297	6.357	921.339	0.665	0.296	4.049	2.628	1.235	0.938
57500.0	0.157	4.511	6.413	919.316	0.694	0.323	3.982	2.683	1.245	1.033
60000.0	0.150	3.813	6.451	917.231	0.721	0.349	3.918	2.729	1.251	1.130
62500.0	0.143	3.198	6.472	915.086	0.745	0.374	3.857	2.768	1.253	1.230
65000.0	0.136	2.662	6.476	912.884	0.768	0.399	3.801	2.799	1.253	1.330
67500.0	0.129	2.201	6.466	910.625	0.788	0.422	3.748	2.822	1.250	1.431
70000.0	0.123	1.808	6.442	908.316	0.806	0.444	3.701	2.840	1.245	1.532

**Table C.51 [] Exposure-Dependent 80% Void
Isotopics (kg/MTU Initial)**

Exposure MWd/MTU	U-234	U-235	U-236	U-238	NP-237	PU-238	PU-239	PU-240	PU-241	PU-242
0.0	0.342	45.328	0.000	954.329	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.342	45.209	0.024	954.267	0.000	0.000	0.019	0.000	0.000	0.000
500.0	0.340	44.733	0.120	954.015	0.002	0.000	0.211	0.001	0.000	0.000
1000.0	0.338	44.148	0.239	953.700	0.004	0.000	0.469	0.007	0.000	0.000
1500.0	0.336	43.572	0.354	953.386	0.007	0.000	0.716	0.016	0.001	0.000
2000.0	0.333	43.004	0.468	953.073	0.010	0.000	0.951	0.028	0.003	0.000
2500.0	0.331	42.445	0.580	952.760	0.014	0.000	1.175	0.043	0.006	0.000
3000.0	0.329	41.894	0.690	952.447	0.017	0.001	1.390	0.060	0.010	0.000
3500.0	0.327	41.350	0.798	952.135	0.021	0.001	1.594	0.079	0.015	0.000
4000.0	0.324	40.814	0.905	951.824	0.025	0.001	1.790	0.099	0.021	0.000
4500.0	0.322	40.285	1.009	951.513	0.029	0.001	1.977	0.122	0.029	0.001
5000.0	0.320	39.762	1.112	951.202	0.033	0.002	2.156	0.145	0.037	0.001
5500.0	0.318	39.245	1.213	950.892	0.038	0.002	2.327	0.170	0.047	0.002
6000.0	0.316	38.735	1.313	950.583	0.043	0.003	2.490	0.195	0.057	0.002
6500.0	0.314	38.231	1.411	950.275	0.048	0.003	2.646	0.222	0.069	0.003
7000.0	0.312	37.733	1.508	949.967	0.053	0.004	2.795	0.249	0.082	0.003
7500.0	0.310	37.240	1.603	949.660	0.059	0.004	2.937	0.277	0.095	0.004
8000.0	0.308	36.752	1.697	949.353	0.064	0.005	3.073	0.306	0.110	0.005
8500.0	0.306	36.270	1.789	949.048	0.070	0.006	3.202	0.336	0.125	0.007
9000.0	0.304	35.792	1.880	948.743	0.075	0.006	3.326	0.366	0.140	0.008
9500.0	0.302	35.320	1.969	948.439	0.081	0.007	3.443	0.396	0.156	0.009
10000.0	0.300	34.852	2.058	948.136	0.087	0.008	3.555	0.427	0.173	0.011
10500.0	0.298	34.389	2.145	947.833	0.093	0.009	3.662	0.459	0.190	0.013
11000.0	0.296	33.930	2.231	947.532	0.099	0.010	3.764	0.491	0.208	0.015
11500.0	0.294	33.476	2.315	947.231	0.106	0.011	3.861	0.523	0.226	0.017
12000.0	0.292	33.026	2.399	946.930	0.112	0.012	3.953	0.555	0.244	0.019
12500.0	0.290	32.580	2.481	946.630	0.118	0.014	4.041	0.588	0.263	0.021
13000.0	0.288	32.137	2.563	946.331	0.125	0.015	4.125	0.621	0.282	0.024
13500.0	0.287	31.699	2.643	946.032	0.131	0.016	4.205	0.654	0.301	0.027
14000.0	0.285	31.265	2.722	945.732	0.138	0.018	4.282	0.688	0.320	0.030
14500.0	0.283	30.835	2.800	945.432	0.145	0.019	4.355	0.721	0.340	0.033
15000.0	0.281	30.408	2.877	945.133	0.151	0.020	4.425	0.754	0.359	0.036
15500.0	0.279	29.985	2.954	944.832	0.158	0.022	4.492	0.788	0.379	0.040
16000.0	0.277	29.566	3.029	944.531	0.165	0.024	4.556	0.822	0.399	0.043
16500.0	0.276	29.151	3.103	944.229	0.172	0.025	4.618	0.856	0.420	0.047
17000.0	0.274	28.740	3.176	943.927	0.179	0.027	4.677	0.889	0.440	0.051
17500.0	0.272	28.332	3.249	943.623	0.187	0.029	4.733	0.923	0.460	0.056
18000.0	0.270	27.928	3.320	943.318	0.194	0.031	4.788	0.957	0.481	0.060
18500.0	0.269	27.527	3.391	943.013	0.201	0.033	4.840	0.991	0.501	0.065
19000.0	0.267	27.130	3.460	942.706	0.209	0.035	4.891	1.025	0.522	0.070
19500.0	0.265	26.737	3.529	942.398	0.216	0.038	4.939	1.058	0.543	0.075
20000.0	0.263	26.348	3.597	942.089	0.224	0.040	4.985	1.092	0.563	0.080
20500.0	0.262	25.962	3.664	941.779	0.231	0.042	5.030	1.126	0.584	0.085
21000.0	0.260	25.579	3.730	941.468	0.239	0.045	5.072	1.159	0.605	0.091
21500.0	0.258	25.201	3.795	941.155	0.247	0.047	5.113	1.193	0.626	0.097
22000.0	0.256	24.825	3.859	940.842	0.254	0.050	5.152	1.226	0.646	0.103
22500.0	0.255	24.454	3.922	940.527	0.262	0.052	5.190	1.260	0.667	0.109
25000.0	0.246	22.647	4.227	938.932	0.302	0.067	5.355	1.424	0.770	0.143
27500.0	0.238	20.927	4.510	937.304	0.342	0.084	5.484	1.586	0.870	0.181
30000.0	0.229	19.290	4.773	935.643	0.383	0.103	5.583	1.743	0.966	0.225
32500.0	0.221	17.736	5.016	933.948	0.424	0.125	5.654	1.895	1.057	0.273
35000.0	0.213	16.264	5.238	932.218	0.466	0.148	5.702	2.041	1.142	0.326
37500.0	0.205	14.871	5.442	930.452	0.507	0.174	5.729	2.181	1.221	0.383
40000.0	0.198	13.558	5.625	928.649	0.548	0.201	5.738	2.315	1.293	0.443
42500.0	0.190	12.322	5.790	926.808	0.588	0.231	5.733	2.441	1.359	0.508
45000.0	0.183	11.164	5.937	924.929	0.628	0.262	5.715	2.559	1.419	0.576
47500.0	0.175	10.080	6.065	923.010	0.666	0.295	5.686	2.670	1.472	0.648
50000.0	0.168	9.072	6.176	921.052	0.704	0.329	5.649	2.773	1.519	0.722
52500.0	0.162	8.135	6.270	919.053	0.739	0.363	5.605	2.868	1.560	0.800
55000.0	0.155	7.270	6.347	917.016	0.773	0.399	5.557	2.955	1.596	0.880
57500.0	0.148	6.474	6.408	914.938	0.806	0.435	5.505	3.033	1.625	0.962
60000.0	0.142	5.744	6.454	912.822	0.836	0.471	5.450	3.104	1.650	1.046
62500.0	0.136	5.079	6.486	910.666	0.864	0.506	5.395	3.167	1.670	1.131
65000.0	0.130	4.476	6.504	908.474	0.891	0.541	5.340	3.223	1.686	1.218
67500.0	0.125	3.931	6.509	906.245	0.915	0.576	5.285	3.271	1.698	1.306
70000.0	0.119	3.441	6.501	903.982	0.936	0.609	5.232	3.313	1.707	1.395

Appendix D Lattice Enrichment Distribution Maps





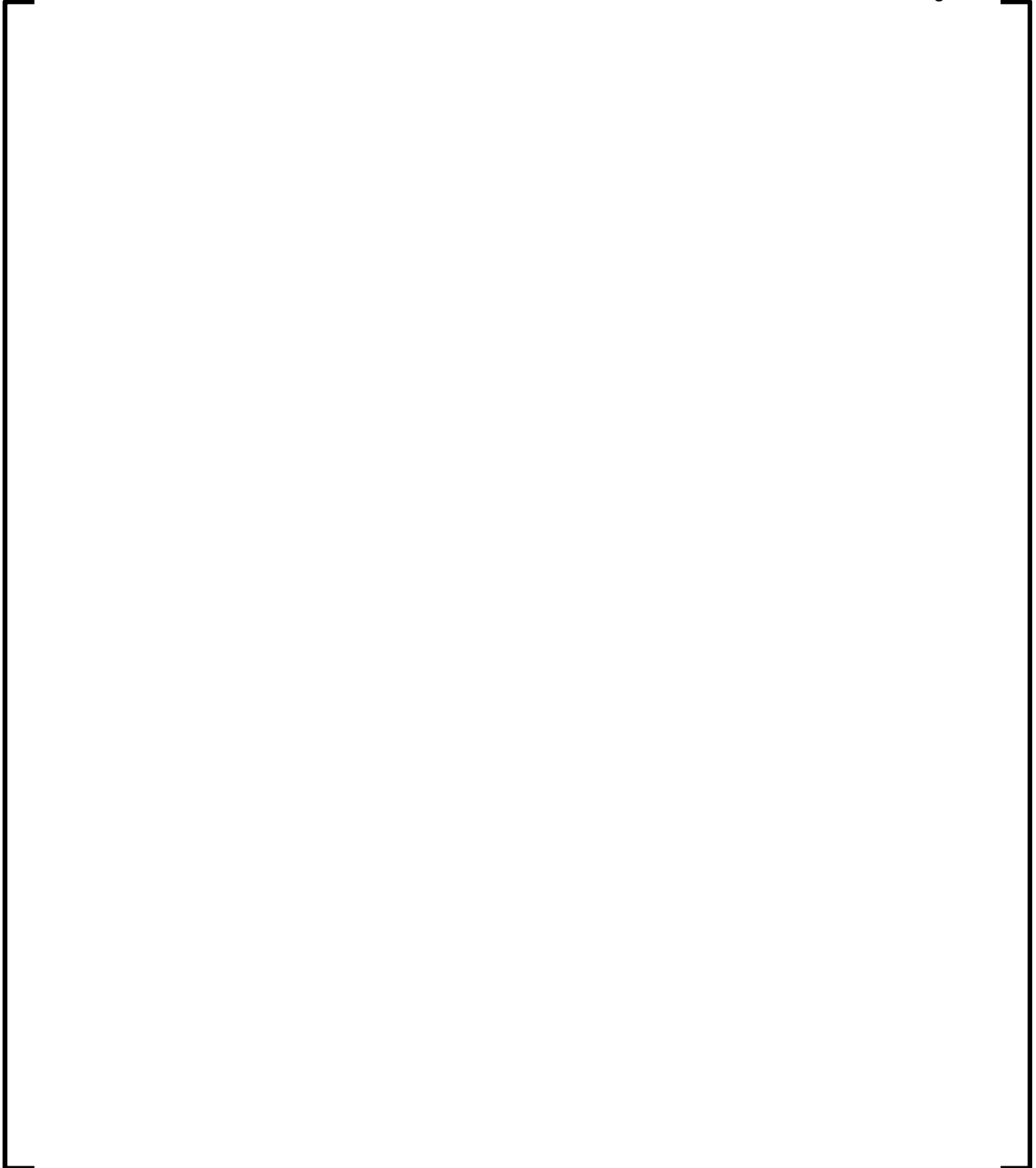
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-4



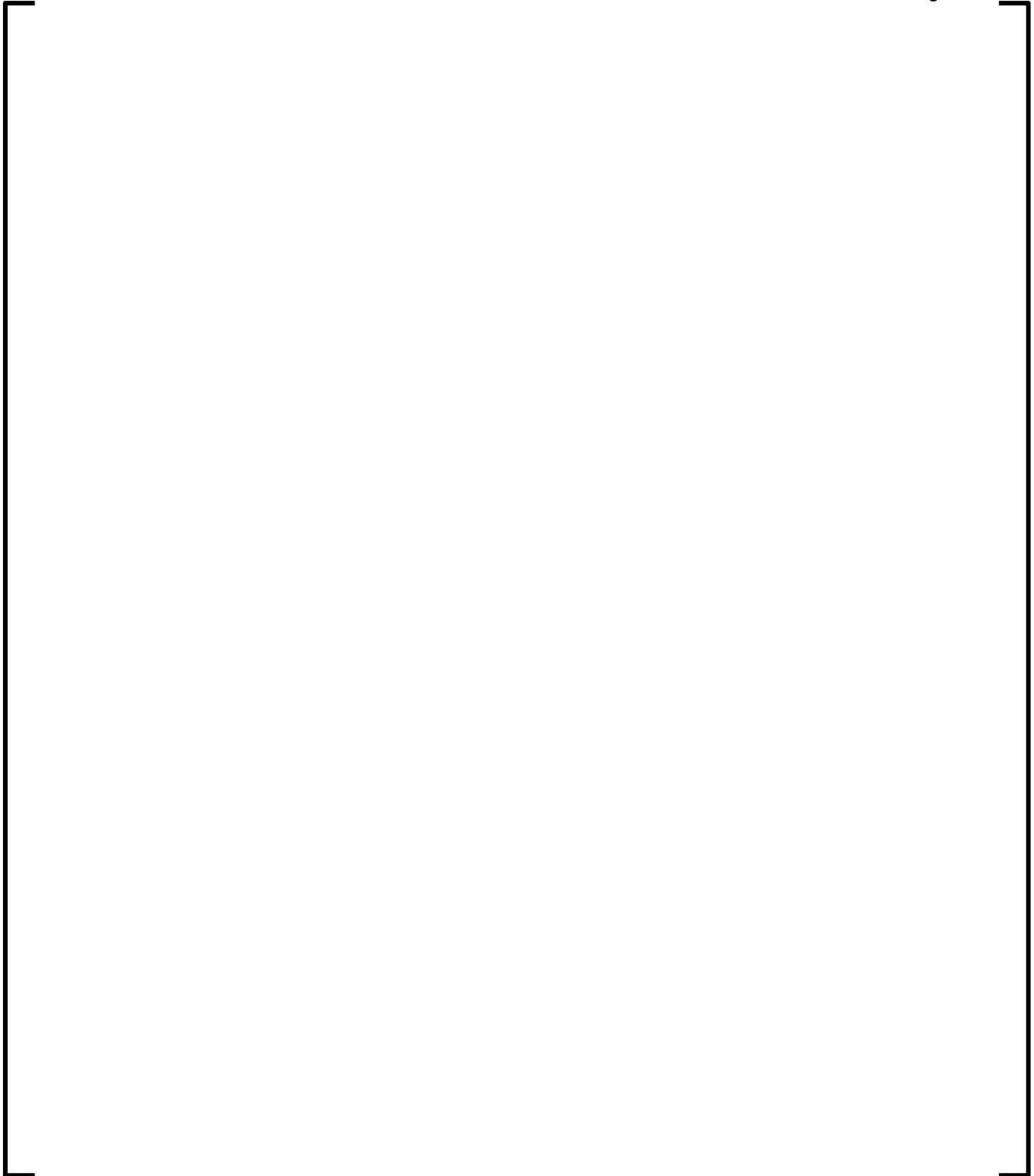
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-5



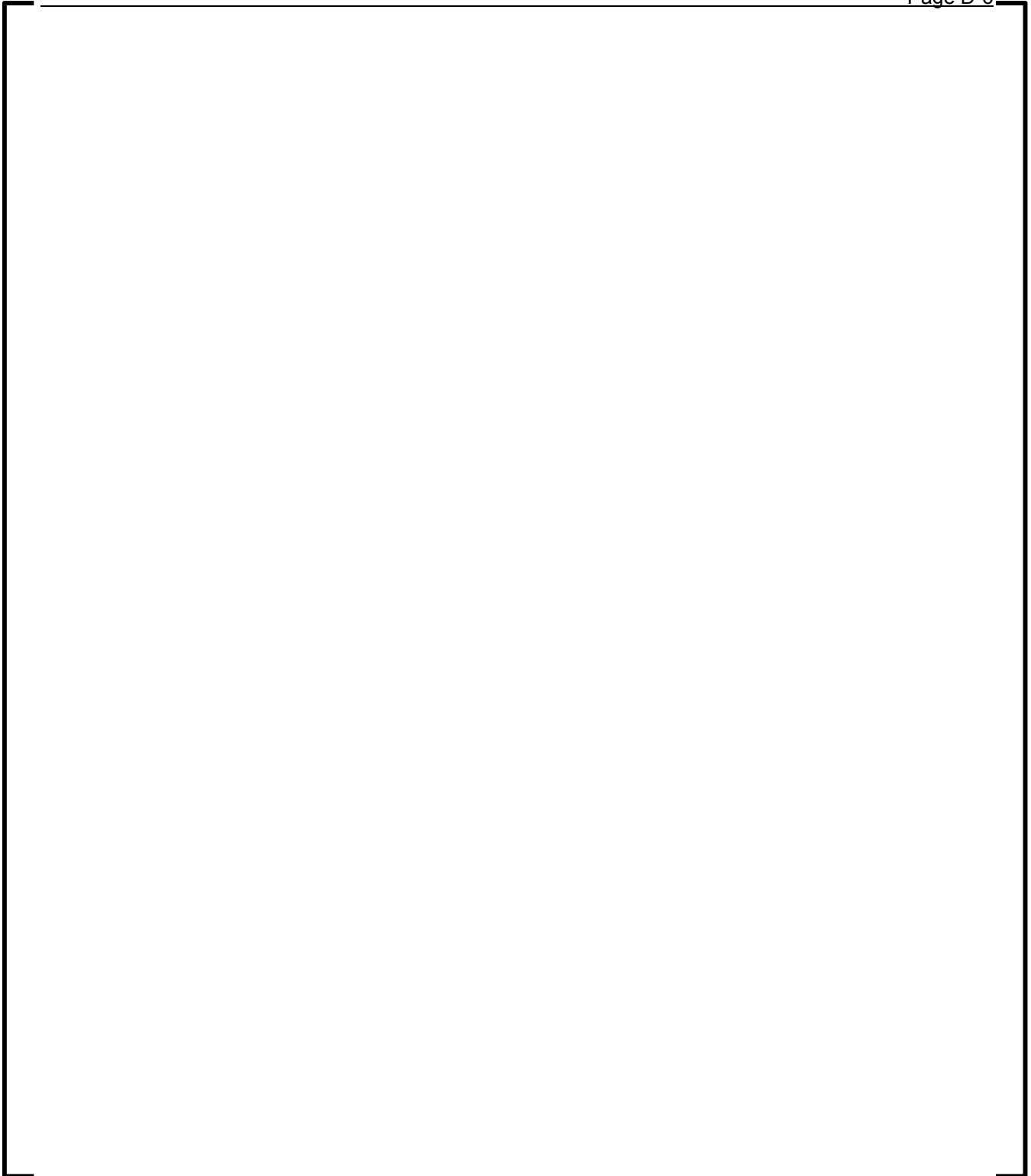
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-6

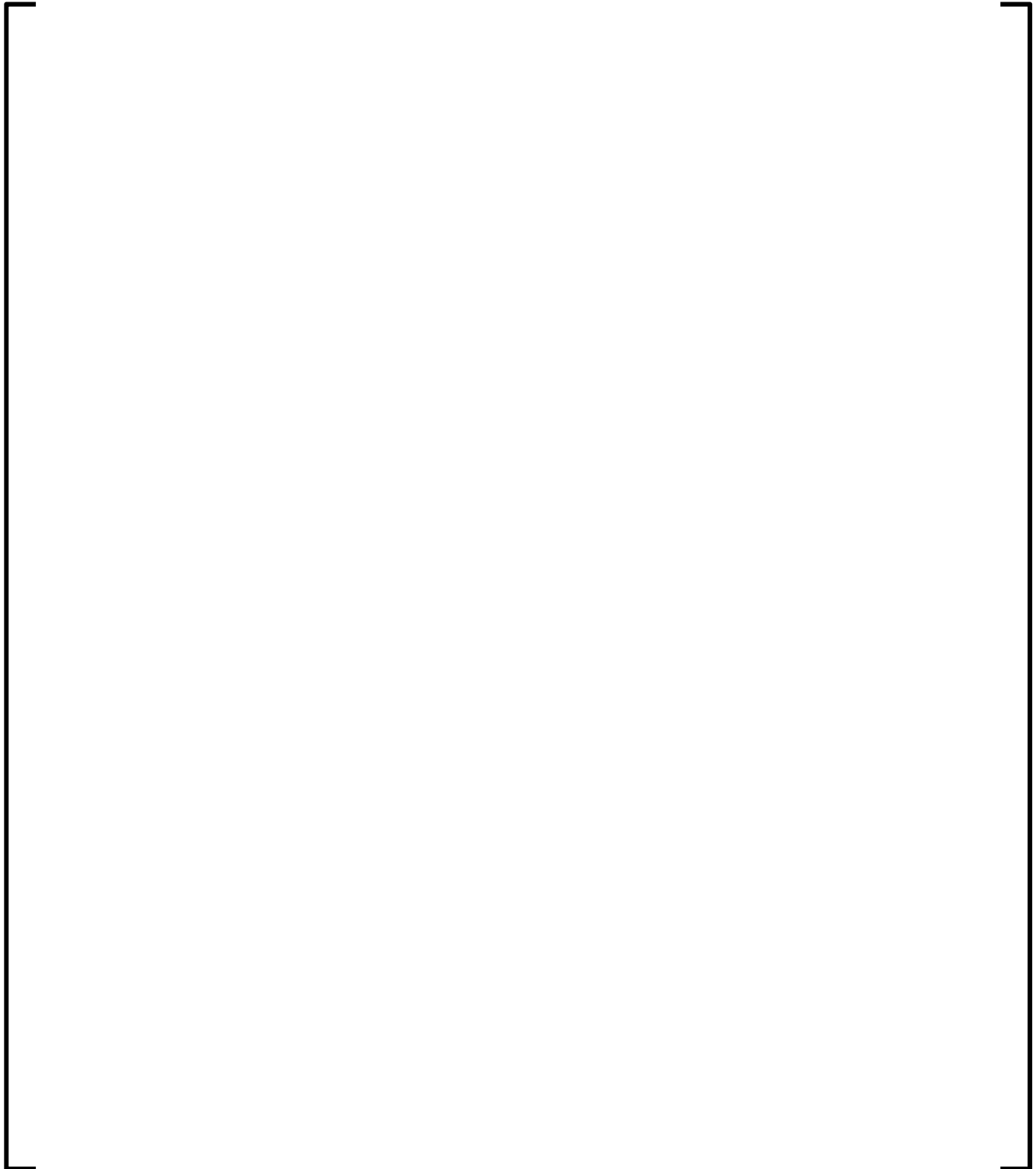


Framatome Inc.

ANP-3667NP
Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-7



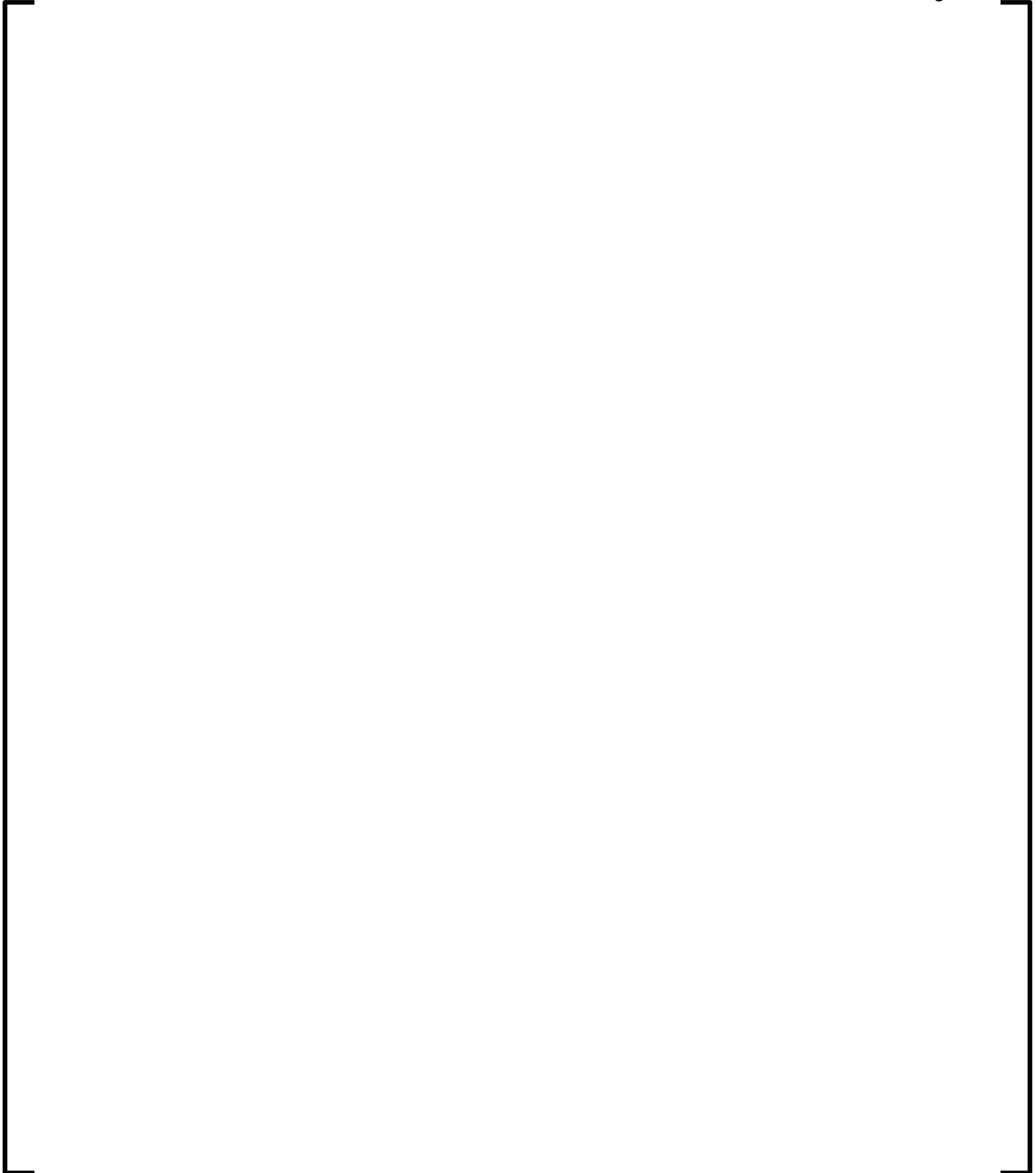
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-8



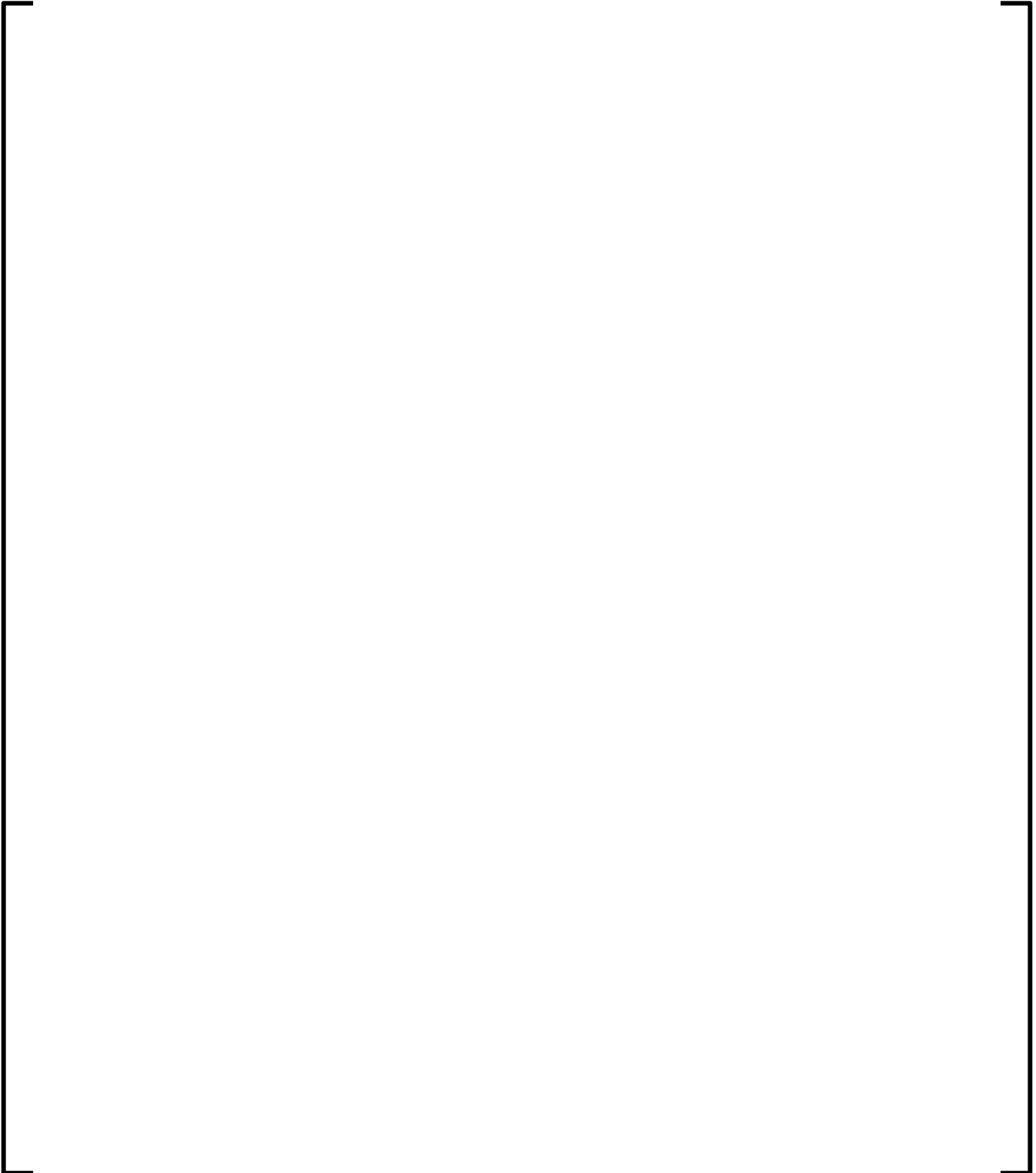
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-9



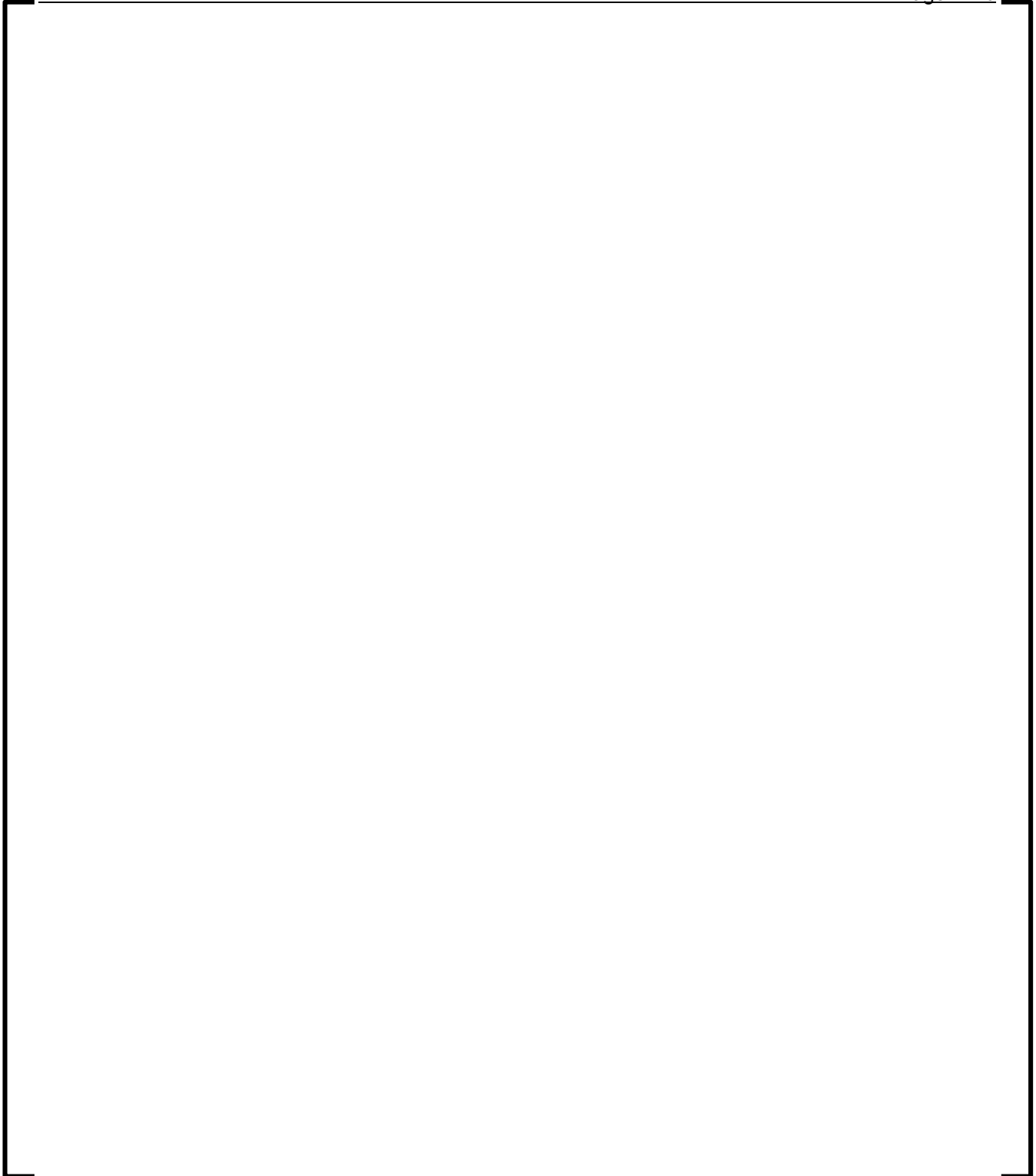
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-10



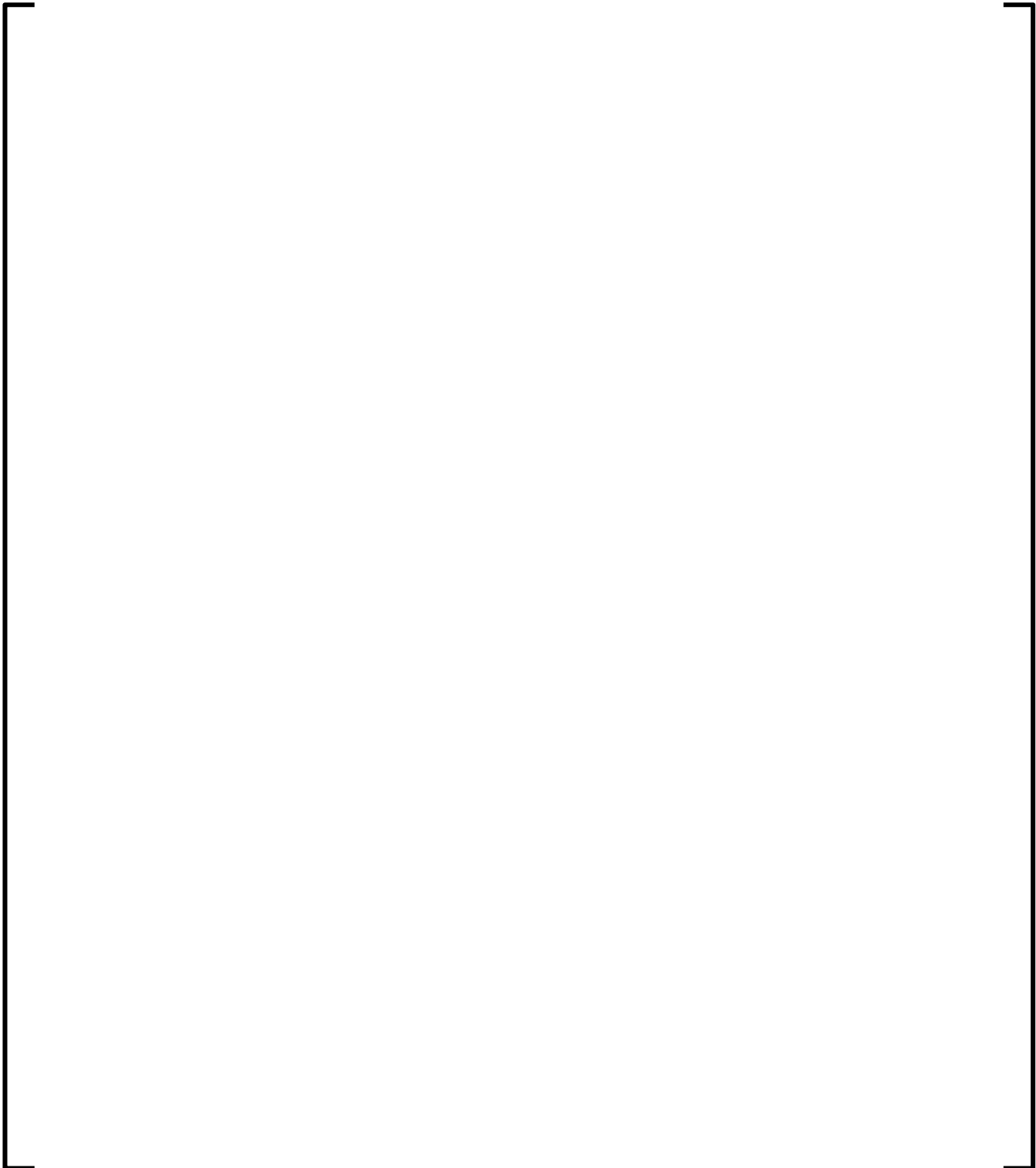
Framatome Inc.

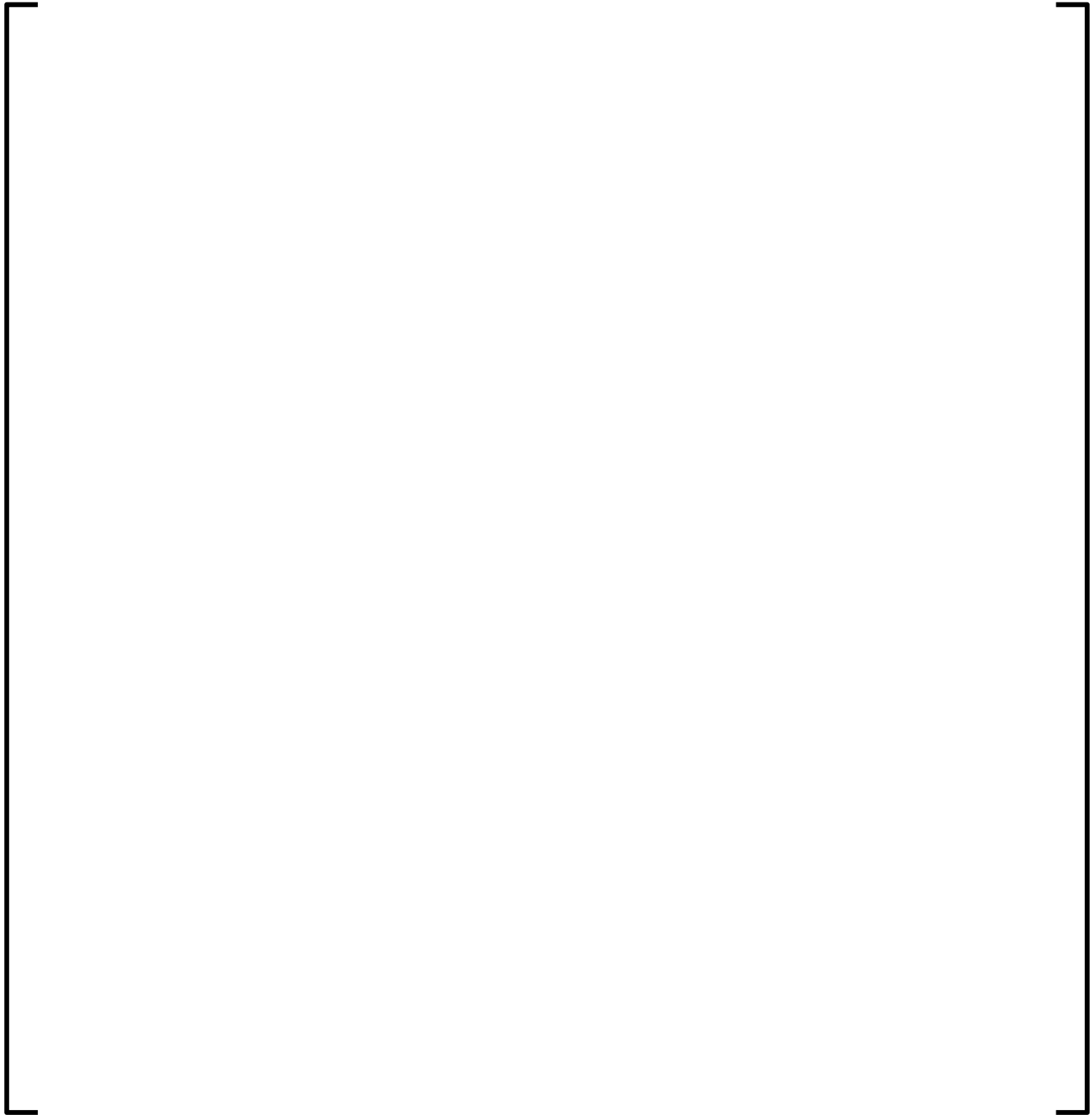
ANP-3667NP

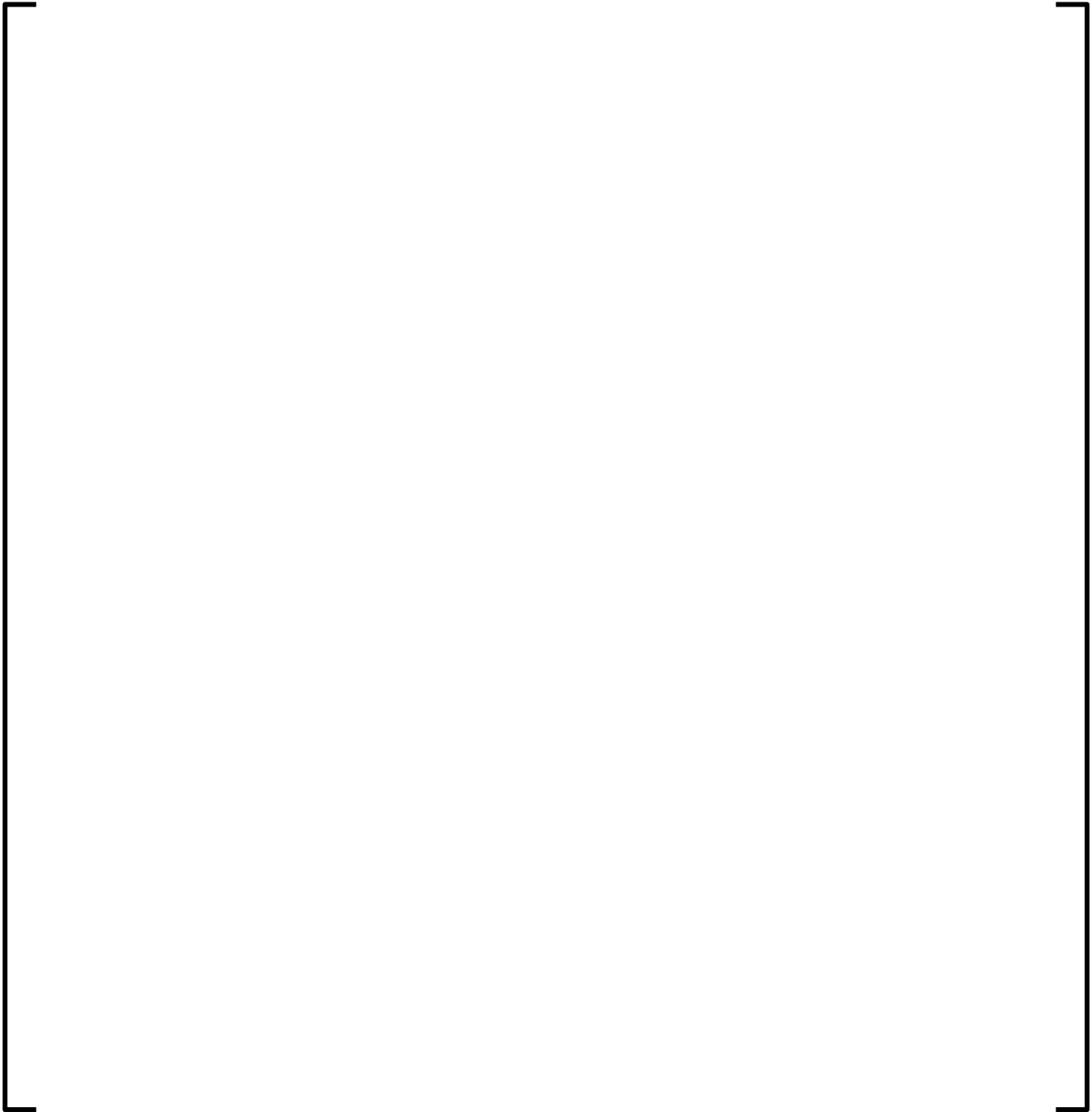
Revision 0

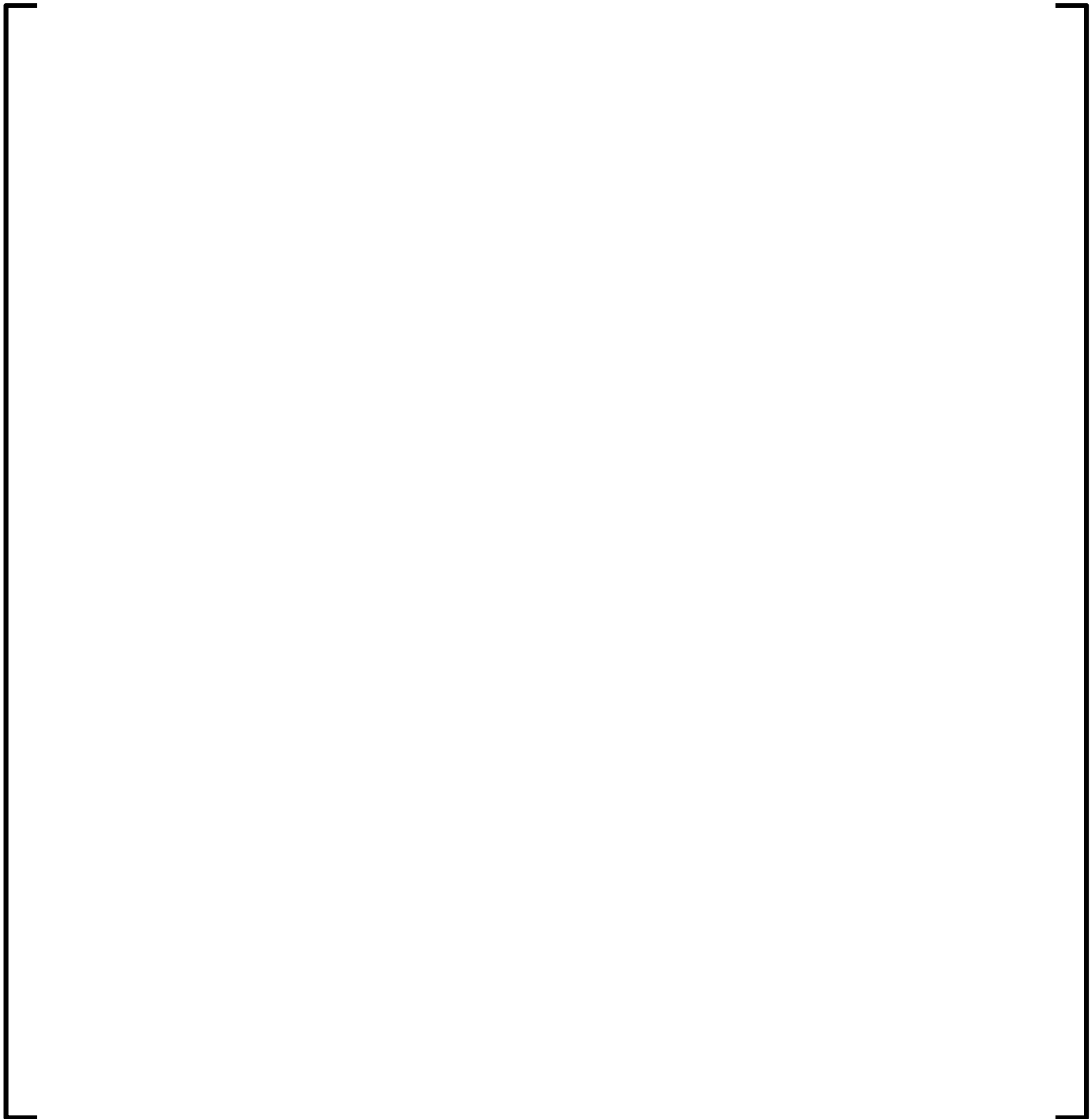
Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-11







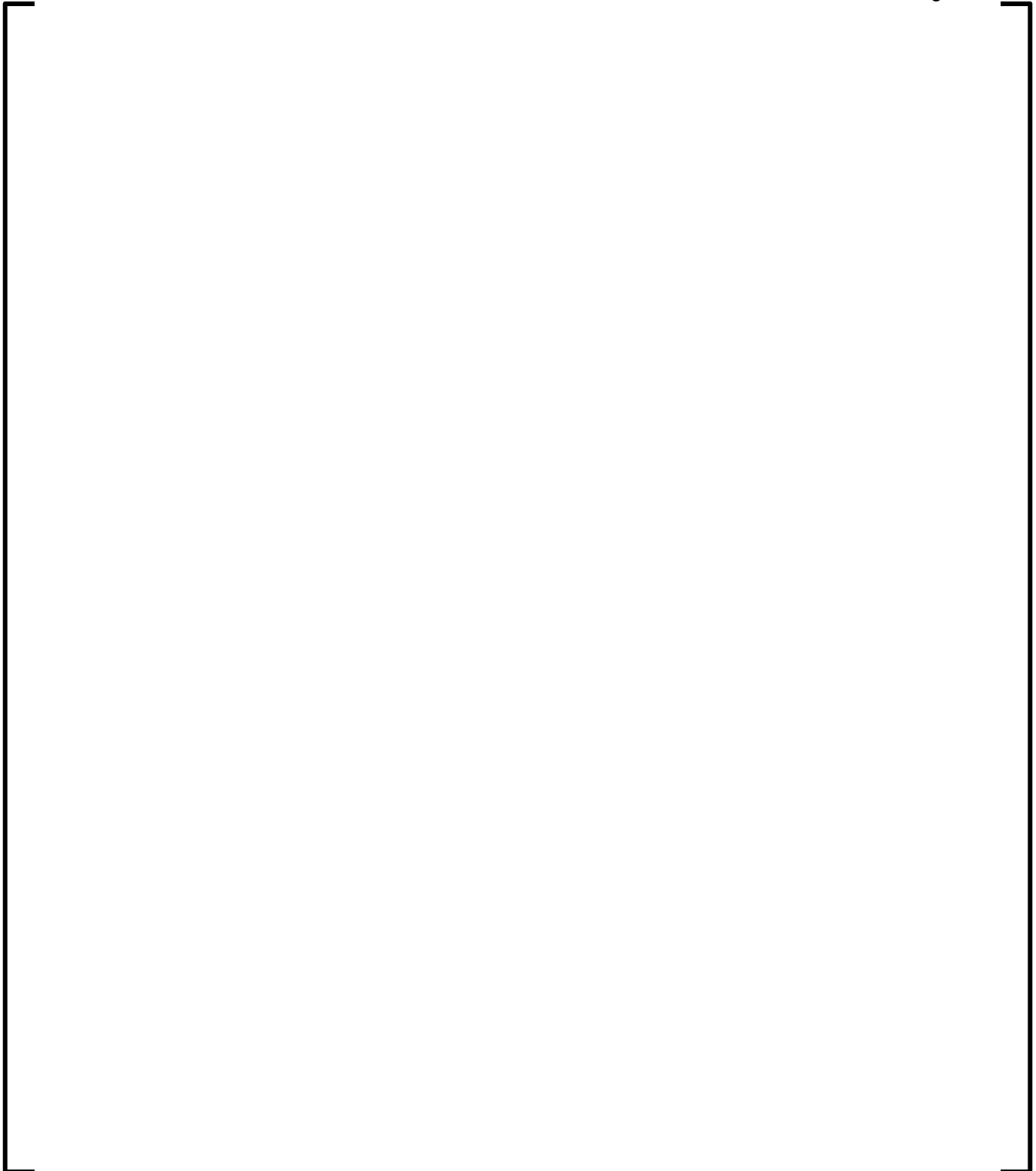


Framatome Inc.

ANP-3667NP
Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-15



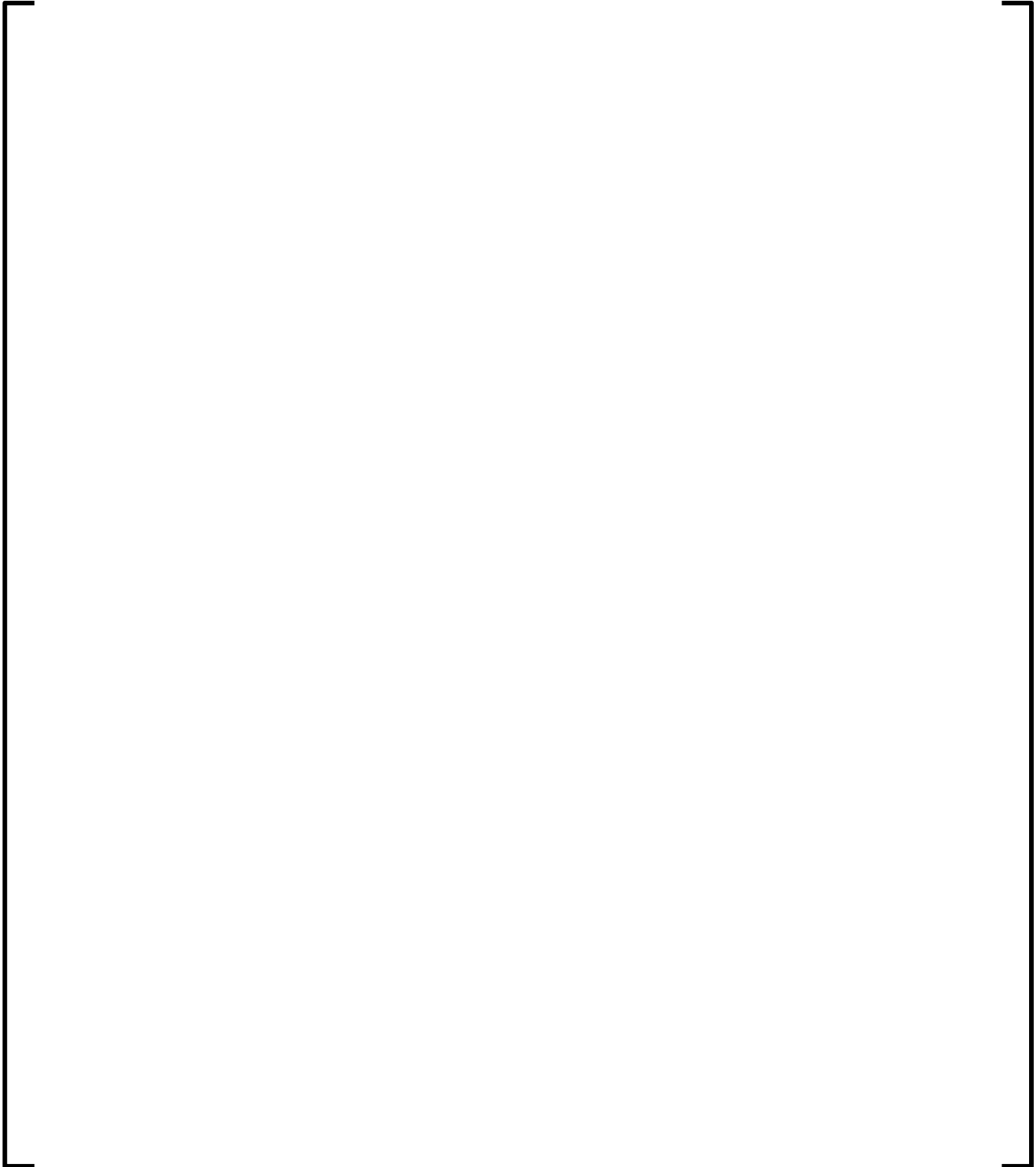
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-16



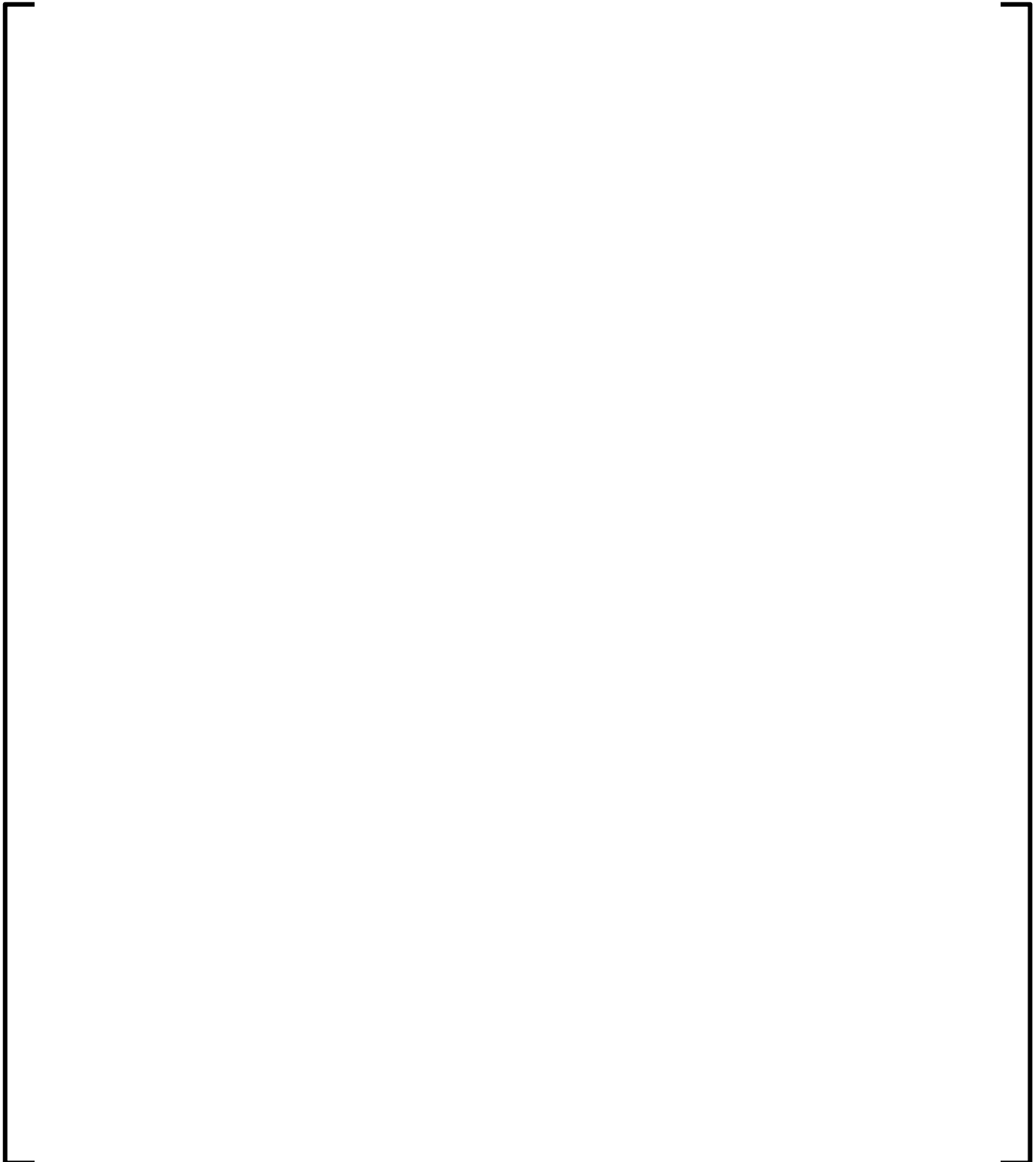
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-17



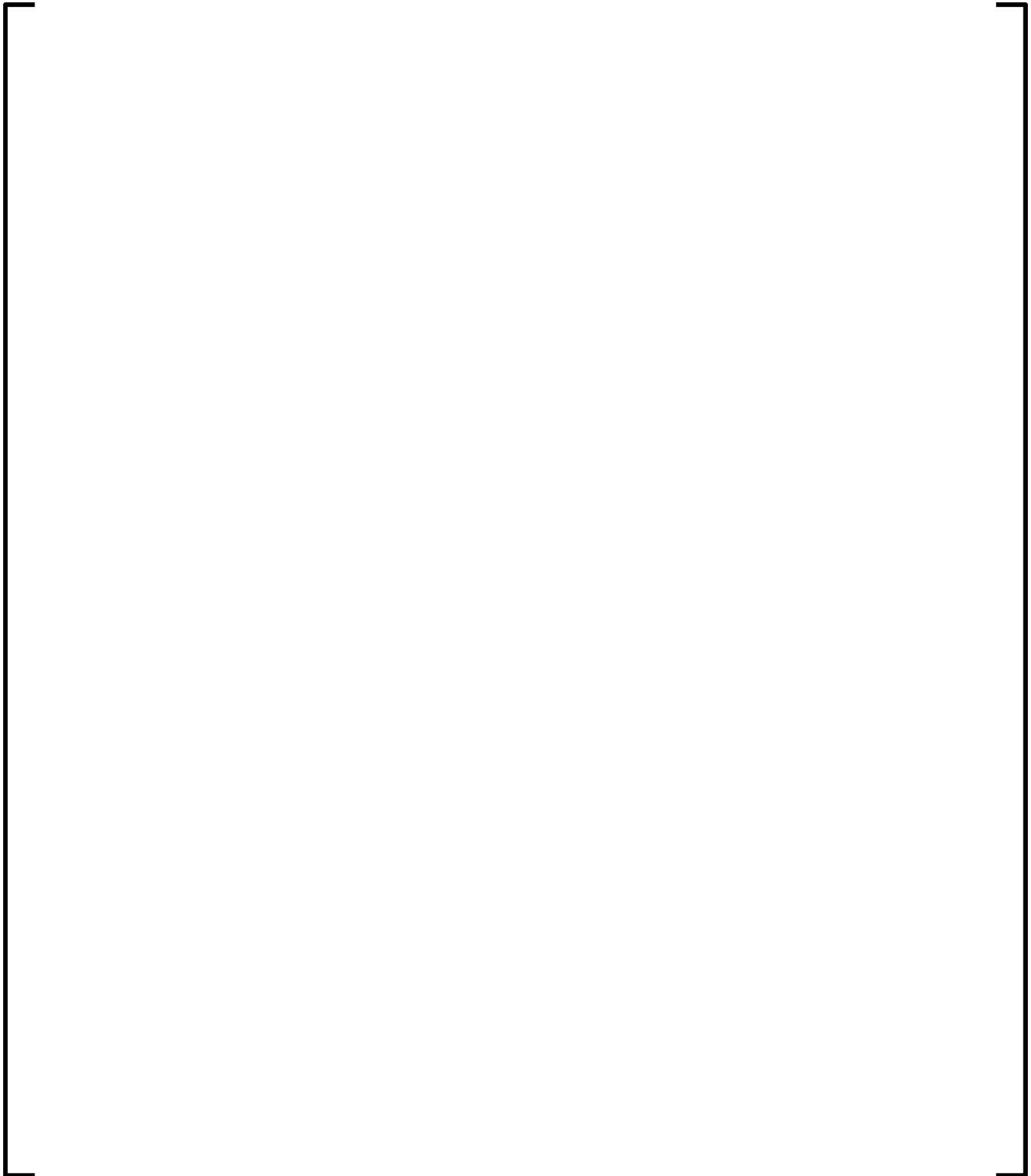
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-18

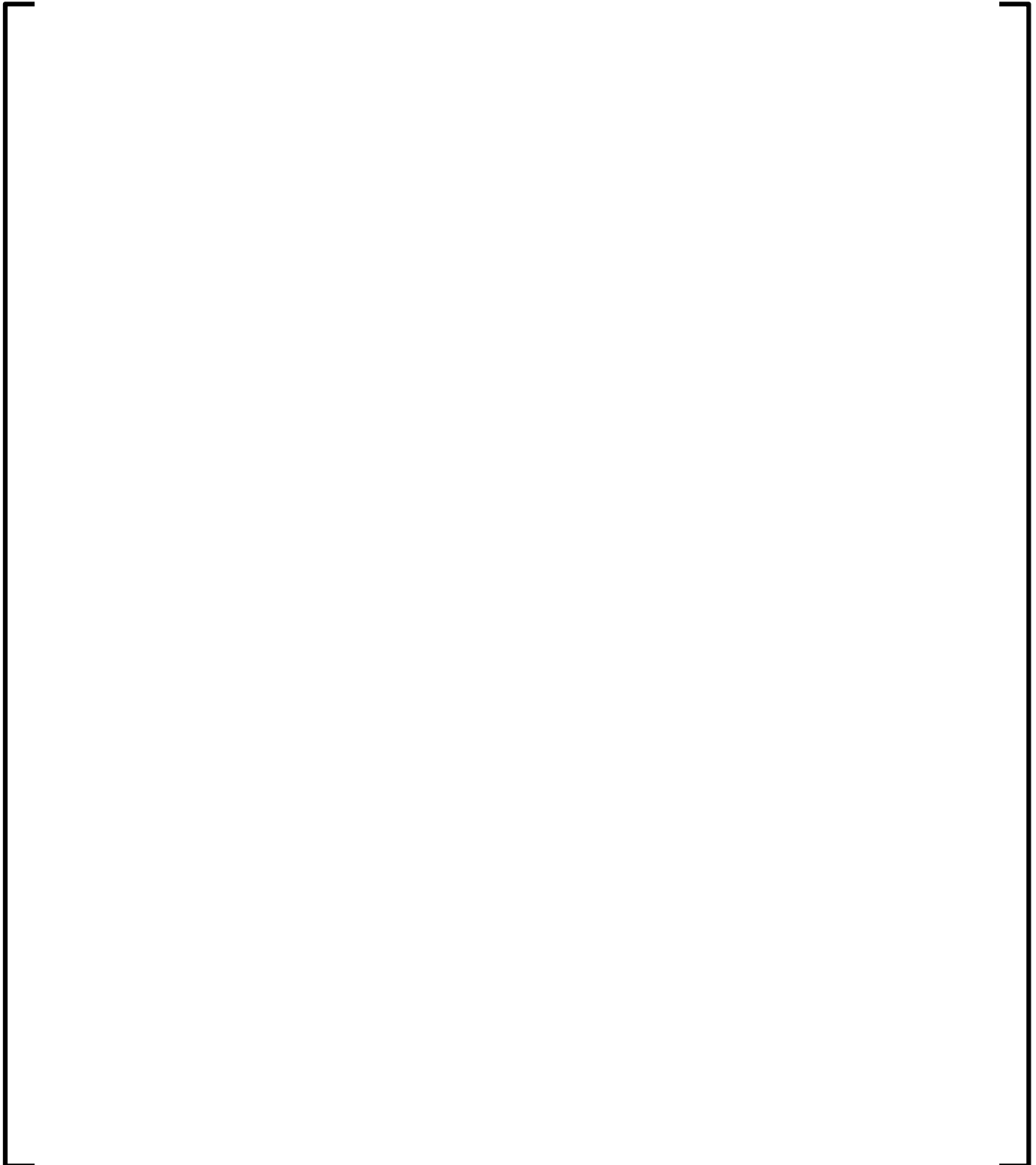


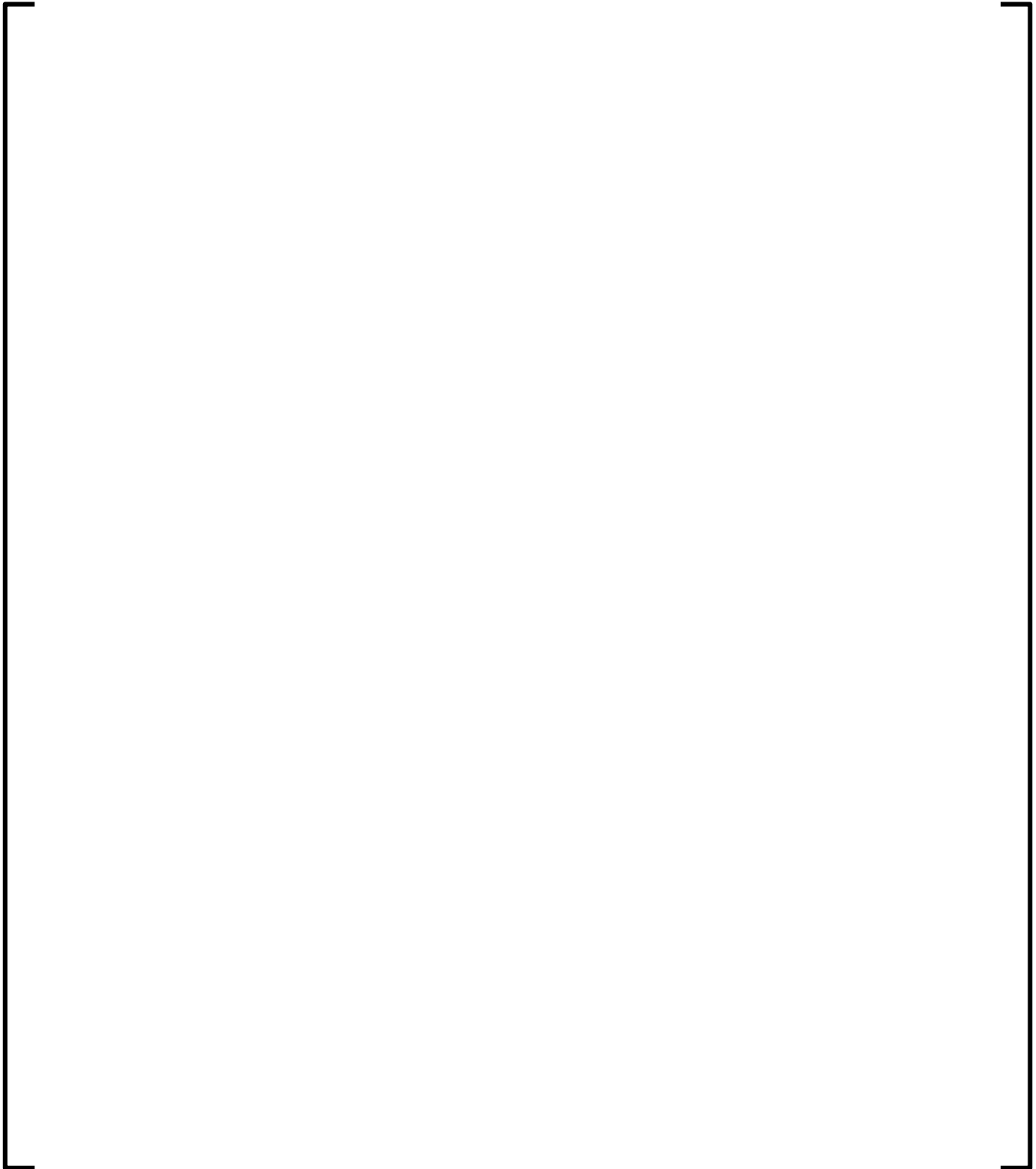
Framatome Inc.

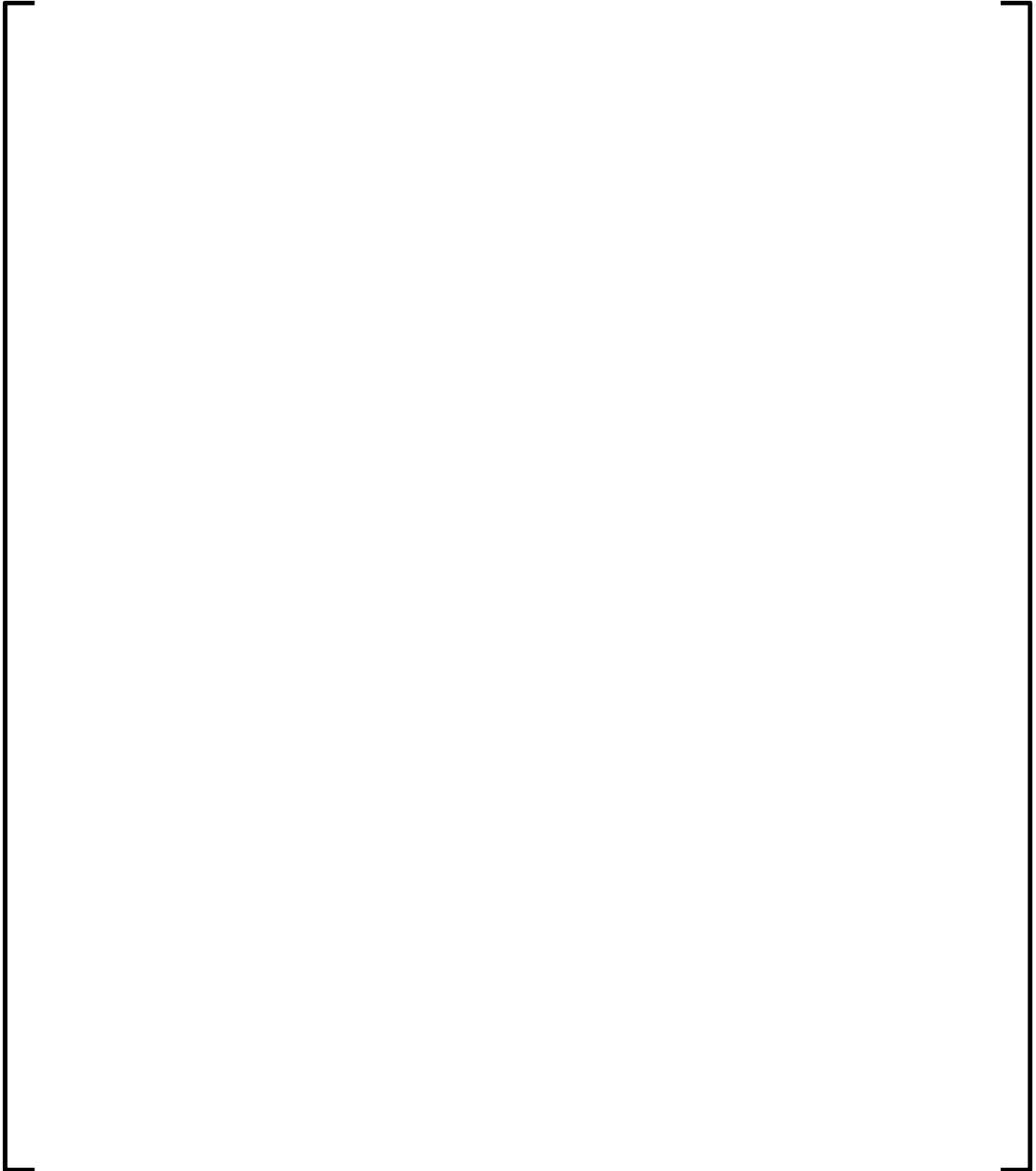
ANP-3667NP
Revision 0

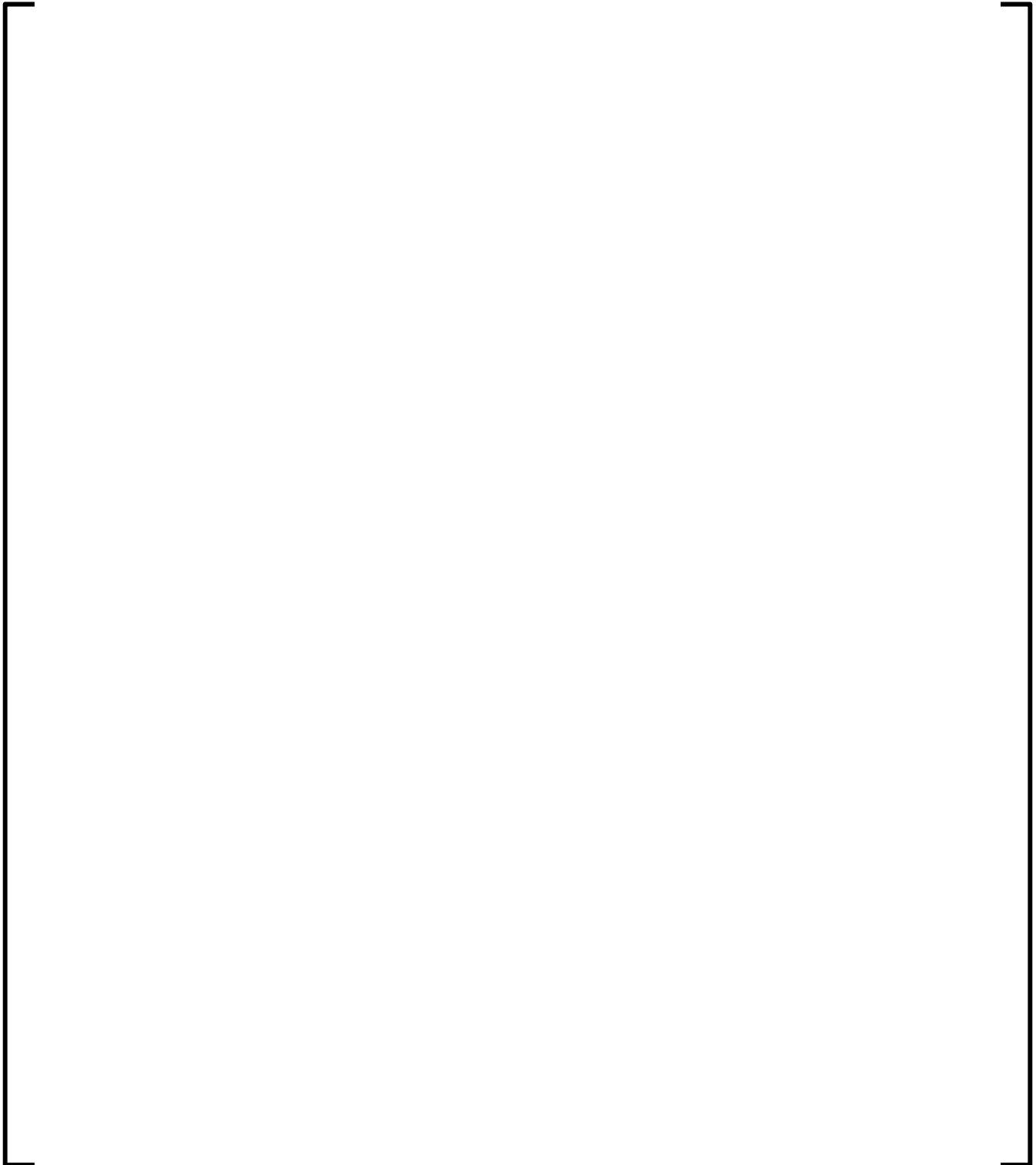
Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-19









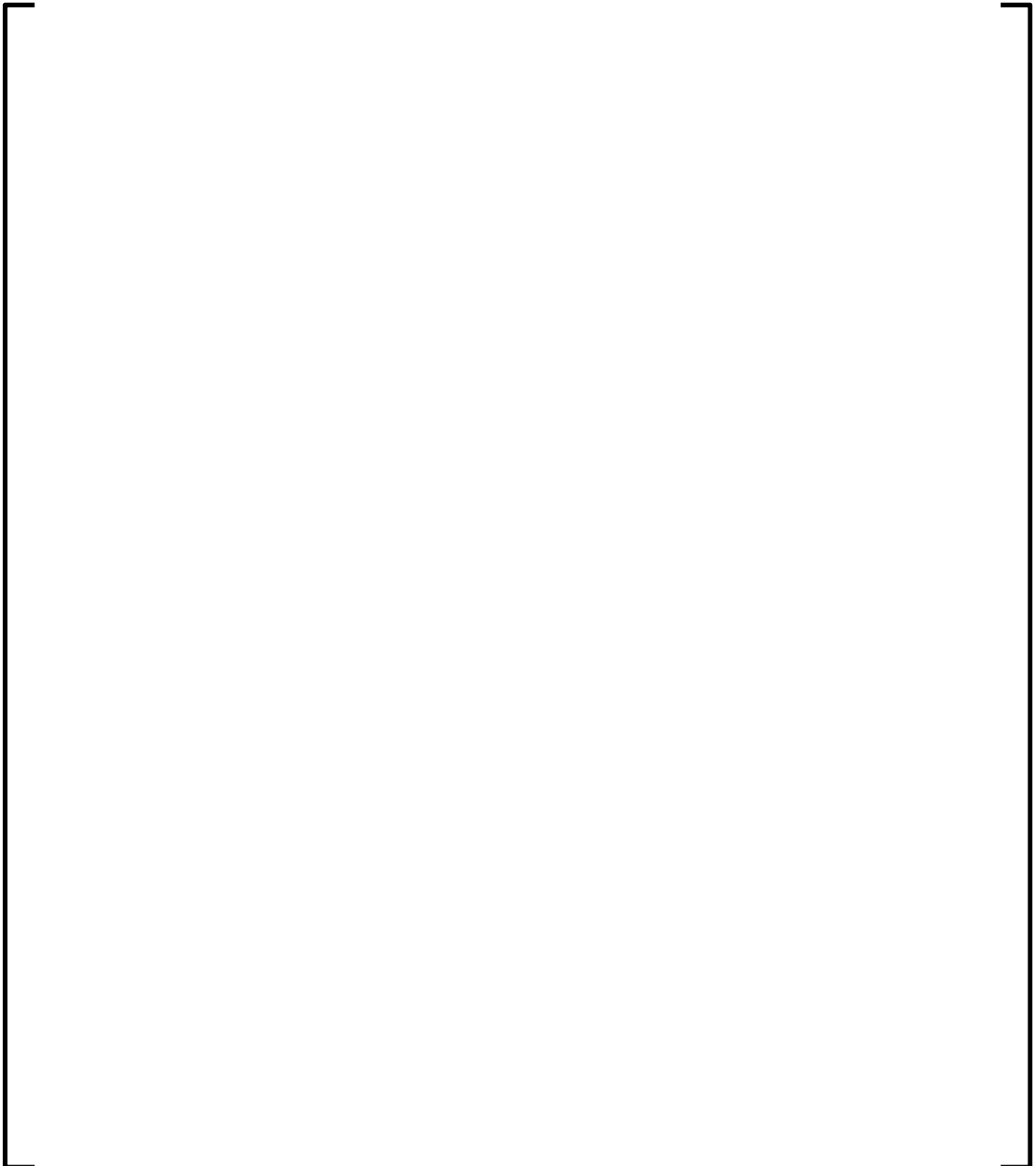
Framatome Inc.

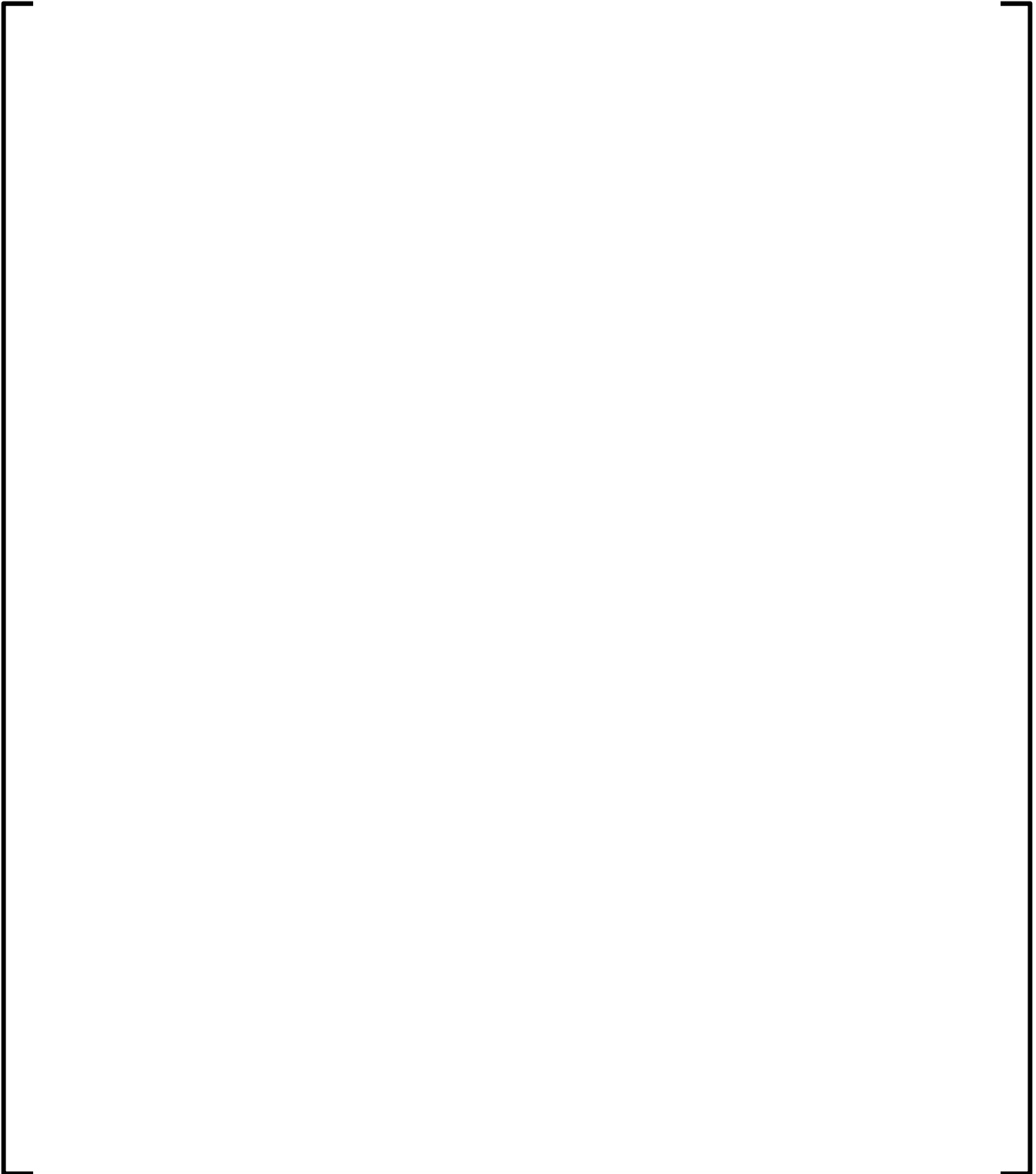
ANP-3667NP

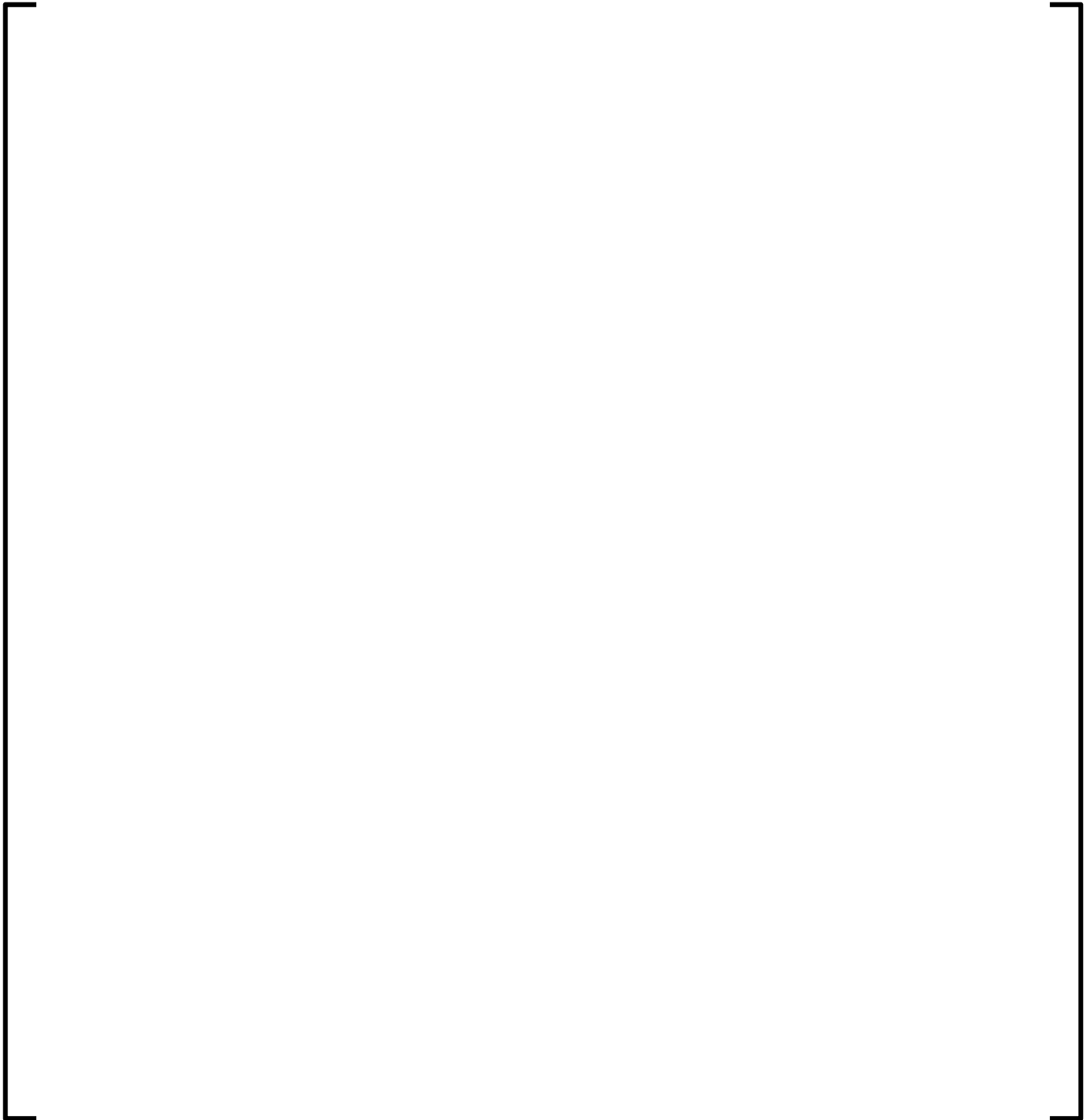
Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-23





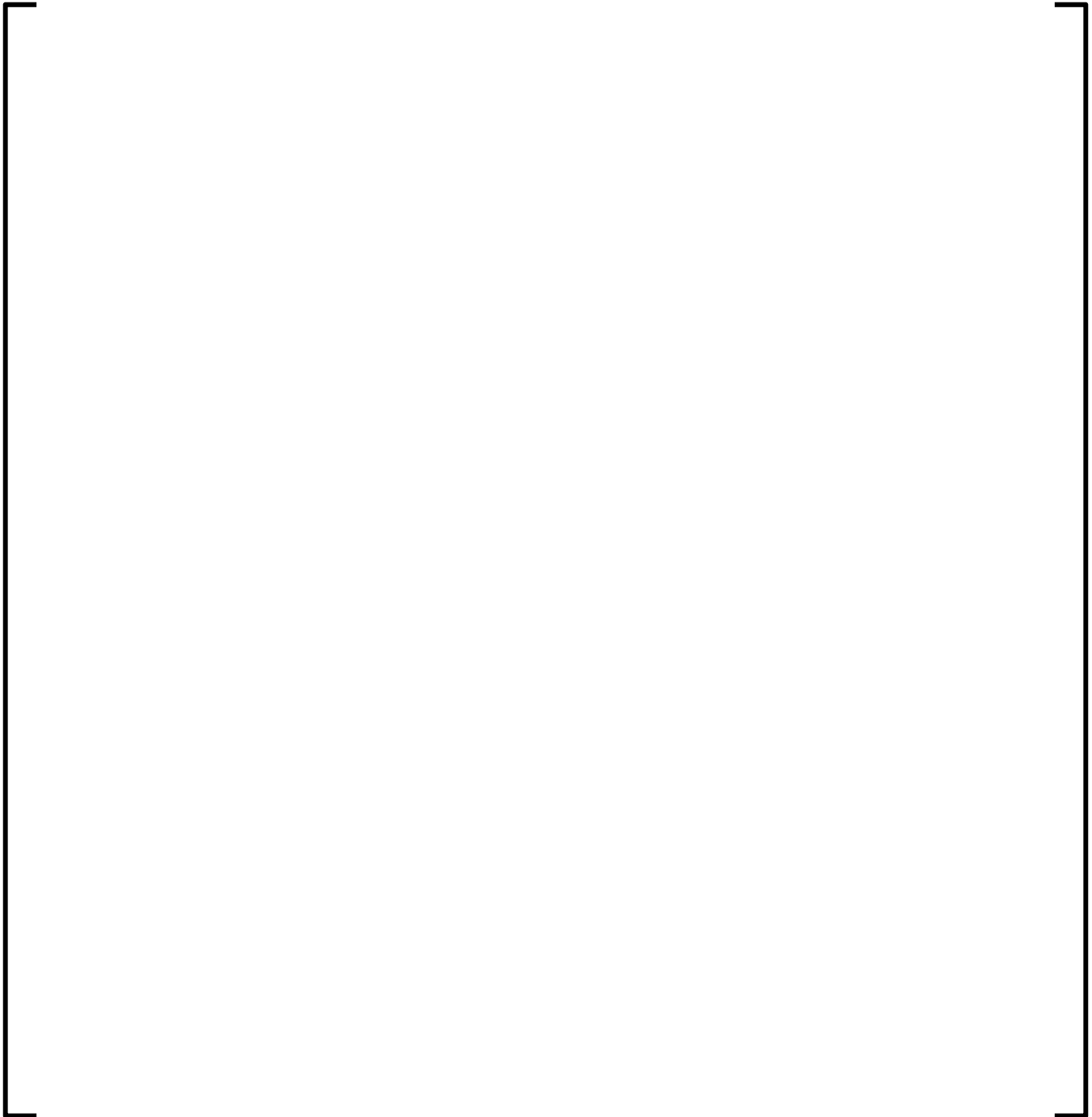


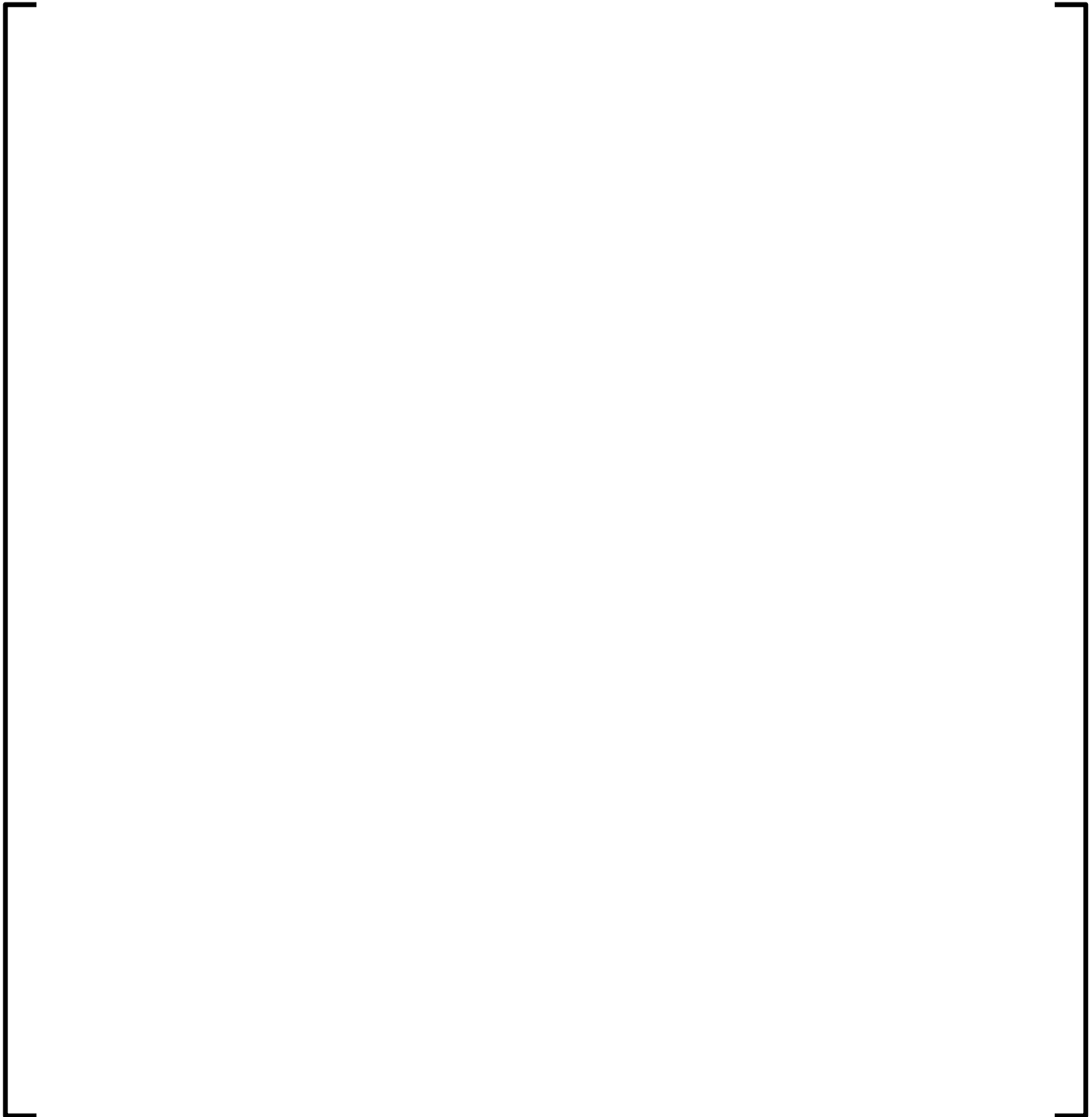
Framatome Inc.

ANP-3667NP
Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-26





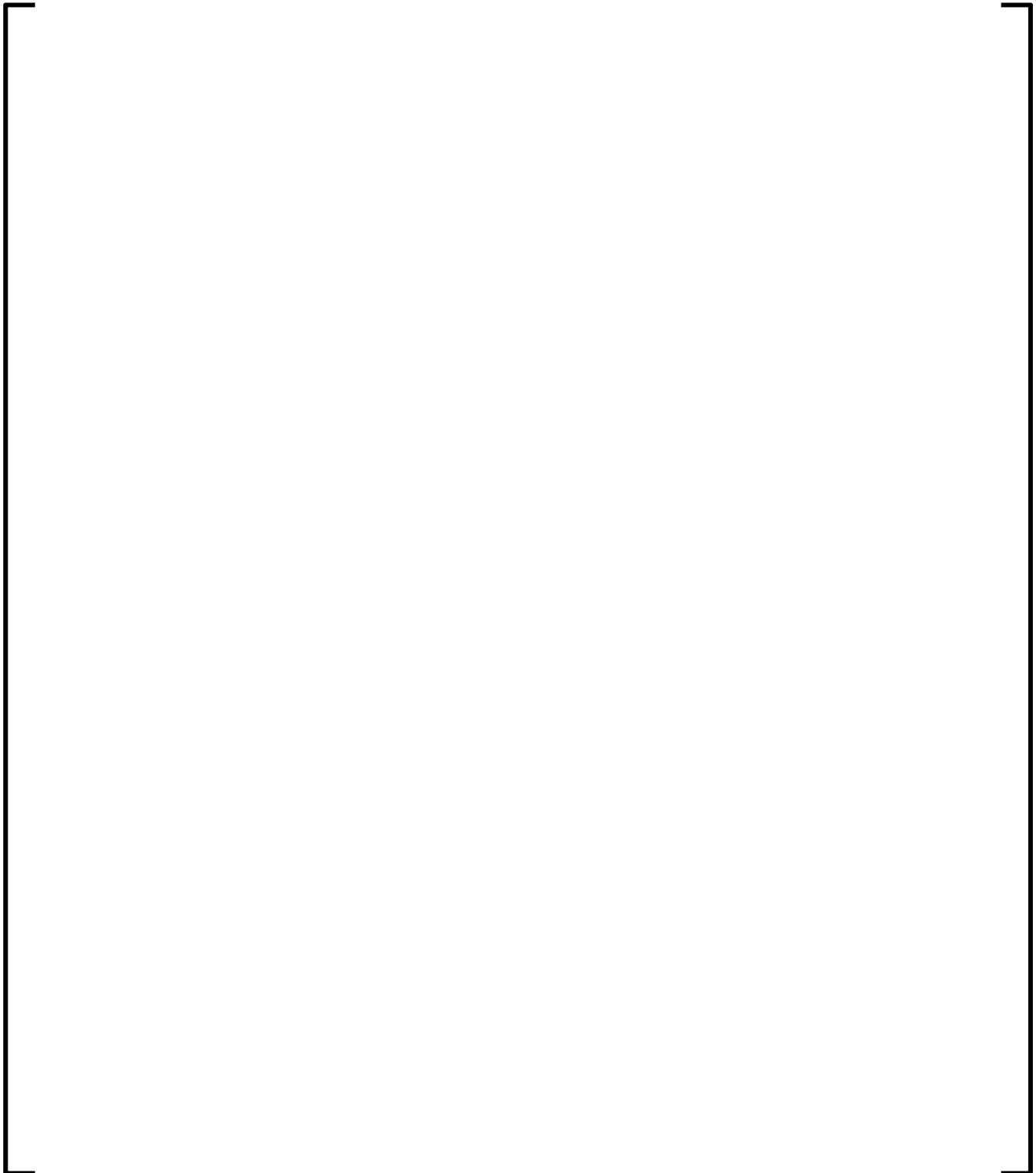
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-28



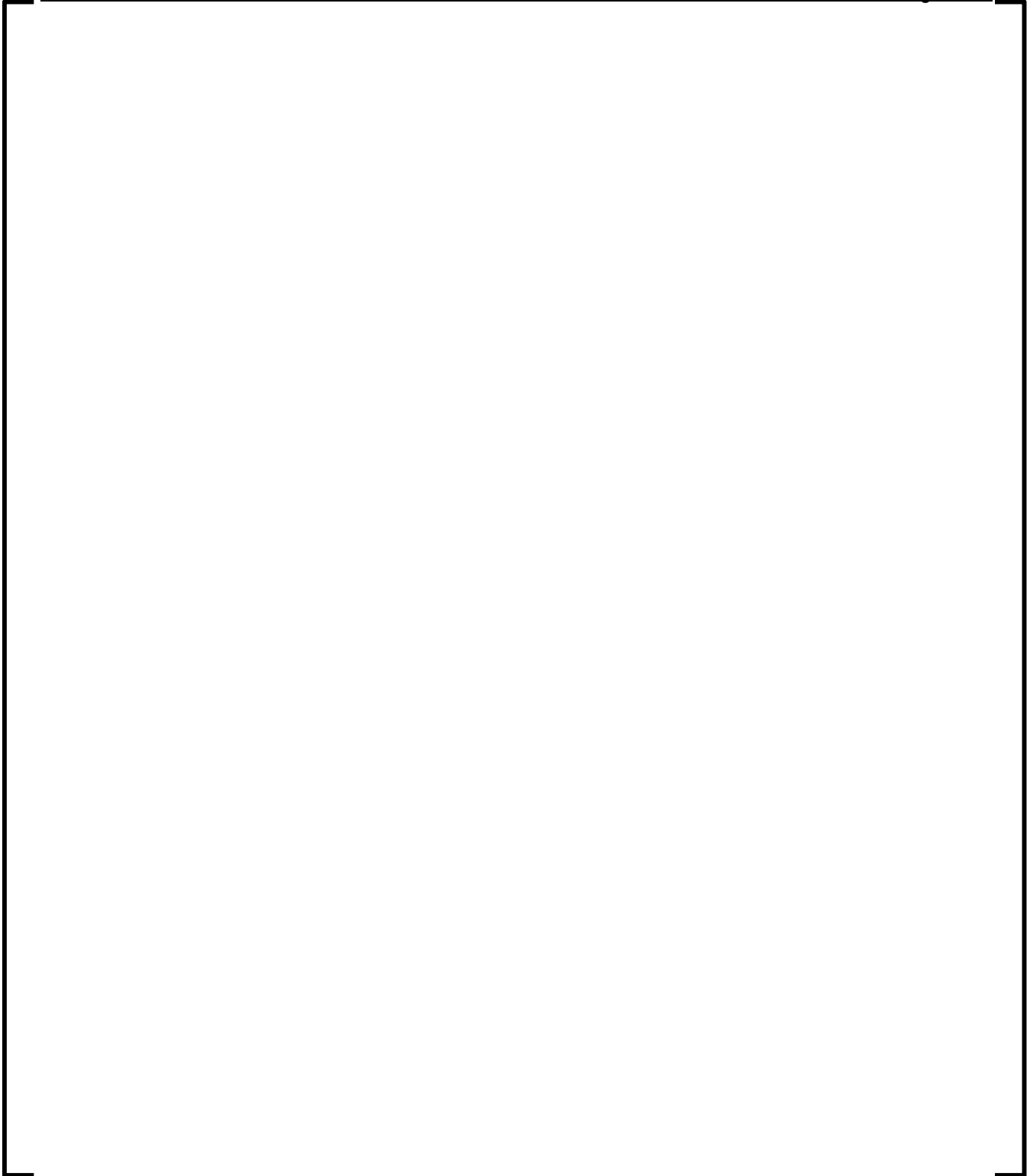
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-29



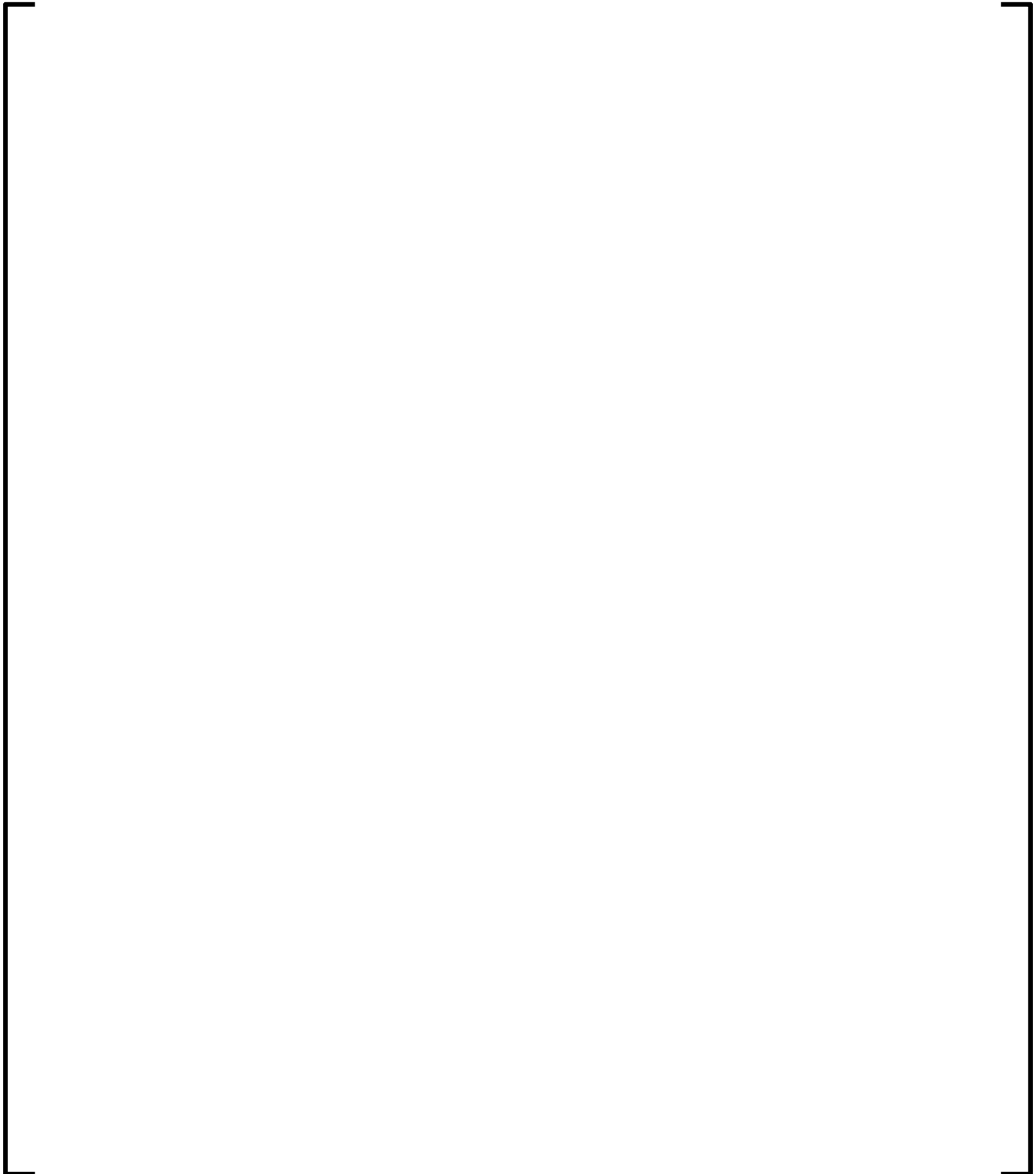
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-30

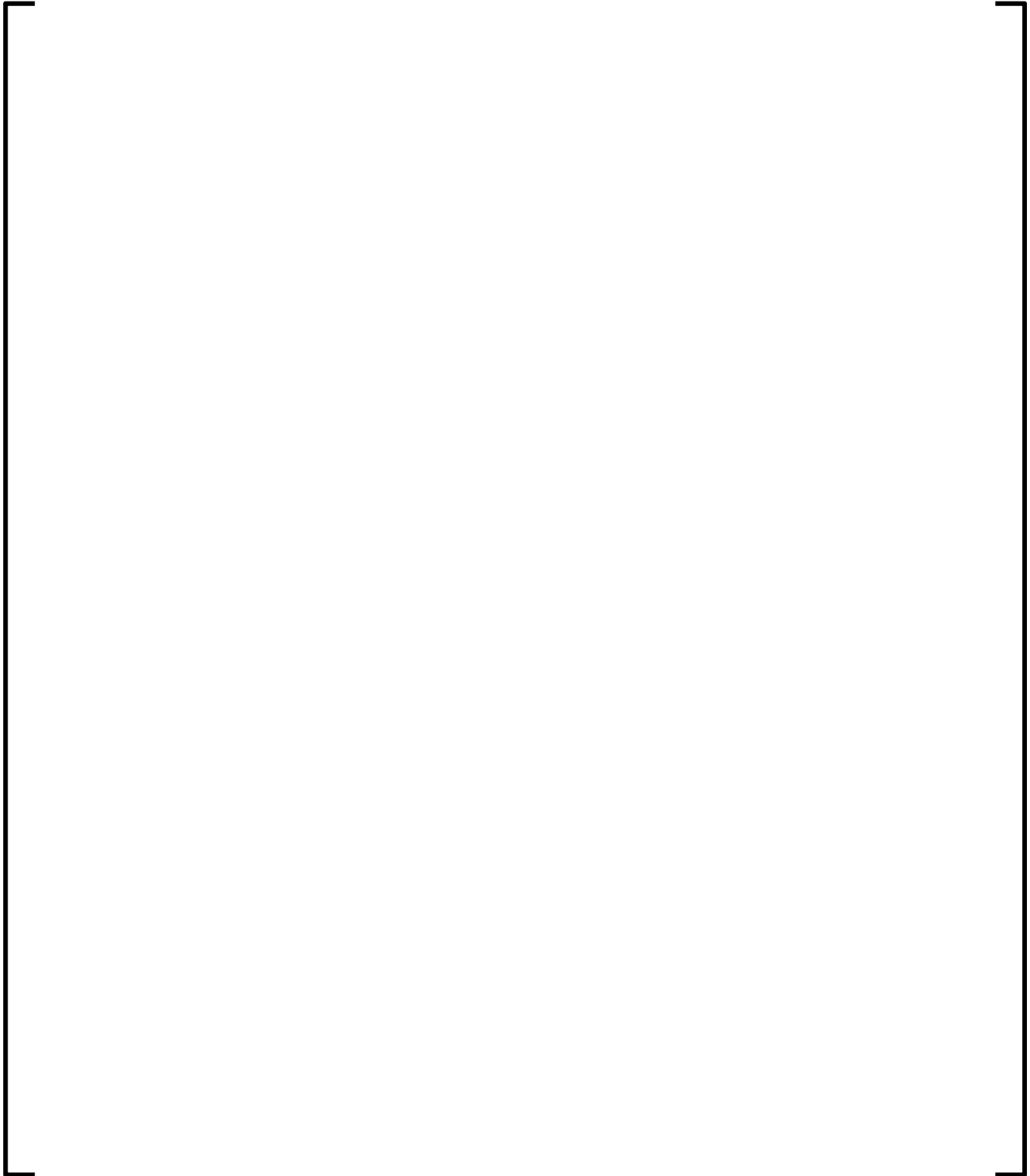


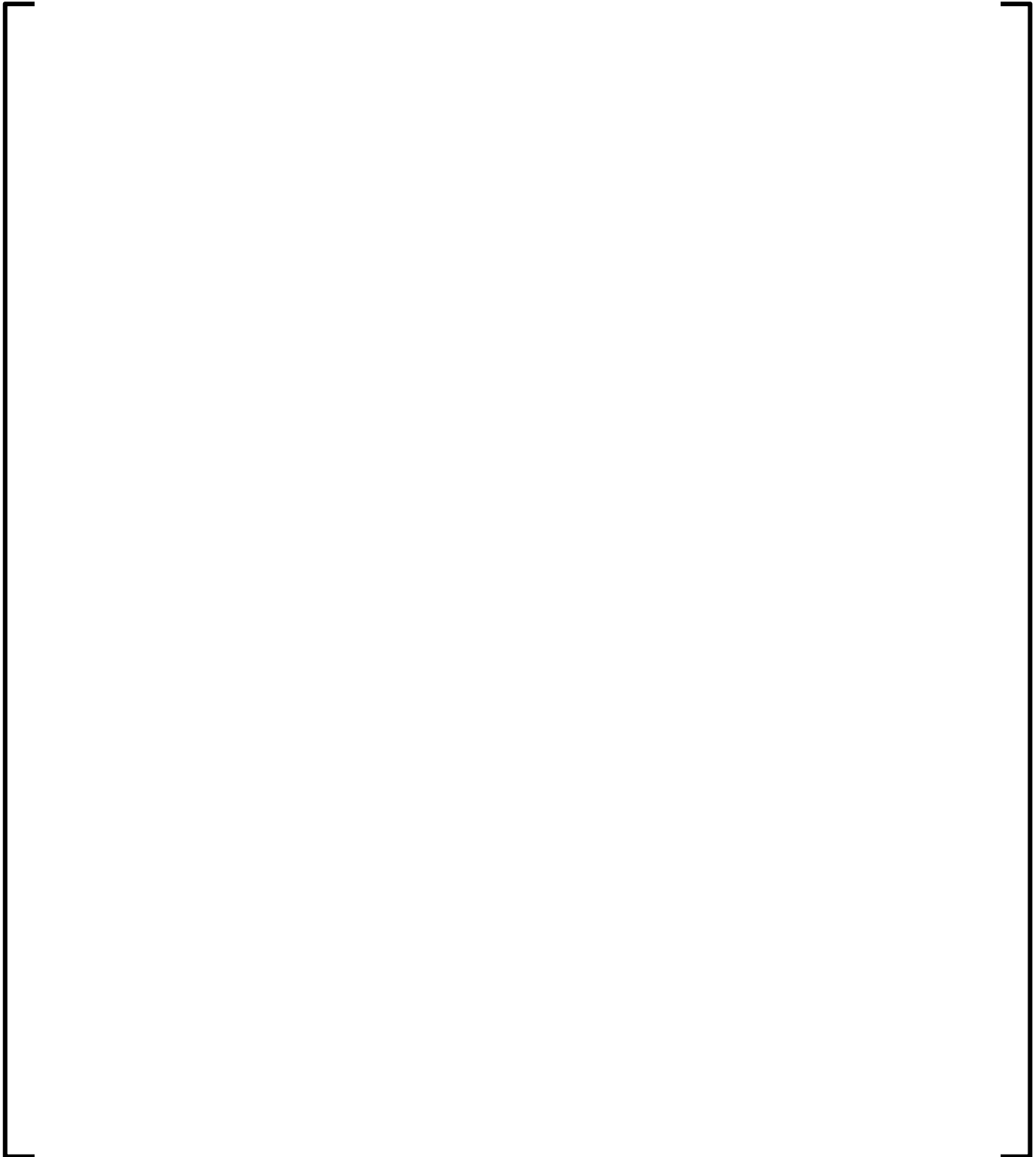
Framatome Inc.

ANP-3667NP
Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-31





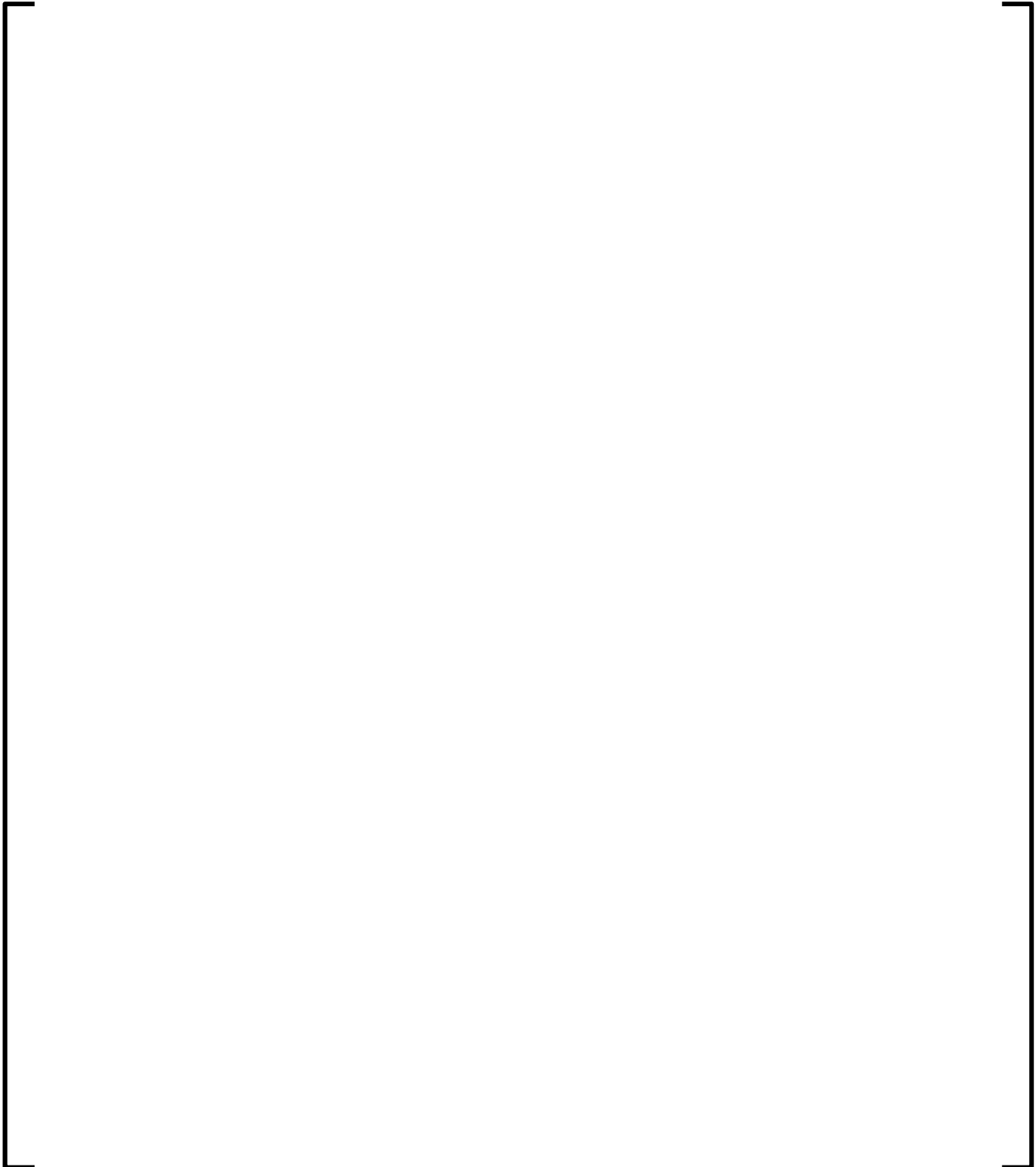
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-33



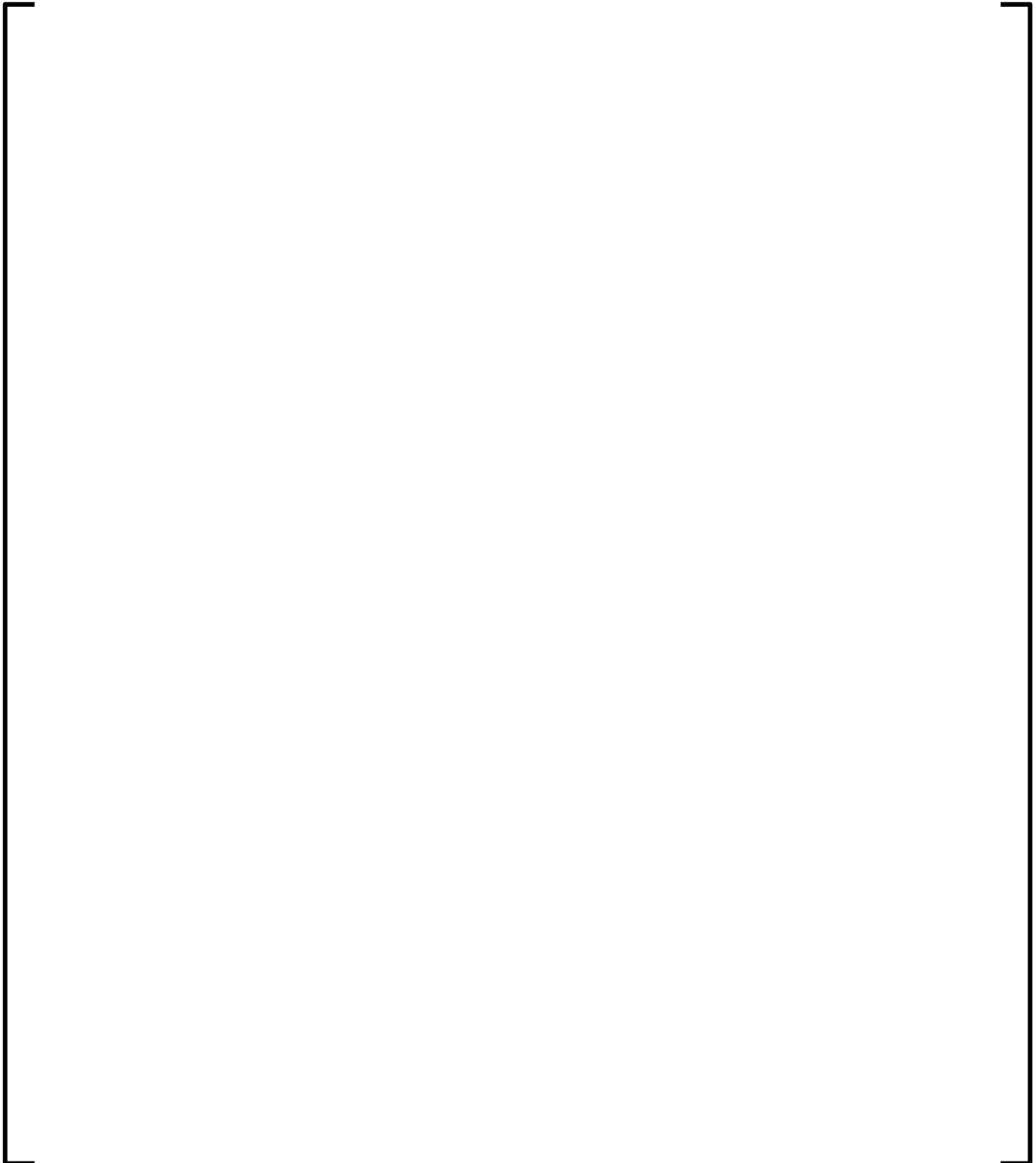
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-34



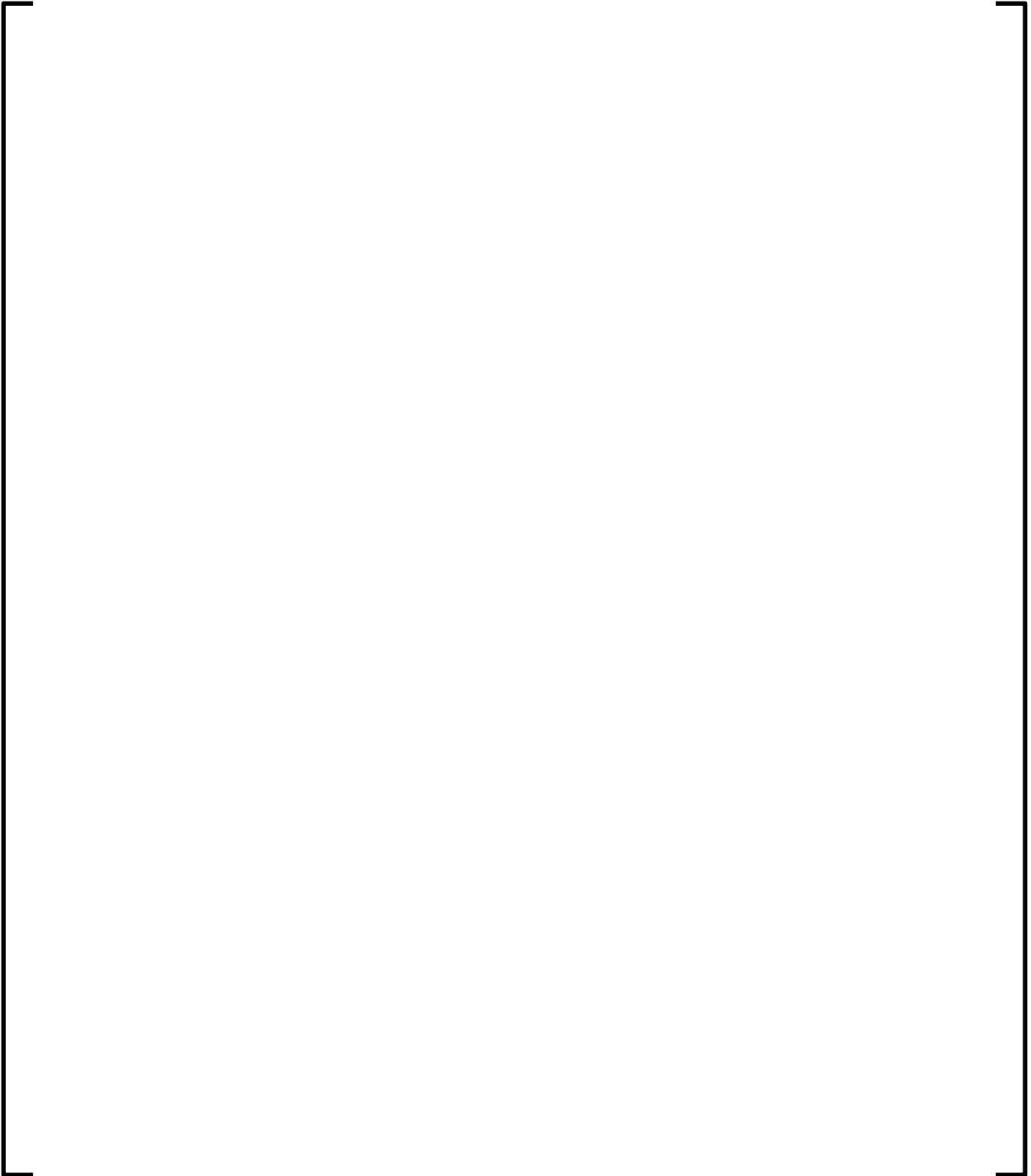
Framatome Inc.

ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-35



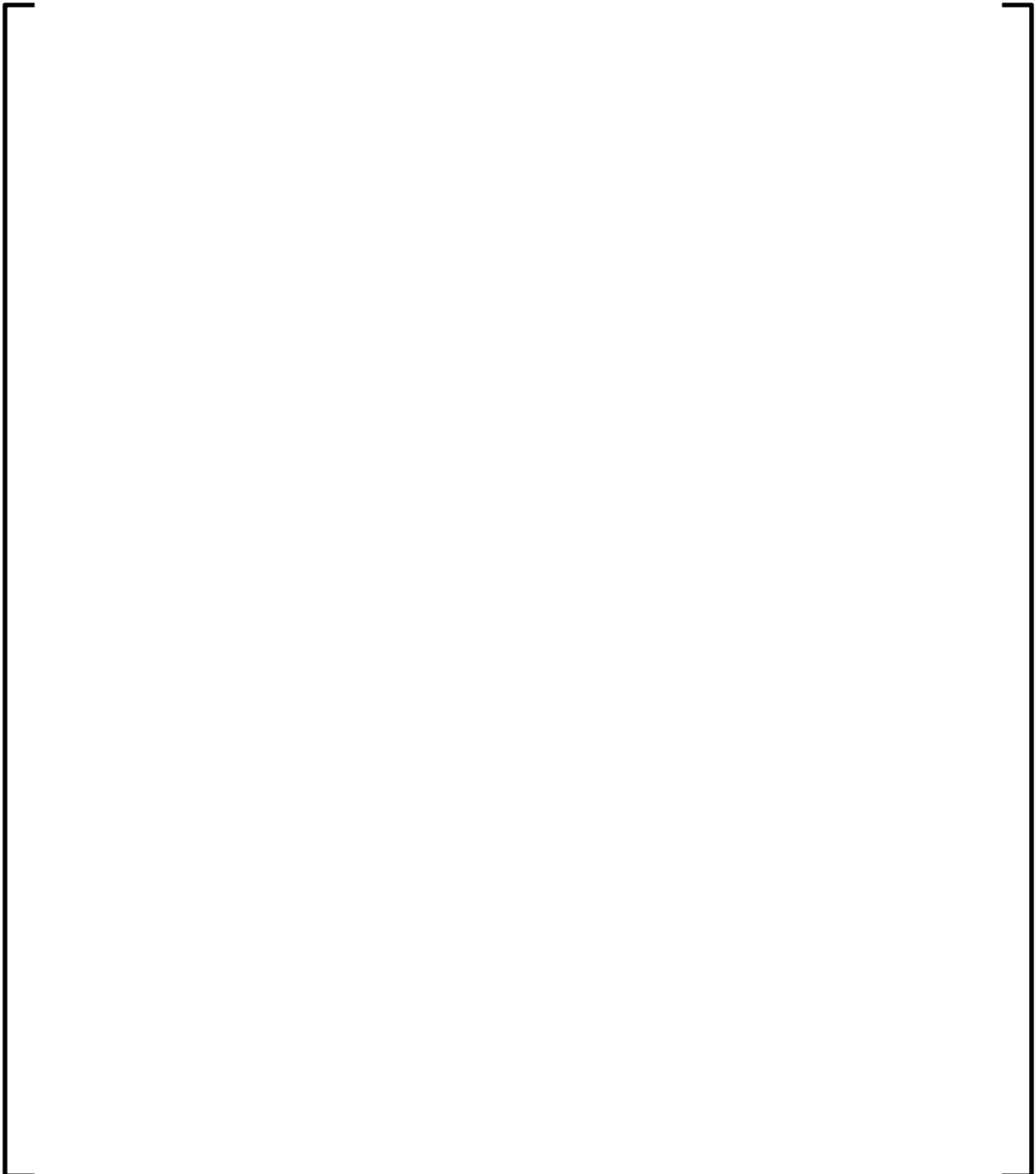
Framatome Inc.

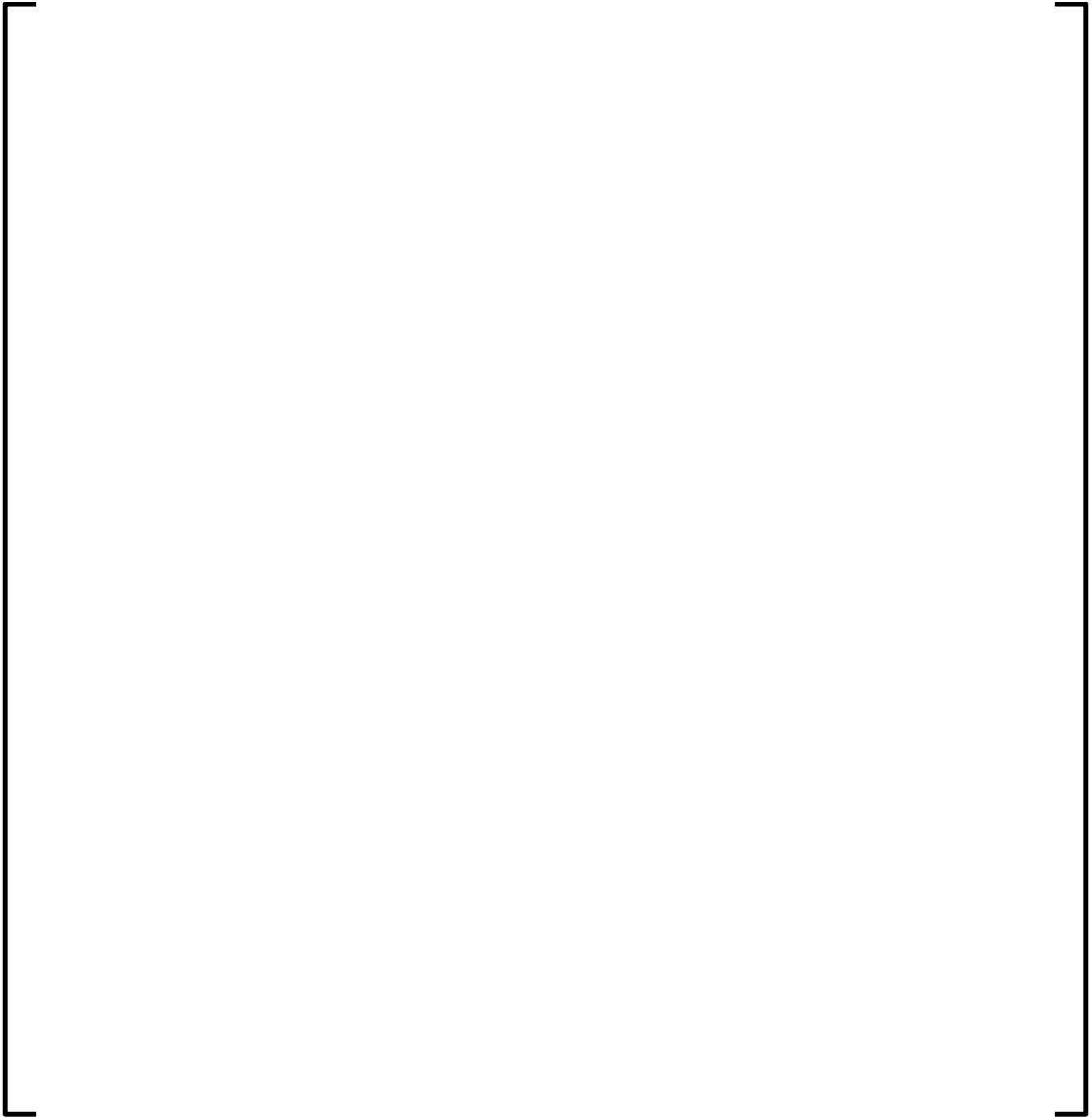
ANP-3667NP

Revision 0

Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle

Page D-36





Affidavit for ANP-3667P, Brunswick Unit 1 ATRIUM 11
Equilibrium Cycle Nuclear Fuel Design Report

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3667P, Revision 0, "Brunswick Unit 1 ATRIUM 11 Equilibrium Cycle Nuclear Fuel Design Report," dated March 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

Alan B. Muz

SUBSCRIBED before me this 14th
day of March, 2018.

Mary Anne Heilman

Mary Anne Heilman
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 6/6/2020



ANP-3702NP, Brunswick ATRIUM 11 Transient
Demonstration



Brunswick ATRIUM 11 Transient Demonstration

ANP-3702NP
Revision 0

August 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

ATRIUM is a trademark or registered trademark of Framatome (formerly known as AREVA Inc.) or its affiliates, in the USA or other countries.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

1.0	INTRODUCTION	1-1
2.0	ANTICIPATED OPERATIONAL OCCURRENCES	2-1
2.1	AURORA-B AOO Evaluation Model	2-1
2.2	Description of [] Analysis Process	2-2
2.2.1	Sampled Parameters []	2-3
2.2.2	Sampling Ranges	2-4
2.3	Application [] for Demonstration Cases	2-7
3.0	ANALYSIS OF PLANT TRANSIENTS	3-1
3.1	Transient Events	3-1
3.1.1	Load Rejection No Bypass (LRNB)	3-1
3.1.2	Turbine Trip No Bypass (TTNB)	3-2
3.1.3	Feedwater Controller Failure (FWCF)	3-3
3.1.4	ASME Overpressurization Analysis	3-4
3.1.5	ATWS Overpressurization Analysis	3-5
4.0	REFERENCES	4-1

Tables

Table 2.1	[	]	2-3
Table 2.2	Sampling Ranges for Uncertainty Parameters		2-6
Table 3.1	Base Case Transient Results		3-7
Table 3.2	Sequence of Events Timing for the LRNB Event		3-8
Table 3.3	Sequence of Events Timing for the TTNB Event		3-9
Table 3.4	Sequence of Events Timing for the FWCF Event		3-10
Table 3.5	ASME and ATWS Overpressurization Analysis Results		3-11
Table 3.6	Sequence of Events Timing for the ASME Overpressurization Event.....		3-12
Table 3.7	Sequence of Events Timing for the ATWS Overpressurization Event.....		3-13

Figures

Figure 3.1	EOFP LRNB at 100P/104.5F – NSS Key Parameters	3-14
Figure 3.2	EOFP LRNB at 100P/104.5F – NSS Sensed Water Level.....	3-15
Figure 3.3	EOFP LRNB at 100P/104.5F – NSS Vessel Pressures	3-16
Figure 3.4	EOFP TTNB at 100P/104.5F – NSS Key Parameters	3-17
Figure 3.5	EOFP TTNB at 100P/104.5F – NSS Sensed Water Level.....	3-18
Figure 3.6	EOFP TTNB at 100P/104.5F – NSS Vessel Pressures	3-19
Figure 3.7	EOFP FWCF at 100P/104.5F – NSS Key Parameters	3-20
Figure 3.8	EOFP FWCF at 100P/104.5F – NSS Sensed Water Level.....	3-21
Figure 3.9	EOFP FWCF at 100P/104.5F – NSS Vessel Pressures	3-22
Figure 3.10	MSIV Overpressurization Event at 102P/104.5F – Key Parameters	3-23
Figure 3.11	MSIV Overpressurization Event at 102P/104.5F – Sensed Water Level.....	3-24
Figure 3.12	MSIV Overpressurization Event at 102P/104.5F – Vessel Pressures.....	3-25

Figure 3.13	MSIV Overpressurization Event at 102P/104.5F – Safety/Relief Valve Flow Rates	3-26
Figure 3.14	MSIV ATWS Overpressurization Event at 100P/85F – Key Parameters	3-27
Figure 3.15	MSIV ATWS Overpressurization Event at 100P/85F – Sensed Water Level.....	3-28
Figure 3.16	MSIV ATWS Overpressurization Event at 100P/85F – Vessel Pressures.....	3-29
Figure 3.17	MSIV ATWS Overpressurization Event at 100P/85F – Safety/Relief Valve Flow Rates.....	3-30

Nomenclature

AOO	anticipated operational occurrence
ASME	American Society of Mechanical Engineers
ATWS	anticipated transient without scram
ATWS-RPT	anticipated transient without scram recirculation pump trip
BOC	beginning of cycle
BSEP	Brunswick Steam Electric Plant
BWR	boiling water reactors
EM	evaluation model
EOFP	end of full power
FoM	figure of merit
FWCF	feedwater controller failure
LAR	license amendment request
LRNB	generator load rejection no bypass
LTR	licensing topical report
MCPR	minimum critical power ratio
MDNBR	minimum departure from nucleate boiling ratio
MELLLA+	maximum extended load line limit analysis plus
MSIV	main steam isolation valve
NSS	nominal scram speed
Pbypass	power below which direct scram on TSV/TCV closure is bypassed
PLU	power load unbalance
PRFO	pressure regulator failure open
SRV	safety/relief valve
SRVOOS	safety/relief valve out-of-service
TCV	turbine control valve
TSSS	technical specification scram speed
TSV	turbine stop valve
TTNB	turbine trip no bypass
UFSAR	updated final safety analysis report
Δ MCPR	change in minimum critical power ratio

1.0 Introduction

This report summarizes the results of a subset of transient analyses performed to support the license amendment request (LAR) to include the Reference 1 and Reference 2 Licensing Topical Reports (LTR) into the Brunswick Steam Electric Plant (BSEP) Technical Specifications.

For a typical reload, a full assessment of the power/flow map, cycle exposure, and scram speed are done on a cycle specific basis for the actual core configuration to develop thermal limits. The intention of this report is to demonstrate the applicability of the AURORA-B AOO methodology (Reference 1) to Brunswick for the transient analyses that are typically limiting on a cycle-specific basis. Therefore, this document is a subset of transient analysis typically performed for each cycle.

The analyses presented in Section 3 of this document are based upon a representative equilibrium cycle of ATRIUM 11 fuel, Reference 3. A variety of power/flow state points are performed at a cycle exposure and scram speed discussed in each subsection of Section 3.

The AURORA-B AOO analysis is used to calculate the change in the minimum critical power ratio (ΔMCPR) during the anticipated operational occurrence (AOO). The ΔMCPR is combined with the safety limit MCPR to establish or confirm the plant operating limits for MCPR.

The AURORA-B AOO analysis is also used to calculate the maximum reactor vessel pressure and the maximum dome pressure during the ASME and ATWS events. The calculated maximum reactor vessel pressure is compared to the ASME acceptance criterion (110% of vessel design pressure) and the calculated maximum steam dome pressure is compared to the pressure safety limit in the plant Technical Specifications. For the ATWS event, the calculated maximum reactor vessel pressure is compared to ASME Service Level C (120% of design pressure) to demonstrate that the event acceptance criterion is met. Meeting the acceptance criteria confirms that the plant

safety valve performance (number of valves available, capacity per valve, and setpoints) is acceptable.

The ACE/ATRIUM 11 critical power correlation (Reference 2) is used to evaluate the thermal margin of the ATRIUM 11 fuel.

2.0 Anticipated Operational Occurrences

2.1 *AURORA-B AOO Evaluation Model*

AURORA-B is a comprehensive evaluation model developed for predicting the dynamic response of boiling water reactors (BWRs) during transient, postulated accident, and beyond design-basis accident scenarios. The evaluation model (EM) contains a multi-physics code system with flexibility to incorporate all the necessary elements for analysis of the full spectrum of BWR events that are postulated to affect the nuclear steam supply system of the BWR plant. Deterministic analysis principles are applied to satisfy plant operational and Technical Specification requirements through the use of conservative initial conditions and boundary conditions.

The foundation of AURORA-B AOO is built upon three computer codes, S-RELAP5, MB2-K, and RODEX4. Working together as a system, they make up the multi-physics evaluation model that provides the necessary systems, components, geometries, processes, etc. to assure adequate predictions of the relevant BWR event characteristics for its intended applications. The three codes making up the foundation of the code system are;

- S-RELAP5 – This code provides the transient thermal-hydraulic, thermal conduction, control systems, and special process capabilities (i.e. valves, jet-pumps, steam separator, critical power correlations, etc.) necessary to simulate a BWR plant.
- MB2-K – This code uses advanced nodal expansion methods to solve the three-dimensional, two-group, neutron kinetics equations. The MB2-K code is consistent with the MICROBURN-B2 steady state core simulator. MB2-K receives a significant portion of its input from the steady state core simulator.

- RODEX4 – A subset of routines from this code are used to evaluate the transient thermal-mechanical fuel rod (including fuel/clad gap) properties as a function of temperature, rod internal pressure, etc. The fuel rod properties are used by S-RELAP5 when solving the transient thermal conduction equations in lieu of standard S-RELAP5 material property tables.

2.2 *Description of [*

] Analysis Process

The AURORA-B AOO methodology (Reference 1) includes an evaluation of the impact of code uncertainties on Figures of Merit (FoM) (e.g. Δ MCPR, peak pressure) [

]

that has wide acceptance in the nuclear industry.

Table 2.1 [

]

2.2.1 Sampled Parameters [

The set of code and modeling uncertainty parameters to be sampled for AOO calculations is shown in Table 2.2.

2.2.2 Sampling Ranges

The sampling ranges shown in Table 2.2 are applicable to Brunswick Units 1 and 2. Per the approved methodology (Reference 1), the sampling ranges address uncertainties inherent in the S-RELAP5 models [

]

* Framatome Inc. formerly known as AREVA Inc.

A description of the basis for the sampling ranges used for each of the above sampled variables is found in Reference 1 Safety Evaluation, Sections 3.6.4.1 – 3.6.4.17.

Table 2.2 Sampling Ranges for Uncertainty Parameters

1

3.0 Analysis of Plant Transients

Framatome's licensing methodology is based upon core conditions established by a detailed step-through calculation. In support of demonstrating the AURORA-B AOO method to the Brunswick units, plant transients are analyzed for a small subset of power and flow conditions at a cycle exposure and scram speed discussed in each subsection. The transient analyses, presented in this section, are performed using plant parameters provided by the utility for a full core of ATRIUM 11 fuel.

The transient events chosen to demonstrate the application of the AURORA-B AOO method are generally limiting events for Brunswick as determined from previous cycle analyses and a review of Chapter 15 of the updated final safety analysis report (UFSAR).

3.1 *Transient Events*

3.1.1 Load Rejection No Bypass (LRNB)

The load rejection causes a fast closure of the turbine control valves. The resulting compression wave travels through the steam lines into the vessel and creates a rapid pressurization. The increase in pressure causes a decrease in core voids, which in turn causes a rapid increase in power. The fast closure of the turbine control valves also causes a reactor scram. Turbine bypass system operation, which also mitigates the consequences of the event, is not credited. The excursion of the core power due to the void collapse is terminated primarily by the reactor scram and revoiding of the core.

For power levels less than 50% of rated, the LRNB analyses assume that the power load unbalance (PLU) is inoperable. With the PLU inoperable, the LRNB sequence of events is different than the standard event. Instead of a fast closure, the turbine control valves (TCVs) close in servo mode and there is no direct scram on TCV closure. The power and pressure excursion continues until the high pressure scram occurs. Given

that there is no direct scram when the PLU is inoperable, the LRNB event above and below P_{bypass} at 26% power is identical.

To demonstrate the AURORA-B AOO transient methodology models the LRNB event appropriately, LRNB analyses were performed for the following range of conditions within the approved MELLLA+ power/flow map:

- 100% core power, with 104.5% and 85% core flow
- 80% core power, with 106% core flow
- 50% core power, with 110% core flow
- 26% core power, with 106% core flow

Table 3.1 presents the change in MCPR for the LRNB event. The transient analyses are performed at the end of full power (EOFP) cycle exposure, utilizing the NSS scram speeds. Table 3.2 presents the sequence of event timing for the LRNB event at 100% power with 104.5% core flow. Figures 3.1 – 3.3 show the responses of various reactor and plant parameters during the limiting LRNB event initiated at 100% of rated power and 104.5% of rated core flow with NSS insertion times.

3.1.2 Turbine Trip No Bypass (TTNB)

The turbine trip causes a closure of the turbine stop valves. The resulting compression wave travels through the steam lines into the vessel and creates a rapid pressurization. The increase in pressure causes a decrease in core voids, which in turn causes a rapid increase in power. The closure of the turbine stop valves also causes a reactor scram. Turbine bypass system operation, which also mitigates the consequences of the event, is not credited. The excursion of the core power due to the void collapse is terminated primarily by the reactor scram and revoiding of the core.

To demonstrate the AURORA-B AOO transient methodology models the TTNB event appropriately, TTNB analyses were performed for the following range of conditions within the approved MELLLA+ power/flow map:

- 100% core power, with 104.5% and 85% core flow
- 80% core power, with 106% core flow
- 26% core power, with 106% core flow (direct scram)
- 26% core power, with 106% core flow (non-direct scram)

Table 3.1 presents the change in MCPR for the TTNB event. The transient analyses are performed at the EOF cycle exposure, utilizing the NSS scram speeds. Table 3.3 presents the sequence of event timing for the TTNB event at 100% power with 104.5% core flow. Figures 3.4 – 3.6 show the responses of various reactor and plant parameters during the limiting TTNB event initiated at 100% of rated power and 104.5% of rated core flow with NSS insertion times.

3.1.3 Feedwater Controller Failure (FWCF)

The increase in feedwater flow due to a failure of the feedwater control system to maximum demand results in an increase in the water level and a decrease in the coolant temperature at the core inlet. The increase in core inlet subcooling causes an increase in core power. As the feedwater flow continues at maximum demand, the water level continues to rise and eventually reaches the high water level trip setpoint. The initial water level is conservatively assumed to be at the low-level normal operating range to delay the high-level trip and maximize the core inlet subcooling that results from the FWCF. The high water level trip causes the turbine stop valves to close in order to prevent damage to the turbine from excessive liquid inventory in the steam line. The valve closures create a compression wave that travels to the core causing a void collapse and subsequent rapid power excursion. The closure of the turbine stop valves also initiates a reactor scram. Three of the four installed turbine bypass valves are assumed operable and provide pressure relief. The core power excursion is mitigated in part by the pressure relief, but the primary mechanism for termination of the event is reactor scram.

To demonstrate the AURORA-B AOO transient methodology models the FWCF event appropriately, FWCF analyses were performed for the following range of conditions within the approved MELLLA+ power/flow map:

- 100% core power, with 104.5% and 85% core flow
- 80% core power, with 106% and 55% core flow
- 26% core power, with 106% core flow (direct scram)
- 26% core power, with 106% core flow (non-direct scram)

Table 3.1 presents the change in MCPR for the FWCF event. The transient analyses are performed at the EOFP cycle exposure, utilizing the NSS scram speeds. Table 3.4 presents the sequence of event timing for the FWCF event at 100% power with 104.5% core flow. Figures 3.7 – 3.9 show the responses of various reactor and plant parameters during the limiting FWCF event initiated at 100% of rated power and 104.5% of rated core flow with NSS insertion times.

3.1.4 ASME Overpressurization Analysis

This section describes the maximum overpressurization analyses performed to demonstrate compliance with the ASME Boiler and Pressure Vessel Code. The analysis shows that the safety/relief valves at Brunswick have sufficient capacity and performance to prevent the reactor vessel pressure from reaching the safety limit of 110% of the design pressure.

To demonstrate the applicability of the AURORA-B AOO (Reference 1) methodology for ASME overpressurization analyses, an MSIV closure analysis was performed for 102% power and 104.5% flow and 102% power and 85% flow at the latest exposure in the cycle design. The main steam isolation valve (MSIV) closure event is similar to the other steam line valve closure events in that the valve closure results in a rapid pressurization of the core. The increase in pressure causes a decrease in void which in turn causes a rapid increase in power. The turbine bypass valves do not impact the

system response and are not modeled in the analysis. The following assumptions were made in the analysis:

- The most critical active component (direct scram on valve position) was assumed to fail. However, scram on high neutron flux and high dome pressure is available.
- The plant configuration analyzed assumed that one of the lowest setpoint safety/relief valves (SRVs) was inoperable.
- TSSS insertion times were used.
- The initial dome pressure was set at the maximum allowed by the Technical Specifications, 1059.7 psia (1045 psig).
- A fast MSIV closure time of 2.7 seconds was used.
- The SRV opening setpoints used in the analysis were increased above the 3% identified in the plant Technical Specifications. The SRV degradation scheme is based on actual plant performance using a 95/95 statistical approach. The SRVs are banked in the following manner, 1 valve assumed out-of-service, 3 valves with a 4% drift, 2 valves with a 6% drift, and 1 valve with an 8% drift.

Results of the MSIV closure overpressurization analysis are presented in Table 3.5. Table 3.6 presents the sequence of event timing for the ASME event at 102% power with 104.5% core flow. Figures 3.10 – 3.13 show the response of various reactor plant parameters during the MSIV closure event. The maximum pressure of 1338 psig occurs in the lower plenum. The maximum dome pressure for the same event is 1304 psig. The results demonstrate that the maximum vessel pressure limit of 1375 psig and dome pressure limit of 1325 psig are not exceeded.

3.1.5 ATWS Overpressurization Analysis

This section describes the analyses performed to demonstrate that the peak vessel pressure for the limiting ATWS event is less than the ASME Service Level C limit of 120% of the design pressure (1500 psig). To demonstrate the applicability of the AURORA-B AOO (Reference 1) methodology for ATWS overpressurization analyses, the ATWS event analyses were performed at 100% power at 85% and 104.5% flow at the beginning of cycle (BOC) exposure based on historically limiting analyses. The MSIV closure and pressure regulator failure open (PRFO) events were evaluated.

Failure of the pressure regulator in the open position causes the turbine control and turbine bypass valves to open such that steam flow increases until the maximum combined steam flow limit is attained. The system pressure decreases until the low pressure setpoint is reached, resulting in the closure of the MSIVs. The resulting pressurization wave causes a decrease in core voids and an increase in core pressure thereby increasing the core power.

The following assumptions were made in the analyses:

- The analytical limit ATWS-RPT setpoint and function were assumed.
- To support operation with one SRVOOS, the plant configuration analyzed assumed that one of the lowest setpoint SRVs was inoperable.
- All scram functions were disabled.
- The initial dome pressure was set to the nominal pressure with a -10 psi uncertainty (1035 psia).
- The MSIV closure is based on a nominal closure time of 4.0 seconds for both events.
- The SRV opening setpoints used in the analysis were increased above the 3% identified in the plant Technical Specifications. The SRV degradation scheme is based on actual plant performance using a 95/95 statistical approach. The SRVs are banked in the following manner, 1 valve assumed out-of-service, 3 valves with a 4% drift, 2 valves with a 6% drift, and 1 valve with an 8% drift.

Results of the ATWS overpressurization analyses are presented in Table 3.5. Table 3.7 presents the sequence of event timing for the ATWS MSIV closure event at 100% power with 85% core flow. Figures 3.14 – 3.17 show the response of various reactor plant parameters during the ATWS MSIV closure event, the event which results in the maximum vessel pressure. The maximum lower plenum pressure is 1451 psig and the maximum dome pressure is 1434 psig. The results demonstrate that the ATWS maximum vessel pressure limit of 1500 psig is not exceeded.

Table 3.1 Base Case Transient Results

State Point Power / Flow (% of rated)	ATRIUM 11 ΔMCPR
Load Rejection No Bypass	
100 / 104.5	[]
100 / 85	[]
80 / 106	[]
50 / 110	[]
26 / 106	[]
Turbine Trip No Bypass	
100 / 104.5	[]
100 / 85	[]
80 / 106	[]
26 / 106	[]
26 / 106 below Pbypass	[]
Feedwater Controller Failure	
100 / 104.5	[]
100 / 85	[]
80 / 106	[]
80 / 55	[]
26 / 106	[]
26 / 106 below Pbypass	[]

Table 3.2 Sequence of Events Timing for the LRNB Event

Event	Time (sec)
TCV Closure Event	0.000
TCV Fast Closure Scram Signal	0.090
Reactor Scram	0.090
Recirculation Pump Runback on Scram	0.095
Time of TCV Full Closure	0.135
Peak Power	0.720
Peak Heat Flux	0.835
Time of MDNBR	0.880
SRV Actuation	1.665
Peak Dome Pressure (1242.48 psia)	1.855
Peak Vessel Pressure (1279.59 psia)	1.870
Peak Steam Line Pressure (1253.42 psia)	2.247

Table 3.3 Sequence of Events Timing for the TTNB Event

Event	Time (sec)
TSV Closure Event	0.000
TSV Fast Closure Scram Signal	0.080
Reactor Scram	0.080
Recirculation Pump Runback on Scram	0.085
Time of TSV Full Closure	0.100
Peak Power	0.725
Peak Heat Flux	0.835
Time of MDNBR	0.880
SRV Actuation	1.675
Peak Dome Pressure (1241.95 psia)	1.860
Peak Vessel Pressure (1278.91 psia)	1.870
Peak Steam Line Pressure (1252.52 psia)	2.247

Table 3.4 Sequence of Events Timing for the FWCF Event

Event	Time (sec)
FWCF Event Initiator	0.000
Level 8 – High Water Level – Trip	15.895
Level 8 – TSV Closure Signal	16.665
TSV Motion Scram Signal	16.745
Reactor Scram	16.745
Recirculation Pump Runback	16.750
Turbine Bypass Valves Open	16.770
Peak Power	17.370
Peak Heat Flux	17.485
Time of MDNBR	17.550
SRV Actuation	18.510
Peak Vessel Pressure (1250.24 psia)	18.695
Peak Dome Pressure (1215.57 psia)	18.725
Peak Steam Line Pressure (1222.89 psia)	18.867

Table 3.5 ASME and ATWS Overpressurization Analysis Results

Event	Maximum Vessel Pressure Lower Plenum (psig)	Maximum Dome Pressure (psig)
ASME Overpressurization		
MSIV closure (102P/104.5F)	1338	1304
MSIV closure (102P/85F)	1330	1303
ATWS Overpressurization		
MSIV closure (100P/104.5F)	1409	1390
MSIV closure (100P/85F)	1451	1434

**Table 3.6 Sequence of Events Timing for the ASME
Overpressurization Event**

Event	Time (sec)
MSIV Closure Event Initiator (2.7 sec full closure time)	0.000
High Neutron Flux Setpoint	2.055
Reactor Scram	2.150
Recirculation Pump Runback	2.155
Peak Power	2.900
SRV Actuation	3.285
Peak Heat Flux	3.565
Peak Vessel Pressure (1352.39 psia)	4.535
Peak Steam Line Pressure (1317.12 psia)	4.600
Peak Dome Pressure (1318.23 psia)	4.625

**Table 3.7 Sequence of Events Timing for the ATWS
Overpressurization Event**

Event	Time (sec)
MSIV Closure Event Initiator (4.0 sec full closure time)	0.000
Recirculation Pump Trip Setpoint – High Pressure	4.135
Peak Power	4.205
Recirculation Pump Trip – High Pressure	4.440
SRV Actuation	4.525
Peak Heat Flux	4.820
Peak Vessel Pressure (1465.53 psia)	11.190
Peak Dome Pressure (1448.30 psia)	11.365
Peak Steam Line Pressure (1446.96 psia)	11.385

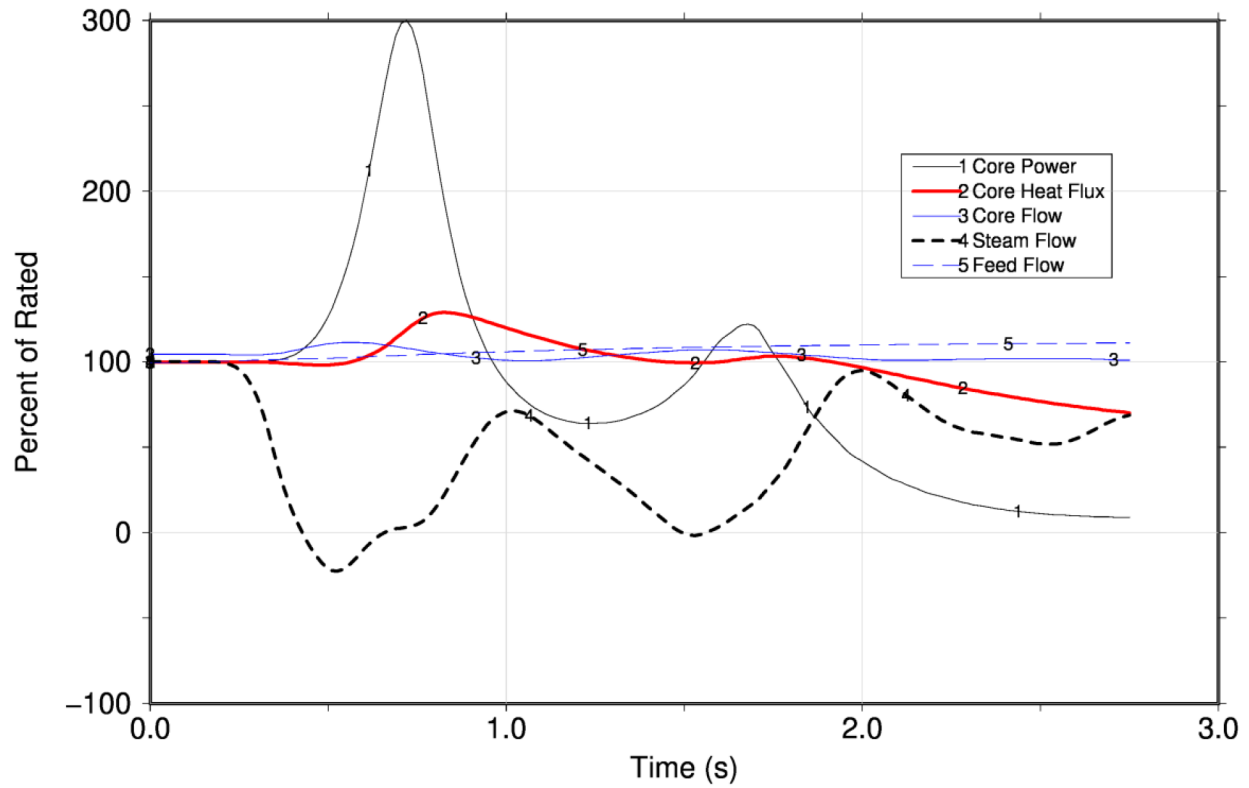


**Figure 3.1 EOFP LRNB at 100P/104.5F – NSS
Key Parameters**

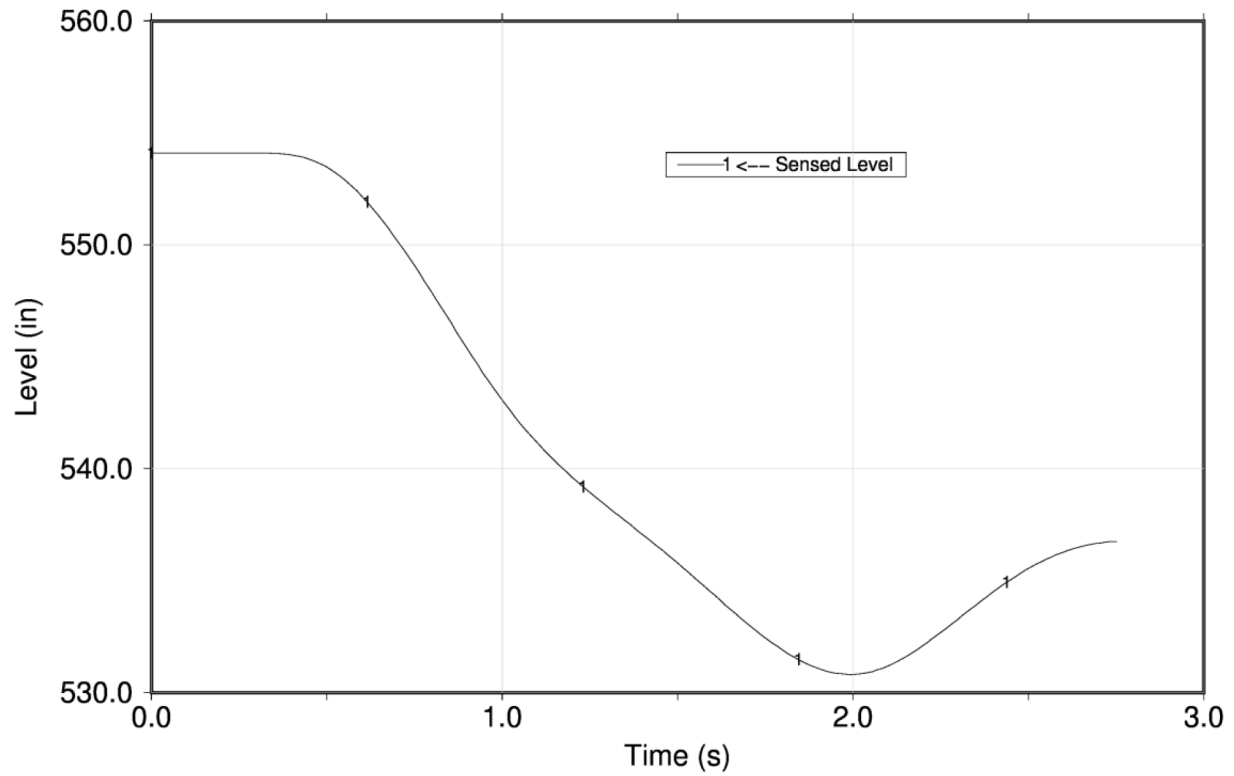


**Figure 3.2 EOFP LRNB at 100P/104.5F – NSS
Sensed Water Level**

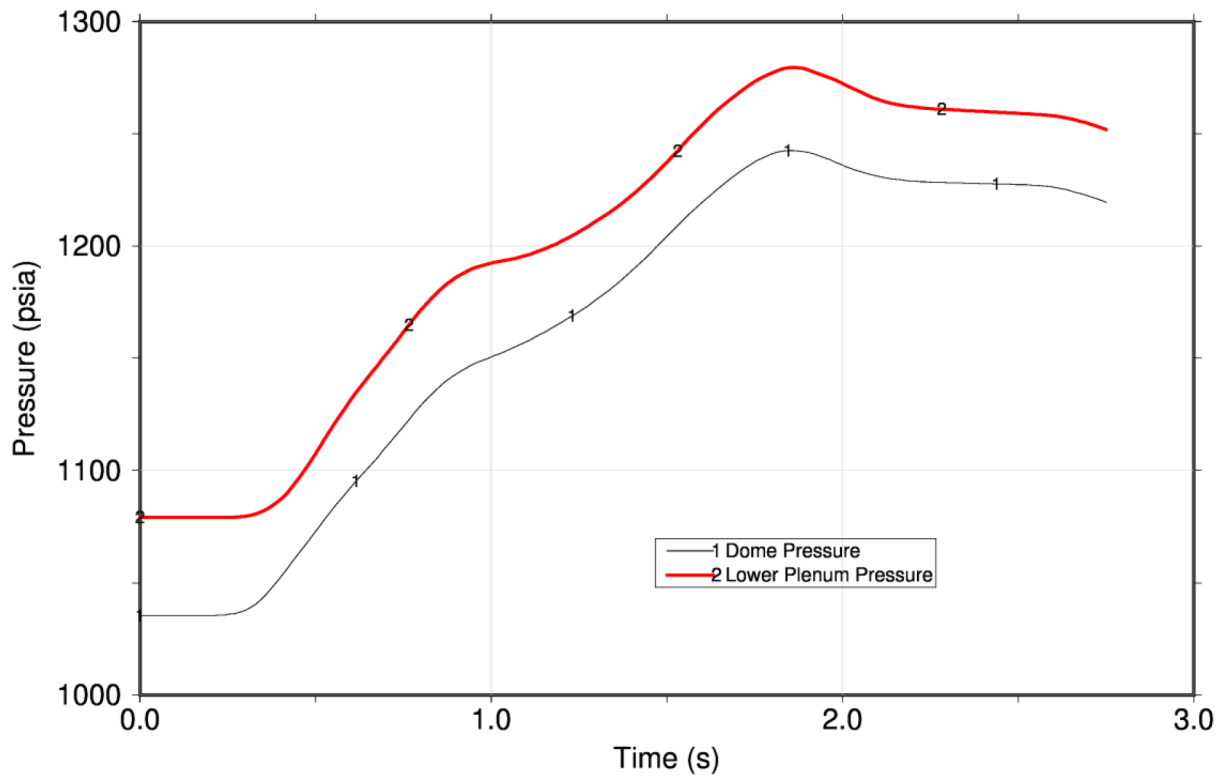


**Figure 3.3 EOFP LRNB at 100P/104.5F – NSS
Vessel Pressures**

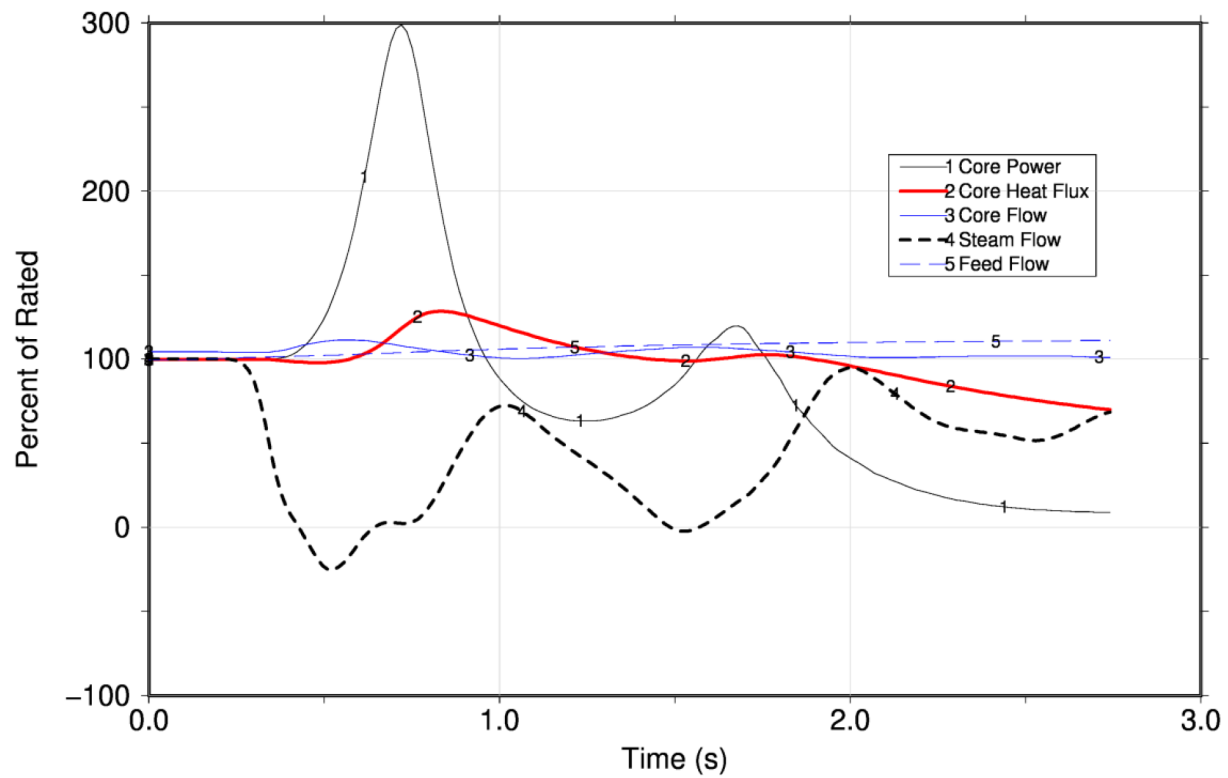


**Figure 3.4 EOFP TTNB at 100P/104.5F – NSS
Key Parameters**

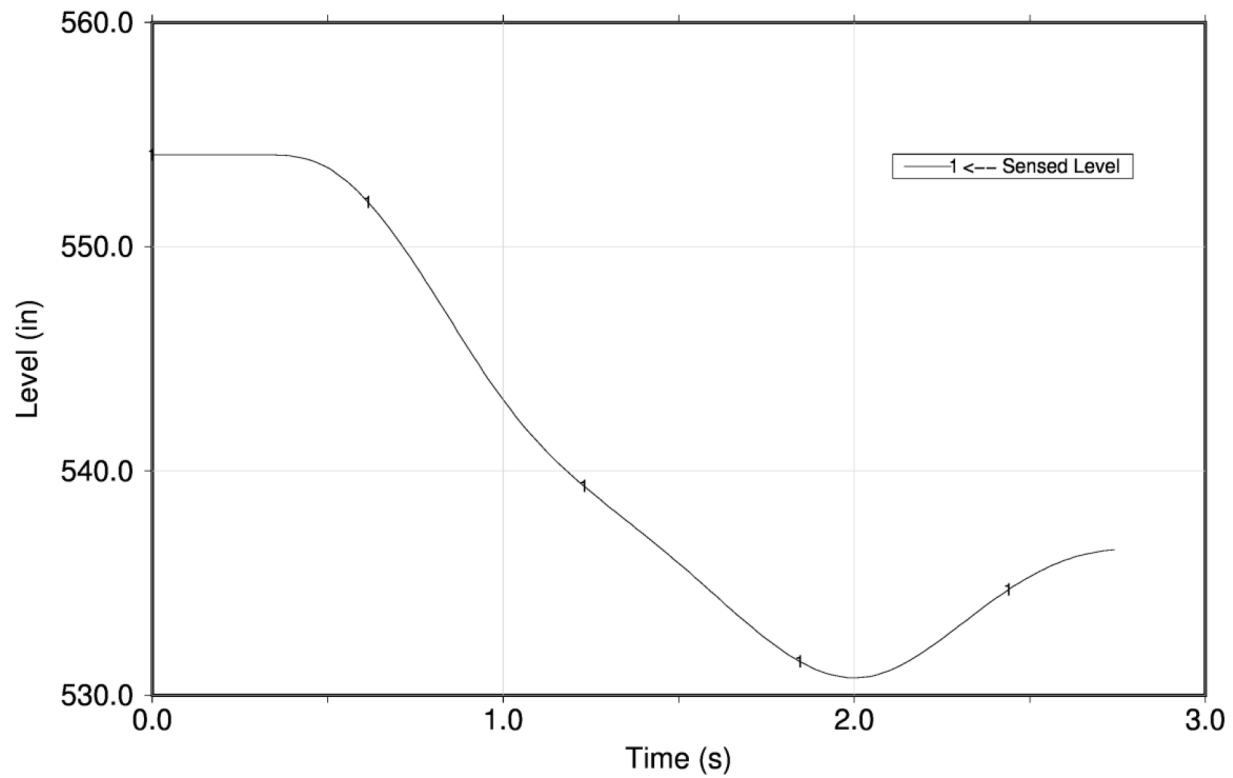


**Figure 3.5 EOFP TTNB at 100P/104.5F – NSS
Sensed Water Level**

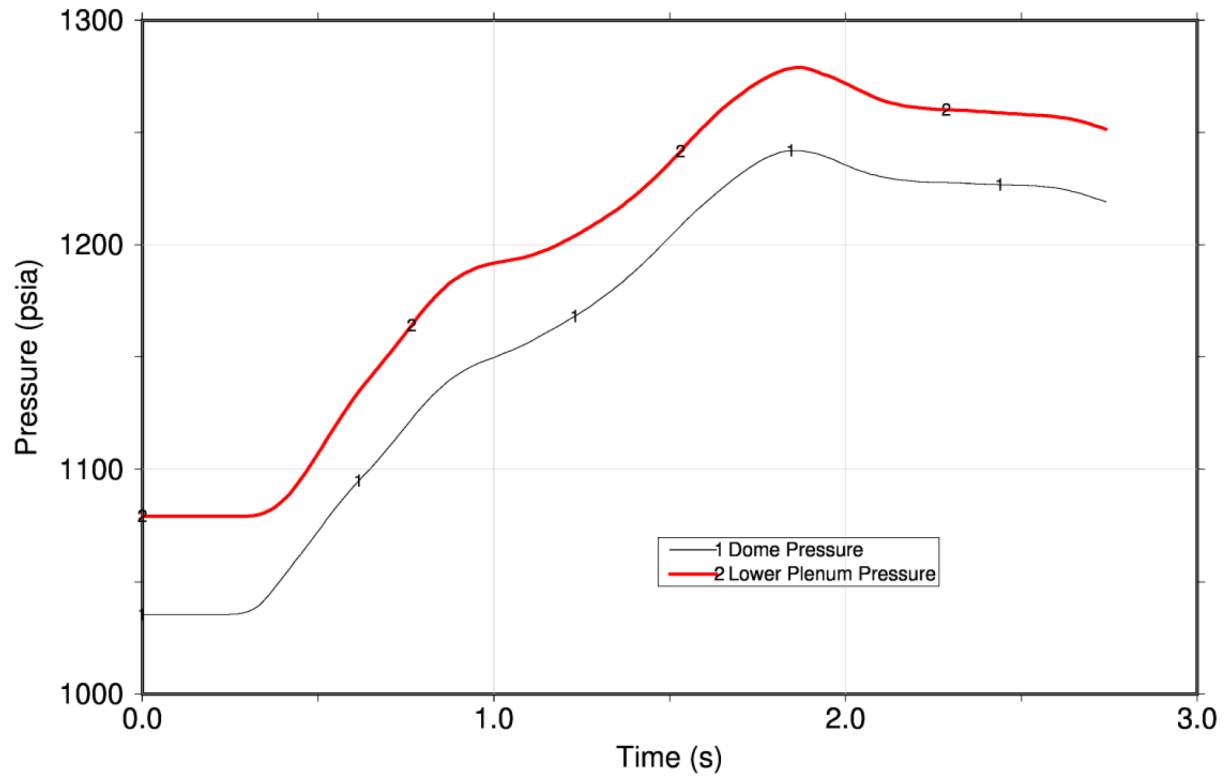


**Figure 3.6 EOFP TTNB at 100P/104.5F – NSS
Vessel Pressures**

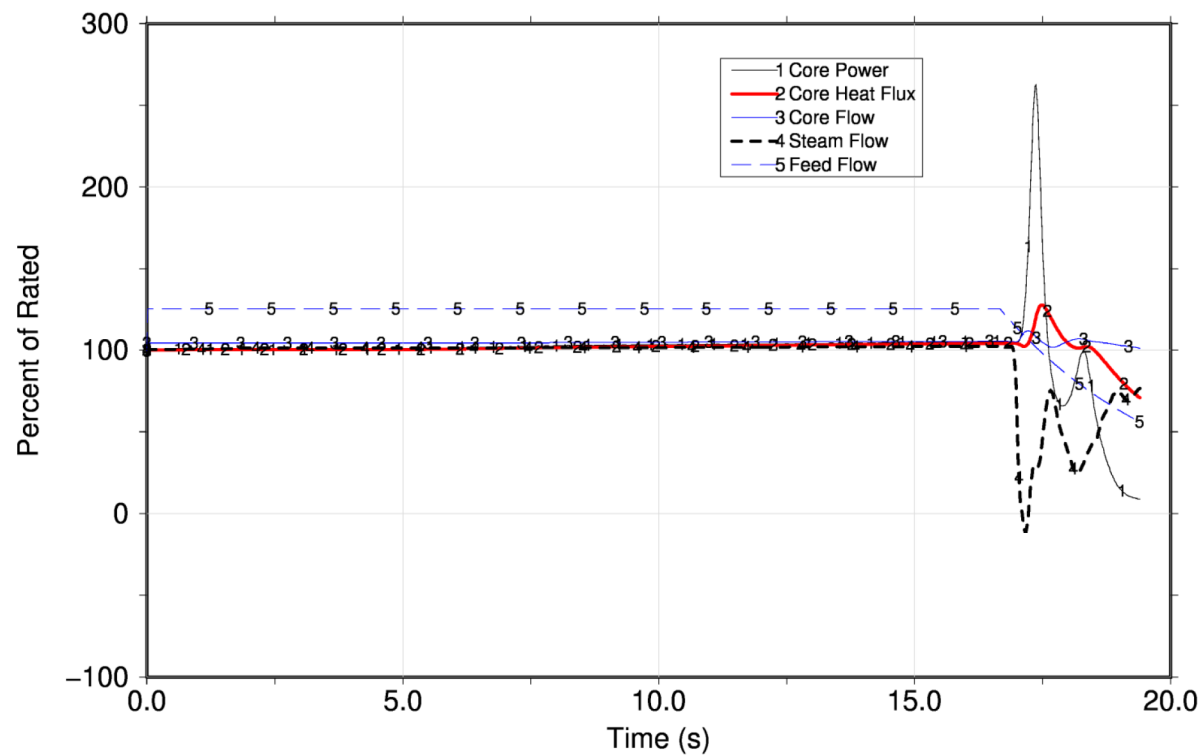


**Figure 3.7 EOFP FWCF at 100P/104.5F – NSS
Key Parameters**

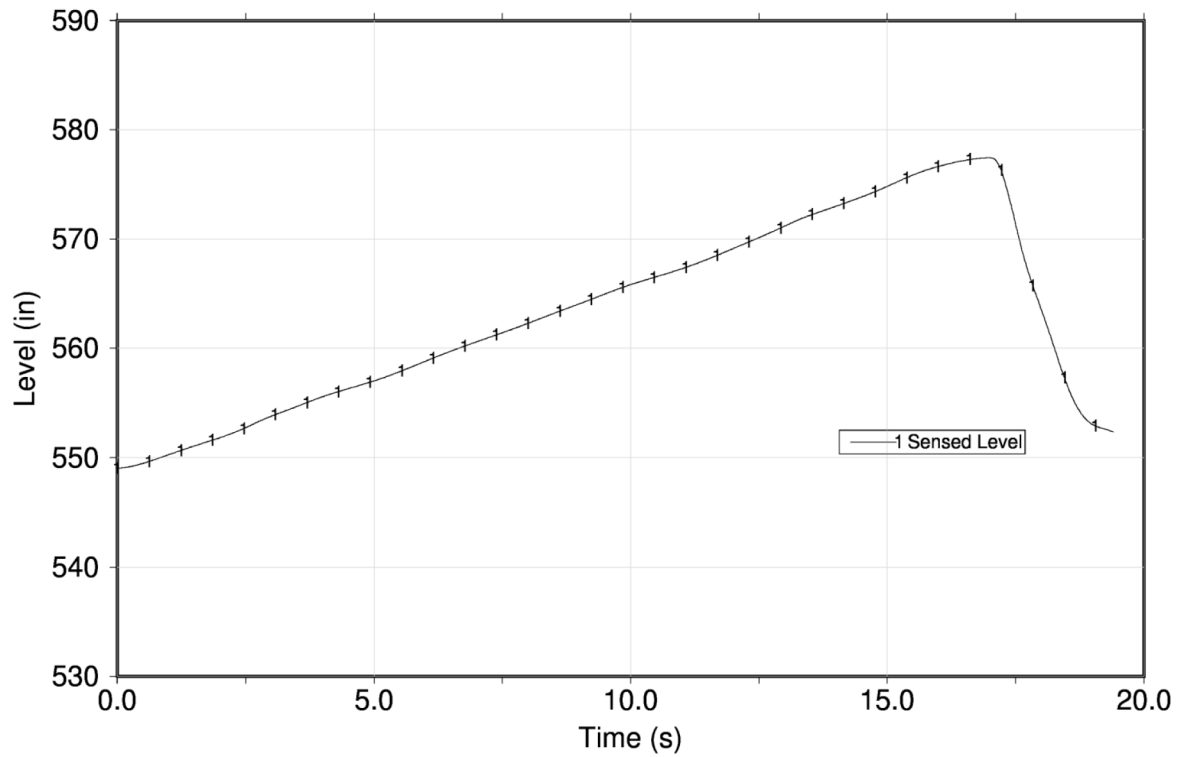


**Figure 3.8 EOFP FWCF at 100P/104.5F – NSS
Sensed Water Level**

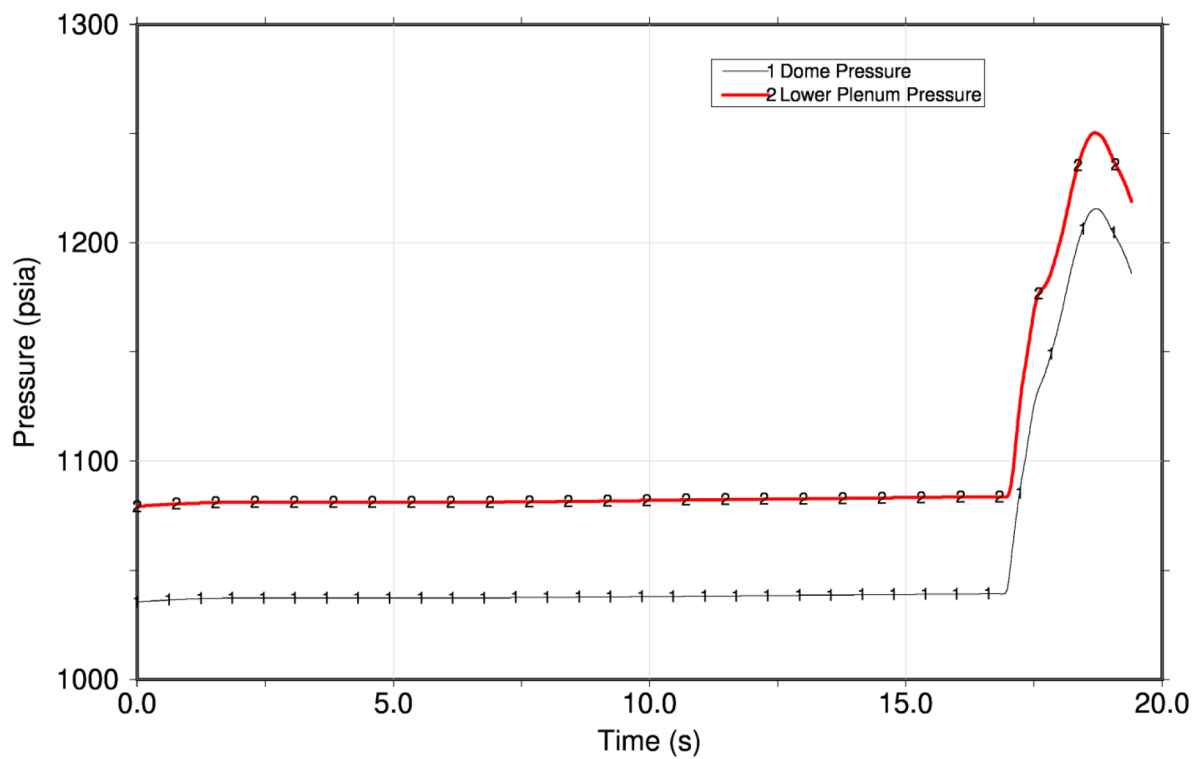


**Figure 3.9 EOFP FWCF at 100P/104.5F – NSS
Vessel Pressures**

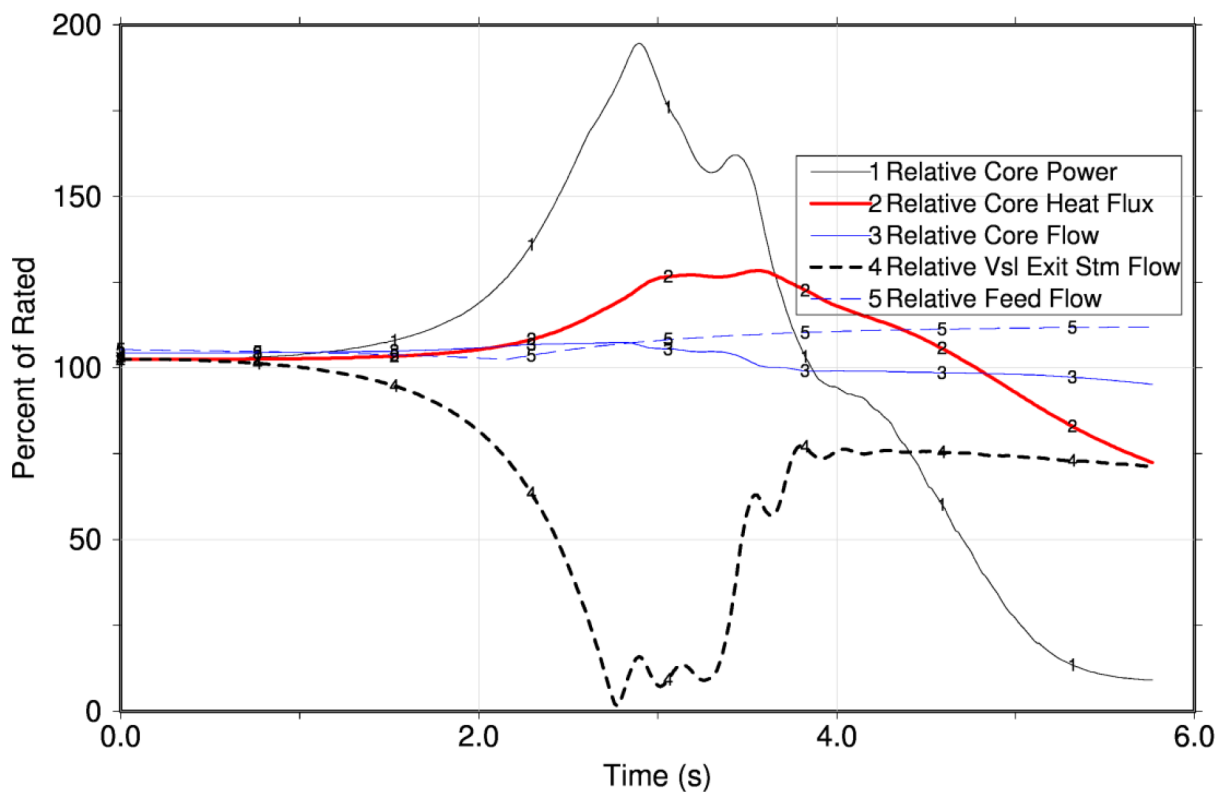


**Figure 3.10 MSIV Overpressurization Event at
102P/104.5F – Key Parameters**

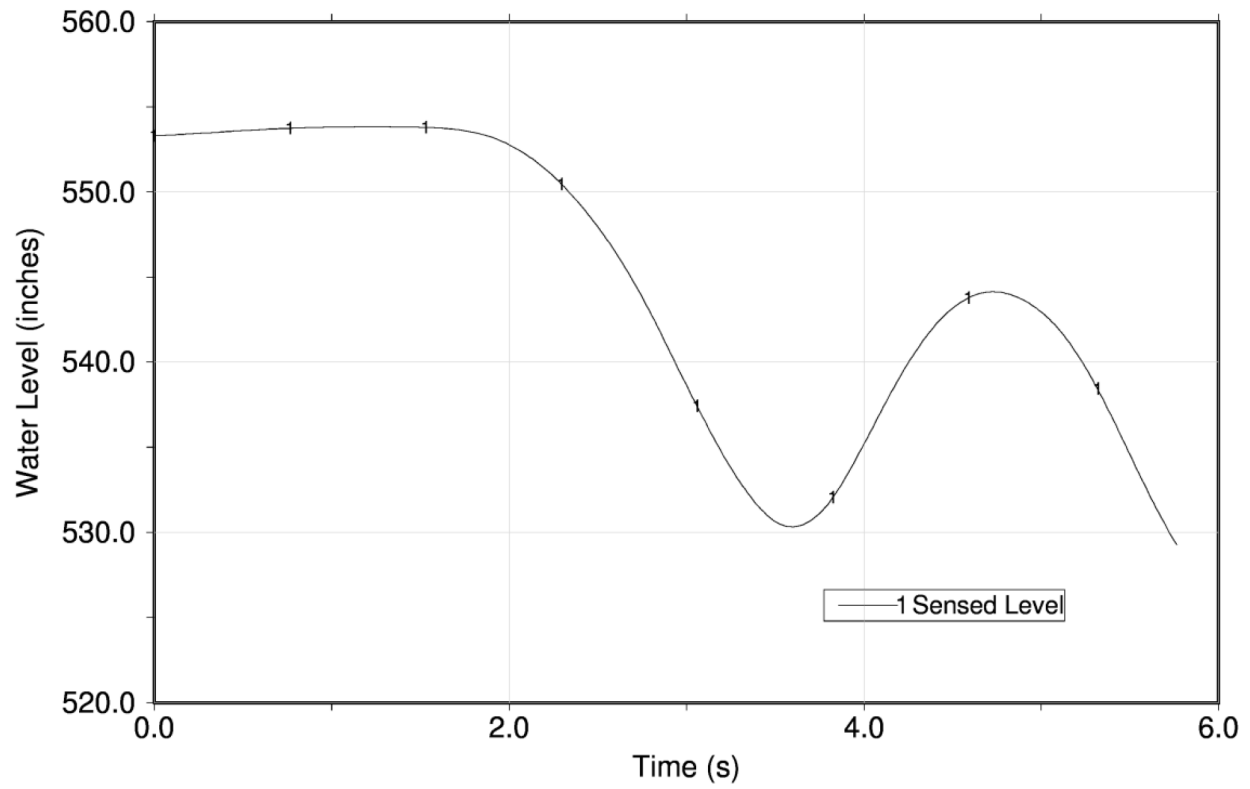


**Figure 3.11 MSIV Overpressurization Event at
102P/104.5F – Sensed Water Level**

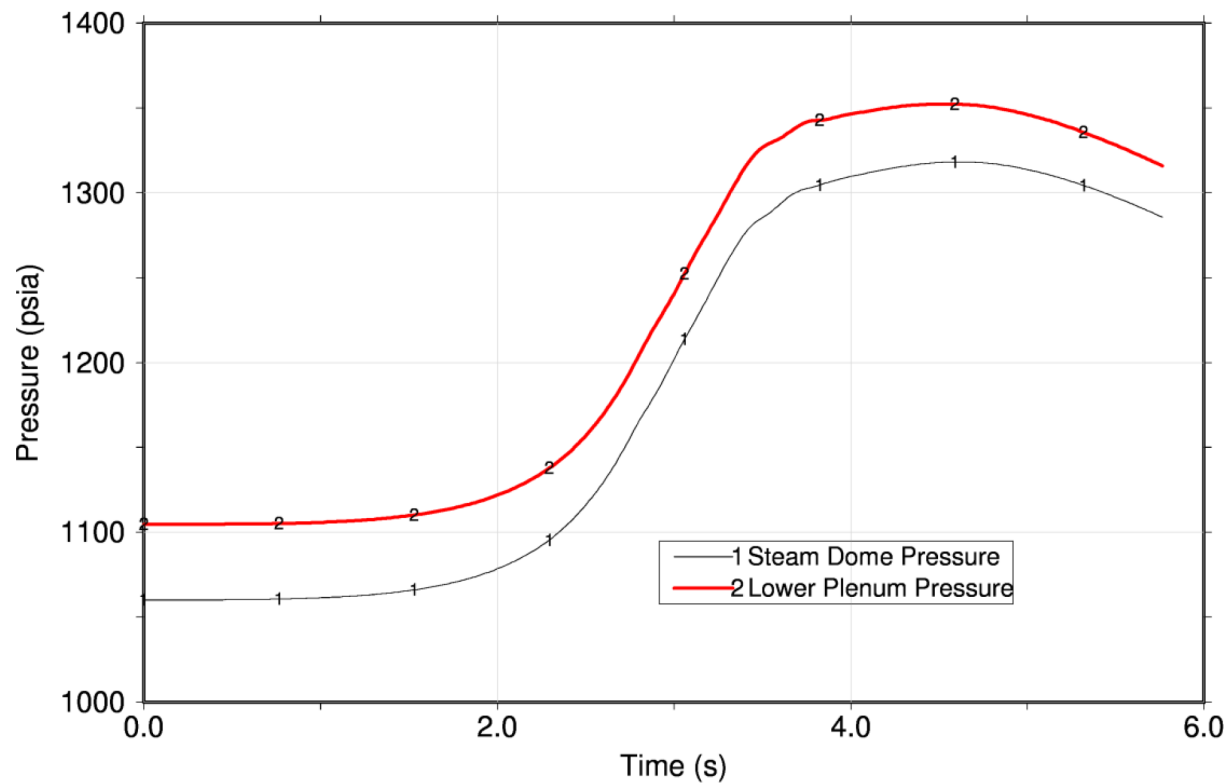


**Figure 3.12 MSIV Overpressurization Event at
102P/104.5F – Vessel Pressures**

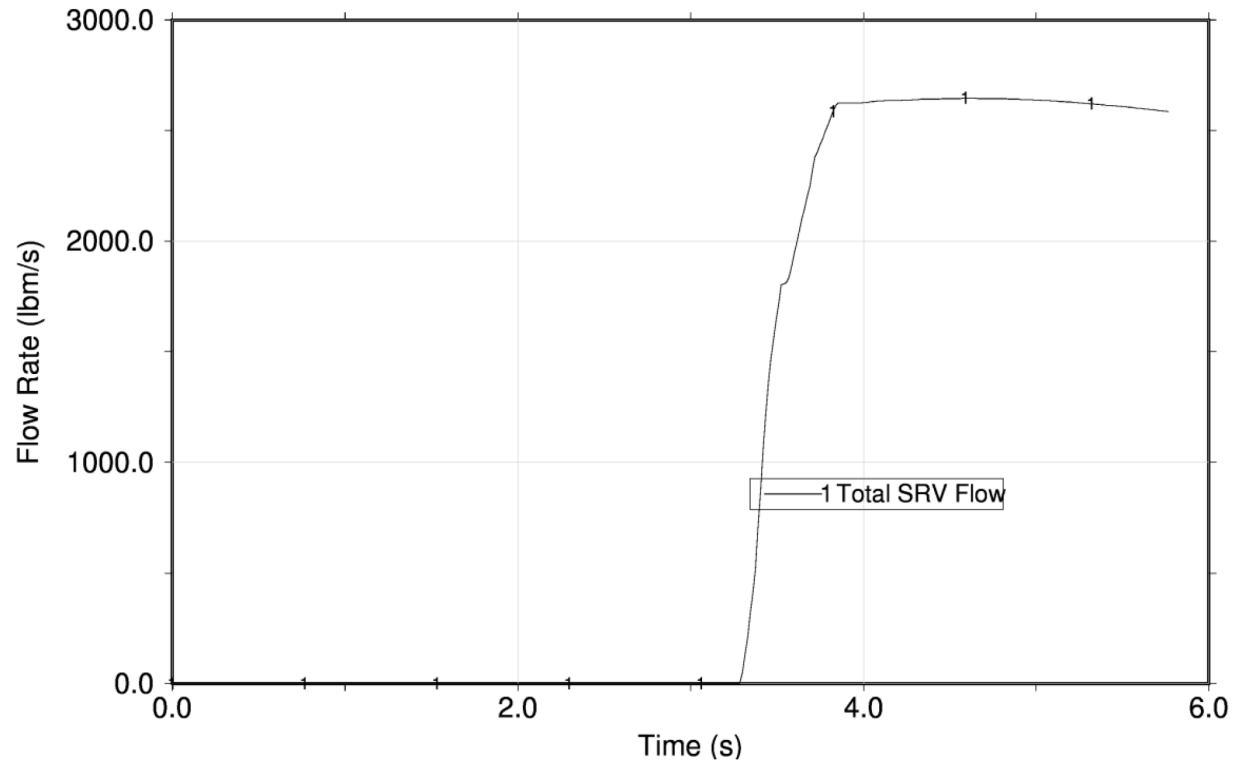


**Figure 3.13 MSIV Overpressurization Event at
102P/104.5F – Safety/Relief Valve Flow Rates**

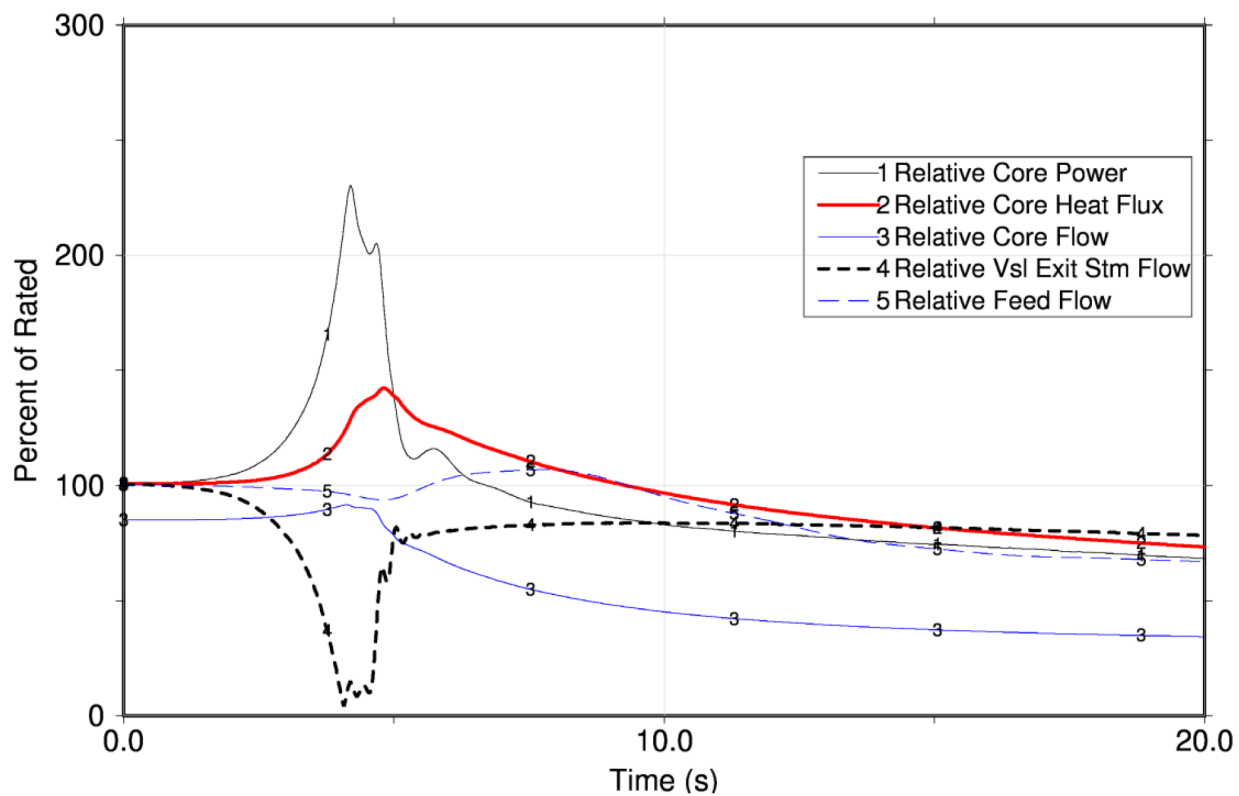


**Figure 3.14 MSIV ATWS Overpressurization Event at
100P/85F – Key Parameters**

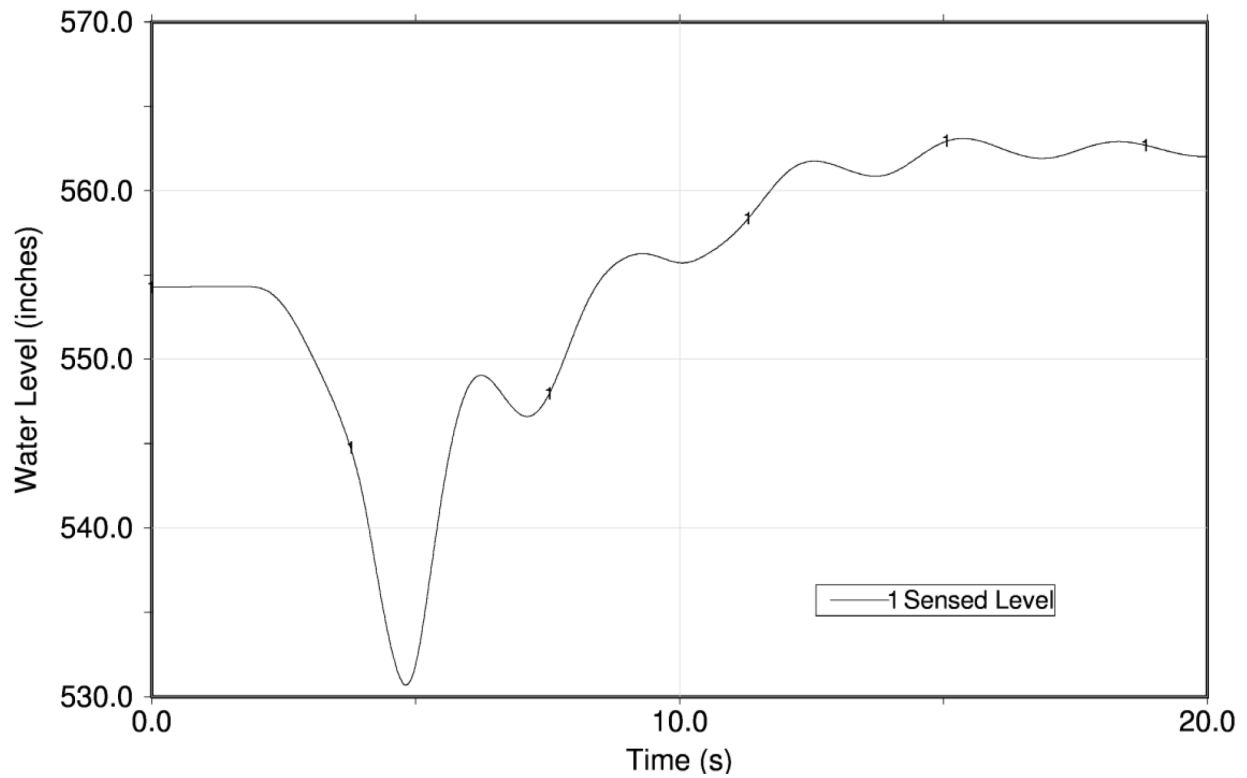


**Figure 3.15 MSIV ATWS Overpressurization Event at
100P/85F – Sensed Water Level**

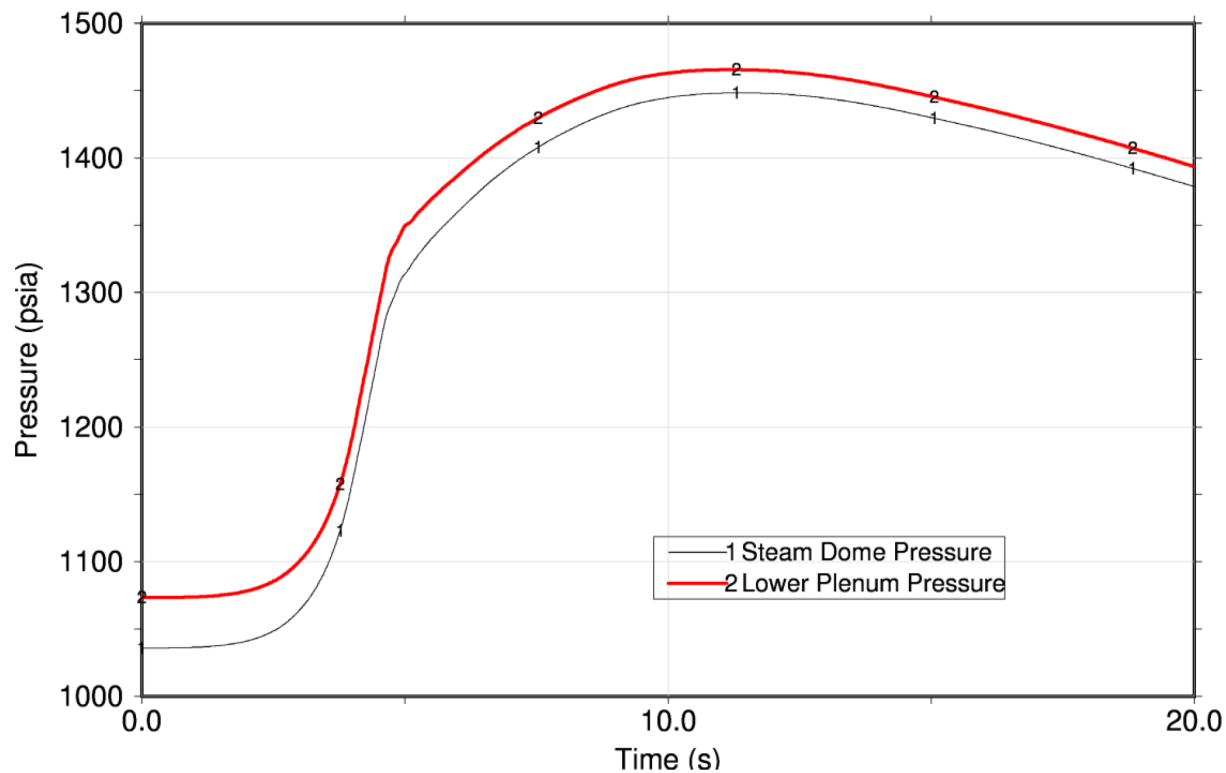


**Figure 3.16 MSIV ATWS Overpressurization Event at
100P/85F – Vessel Pressures**

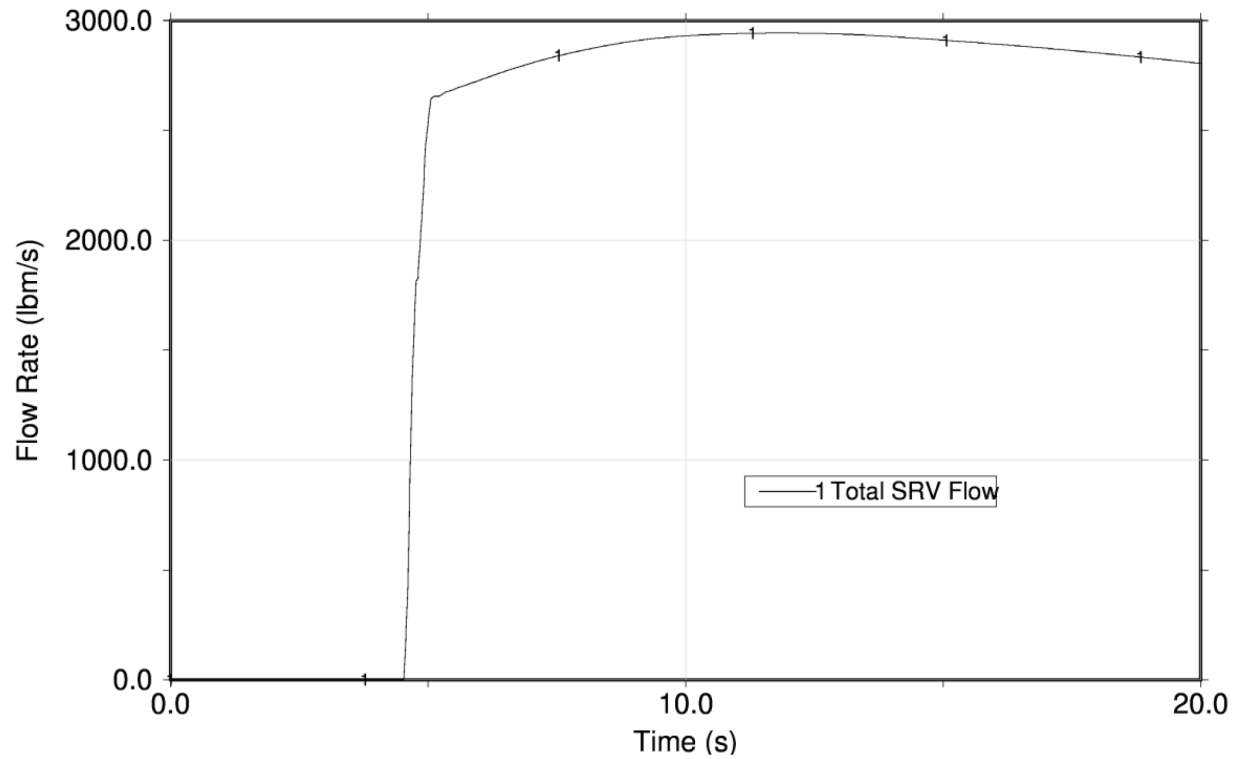


**Figure 3.17 MSIV ATWS Overpressurization Event at
100P/85F – Safety/Relief Valve Flow Rates**

4.0 References

1. ANP-10300P-A Revision 1, *AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios*, Framatome, January 2018.
2. ANP-10335P-A Revision 0, *ACE/ATRUM 11 Critical Power Correlation*, Framatome, May 2018.
3. ANP-3661P Revision 0, *Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design*, Framatome, July 2018.

Affidavit for ANP-3702P, Brunswick ATRIUM 11 Transient
Demonstration

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3702P, Revision 0 "Brunswick ATRIUM 11 Transient Demonstration," dated August 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

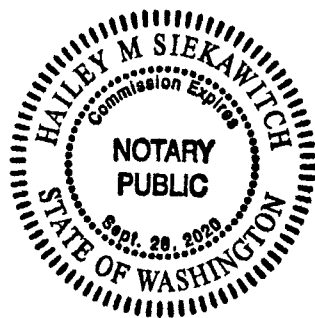
9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

Ala E Mag

SUBSCRIBED before me this 16th
day of August, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3674NP, Brunswick Units 1 and 2 LOCA Analysis for
ATRIUM 11 Fuel



Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel

ANP-3674NP
Revision 1

October 2018

Framatome Inc.

© 2018 Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

**ATRIUM, AURORA-B and S-RELAP5 are trademarks or registered
trademarks of Framatome or its affiliates, in the USA or other countries.**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1.	Page 2-1	The values provided for PCT, oxidation, and total hydrogen in both the table and the footnote are update based on new analyses.
2.	Page 6-1	In Section 6.1, there are 2 instances where the rated core flow is updated based on new analyses.
3.	Table 6.1	There are 2 instances where the rated core flow is updated based on new analyses.
4.	Table 6.2	The PCT results provided in Table 6-2 based on new analyses.
5.	Table 6.3	There are 8 instances where event times are updated based on new analyses.
6.	Figures 6.1 through 6.15	The figures are updated based on new analyses.
7.	Page 7-2	Next to last paragraph, there is one instance where the limiting SLO axial power shape is updated based on new analyses.
8.	Table 7.1	The limiting SLO axial power shape is updated based on new analyses. The 2 instances of PCT results based on new analyses.
9.	Page 9-1	In the last 2 paragraphs, the values proved for PCT (2 instances), maximum local MWR (1 instance), hot rod MWR (1 instance), CMWR (1 instance), and time of PCT (1 instance) are updated based on new analyses.
10.	Table 9.1	The results in the table and footnote are updated based on new analyses.
11.	Figure 9.1	The figure is updated based on new analyses.
12.	Page 10-1	First bullet item, the rated core flow is updated based on new analyses

Contents

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 SUMMARY OF RESULTS	2-1
3.0 LOCA DESCRIPTION	3-1
3.1 Accident Description	3-1
3.2 Acceptance Criteria	3-2
4.0 LOCA ANALYSIS DESCRIPTION	4-1
4.1 Break Spectrum Analysis	4-1
4.2 Exposure Analysis	4-2
4.3 Plant Parameters	4-2
4.4 ECCS Parameters	4-2
5.0 BREAK SPECTRUM ANALYSIS DESCRIPTION	5-1
5.1 Limiting Single Failure	5-1
5.2 Recirculation Line Breaks	5-2
5.3 Non-Recirculation Line Breaks	5-3
5.3.1 Main Steam Line Breaks	5-4
5.3.2 Feedwater Line Breaks	5-4
5.3.3 HPCI Line Breaks	5-5
5.3.4 LPCS Line Breaks	5-5
5.3.5 LPCI Line Breaks	5-5
5.3.6 RWCU Line Breaks	5-5
5.3.7 Shutdown Cooling Line Breaks	5-6
5.3.8 Instrument Line Breaks	5-6
6.0 TLO RECIRCULATION LINE BREAK SPECTRUM ANALYSES	6-1
6.1 Break Spectrum Analysis Results	6-1
7.0 SINGLE-LOOP OPERATION LOCA ANALYSIS	7-1
7.1 SLO Analysis Modeling Methodology	7-1
7.2 SLO Analysis Results	7-1
8.0 LONG-TERM COOLABILITY	8-1
9.0 EXPOSURE-DEPENDENT LOCA ANALYSIS DESCRIPTION AND RESULTS	9-1
10.0 CONCLUSIONS	10-1

11.0 REFERENCES	11-1
APPENDIX A LIMITATIONS FROM THE DRAFT SAFETY EVALUATION FOR LTR ANP-10332P	A-1

Tables

Table 4.1	Initial Conditions	4-4
Table 4.2	Reactor System Parameters	4-5
Table 4.3	ATRIUM 11 Fuel Assembly Parameters	4-6
Table 4.4	High-Pressure Coolant Injection Parameters	4-7
Table 4.5	Low-Pressure Coolant Injection Parameters	4-8
Table 4.6	Low-Pressure Core Spray Parameters	4-9
Table 4.7	Automatic Depressurization System Parameters	4-10
Table 5.1	Available ECCS for Recirculation Line Break LOCAs	5-7
Table 6.1	Break Spectrum Results for TLO Recirculation Line Breaks	6-2
Table 6.2	Summary of Break Spectrum [] for TLO Recirculation Line Breaks	6-3
Table 6.3	Event Times for the [] from the TLO Recirculation Line Break Spectrum Analysis	6-4
Table 7.1	Single- and Two-Loop Operation PCT Summary	7-3
Table 9.1	ATRIUM 11 Exposure-Dependent LOCA Analysis Results	9-2

Figures

Figure 1.1	Brunswick MELLLA+ Power / Flow Map	1-3
Figure 2.1	MAPLHGR Limit for ATRIUM 11 Fuel.....	2-3
Figure 2.2	[] for ATRIUM 11 Fuel.....	2-4
Figure 4.1	S-RELAP5 Vessel Model	4-11
Figure 4.2	S-RELAP5 Core Model	4-12
Figure 4.3	ECCS Schematic	4-13
Figure 4.4	Rod Average Power Distributions for 102%P and [] Mid- and Top-Peaked	4-14
Figure 4.5	Rod Average Power Distributions for 102%P and [] Mid- and Top-Peaked	4-15
Figure 4.6	Rod Average Power Distributions for [] Mid- and Top-Peaked	4-16
Figure 4.7	Rod Average Power Distributions for [] Mid- and Top-Peaked	4-17
Figure 6.1	[] from the TLO Recirculation Line Break Spectrum Analysis Upper Plenum Pressure	6-5
Figure 6.2	[] from the TLO Recirculation Line Break Spectrum Analysis Total Break Flow Rate.....	6-5
Figure 6.3	[] from the TLO Recirculation Line Break Spectrum Analysis Core Inlet Flow Rate.....	6-6
Figure 6.4	[] from the TLO Recirculation Line Break Spectrum Analysis ADS Flow	6-6
Figure 6.5	[] from the TLO Recirculation Line Break Spectrum Analysis HPCI Flow	6-7
Figure 6.6	[] from the TLO Recirculation Line Break Spectrum Analysis LPCS Flow	6-7
Figure 6.7	[] from the TLO Recirculation Line Break Spectrum Analysis LPCI Flow.....	6-8
Figure 6.8	[] from the TLO Recirculation Line Break Spectrum Analysis RDIV Flows	6-8
Figure 6.9	[] from the TLO Recirculation Line Break Spectrum Analysis Relief Valve Flow	6-9
Figure 6.10	[] from the TLO Recirculation Line Break Spectrum Analysis Downcomer LOCA Water Level	6-9

Figure 6.11	[] from the TLO Recirculation Line Break Spectrum Analysis Upper Plenum Liquid Level	6-10
Figure 6.12	[] from the TLO Recirculation Line Break Spectrum Analysis Hot Channel Liquid Level	6-10
Figure 6.13	[] from the TLO Recirculation Line Break Spectrum Analysis Core Bypass Liquid Level.....	6-11
Figure 6.14	[] from the TLO Recirculation Line Break Spectrum Analysis Lower Plenum Liquid Level	6-11
Figure 6.15	[] from the TLO Recirculation Line Break Spectrum Analysis Hot Channel Inlet Flow	6-12
Figure 9.1	Limiting [] PCT Exposure-Dependent LOCA Analysis	9-3

Nomenclature

ADS	automatic depressurization system
ADSV OOS	ADS valve out-of-service
BOL	beginning of life
BWR	boiling-water reactor
CFR	Code of Federal Regulations
CMWR	core average metal-water reaction
DC	direct current
DEG	double-ended guillotine
DG	diesel generator
ECCS	emergency core cooling system
FHOOS	feedwater heaters out-of-service
HPCI	high-pressure coolant injection
ICF	increased core flow
ID	inside diameter
LHGR	linear heat generation rate
LOCA	loss-of-coolant accident
LPCI	low-pressure coolant injection
LPCS	low-pressure core spray
MAPLHGR	maximum average planar linear heat generation rate
MCPR	minimum critical power ratio
MELLLA+	maximum extended load line limit analysis plus
MSIV	main stream isolation valve
MSIVOOS	main steam isolation valve out-of-service
MWR	metal-water reaction
NSSS	nuclear steam supply system
NRC	Nuclear Regulatory Commission, U.S.
OD	outside diameter
PCT	peak cladding temperature
RDIV	recirculation discharge isolation valve
RHR	residual heat removal
RWCU	reactor water cleanup

SF-BATT	single failure of battery (DC) power
SF-HPCI	single failure of the HPCI system
SF-LPCI	single failure of an LPCI injection valve
SLO	single-loop operation
TLO	two-loop operation
UFSAR	updated final safety analysis report

1.0 Introduction

The results of a loss-of-coolant accident (LOCA) break spectrum and emergency core cooling system (LOCA-ECCS) analyses for Brunswick Units 1 and 2 are documented in this report. The purpose of the break spectrum analysis is to identify the break characteristics that result in the highest calculated peak cladding temperature (PCT) [] during a postulated LOCA. The results provide the maximum average planar linear heat generation rate (MAPLHGR) limit for ATRIUM™ 11 fuel as a function of exposure for normal (two-loop) operation.

Variation in the following LOCA parameters is examined:

- Break location
- Break type (double-ended guillotine (DEG) or split)
- Break size
- Limiting ECCS single failure
- Axial power shape (top- or mid-peaked)
- Initial statepoint
- Fuel rod type

The analyses documented in this report are performed with LOCA Evaluation Models developed by Framatome*, and approved for reactor licensing analyses by the U.S. Nuclear Regulatory Commission (NRC). The models and computer codes used by Framatome for LOCA analyses are collectively referred to as the AURORA-B LOCA Evaluation Model (References 1 – 4). The calculations described in this report are performed in conformance with 10 CFR 50 Appendix K requirements and satisfy the event acceptance criteria identified in 10 CFR 50.46.

Key model characteristics included in the report analyses are shown below. Other initial conditions used in the analyses are described in Section 4.0.

Operation in the MELLLA+ domain of Figure 1.1 is supported. [

]

* Framatome Inc. formerly known as AREVA Inc.

- []
- Analyses support operation with one automatic depressurization system (ADS) valve out-of-service (ADSVOOS) and the potential failure of one ADS valve during the LOCA.
 - []
-]
- The core is composed entirely of ATRIUM 11 fuel.
 - A 2.0% increase in initial core power to address the maximum uncertainty in monitoring reactor power, as per NRC requirements, is included.
 - [] were assumed to be at the MAPLHGR limit shown in Figure 2.1.
 - []

The limiting break characteristics from the break spectrum study are used in analyses to determine the MAPLHGR limit and [] versus exposure. Even though the limiting break will not change with exposure or nuclear fuel design, the value of PCT calculated for any given set of break characteristics is dependent on exposure and the corresponding MAPLHGR and [].

Single-loop operation (SLO) results are discussed in Section 7.0. Long term coolability is addressed in Section 8.0.

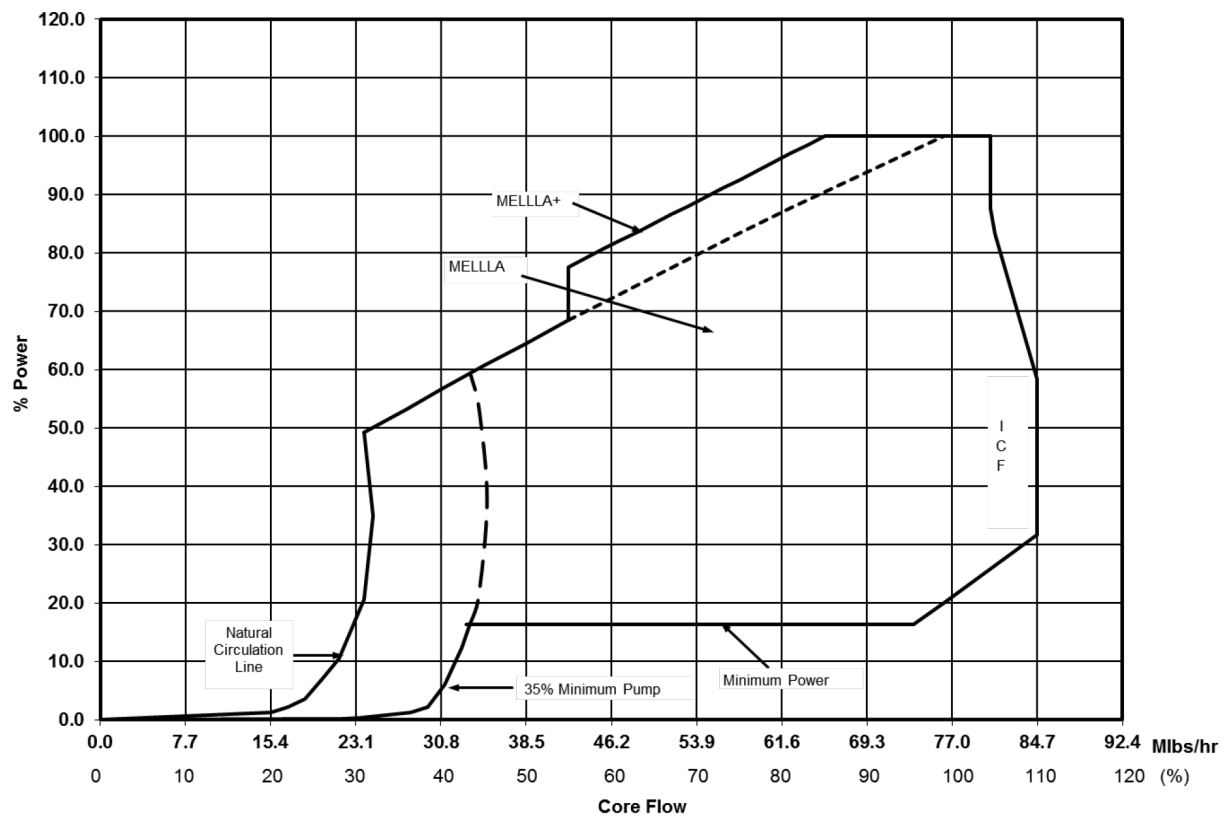


**Figure 1.1 Brunswick MELLLA+ Power
/ Flow Map**

2.0 Summary of Results

The LOCA break spectrum analysis results presented in this report are for Brunswick Unit 2 which are conservatively applicable to Unit 1. Analyses performed with AURORA-B LOCA confirm the PCT results of Unit 2 bound Unit 1. A more detailed discussion of results is provided in Sections 6.0 – 7.0.

The PCT and metal-water reaction (MWR) results, from the ATRIUM 11 fuel exposure-dependent analysis presented in Section 9.0, are presented below.

Parameter	ATRIUM 11*
Peak cladding temperature (°F)	1882
Local cladding oxidation (max %)	4.56
Total hydrogen generated (% of total hydrogen possible)	0.27

The MAPLHGR limit was determined by applying the AURORA-B LOCA Evaluation Model for the analysis of the limiting LOCA event. The exposure-dependent MAPLHGR limit for ATRIUM 11 fuel is shown in Figure 2.1. Exposure dependent results with the [

] are presented in

Section 9.0. The results of these calculations confirm that the LOCA acceptance criteria in the Code of Federal Regulations (10 CFR 50.46) are met for operation at or below these limits.

The LOCA analysis results (i.e., the limiting break characteristics and exposure analysis) presented in this report are applicable for a full core of ATRIUM 11 fuel as well as transition cores containing ATRIUM 11 fuel. [

]

* [

]

[

]

The SLO LOCA analyses support operation with an ATRIUM 11 multiplier of 0.85 applied to the normal two-loop operation MAPLHGR limit. []

The long-term coolability evaluation confirms that the ECCS capacity is sufficient to maintain adequate cooling in an ATRIUM 11 core for an extended period after a LOCA.

All analyses support operation with one ADSVOOS. All analyses also support the [

] All analyses

were performed assuming nominal feedwater temperature. [

] Therefore, this LOCA analysis

supports FHOOS operation.

The analysis supports operation in the MELLLA+ domain of the Brunswick power/flow map shown in Figure 1.1.

At Brunswick, operation with 1 MSIVOOS is limited to two-loop operation and power levels less than 70% of rated. For a given power level, 1 MSIVOOS can result in a higher reactor pressure at the initiation of a LOCA and a slightly higher break flow. [

] Therefore, this LOCA analysis supports operation with 1 MSIVOOS.



**Figure 2.1 MAPLHGR Limit
for ATRIUM 11 Fuel**

Figure 2.2 []
for ATRIUM 11 Fuel

3.0 LOCA Description

3.1 *Accident Description*

The LOCA is described in the Code of Federal Regulations 10 CFR 50.46 as a hypothetical accident that results in a loss of reactor coolant from breaks in reactor coolant pressure boundary piping up to and including a break equivalent in size to a double-ended rupture of the largest pipe in the reactor coolant system. There is not a specifically identified cause that results in the pipe break. However, for the purpose of identifying a design basis accident, the pipe break is postulated to occur inside the primary containment before the first isolation valve.

For a boiling water reactor (BWR), a LOCA may occur over a wide spectrum of break locations and sizes. Responses to the break vary significantly over the break spectrum. The largest possible break is a double-ended rupture of a recirculation pipe; however, this is not necessarily the most severe challenge to the ECCS. A double-ended rupture of a main steam line causes the most rapid primary system depressurization, but because of other phenomena, steam line breaks are seldom limiting with respect to the event acceptance criteria (10 CFR 50.46). Because of these complexities, an analysis covering the full range of break sizes and locations is performed to identify the limiting break characteristics.

Regardless of the initiating break characteristics, the event response is conveniently separated into three phases: the blowdown phase, the refill phase, and the reflood phase. The relative duration of each phase is strongly dependent upon the break size and location. [

]

During the blowdown phase of a LOCA, there is a net loss of coolant inventory, an increase in fuel cladding temperature due to core flow degradation, and for the larger breaks, the core becomes fully or partially uncovered. There is a rapid decrease in pressure during the blowdown phase. During the early phase of the depressurization, the exiting coolant provides core cooling. Consistent with the discussion presented in Reference 1, [

]

In the refill phase of a LOCA, the ECCS is functioning and there is a net increase of coolant inventory. During this phase the core sprays provide core cooling and, along with low-pressure and high-pressure coolant injection (LPCI and HPCI), supply liquid to refill the lower portion of the reactor vessel. In general, the core heat transfer to the coolant is less than the fuel decay heat rate and the fuel cladding temperature continues to increase during the refill phase.

In the reflood phase, the coolant inventory has increased to the point where the mixture level re-enters the core region. During the core reflood phase, cooling is provided above the mixture level by entrained reflood liquid and below the mixture level by pool boiling. Sufficient coolant eventually reaches the core hot node and the fuel cladding temperature decreases. [

]

3.2 Acceptance Criteria

A LOCA is a potentially limiting event that may place constraints on fuel design, local power peaking, and in some cases, acceptable core power level. During a LOCA, the normal transfer of heat from the fuel to the coolant is disrupted. As the liquid inventory in the reactor decreases, the decay heat and stored energy of the fuel cause a heatup of the undercooled fuel assembly. In order to limit the amount of heat that can contribute to the heatup of the fuel assembly during a LOCA, an operating limit on the MAPLHGR is applied to each fuel assembly in the core.

The Code of Federal Regulations prescribes specific acceptance criteria (10 CFR 50.46) for a LOCA event as well as specific requirements and acceptable features for Evaluation Models (10 CFR 50 Appendix K). The conformance of the AURORA-B LOCA Evaluation Models to Appendix K is described in Reference 1. The ECCS must be designed such that the plant response to a LOCA meets the following acceptance criteria specified in 10 CFR 50.46:

- The calculated maximum fuel element cladding temperature shall not exceed 2200°F.
- The calculated local oxidation of the cladding shall nowhere exceed 0.17 times the local cladding thickness.
- The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, except the cladding surrounding the plenum volume, were to react.
- Calculated changes in core geometry shall be such that the core remains amenable to cooling.

- After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

These criteria are commonly referred to as the PCT criterion, the local oxidation criterion, the hydrogen generation criterion, the coolable geometry criterion, and the long-term cooling criterion. A MAPLHGR limit is established for each fuel type to ensure that these criteria are met.

LOCA results are provided in Section 6.0 to identify the LOCA events which produce the highest PCT [] LOCA analysis results demonstrating that the PCT, local oxidation, and hydrogen generation (core wide oxidation) criteria are met are provided in Section 9.0. Compliance with these three criteria ensures that a coolable geometry is maintained. Long-term coolability criterion is discussed in Section 8.0.

4.0 LOCA Analysis Description

The Evaluation Model used for the break spectrum analysis is the AURORA-B LOCA analysis methodology described in Reference 1. The AURORA-B LOCA methodology employs two major computer codes to evaluate the system and fuel response during all phases of a LOCA. These are the S-RELAP5 and RODEX4 computer codes. A [

] of the

LOCA to determine the PCT and maximum local clad oxidation for [

]

A complete analysis starts with the specification of fuel parameters using RODEX4 (Reference 4). RODEX4 is used to determine the [

] The initial stored energy used in S-RELAP5 is [

]

4.1 Break Spectrum Analysis

S-RELAP5 is used to calculate the thermal-hydraulic response during all phases of the LOCA using a [

] The reactor vessel nodalization is shown in Figure 4.1 and the core nodalization is shown in Figure 4.2 consistent with those in the topical report submitted to the NRC (Reference 1). The reactor core is modeled with heat generation rates determined from reactor kinetics equations with reactivity feedback and decay heat as required by Appendix K of 10 CFR 50. The clad swelling and rupture models from NUREG-0630 (Reference 3) have been incorporated into S-RELAP5.

The S-RELAP5 model is executed over a range of break locations, break sizes, break types, initial statepoints, axial shapes and assumed single-failures to determine the break that yields the highest PCT [

]

4.2 *Exposure Analysis*

The [] from beginning-of-life to end-of-life [] increments to determine an exposure-dependent MAPLHGR limit and [] Figures of merit including PCT, local cladding oxidation, and core-wide metal-water reaction are evaluated over the range of exposures to confirm the acceptability of the LOCA analysis with respect to 10 CFR 50.46 criteria. []

]

4.3 *Plant Parameters*

The LOCA analysis is performed using the plant parameters provided by the utility. Table 4.1 provides a summary of reactor initial conditions used in the break spectrum analysis. Table 4.2 lists selected reactor system parameters.

The LOCA analysis is performed for a full core of ATRIUM 11 fuel. Some of the key fuel parameters used in the analysis are summarized in Table 4.3.

4.4 *ECCS Parameters*

The ECCS configuration is shown in Figure 4.3. Table 4.4 – Table 4.7 provide the important ECCS characteristics assumed in the analysis. The ECCS is modeled as time-dependent junctions connected to the appropriate reactor locations: LPCS injects into the upper plenum, HPCI injects into the upper downcomer, and LPCI injects into the recirculation lines. Although HPCI is expected to be available, no analysis mitigation credit is assumed for the HPCI system in any of the analyses discussed in this report.

The flow through each ECCS valve is determined based on system pressure and valve position. Flow versus pressure for a fully open valve is obtained by linearly interpolating the pump capacity data provided in Table 4.4 – Table 4.6. No credit for ECCS flow is assumed until the ECCS injection valves are fully open and the ECCS pumps reach rated speed.

The ADS valves are modeled as a junction connecting the reactor steam line to the suppression pool. The flow through the ADS valves is calculated based on pressure and valve flow characteristics. The valve flow characteristics are determined such that the calculated flow is equal to the rated capacity at the reference pressure shown in Table 4.7. Only five ADS valves are assumed operable in the analyses to support operation with one ADSVOOS and the potential single failure of one ADS valve during the LOCA.

In the Framatome LOCA analysis model, ECCS initiation is assumed to occur when the water level drops to the applicable level setpoint. No credit is assumed for the start of LPCS or LPCI due to high drywell pressure. [

]

Table 4.1 Initial Conditions

Reactor power (% of rated)	102	102	[	]
Reactor power (MWt)	2981.5	2981.5	[	]
Steam flow rate (Mlb/hr)	13.1	13.1	11.6	8.9
Steam dome pressure (psia)	1047.6	1047.4	1034.9	1014.3
Core inlet enthalpy (Btu/lb)	527.6	522.3	516.4	512.1
Rod average power distributions	Figure 4.4	Figure 4.5	Figure 4.6	Figure 4.7

**Table 4.2 Reactor System
Parameters**

Parameter	Value
Vessel ID (in)	220.5
Number of fuel assemblies	560
Recirculation suction pipe area (ft ²)	3.67
1.0 DEG suction break area (ft ²)	7.33
Recirculation discharge pipe area (ft ²)	3.67
1.0 DEG discharge break area (ft ²)	7.33

**Table 4.3 ATRIUM 11 Fuel Assembly
Parameters**

Parameter	Value
Fuel rod array	11x11
Number of fuel rods per assembly	92 (full-length rods) 8 (long part-length rods) 12 (short part-length rods)
Non-fuel rod type	Water channel replaces 9 fuel rods
Fuel rod OD (in)	0.3701
Active fuel length (in) (including blankets)	150.0 (full-length rods) 88.03 (long part-length rods) 55.87 (short part-length rods)
Water channel outside width (in)	1.299
Fuel channel thickness (in)	0.071 (minimum wall) * 0.100 (corner)
Fuel channel internal width (in)	5.283

* Does not include additional inner channel milling near the top of the channel.

**Table 4.4 High-Pressure Coolant Injection
Parameters**

Parameter	Value
Coolant temperature (maximum) (°F)	140
<i>Initiating Signals and Setpoints</i>	
Water level (in)*	459
High drywell pressure (psig)	Not used
<i>Time Delays</i>	
Time for HPCI pump to reach rated speed and injection valve wide open (sec)	60
<i>Delivered Coolant Flow Rate Versus Pressure</i>	
Vessel to Torus ΔP (psid)	Flow Rate (gpm)
0	0
150	3825
1164	3825

* Relative to vessel zero.

**Table 4.5 Low-Pressure Coolant Injection
Parameters**

Parameter	Value	
Reactor pressure permissive for opening valves - analytical (psia)	410	
Coolant temperature (maximum) (°F)	160	
<i>Initiating Signals and Setpoints</i>		
Water level (in)*	358	
High drywell pressure (psig)	Not used	
<i>Time Delays</i>		
Time for LPCI pumps to reach rated speed (maximum) (sec)	31.8	
LPCI injection valve stroke time (sec)	37.5	
<i>Delivered Coolant Flow Rate Versus Pressure</i>		
Vessel to Torus ΔP (psid)	Flow Rate for 1 Pump Injecting Into 1 Recirculation Loop (gpm)	Flow Rate for 2 Pumps Injecting Into 1 Recirculation Loop (gpm)
0	8,690	14,420
20	7,000	12,000
202	0	0

* Relative to vessel zero.

**Table 4.6 Low-Pressure Core Spray
Parameters**

Parameter	Value
Reactor pressure permissive for opening valves - analytical (psia)	410
Coolant temperature (maximum) (°F)	160
<i>Initiating Signals and Setpoints</i>	
Water level (in)*	358
High drywell pressure (psig)	Not used
<i>Time Delays</i>	
Time for LPCS pumps to reach rated speed (maximum) (sec)	39.7
LPCS injection valve stroke time (sec)	14.0
<i>Delivered Coolant Flow Rate Versus Pressure[†]</i>	
Vessel to Torus ΔP (psid)	Flow Rate for 1 Pump (gpm)
0	5100
113	3850
265	0

* Relative to vessel zero.

† The delivered LPCS flow rate is reduced by a conservative 150 gpm to account for additional core shroud leakage.

**Table 4.7 Automatic Depressurization
System Parameters**

Parameter	Value
Number of valves installed	7
Number of valves available*	5
Minimum flow capacity of available valves (Mlbm/hr at psig)	4.15 at 1112.4
<i>Initiating Signals and Setpoints</i>	
Water level (in) [†]	358
High drywell pressure (psig)	Not used
<i>Time Delays</i>	
ADS timer (delay time from initiating signal to time valves are open (sec))	121

* Only 5 valves are assumed operable in the analyses to support 1 ADSVOOS operation and the potential single failure of 1 ADS valve during the LOCA.

[†] Relative to vessel zero.

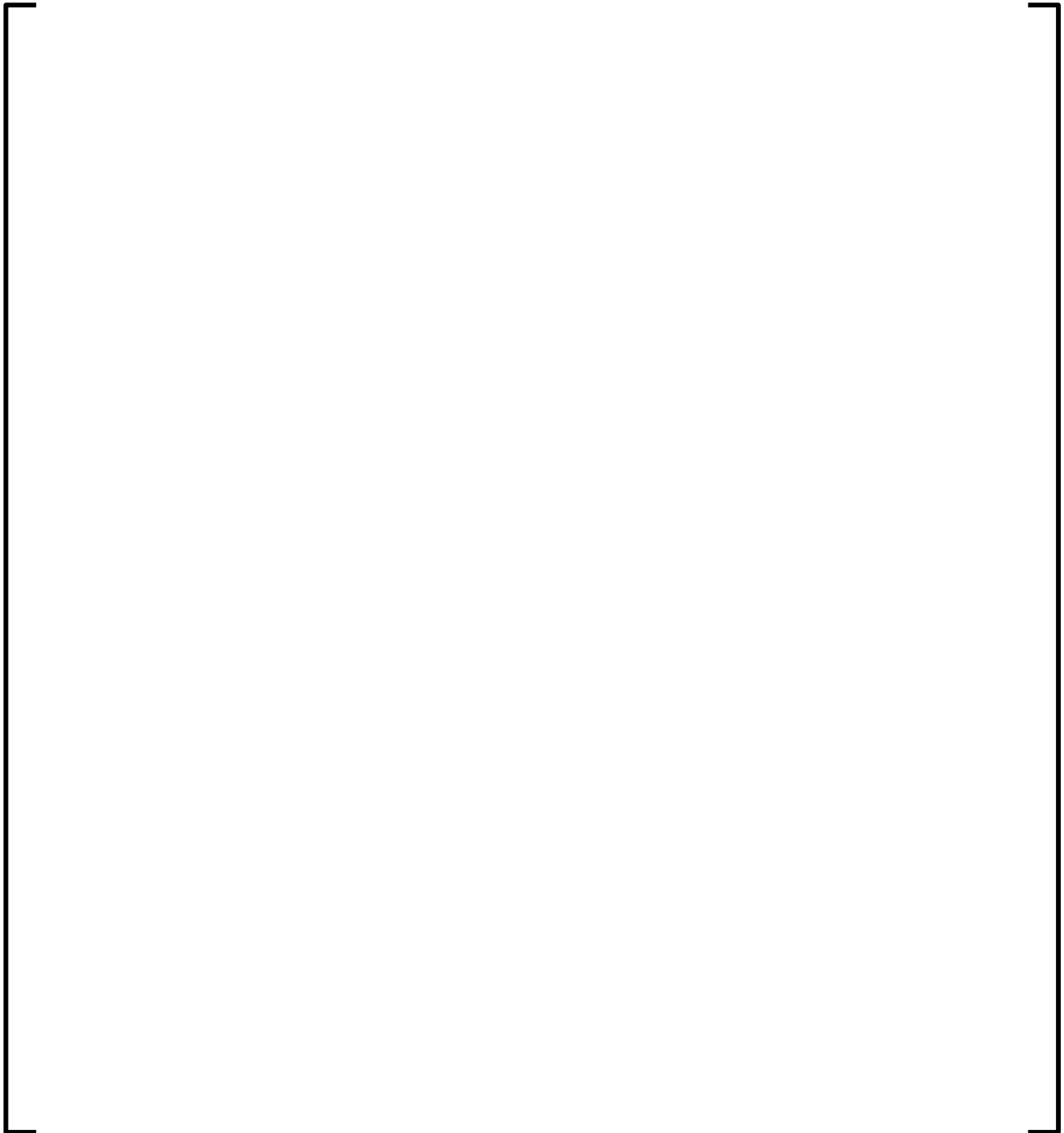


Figure 4.1 S-RELAP5 Vessel Model

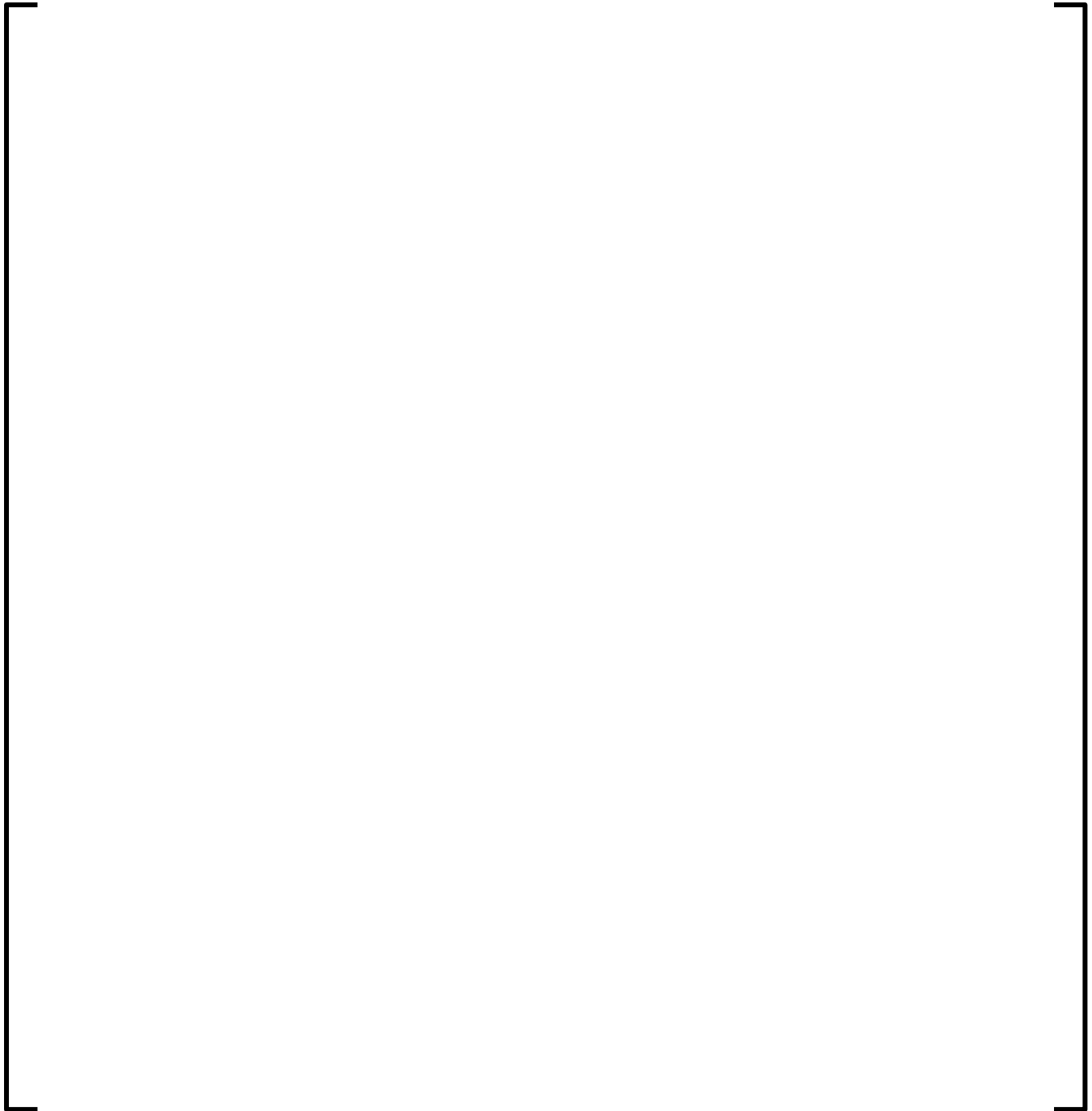


Figure 4.2 S-RELAP5 Core Model

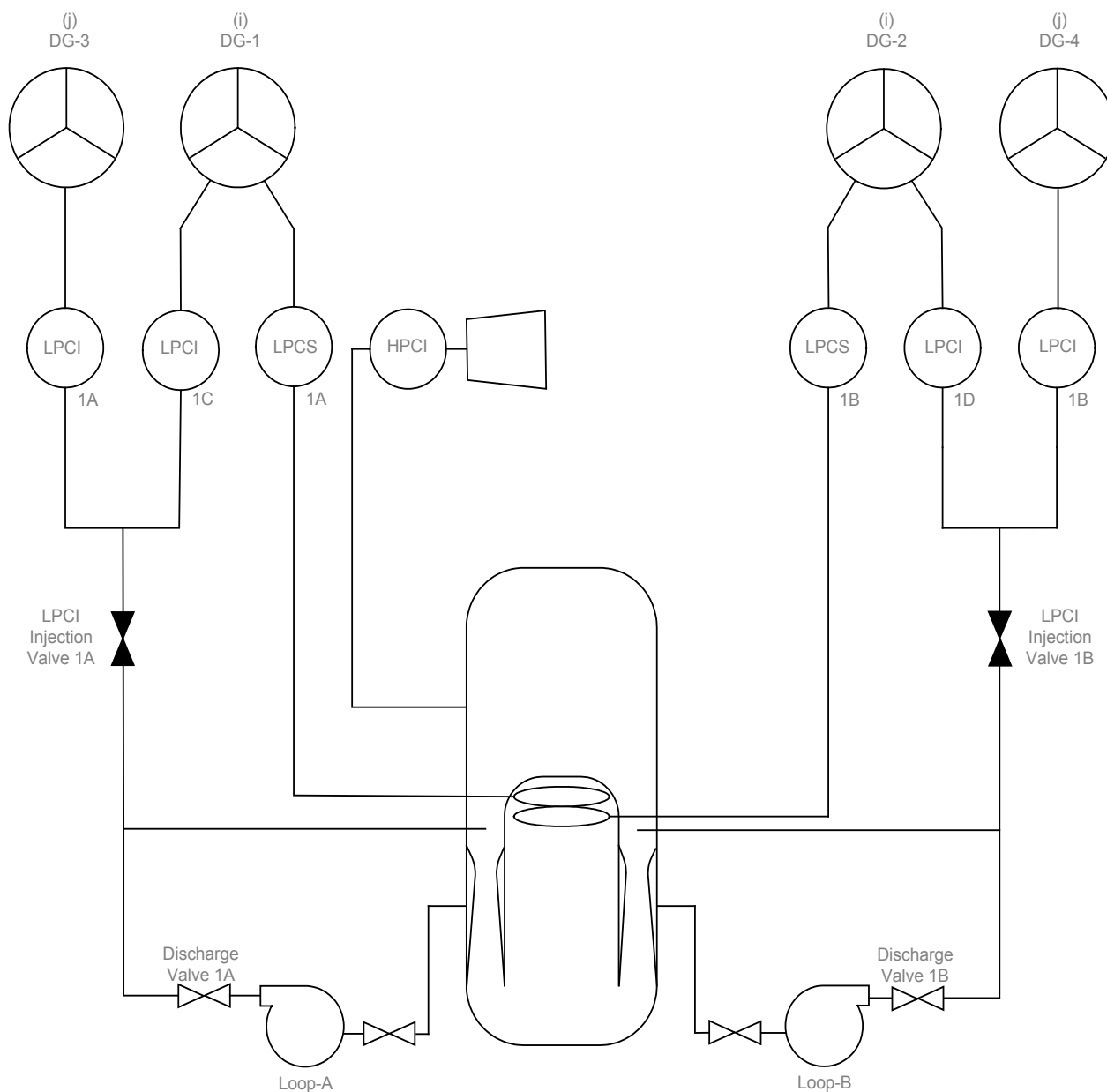


Figure 4.3 ECCS Schematic*

* This ECCS schematic is functionally equivalent for both units as it relates to single failure and ECCS availability. The schematic is provided for Unit 1, but representative of both Units 1 and 2.



**Figure 4.4 Rod Average Power Distributions
for 102%P and []
Mid- and Top-Peaked**



**Figure 4.5 Rod Average Power Distributions
for 102%P and []
Mid- and Top-Peaked**



**Figure 4.6 Rod Average Power Distributions
for []
Mid- and Top-Peaked**



**Figure 4.7 Rod Average Power Distributions
for []
Mid- and Top-Peaked**

5.0 Break Spectrum Analysis Description

The objective of the LOCA break spectrum analyses is to ensure that the operating conditions, break location, break type, break size, and ECCS single failure which produce the maximum PCT [] are identified. The LOCA response scenario varies considerably over the spectrum of break locations. Potential break locations have been separated into two groups: recirculation line breaks and non-recirculation line breaks. The basis for the break locations and potentially limiting single failures analyzed in this report is described in the following sections.

5.1 Limiting Single Failure

Regulatory requirements specify that the LOCA analysis be performed assuming that all offsite power supplies are lost instantaneously and that only safety grade systems and components are available. In addition, regulatory requirements also specify that the most limiting single failure of ECCS equipment must be assumed in the LOCA analysis. The term "most limiting" refers to the ECCS equipment failure that produces the greatest challenge to event acceptance criteria. The limiting single failure can be a common power supply, an injection valve, a system pump, or system initiation logic. The most limiting single failure may vary with break size and location. The potential limiting single failures identified in the UFSAR (Reference 6) are shown below:

- DC power (i) (SF-BATT)
- DC power (j)
- Diesel generator (i)
- Diesel generator (j)
- LPCI injection valve (SF-LPCI)
- High-pressure coolant injection system (SF-HPCI)

The single failures and the available ECCS for each failure assumed in these analyses are summarized in Table 5.1. Other potential failures are not specifically considered because they result in as much or more ECCS capacity.

As indicated earlier, no analysis mitigation credit is assumed for the HPCI system in any of the LOCA analyses presented in this report. A review of Table 5.1 shows that the DC power (i) and LPCI injection valve failures are the two potentially limiting single failures as the other single

failures result in as much or more ECCS capacity. Only five ADS valves are assumed operable in the analyses to support operation with one ADSVOOS and the potential single failure of one ADS valve during the LOCA.

5.2 *Recirculation Line Breaks*

The response during a recirculation line LOCA is dependent on break size. The rate of reactor vessel depressurization decreases as the break size decreases. The high-pressure ECCS and ADS will assist in reducing the reactor vessel pressure to the pressure where the LPCI and LPCS flows start. For large breaks, rated LPCS and LPCI flow is generally reached before or shortly after the time when the ADS valves open so the ADS system is not required to mitigate the LOCA. ADS operation is an important emergency system for small breaks where it assists in depressurizing the reactor system faster, and thereby reduces the time required to reach rated LPCS and LPCI flow.

The two largest flow resistances in the recirculation piping are the recirculation pump and the jet pump nozzle. For breaks in the discharge piping, there is a major flow resistance in both flow paths from the reactor vessel to the break. For breaks in the suction piping, both major flow resistances are in the flow path from the vessel to the pump side of the break. As a result, pump suction side breaks experience a more rapid blowdown, which tends to make the event more severe. For suction side breaks, the recirculation discharge isolation valve on the broken loop closes which allows the LPCI flow to fill the discharge piping and supply flow to the lower plenum and core. For discharge side breaks, the LPCI flow in the broken loop is assumed to exit the system through the break resulting in a decrease in available LPCI flow to the core, thereby increasing the severity of the event. Both suction and discharge recirculation pipe breaks are considered in the break spectrum analysis.

Two break types (geometries) are considered for the recirculation line break. The two types are the double-ended guillotine (DEG) break and the split break.

For a DEG break, the piping is assumed to be completely severed resulting in two independent flow paths to the containment. The DEG break is modeled by setting the break area (at both ends of the pipe) equal to the full pipe cross-sectional area and varying the discharge coefficient between 1.0 and 0.4. The range of discharge coefficients is used to cover uncertainty in the

actual geometry at the break. [

] The most limiting DEG break is determined by varying the discharge coefficient.

A split type break is assumed to be a longitudinal opening or hole in the piping that results in a single break flow path to the containment. Appendix K of 10 CFR 50 defines the cross-sectional area of the piping as the maximum split break area required for analysis.

Break types, break sizes, and single failures are analyzed for both suction and discharge recirculation line breaks.

Section 6.0 provides a description and results summary for breaks in the recirculation line.

5.3 *Non-Recirculation Line Breaks*

In addition to breaks in the recirculation line, breaks in other reactor coolant system piping must be considered in the LOCA break spectrum analysis. Although the recirculation line large breaks result in the largest coolant inventory loss, they do not necessarily result in the most severe challenge to event acceptance criteria. The double-ended rupture of a main steam line is expected to result in the fastest depressurization of the reactor vessel. Special consideration is required when the postulated break occurs in ECCS piping. Although ECCS piping breaks are small relative to a recirculation pipe DEG break, the potential to disable an ECCS system increases their severity.

The following sections address potential LOCAs due to breaks in non-recirculation line piping.

Non-recirculation line breaks outside containment are inherently less challenging to fuel limits than breaks inside containment. For breaks outside containment, isolation or check valve closure will terminate break flow prior to the loss of significant liquid inventory and the core will remain covered. If high-pressure coolant inventory makeup cannot be reestablished, ADS actuation may become necessary. [

] Although analyses of breaks outside containment may be required to address non-fuel

related regulatory requirements, these breaks are not limiting relative to fuel acceptance criteria such as PCT.

5.3.1 Main Steam Line Breaks

A steam line break [

] The break

results in high steam flow out of the broken line and into the containment. Prior to MSIV closure, a steam line break also results in high steam flow in the intact steam lines as they feed the break via the steam line manifold. A steam line break inside containment results in a rapid depressurization of the reactor vessel. Initially the break flow will be high quality steam; however, the rapid depressurization produces a water level swell that results in liquid discharge at the break. For steam line breaks, the largest break size is most limiting because it results in the most level swell and liquid loss out of the break.

[

]

5.3.2 Feedwater Line Breaks

[

]

[
]

5.3.3 HPCI Line Breaks

The HPCI injection line is connected to the feedwater line outside containment.

[
]

The HPCI steam supply line is connected to the main steam line inside containment.

[
]

5.3.4 LPCS Line Breaks

A break in the LPCS line is expected to have many characteristics similar to [

] However, some characteristics of the LPCS line break are unique and are not addressed in other LOCA analyses. Two important differences from other LOCA analyses are that the break flow will exit from the region inside the core shroud and the break will disable one LPCS system. The LPCS line break is assumed to occur just outside the reactor vessel. [

]

5.3.5 LPCI Line Breaks

The LPCI injection lines are connected to the larger recirculation discharge lines. [
]

5.3.6 RWCU Line Breaks

The reactor water cleanup (RWCU) extraction line is connected to a recirculation suction line with an additional connection to the vessel bottom head. [
]

[
]

The RWCU return line is connected to the feedwater line; [
]

5.3.7 Shutdown Cooling Line Breaks

The shutdown cooling suction piping is connected to a recirculation suction line and the shutdown cooling return line is connected to a recirculation discharge line. [
]

5.3.8 Instrument Line Breaks

[

]

**Table 5.1 Available ECCS for
Recirculation Line Break LOCAs**

Assumed Failure *	Recirculation Suction Break	Recirculation Discharge Break
	Systems Remaining ^{†, ‡, §}	Systems Remaining ^{‡, §}
DC power (i) (SF-BATT)	1LPCS + 3LPCI + ADS	1LPCS + 1LPCI + ADS
DC power (j)	2LPCS + 2LPCI + HPCI + ADS	2LPCS + HPCI + ADS
Diesel generator (i)	1LPCS + 3LPCI + HPCI + ADS	1LPCS + 1LPCI + HPCI + ADS
Diesel generator (j)	2LPCS + 2LPCI + HPCI + ADS	2LPCS + HPCI + ADS
LPCI injection valve (SF-LPCI)	2LPCS + 2LPCI + HPCI + ADS	2LPCS + HPCI + ADS
HPCI system (SF-HPCI)	2LPCS + 4LPCI + ADS	2LPCS + 2LPCI + ADS

* Failure of either DC power (i) or diesel generator (i) will result in the loss of one diesel generator (DG-1 or DG-2). The loss of DC power (i) will also result in the loss of the HPCI. The loss of DC power (j) or diesel generator (j) will result in the loss of one diesel generator (DG-3 or DG-4). The ECCS availability presented is consistent with the Unit 1 schematic, Figure 4.3. Since the ECCS availability is functionally equivalent for both units, the information identified in Table 5.1 is representative of both Units 1 and 2.

[†] Systems remaining, as identified in this table for recirculation suction line breaks, are applicable to other non-ECCS line breaks. For a LOCA from an ECCS line break, the systems remaining are those listed for recirculation suction breaks, less the ECCS in which the break is assumed.

[‡] 1LPCI (1 pump into 1 loop) means one RHR pump operating in one LPCI loop, 2LPCI (2 pumps into 1 loop) means two RHR pumps operating in one loop, 3LPCI (3 pumps into 2 loops) means three RHR pumps operating in two loops, 4LPCI (4 pumps into 2 loops) means four RHR pumps operating in two loops.

[§] Although HPCI is expected to be available for some events, no accident analysis mitigation credit is assumed for this system.

6.0 TLO Recirculation Line Break Spectrum Analyses

The largest diameter recirculation system pipes are the suction line between the reactor vessel and the recirculation pump and the discharge line between the recirculation pump and the riser manifold ring. LOCA analyses are performed for breaks in both of these locations with consideration for both DEG and split break geometries. The break sizes considered included DEG breaks with discharge coefficients from 1.0 to 0.4 and split breaks with areas ranging between the full pipe area and [] ft². As discussed in Section 5.0, the single failures considered in the recirculation line break analyses are SF-BATT and SF-LPCI.

[

]

6.1 Break Spectrum Analysis Results

The break spectrum analyses demonstrate that the recirculation line break case with the highest PCT [] is the 1.0 DEG break in the pump suction piping with a single failure of SF-BATT and a top-peaked axial power shape when operating at 102% rated core power and [] These two cases are presented in Table 6.1.

Table 6.2 provides a summary of the [] from the recirculation line break calculations for each of the single failures, state points, and axial power shapes. The event times for the 1.0 DEG break in the pump suction piping with a single failure of SF-BATT and a top-peaked axial power shape when operating at 102% rated core power and []

[] are presented in Table 6.3 and plots of key parameters from the LOCA analyses of this case are provided in Figures 6.1 – 6.15.

**Table 6.1 Break Spectrum Results* for
TLO Recirculation Line Breaks**

Break spectrum case resulting []	1.0 DEG pump suction SF-BATT Top-peaked axial 102%P/[]
Break spectrum case resulting []	1.0 DEG pump suction SF-BATT Top-peaked axial 102%P/[]

* The cases identified in Table 6.1 from the TLO break spectrum analyses are further evaluated in Section 9.0 with exposure dependent analysis.

**Table 6.2 Summary of Break Spectrum [] for
TLO Recirculation Line Breaks**

**Table 6.3 Event Times for the [] from
the TLO Recirculation Line Break Spectrum Analysis**



**Figure 6.1 [] from the
TLO Recirculation Line Break Spectrum Analysis
Upper Plenum Pressure**



**Figure 6.2 [] from the
TLO Recirculation Line Break Spectrum Analysis
Total Break Flow Rate**



**Figure 6.3 [] from the
TLO Recirculation Line Break Spectrum Analysis
Core Inlet Flow Rate**



**Figure 6.4 [] from the
TLO Recirculation Line Break Spectrum Analysis
ADS Flow**



**Figure 6.5 [] from the
TLO Recirculation Line Break Spectrum Analysis
HPCI Flow**



**Figure 6.6 [] from the
TLO Recirculation Line Break Spectrum Analysis
LPCS Flow**



**Figure 6.7 [] from the
TLO Recirculation Line Break Spectrum Analysis
LPCI Flow**



**Figure 6.8 [] from the
TLO Recirculation Line Break Spectrum Analysis
RDIV Flows**



Figure 6.9 [] from the
TLO Recirculation Line Break Spectrum Analysis
Relief Valve Flow



Figure 6.10 [] from the
TLO Recirculation Line Break Spectrum Analysis
Downcomer LOCA Water Level



**Figure 6.11 [] from the
TLO Recirculation Line Break Spectrum Analysis
Upper Plenum Liquid Level**



**Figure 6.12 [] from the
TLO Recirculation Line Break Spectrum Analysis
Hot Channel Liquid Level**



Figure 6.13 [] from the
TLO Recirculation Line Break Spectrum Analysis
Core Bypass Liquid Level



Figure 6.14 [] from the
TLO Recirculation Line Break Spectrum Analysis
Lower Plenum Liquid Level



**Figure 6.15 [] from the
TLO Recirculation Line Break Spectrum Analysis
Hot Channel Inlet Flow**

7.0 Single-Loop Operation LOCA Analysis

During SLO, the pump in one recirculation loop is not operating. A break may occur in either loop, but results from a break in the inactive loop would be similar to those from a two-loop operation break. If a break occurs in the inactive loop during SLO, the intact active loop flow to the reactor vessel would continue during the recirculation pump coastdown period and would provide core cooling similar to that which would occur in breaks during TLO. The system response would be similar to that resulting from an equal-sized break during two-loop operation. A break in the active loop during SLO results in a more rapid loss of core flow and earlier degraded core conditions relative to those from a break in the inactive loop. Therefore, only breaks in the active recirculation loop are analyzed.

A break in the active recirculation loop during SLO will result in an earlier loss of core heat transfer relative to a similar break occurring during two-loop operation. This occurs because there will be an immediate loss of jet pump drive flow. Therefore, fuel rod surface temperatures will increase faster in an SLO LOCA relative to a TLO LOCA. Also, the early loss of core heat transfer will result in higher stored energy in the fuel rods at the start of the heatup. The increased severity of an SLO LOCA can be reduced by applying an SLO multiplier to the two-loop MAPLHGR limit.

7.1 *SLO Analysis Modeling Methodology*

[

]

7.2 *SLO Analysis Results*

[

]

[

]

The SLO analyses are performed with a 0.85 multiplier applied to the two-loop MAPLHGR limit resulting in an SLO MAPLHGR limit of [] kW/ft. [

] The analyses are performed at maximum stored energy fuel conditions. The limiting SLO LOCA is the 1.0 DEG break in the pump suction piping with a single failure of SF-LPCI and a top-peaked axial power shape when operating at [

]

A comparison of the limiting SLO and the limiting two-loop results is provided in Table 7.1. The results in Table 7.1 show that the two-loop LOCA results bound the limiting SLO results when a 0.85 multiplier is applied to the two-loop MAPLHGR limit. [

]

**Table 7.1 Single- and Two-Loop Operation
PCT Summary**

Operation	Limiting Case	PCT (°F)
Single-loop	1.0 DEG pump suction top-peaked SF-LPCI	[]
Two-loop	1.0 DEG pump suction top-peaked SF-BATT	[]

8.0 Long-Term Coolability

Long-term coolability addresses the issue of reflooding the core and maintaining a water level adequate to cool the core and remove decay heat for an extended time period following a LOCA. For non-recirculation line breaks, the core can be reflooded to the top of the active fuel and be adequately cooled indefinitely. For recirculation line breaks, the core will initially remain covered following reflood due to the static head provided by the water filling the jet pumps to a level of approximately two-thirds core height. Eventually, the heat flux in the core will not be adequate to maintain a two-phase water level over the entire length of the core. Beyond this time, the upper third of the core will remain wetted and adequately cooled by core spray. Maintaining water level at two-thirds core height with one core spray system operating is sufficient to maintain long-term coolability as demonstrated by the NSSS vendor (Reference 7). Since fuel temperatures during long-term cooling are low relative to the PCT and are not significantly affected by fuel design, this conclusion is applicable to ATRIUM 11 fuel. This LOCA analysis assesses conditions from the time of the initiation of the break to the time when long term cooling conditions can be established as demonstrated in Reference 7.

9.0 Exposure-Dependent LOCA Analysis Description and Results

Exposure-dependent LOCA results for ATRIUM 11 fuel are obtained by repeated analyses based on the cases identified in Table 6.1 from the break spectrum analysis []

Table 9.1 shows the exposure-dependent LOCA analysis results for the ATRIUM 11 fuel. The S-RELAP5 model is applied to obtain these results as described in Section 4.2. The analysis is performed at []

[] which ensures appropriate limits are applied up to the monitored maximum assembly average and rod average exposure limits. The MAPLHGR input is consistent with the data in Figure 2.1. []

[] Exposure-dependent fuel rod data is provided from RODEX4 results []

[] The impact of thermal conductivity degradation is addressed with RODEX4.

The ATRIUM 11 limiting PCT is 1882°F at [] exposure for the 1.0 DEG break in the pump suction piping with a single failure of SF-BATT and a top-peaked axial power shape when operating at 102% rated core power and []. The maximum local MWR of 4.56% occurred at [] exposure, [] Analysis results show that the hot rod average MWR is 0.27%. Since all other planes in the core are at lower power, the core average metal water reaction (CMWR) will be significantly less than 0.27%.

Figure 9.1 shows the cladding temperature of the ATRIUM 11 PCT rod as a function of time for the limiting PCT result from the exposure-dependent LOCA analysis. The maximum temperature of 1882°F occurs at []. These results demonstrate the acceptability of the ATRIUM 11 MAPLHGR limit shown in Figure 2.1.

**Table 9.1 ATRIUM 11 Exposure-Dependent
LOCA Analysis Results**

CMWR is < 0.27% at all exposures.*

* The rod average MWR for the hot rod is 0.27% which supports the conclusion that the CMWR is less than 0.27%.



**Figure 9.1 Limiting [] PCT
Exposure-Dependent LOCA Analysis**

10.0 Conclusions

The AURORA-B LOCA Evaluation Model was applied to confirm the acceptability of the ATRIUM 11 MAPLHGR limit and [] for Brunswick Units 1 and 2. The following conclusions were made from the analyses presented in this report.

- The limiting PCT is obtained from Section 9.0 based on a recirculation line break of 1.0 DEG break in the pump suction piping with a single failure of SF-BATT and a top-peaked axial power shape when operating at 102% of rated core power and [].
- The limiting break analysis identified above satisfies all the acceptance criteria specified in 10 CFR 50.46. The analysis is performed in accordance with 10 CFR 50.46 Appendix K requirements.
- The multiplier applied to the MAPLHGR limit for SLO is 0.85 for ATRIUM 11 fuel. [] This multiplier ensures that a LOCA from SLO is less limiting than a LOCA from two-loop operation.
- The acceptance criteria of the Code of Federal Regulations (10 CFR 50.46) are met for operation at or below the ATRIUM 11 MAPLHGR limit given in Figure 2.1 [].
 - Peak PCT < 2200°F.
 - Local cladding oxidation thickness < 17%.
 - Total hydrogen generation < 1%.
 - Coolable geometry, satisfied by meeting peak PCT, local cladding oxidation, and total hydrogen generation criteria.
 - Core long-term cooling, satisfied by concluding core flooded to top of active fuel or core flooded to the jet pump suction elevation (Reference 1).
- The MAPLHGR limit and [] are applicable for ATRIUM 11 full cores as well as transition cores containing ATRIUM 11 fuel.

11.0 References

1. ANP-10332(P) Revision 0, *AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios*, Framatome, February 2014.
2. PROJECT NO.: 728/DOCKET NO. 99902041, Draft Safety Evaluation for Framatome Inc. Topical Report ANP-10332P, Revision 0, *AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios*, (CAC NO. MF3829/EPID: L-2014-TOP-0004) US NRC, August 2018.
3. XN-NF-82-07(P)(A) Revision 1, *Exxon Nuclear Company ECCS Cladding Swelling and Rupture Model*, Exxon Nuclear Company, November 1982.
4. BAW-10247(P)(A) Revision 0, *Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors*, Framatome, February 2008.
5. Safety Evaluation by the Office of Nuclear Reactor Regulation, Licensing Topical Report NEDC-33006P, "General Electric Boiling Water Reactor Maximum Extended Load Line Limit Analysis Plus," General Electric Hitachi Nuclear Energy America, LLC, October 2008 (ML081130008).
6. *Updated FSAR Brunswick Steam Electric Plant, Units 1 and 2*, Revision 25.
7. NEDO-20566A, *General Electric Company Analytical Model for Loss of Coolant Analysis in Accordance with 10CFR50 Appendix K*, September 1986.

Appendix A Limitations from the Draft Safety Evaluation for LTR ANP-10332P

Disposition of additional limitations and conditions related to the draft SE for ANP-10332P, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios."

There are 40 limitations and conditions listed in the Methods LTR SER (Reference 2). The table below lists each of the 40 limitations and conditions and provides a description of compliance for each limitation and condition.

Appendix A (Continued)

Disposition of additional limitations and conditions related to the Draft SE for ANP-10332P, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios"

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
1	The AURORA-B LOCA evaluation model shall be supported by an approved nodal core simulator and lattice physics methodology. Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model shall identify the nodal core simulator and lattice physics methods supporting the AURORA-B LOCA analysis and reference an NRC-approved TR that confirms compatibility of these methods with the AURORA-B LOCA evaluation model.	MICROBURN-B2 and the underlying cross section generation code, CASMO-4, are used for the nodal core simulator and lattice physics methodology from the following NRC-approved TR: EMF-2158(P)(A) Revision 0, "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2," Siemens Power Corporation, October 1999.
2	The full, stand-alone version of the RODEX4 code shall be used in accordance with an approved methodology to supply steady-state fuel thermal-mechanical inputs to the AURORA-B LOCA evaluation model.	The stand-alone version of RODEX4 is used to supply steady-state fuel thermal-mechanical input in accordance with the following NRC-approved methodology: BAW-10247PA Revision 0, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors," AREVA NP Inc., February 2008.
3	The AURORA-B LOCA evaluation model may not be used to perform analyses that result in any of its constituent components or supporting codes (i.e., S-RELAP5, RODEX4 kernel, RODEX4, core simulator and lattice physics methods) being operated outside approved limits documented in their respective TRs, SEs, code manuals, and plant-specific licensing applications.	The analyses are within the limits of the TRs, SEs, code manuals and plant-specific licensing applications.

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
4	TR ANP-10332P [].	[LOCA report.]
5	The conclusions of this SE apply only to the use of the AURORA-B LOCA evaluation model for the purpose of demonstrating compliance against currently existing regulatory requirements discussed above in Section 2.1; [].	The analyses [].
6	This SE does not constitute []. [] of the evaluation model.	The evaluation model [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
7	[].	The [].
8	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model shall provide [].	Analysis was [].
9	The AURORA-B LOCA evaluation model shall [] in the response to RAI 114.	The analyses were [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
10	The AURORA-B LOCA evaluation model [].	The [] in the analyses.
11	Safety analyses performed with the AURORA-B LOCA evaluation model [].	[].
12	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	A [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
13	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	The [].
14	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	A [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
15	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1.	NRC staff [1.
16	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1.	The S-RELAP5 [1.

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
		This arrangement []. The [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
17	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	A [].
18	The AURORA-B LOCA evaluation model [].	The analyses [].
19	The AURORA-B LOCA evaluation model [].	A [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
20	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	Analyses [].
21	The AURORA-B LOCA evaluation model [].	The [].
22	In lieu of the conservative approach of using [].	The analyses [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
23	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	The [].
24	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	The analyses [].
25	Safety analyses performed with the AURORA-B LOCA evaluation model [].	A [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
26	Safety analyses performed with the AURORA-B LOCA evaluation model [].	The analyses [].
27	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [].	[].
28	To assure satisfaction of GDC 35 (or similar plant-specific requirement), [].	The [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
29	Safety analyses for [].	The application of AURORA-B LOCA []. []. Approximately [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
30	Simulations supporting plant safety analyses [1.	Simulations [1.

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
31	As discussed in Section 3.3.5.7, Framatome used [1.	The [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
32	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1.	The NRC staff [1.
33	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1.	The [1.

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
34	The NRC staff has not specifically reviewed any plant parameters in ANP-10332P or deemed them acceptable for use in plant safety analyses. Therefore, [].	The licensee [].
35	Safety analyses performed with the AURORA-B LOCA evaluation model [].	A [].
36	The AURORA-B LOCA evaluation model [].	The surrounding rods were considered when assessing calculated results and determining figures of merit.

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
37	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1]	The [].
38	Plant-specific licensing applications referencing the AURORA-B LOCA evaluation model [1].	The [].

Limitation and Condition Number from NRC SER	Limitation and Condition Description	Disposition/Discussion
39	New or modified Framatome [].	The analyses [].
40	Except as discussed in Section 4.3 of this SE, the NRC staff [].	The [].

Affidavit for ANP-3674P, Brunswick Units 1 and 2 LOCA
Analysis for ATRIUM 11 Fuel

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3674P, Revision 1, "Brunswick Units 1 and 2 LOCA Analysis for ATRIUM 11 Fuel," dated October 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

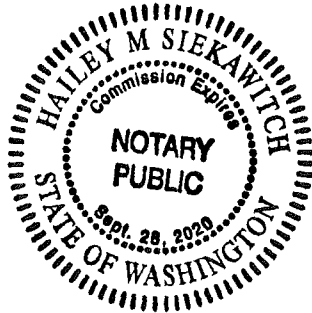
9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Alan E. McGinnis

SUBSCRIBED before me this 8th
day of October, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3694NP, ATWS-I Analysis Methodology for
Brunswick Using RAMONA5-FA



ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA

ANP-3694NP
Revision 0

June 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
LIST OF TABLES	vii
LIST OF FIGURES	viii
NOMENCLATURE	x
1.0 INTRODUCTION AND SCOPE	1-1
2.0 SUMMARY	2-1
3.0 REGULATORY REQUIREMENTS	3-1
3.1 Compliance with Standard Review Plan, Chapter 15, Section 15.0.2.....	3-2
3.2 ATWS-I Transient Scenarios	3-2
3.2.1 Turbine Trip.....	3-3
3.2.2 Two Recirculation Pump Trip	3-4
4.0 PHYSICAL PHENOMENA.....	4-1
4.1 Unstable Oscillations in General.....	4-1
4.2 Density Waves in a Boiling Channel	4-2
4.2.1 Density Waves in Parallel Channels between Two Plena	4-4
4.2.2 Density Wave with Power Oscillations due to Density- Reactivity Coupling	4-5
4.3 Oscillation Modes – The Global Mode	4-6
4.4 Oscillation Modes – The Regional Mode	4-7
4.5 Oscillation Modes – The Rotational Mode	4-8
4.6 Oscillation Modes – Axial Power Shape	4-9
4.7 Large Amplitude and Limit Cycles of Global Mode Oscillations with Linearized Hydraulics	4-10
4.8 Large Amplitude Regional Mode Oscillations with Linearized Hydraulics	4-11
4.9 Large Amplitude Pure Thermal-Hydraulic Density Waves	4-11
4.10 Very Large Nonlinear Oscillations of Global and Regional Types	4-13
4.11 Prompt-Criticality	4-15
4.12 Effect of Bypass Flow with Possible Boiling.....	4-16

4.13	Cyclical Dryout and Rewetting	4-16
4.13.1	Impact of Cyclical Dryout and Rewetting on Very Large Oscillations.....	4-18
4.14	Vessel Considerations	4-19
4.15	Phenomena Ranking	4-21
4.16	Major Assumptions	4-27
5.0	CODE DESCRIPTION.....	5-1
5.1	Neutronics.....	5-1
5.1.1	Adaptive Two-Group 3-D Neutron Kinetics	5-2
5.1.2	Numerical Solution	5-7
5.1.2.1	Interfacial Diffusion Coefficient Approximation	5-8
5.1.2.2	Steady State and Initialization	5-11
5.1.2.3	Time Integration Procedure	5-11
5.1.3	Cross Section Representation	5-15
5.1.4	Power Generation	5-15
5.1.4.1	Prompt Fission Heat.....	5-16
5.1.4.2	Decay Heat.....	5-16
5.1.5	Power Deposition	5-19
5.2	Fuel Thermodynamics	5-20
5.2.1	ATWS-I Fuel Pin Heat Conduction.....	5-20
5.2.2	ATWS-I Heater Rod Heat Conduction.....	5-29
5.2.3	Heat Transfer Coefficient	5-36
5.2.4	Hot Fuel Pin Model.....	5-41
5.2.5	Material Properties	5-43
5.2.6	Pellet-Clad Gap Heat Transfer Coefficient	5-45
5.2.7	Radial Power Deposition Distributions in Fuel Pellets.....	5-51
5.3	Thermal-hydraulic Model	5-52
5.3.1	General Description of the System Considered	5-53
5.3.2	[]	5-56
5.3.3	Vapor generation rate	5-60
5.3.4	Mass conservation	5-62
5.3.5	Energy Conservation.....	5-63
5.3.6	[].....	5-67
5.3.7	[] Momentum Conservation	5-69
5.3.7.1	[]	5-74
5.3.7.2	[] Formulation in the Core.....	5-76
5.3.8	Pressure Calculation	5-78
5.3.9	Steam Dome Equations	5-81

5.3.10	Recirculation Flow	5-83
5.3.11	Constitutive Equations	5-86
5.3.11.1	Friction and Two Phase Friction Multiplier	5-86
5.3.11.2	Local Pressure Loss Models	5-88
5.3.11.3	Abrupt Contraction/Expansion Pressure Change Model	5-89
5.3.11.4	[.....]	5-90
5.3.11.5	Thermodynamic Steam-Water Properties	5-91
5.3.11.6	[.....]	5-91
5.3.12	Numerical Integration Techniques	5-93
5.4	Steam Line Flow Dynamics	5-94
5.5	SPECIAL MODELS	5-97
5.5.1	Recirculation Pump Model	5-97
5.5.1.1	Pump Model 1	5-98
5.5.1.2	Pump Model 2	5-98
5.5.1.3	Pump Model 3	5-99
5.5.2	Jet Pump Model	5-100
5.5.3	Steam Separator Model	5-102
5.5.3.1	Flow Inertia	5-103
5.5.3.2	Carry under Flow	5-103
5.5.4	Feedwater Sparger Condensation Model	5-107
5.5.5	Dryout and Rewetting Model	5-108
5.6	PLANT CONTROL AND PROTECTION SYSTEMS	5-116
5.6.1	Pressure Control System	5-117
5.6.2	Turbine Valve Regulator	5-117
5.6.3	Bypass Valve Regulator	5-117
5.6.4	Feedwater Controller	5-118
5.6.5	Safety and Relief Valves	5-118
5.6.6	Main Steam Isolation Valve (MSIV)	5-119
5.6.7	Plant Protection System (PPS)	5-120
5.6.8	Manual Operator Actions	5-120
5.7	NUMERICAL TIME INTEGRATION	5-120
5.7.1	Neutron Kinetics	5-121
5.7.2	Fuel Thermodynamics	5-121
5.7.3	Vessel Hydraulics	5-121
5.7.4	Coupling of the Neutronics and Hydraulics Integration	5-122
6.0	CODE VALIDATION	6-1
6.1	Test Suite and Acceptance Criteria	6-2
6.2	Benchmarking to Void Fraction Tests	6-4

6.3	Benchmarking to KATHY Pressure Drop Tests	6-7
6.4	Benchmarking to KATHY Stability Tests.....	6-11
6.5	Benchmarking to KATHY Dryout/Rewet Tests.....	6-14
6.6	Benchmarking to Linear Reactor Stability Benchmarks	6-27
6.6.1	[.....]	6-27
6.6.2	[.....]	6-28
6.6.3	[.....]	6-28
6.6.4	[.....]	6-29
6.7	Benchmarking to Non-Linear Reactor Benchmarks.....	6-29
6.7.1	Oskarshamn Nonlinear Instability.....	6-29
6.7.2	BWR A Feedwater Transient with Non-Linear Instability	6-34
7.0	SAMPLE PROBLEMS	7-1
7.1	Turbine Trip	7-1
7.2	Two Recirculation Pump Trip.....	7-8
8.0	CALCULATION PROCEDURE.....	8-1
9.0	REFERENCES	9-1
APPENDIX A STEADY STATE DRYOUT CORRELATION CPROM.....		A-1
A.1	DESCRIPTION OF CPROM CORRELATION	A-1
A.2	CPROM CORRELATION FOR ATRIUM 10XM	A-5
A.3	CPROM BOUNDS OF APPLICABILITY	A-19
A.4	CPROM COEFFICIENT GENERATION FOR NEW FUEL DESIGNS.....	A-20
APPENDIX B HEAT TRANSFER DATA FROM KATHY LOOP STABILITY TESTING OF ATRIUM 10XM		B-1
B.1	SUMMARY OF HEAT TRANSFER COEFFICIENT DATA AND OBSERVATIONS	B-1
B.2	HEAT TRANSFER COEFFICIENT UNDER WETTED CONDITIONS	B-3
B.3	[.....]	B-3
B.4	REFERENCES	B-6

APPENDIX C	INVESTIGATION OF THE DYNAMIC EFFECTS OF INTERFACIAL FRICTION.....	C-1
APPENDIX D	ATRIUM 11 CPROM CORRELATION	D-1
D.1	CPROM CORRELATION FOR ATRIUM 11	D-1
D.2	ATRIUM 11 CPROM BOUNDS OF APPLICABILITY	D-14
APPENDIX E	CHROMIA FUEL ROD PROPERTIES	E-1
E.1	FUEL CONDUCTIVITY	E-1
E.2	[]	E-2
E.3	REFERENCES	E-3
APPENDIX F	BRUNSWICK ATRIUM 11 ATWS-I ANALYSES	F-1

List of Tables

Table 4-1: Ranking of Phenomena and Processes	4-23
Table 5-1: Summary of State Equations	5-94
Table 5-2: Homologous Pump Curves Definition	5-100
Table 6-1: Summary of Void Fraction Test Conditions	6-5
Table 6-2: Summary of Pressure Drop Test Conditions	6-8
Table 6-3: Dryout and rewetting ATRIUM 10XM KATHY test runs.....	6-17
Table 7-1: TTWB Sensitivity Study Results	7-4
Table 7-2: 2RPT Sensitivity Study Results	7-9
Table 8-1: ATWS-I Limitation and Conditions.....	8-4

List of Figures

Figure 5-1:	Fuel rod discretization	5-24
Figure 5-2:	Heater rod discretization.....	5-31
Figure 5-3:	Loop Parts in the Vessel Hydraulics Model	5-54
Figure 5-4:	Recirculation Loop.....	5-84
Figure 5-5:	Steam Line Model.....	5-95
Figure 5-6:	The Loop Parts of the Vessel Hydraulics.....	5-105
Figure 6-1:	Validation of [] using FRIGG, ATRIUM-10 and ATRIUM 10XM Void Data.....	6-6
Figure 6-2:	Validation of Pressure Drop Prediction versus KATHY ATRIUM-10 Measured Data	6-9
Figure 6-3:	Validation of Pressure Drop Prediction versus KATHY ATRIUM 10XM Measured Data.....	6-10
Figure 6-4:	Validation of Decay Ratio Prediction versus KATHY Measured Data	6-13
Figure 6-5:	Validation of Frequency Prediction versus KATHY Measured Data	6-13
Figure 6-6:	Limiting Temperature for KATHY ATRIUM 10XM []	6-18
Figure 6-7:	Limiting Temperature for KATHY ATRIUM 10XM []	6-18
Figure 6-8:	Limiting Temperature for KATHY ATRIUM 10XM []	6-19
Figure 6-9:	Limiting Temperature for KATHY ATRIUM 10XM []	6-19
Figure 6-10:	Limiting Temperature for KATHY ATRIUM 10XM test []	6-20
Figure 6-11:	Limiting Temperature for KATHY ATRIUM 10XM []	6-20
Figure 6-12:	Limiting Temperature for KATHY ATRIUM 10XM []	6-21
Figure 6-13:	Limiting Temperature for KATHY ATRIUM 10XM []	6-21
Figure 6-14:	Limiting Temperature for KATHY ATRIUM 10XM []	6-22
Figure 6-15:	Limiting Temperature for KATHY ATRIUM 10XM []	6-22
Figure 6-16:	Limiting Temperature for KATHY ATRIUM 10XM []	6-23
Figure 6-17:	Limiting Temperature for KATHY ATRIUM 10XM []	6-23
Figure 6-18:	Limiting Temperature for KATHY ATRIUM 10XM []	6-24
Figure 6-19:	Limiting Temperature for KATHY ATRIUM 10XM []	6-24
Figure 6-20:	Limiting Temperature for KATHY ATRIUM 10XM []	6-25

Figure 6-21:	Limiting Temperature for KATHY ATRIUM 10XM [].....	6-25
Figure 6-22:	Limiting Temperature for KATHY [].....	6-26
Figure 6-23:	Limiting Temperature for KATHY [].....	6-26
Figure 6-24:	Oskarshamn-2 Non-Linear Stability Simulation Core Power, Imposed Pump Speed	6-31
Figure 6-25:	Oskarshamn-2 Non-Linear Stability Simulation Core Power - Zoom, Imposed Pump Speed	6-31
Figure 6-26:	Oskarshamn-2 Non-Linear Stability Simulation Recirculation Flow, Imposed Pump Speed	6-32
Figure 6-27:	Oskarshamn-2 Non-Linear Stability Simulation Core Power, Match Recirculation Flow	6-32
Figure 6-28:	Oskarshamn-2 Non-Linear Stability Simulation Core Power - Zoom, Match Recirculation Flow	6-33
Figure 6-29:	Oskarshamn-2 Non-Linear Stability Simulation Recirculation Flow, Match Recirculation Flow	6-33
Figure 6-30:	BWR [] Transient Non-Linear Stability Simulation.....	6-35
Figure 7-1:	TTWB Base Case Core Power	7-5
Figure 7-2:	TTWB Base Case Core Inlet Flow.....	7-5
Figure 7-3:	TTWB Base Case Core Inlet Subcooling.....	7-6
Figure 7-4:	TTWB Base Case Limiting Channel Inlet Flow	7-6
Figure 7-5:	TTWB Base Case Vessel Water Level	7-7
Figure 7-6:	TTWB Base Case Limiting Channel PCT	7-7
Figure 7-7:	2RPT Base Case Core Power	7-9
Figure 7-8:	2RPT Base Case Core Inlet Flow.....	7-10
Figure 7-9:	2RPT Base Case Limiting Channel Inlet Flow	7-10
Figure 7-10:	2RPT Base Case Core Inlet Subcooling.....	7-11
Figure 7-11:	2RPT Base Case Vessel Water Level	7-11
Figure 7-12:	2RPT Base Case Limiting Channel PCT	7-12

Nomenclature

Acronym	Definition
2RPT	Two Recirculation Pump Trip
ANS	American Nuclear Society
ATWS	Anticipated Transient Without Scram
ATWS-I	Anticipated Transient Without Scram With Instability
BOC	Beginning of Cycle
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CHF	Critical Heat Flux
CPR	Critical Power Ratio
CPRM	Critical Power Reduced Order Model
DC	Downcomer
DNB	Departure from Nucleate Boiling
DIVOM	Delta over Initial Versus Oscillation Magnitude
EFW	Extended Flow Window
EM	Evaluation Model
EOC	End of Cycle
EOI	Emergency Operating Instructions
EOP	Emergency Operating Procedure
EPU	Extended Power Uprate
FoM	Figure of Merit
GDC	General Design Criteria
HPCI	High Pressure Coolant Injection
HTC	Heat Transfer Coefficient
KATHY	Karlstein thermal-hydraulic loop test facility
LCA	Limit Cycle Amplitude
LHGR	Linear Heat Generation Rate
LP	Lower Plenum
LPRM	Local Power Range Monitor

Acronym	Definition
MCPR	Minimum Critical Power Ratio
MELLLA	Maximum Extended Load Line Limit Analysis
MSIV	Main Steam Isolation Valve
OI	Oscillation Inception
PBDA	Period Based Detection Algorithm
PCT	Peak Clad Temperature
PDO	Post Dryout
PHE	Peak Hot Excess
PIRT	Phenomena Identification and Ranking Table
PPS	Plant Protection System
PWR	Pressurized Water Reactor
QA	Quality Assurance
RCIC	Reactor Core Isolation Cooling
SLC	Standby Liquid Control
SP	Standpipe
SRP	Standard Review Plan
SRV	Safety/Relief Valve
SS	Steam Separators
TR	Topical Report
TTWB	Turbine Trip With Bypass
UP	Upper Plenum
USNRC	United States Nuclear Regulatory Commission

Abstract

This report presents a Brunswick plant specific methodology for licensing the Extended Flow Window (EFW) operation of BWR3 to BWR6 plants with regard to Anticipated Transient without Scram with Instability (ATWS-I). The method aims at addressing the fuel specific impacts of the ATWS-I event. The methodology presented in this report utilizes the RAMONA5-FA computer code. The presented version of RAMONA5-FA has been modified to be capable of simulating the severe power and flow oscillations associated with core instabilities unsuppressed with scram. The code applies advanced models for post-dryout heat transfer for the calculation of the cladding temperature excursion. These post-dryout models are based on, and benchmarked against, data obtained from the Karlstein thermal-hydraulic loop (KATHY) test facility where a full scale electrically heated ATRIUM 10XM bundle was tested under realistic ATWS-I conditions of severe unstable density waves with simulated reactivity and power feedback.

The RAMONA5-FA code has been benchmarked against both single bundle KATHY measurements as well as regional and global oscillations in actual BWR plants. The KATHY benchmarks include pressure drop, void fraction, and stability measurements for several bundle designs. The plant stability benchmarks include benchmarks in both the linear and nonlinear instability domains.

In addition to benchmarking, sample ATWS-I transients, along with selected sensitivities are presented to better understand the event. Finally, a calculation procedure is described to define the process and conservatisms to be used in licensing calculations.

1.0 INTRODUCTION AND SCOPE

This document presents a description of BWR instability transients that are not terminated by scram, and thus power and flow oscillations grow to large amplitudes (see References 1 and 2). This class of transients is referred to as Anticipated Transients Without Scram with Instability (ATWS-I). This report documents a RAMONA5-FA based method for evaluating the fuel-related aspects of these events.

The methodology complies with the USNRC requirements of Section 15.8 of NUREG-800, Reference 3. The method is applicable to the limiting ATWS-I events covering the event from the initiation through inception of oscillations and final suppression through operator action.

Section 2 presents a summary of the method and its intended application. Section 3 identifies the regulatory requirements, as well as the potential limiting ATWS-I transients. Section 4 is devoted to a detailed qualitative discussion of the physical phenomena pertinent to the ATWS-I evaluation. With this background, the development campaign to prepare the transient system code, RAMONA5-FA, for the task of calculating ATWS-I transients is put in perspective. The modifications to the approved RAMONA5-FA code (Reference 22) are presented in Section 5. The validation of the code capabilities with regard to reactor oscillations as well as transient hydraulic test loop measurements is presented in Section 6. Having demonstrated the capability of the code to calculate an ATWS-I transient, Section 7 presents the sensitivity to important phenomena to demonstrate that the methodology is robust. The remaining element of the methodology is the ATWS-I licensing basis procedure for demonstrating that the ATWS/Stability Mitigation Actions are effective in maintaining core coolability described in Section 8.

Appendices present special topics; Appendix A is devoted to presenting a step by step derivation of the new critical power reduced order model (CPROM) formulation for ATRIUM 10XM, Appendix B presents the special topic of [

]

[

] Appendix D

presents the application of the CPROM correlation to ATRIUM 11 fuel, and Appendix E provides the Chromia doped pellet property models. Appendix F provides the results of the application of the methodology to ATRIUM 11 fuel and the Brunswick plants.

2.0 SUMMARY

A new plant specific methodology for the evaluation of Anticipated Transients Without Scram with Instability (ATWS-I) is presented. This report documents a RAMONA5-FA based method for evaluating the fuel specific portion of the event. This method is intended to cover the initial ATWS-I event through the time that operator actions suppress core oscillations for Brunswick Units 1 and 2. This method is not intended for use in evaluating containment effects or over pressurization during the event.

A key improvement of the RAMONA5-FA code is the addition of [

]

RAMONA5-FA has been benchmarked against both linear and non-linear stability transients. These benchmarks include hydraulic-only oscillations at the KATHY test facility as well as full core reactor transients. These benchmarks demonstrate that RAMONA5-FA can adequately predict oscillatory behavior.

A sample ATWS-I application problem based on the Brunswick BWR4 reactor has been presented. Various sensitivities have been performed to examine the sensitivity to important parameters and to help validate the conclusions of the PIRT. The application of this methodology to ATRIUM 11 at Brunswick is provided in Appendix F.

3.0 REGULATORY REQUIREMENTS

The regulatory requirements for the ATWS-I event are defined in 10 CFR 50.62.

Specifically, 10 CFR 50.62 lays out the required design features and the requirements for the assessment of their adequacy. Additional regulatory requirements that could be affected by fuel design for these events are compliance with General Design Criteria (GDC) 12 and 35 in Appendix A to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50). Specifically:

“GDC 12: The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.”

“GDC 35: A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.”

While NUREG-0800 Standard Review Plan (SRP) Chapter 15, Section 15.8 (Reference 3) also identifies GDC 14, 16, 38, and 50 as applicable to an ATWS-I event. These general design criteria define requirements for the vessel and containment and [] and are therefore not addressed in this report.

The ATWS-I event was originally addressed generically for operation within the MELLLA domain (Reference 1), SRP 15.8 states:

“BWRs that implement both extended power uprate (EPU) and expanded power-flow domains (e.g., MELLLA+), the licensee will demonstrate that the ATWS/Stability Mitigation Actions are effective in maintaining core coolability.”

The modification of the RAMONA5-FA evaluation model (EM), that was originally developed and approved for application to DIVOM linear instabilities in Reference 7, has been extended to be the transient simulator that will be used to assess the fuel specific impact of the mitigation actions on the ATWS-I event. This methodology is not intended to cover system or containment impacts of the ATWS-I event.

3.1 *Compliance with Standard Review Plan, Chapter 15, Section 15.0.2*

NUREG-0800 Chapter 15, Section 15.0.2 provides guidance to the Nuclear Regulatory Commission (USNRC) reviewer with respect to reviewing the technical contents of a submittal, typically a Topical Report (TR) pertinent to transient and accident analysis methodology. To accomplish this task, the USNRC provided the reviewer a list of criteria in Chapter 15.0.2 of the SRP as a means of arriving at a sound technical conclusion. The areas of considerations listed in Chapter 15.0.2 are provided below:

- Item 1. Documentation. This document satisfies this requirement.
- Item 2. Evaluation Model. Refer to Section 5.0.
- Item 3. Accident Scenario Identification Process. Refer to Section 3.2.
- Item 4. Code Assessment Database. Refer to Section 3.2.
- Item 5. Uncertainty Analysis. Refer to Section 8.0.
- Item 6. Quality Assurance (QA) Plan. Refer to Reference 4. Reference 4 is the basis for quality assurance in both the development and application of RAMONA5-FA for ATWS-I.

3.2 *ATWS-I Transient Scenarios*

Two events are considered as potentially limiting. Both events result in a trip of the recirculation pumps. This trip reduces core flow to natural circulation while core power remains high which can quickly put the reactor deep within the instability region. These two events are (1) Turbine Trip With Bypass (TTWB), and (2) Two Recirculation Pump Trip (2RPT).

3.2.1 Turbine Trip

The first event, the TTWB, is initiated by a turbine trip. The recirculation pumps are tripped either by the turbine stop valve closure, or an ATWS high pressure pump trip. Core flow drops rapidly to natural circulation which drives core power lower. As the core settles at natural circulation, the feedwater temperature begins to decrease due to the loss of extraction steam. The feedwater temperature decrease causes core power to rise. If no action is taken, then core power will rise to the point that it crosses the instability boundary. Without the ability to scram, and if mitigating operator action is sufficiently delayed, oscillations will begin to grow and will reach large magnitudes, accompanied by reverse flow at the inlet of the hot channels. Once the oscillations reach sufficient magnitude, cyclical dryout and rewetting of the cladding surface will begin. If the oscillations continue to grow, they can reach sufficient magnitude that rewetting is no longer possible and large excursions of clad temperature that could potentially challenge acceptance criteria will occur.

In order to prevent large amplitude oscillations plant Emergency Operating Instructions (EOI) or Emergency Operating Procedures (EOP) instruct the operators to reduce water level upon recognition of an ATWS scenario. This reduction in water level has two primary effects. The first is to reduce core flow by reducing the density head on the downcomer side of the loop. The resulting reduction in core flow also serves to reduce core power. In addition, the water level is reduced to a level that is below the elevation of the feedwater spargers. At this point in the transient scenario, the cold feedwater is spraying through a steam environment and falling a significant distance until it reaches the water level. Passing through the steam environment heats the feedwater to the point that it approaches saturation. This significantly reduces the core inlet subcooling, which not only directly adds a stabilizing force to the system, but also reduces core power further stabilizing the system. The suppression of oscillations and reduction in power terminate any temperature excursion in the fuel and ends the fuel-specific portion of the ATWS-I event.

The EOI/EOP also specify that operators initiate boron injection upon recognition of an ATWS condition. Boron injection normally happens after water level reduction due to system delays in the Standby Liquid Control (SLC) system. The boron injection serves to shutdown core power and terminates the ATWS-I event. As this action occurs after the limiting fuel portion of the event, this operator action will not be simulated.

3.2.2 Two Recirculation Pump Trip

The two recirculation pump trip event (2RPT) evolves similarly to the TTWB event with two exceptions, the event initiation and the feedwater temperature excursion. Since the 2RPT event does not involve a turbine isolation, the turbine remains online and extraction steam to the feedwater heaters is maintained so the feedwater temperature remains significantly higher than the TTWB event. Because of this, the power excursion in the 2RPT event is mild which results in a less severe event for the same operator intervention times. One difference between the two transient scenarios is that the TTWB event should generate an automatic scram very early in the event leading to earlier identification of the ATWS scenario by the operators. There may not be a scram signal at the initiation of the 2RPT which means the event may be allowed to progress further due to a delayed identification of ATWS by the operator. As such, the 2RPT may become limiting if operator action in the TTWB event occurs fast enough to suppress oscillations prior to dryout.

4.0 **PHYSICAL PHENOMENA**

In this section, a review of the basic physical phenomena that occurs during an ATWS-I event is presented. These can be divided into the phenomena leading to power and flow oscillations, and the dryout phenomena under these oscillatory conditions. [

]

4.1 ***Unstable Oscillations in General***

A feedback system is unconditionally unstable in the case of positive feedback, i.e., a perturbation in a system parameter results in enforcing the perturbation. This kind of divergence is not oscillatory. In systems with negative feedback, i.e., a perturbation in a system parameter results in reducing the perturbation may or may not be stable depending on other system characteristics. Immediate negative feedback makes the system unconditionally stable. On the other hand, delayed negative feedback may render the system unstable if the magnitude of the feedback is sufficiently large. In the case of strong delayed negative feedback, the corrective effect of the feedback overshoots the original perturbation and the system undergoes oscillations of exponentially increasing magnitude. This type of oscillation is possible in BWRs.

The simple description of the feedback effects outlined above applies to linear systems, or nonlinear systems that behave as a linear system when the oscillation magnitude is sufficiently small. As the oscillation magnitude grows, the magnitude of the feedback is no longer proportional to the original perturbation due to the nonlinear effects. The nonlinear effects can be stabilizing, and in this case an initially exponentially growing oscillation will grow at a slower rate as the oscillation magnitude increases, and finally reach a stable limit cycle. Nonlinear effects may also act in the opposite direction, and an initially exponentially growing oscillation will accelerate its growth rate further as the oscillation magnitude increases. Normally in a complex nonlinear system, like a BWR, there are regions of different nonlinear effects. [

]

[

]

4.2 *Density Waves in a Boiling Channel*

The mechanism capable of inducing a strong and delayed negative feedback in a boiling channel is the propagation of density waves (See Reference 5 for a comprehensive review). The kinematic description of density waves can be best described in the idealized boiling channel where the rate and axial distribution of the heat source remain invariant, and the pressure drop between the inlet and exit of the channel is kept constant. A perturbation of the inlet mass flow rate travels up the channel and its magnitude changes and phase lag increases. The mass flow rate wave generates a corresponding change in the steam quality and void fraction and equivalently the mixture density. The single-phase and two-phase friction components will also respond to the perturbation in the mass flow rate and the resulting steam quality response. In a slow (quasi-steady state) perturbation, the net resulting feedback is negative, that is for a positive inlet mass flow perturbation, the average void fraction decreases lowering the density head that drives the flow and the frictional pressure drop will increase forcing the restoration of the original inlet mass flow. The inlet flow perturbation can take any functional form, which can be linearly decomposed into sinusoidal waves of different magnitudes and frequencies. The variation in density results in gravitational head change, while the mass flux variation results in friction variations. The net pressure drop variation across the channel due to the gravitational and frictional components must be compensated for by flow acceleration in order to satisfy the constant channel pressure drop boundary condition. The feedback strength is maximal for an inlet flow perturbation with a frequency comparable to the inverse of the delay time, and if the magnitude of the feedback is sufficiently strong, the channel hydraulic parameters will oscillate at that preferred frequency with an increasing

magnitude. The hydraulic stability of the density waves depends on the strength of the feedback processes.

The quantitative parameter for measuring the degree of stability is the decay ratio defined as the oscillation magnitude at a given cycle relative to the previous cycle's magnitude. Under typical BWR conditions, the decay ratio is increased (less stable) with the following system variables:

- High power to flow ratio: This increases the density contrast along the channel (and hence the gravity head) which drives the instability.
- Low flow: In addition to being the denominator in the power-to-flow ratio, low flow is destabilizing because it decreases the preferred frequency (because lower flow speed increases bubble transit time) and thus reduces the axial attenuation of the mass flux and void fraction.
- Bottom-skewed power peaking: This power shape results in creating the bubbles at lower elevations which remain for a longer time, thus increasing the average density contrast and thus is destabilizing.
- Low system pressure: Low system pressure is destabilizing as the difference in saturated liquid and vapor densities increases which drives the gravitational component, hence a destabilizing effect.

- [

]

- High inlet subcooling: The inlet subcooling does not have a monotonic effect on stability, as very high and very low inlet subcooling are both stabilizing. Very high inlet subcooling prevents boiling and suppresses density response by preventing

phase change. Reducing inlet subcooling to allow boiling, while remaining sufficiently high such that the boiling boundary is high, the two-phase-to-single-phase pressure drop ratio is low and the system remains stable. [

]

The discussion of the hydraulic density waves, idealized under constant pressure drop and constant rate of heating, remained in the linear small amplitude regime. The large oscillation amplitude effects will be discussed separately.

4.2.1 Density Waves in Parallel Channels between Two Plena

In describing the idealized density wave instability a constant channel pressure drop was imposed as a boundary condition, which can be assured using a recirculation loop much larger than the boiling channel. In the case the recirculation loop is not so large the oscillating flow will result in pressure drop boundary changes which are stabilizing. Two identical boiling channels connected in parallel to the same recirculation plena will be coupled only if the recirculation loop is finite and the common pressure drop responds to the net flow change in the two boiling channels. The coupling results in the two channels oscillating out-of-phase (180 degrees phase shift) such that the pressure drop boundary fluctuation is minimized. For three identical boiling channels connected in parallel to the same plena, the coupling forced by the recirculation loop will result in the channels oscillating 120 degrees apart. However, for four channels, there are two possibilities, either the four channels will oscillate 90 degrees apart, or two channels will oscillate in-phase with each other and out-of-phase with the other two channels. The situation can become very complicated when hundreds of channels are connected to the same plena. In real situations, the channels are not identical and therefore have natural frequencies that are not identical, and their respective degrees of stability are also different. Coherent oscillations where many channels share the frequency and phase depend on the coupling mechanism of the neutron flux in addition to the

recirculation loop. Yet, hydraulically unstable channels, if sufficiently destabilized, may break away and oscillate independently from other channels and experience a superposition of multiple oscillation modes.

4.2.2 Density Wave with Power Oscillations due to Density-Reactivity Coupling

The propagation of the density wave along the boiling channel results in an oscillation of the bundle average coolant density (equivalently void fraction). The change in void fraction changes the neutron absorption and fission cross sections and produces a neutron reactivity response. The reactivity oscillation in turn produces a fission power response. There are two components of the power response, the first is the fission power deposited in the UO_2 pellets, and the second is the power deposited directly in the coolant as gamma radiation and neutron moderation.

The direct energy response is practically immediate, i.e. in-phase, with the original density change and results in an opposing effect on coolant density, i.e. negative feedback. The in-phase negative feedback of the direct energy deposition in response to density change has a stabilizing effect on the density wave.

The fission energy deposition is eventually transported to the coolant via heat conduction through the fuel rod. The dynamics of the transport of heat through the fuel rod to the coolant are governed by the heat capacity and the various thermal resistance components between the pellet interior and the coolant. These thermal resistances include the UO_2 pellet, the Zircaloy clad wall, the gap between pellets and clad, and the coolant in contact with the outer clad wall. The result of the thermal resistance and heat capacity inertia is a delay of the heat transport to the coolant, i.e. phase lag, of slightly less than 90 degrees. It also accounts for considerable attenuation of the heat source to the coolant. The attenuation of the heat flux amplitude relative to the fission power oscillation amplitude is of the order of 10^{-1} and increases with increasing the conduction time constant, which in turn increases with increasing the fuel rod diameter and increasing pellet-gap resistance. Unlike the direct energy deposition in the coolant, the

time lag of the coolant heating response through clad wall heat flux relative to the perturbation of the fission power deposition in the pellet results in destabilizing the density wave.

The void reactivity-to-power feedback not only provides the coupling needed for the different channels to oscillate coherently, but also has a destabilizing effect that makes it possible for the system to be unstable even when every channel in it is stable hydraulically. The coherence is broken if a single channel becomes hydraulically unstable at which point the flow in that channel will reflect a superposition of its intrinsic instability and the driven component via the oscillating power. Unstable single channel oscillations have been observed in unusual situations, for instance when a BWR bundle is not properly seated and deprived of flow (as occurred in Forsmark-I and Brunsbüttel Reference 6). Single channel instability also occurred in Garigliano during a special test (Reference 5). Aside from these unusual situations, single channel instabilities have been predicted and special effort has been made to exclude the possibility of their occurrence in the approved Framatome* methodology for DIVOM calculations (Reference 7).

4.3 *Oscillation Modes – The Global Mode*

As mentioned earlier, several boiling channels connected in parallel to two plena may not oscillate coherently absent a mechanism for coupling the density waves among the individual channels. In the case of a BWR core, the density-reactivity feedback provides the required coupling. The neutron flux in the core responds to reactivity changes anywhere in the core due to neutron diffusion. Thus the reactivity change in one channel results in a corresponding power change not only in that channel but to all other channels - with varying strength.

The oscillation mode where the power in every channel oscillates coherently, and in-phase with the power in all other channels, is called the global mode. The inlet mass

* Framatome Inc. formerly known as AREVA Inc.

flows in all the channels oscillate similarly, with the same frequency and in-phase. As the inlet mass flow rate in all channels is in-phase, the total core inlet mass flow rate must also oscillate, and similarly for the core exit mass flow rate. The core pressure drop (between the upper and lower plena) must also oscillate. Accordingly, the recirculation loop flow must interact with the core flow, and its dynamics must be considered in the analysis of the global mode oscillations. Generally, the friction and inertia of the recirculation loop exert a stabilizing influence on the global mode, and the extent of this stabilizing effect depends mostly on the dynamics of the steam separator assembly.

In a BWR core oscillating in-phase the fundamental mode of the neutron flux distribution function is excited. The excitation of all the other planar harmonics is not needed for the global mode. The axial flux harmonics must be driven as a result of the density waves causing the observed phase lag between neutron detector responses of the upper core elevation relative to lower elevation. [

]

4.4 *Oscillation Modes – The Regional Mode*

The regional mode is characterized with half the core bundles oscillating out-of-phase with the other half. The two core halves are separated by a vertical plane, which is also called the neutral line when a planar projection is considered. The net core flow remains unchanged during the regional oscillation provided its magnitude is not so large as to introduce nonlinear effects that do not cancel out.

The main reason the hydraulic channels prefer to oscillate out-of-phase is the cancellation of the recirculation loop damping. The regional mode oscillation in a BWR is forced to be coherent with half the core bundles oscillating in-phase and the other half oscillating with a 180 degree shift due to neutronics coupling. The half-core oscillation is preferred because it excites the first azimuthal neutron flux mode and thus receives the highest possible amplification. The other flux harmonics that can be excited by other channel groupings are characterized by larger subcritical reactivities, and therefore are significantly damped.

It is important to notice that the decay ratios of the regional and global modes are comparable. The regional mode is preferred for

- Large cores, which result in small eigenvalue separation for the first azimuthal flux mode.
- Low center power peaking (ring of fire), which also decreases the eigenvalue separation.
- Loose inlet orifice, which destabilize the hydraulic channels. This effect favors the regional mode in the absence of recirculation loop damping. It must be emphasized that the regional oscillations are isolated, and thus independent from the recirculation loop.

4.5 *Oscillation Modes – The Rotational Mode*

In the regional oscillations described above, the neutral symmetry line is stationary. The rotational mode is similar to the regional mode where the neutral line is oscillating or rotating (See Reference 8). The rotational mode essentially results from the simultaneous excitation of two orthogonal azimuthal modes. Assuming the core loading and control rod patterns are symmetric, the first two azimuthal modes are degenerate (approximately equal eigenvalues), and are thus indistinguishable. In the case the stability threshold is crossed with a decay ratio slightly greater than unity, and the core symmetry is not exact, it is expected that only one first azimuthal flux harmonic is excited leading to a regional mode oscillation with fixed neutral line. In the case the core is destabilized further, the orthogonal azimuthal mode is excited next, and

interference patterns emerge depending on the relative amplitude and frequency differences between the two modes. The neutral line may oscillate or rotate slowly in response to unequal magnitude and frequency of the two excited azimuthal modes. The most interesting case is when the two azimuthal modes are degenerate and oscillate with the same frequency and amplitude, which leads to the neutral line rotating at the same frequency.

[

]

4.6 *Oscillation Modes – Axial Power Shape*

As the density wave propagates upward, not only the total reactivity oscillates, but also the axial reactivity distribution is altered where oscillating reactivity difference between the upper and the lower parts of the core is created. As a result, the axial neutron flux harmonic is driven by density waves. The effect of the axial power shape oscillation on the decay ratio is minimal but it is noticeable as the cause of the phase lag of the upper local power range monitor (LPRM) power signal relative to the power signal from the lower LPRM on the same string.

The axial mode excitation is significant when the global or regional/rotational oscillation amplitude is large and large axial power shape changes are expected during the oscillations. [

]

[
]

4.7 *Large Amplitude and Limit Cycles of Global Mode Oscillations with Linearized Hydraulics*

As the oscillation magnitude increases, nonlinear effects are introduced (Reference 9). The neutron kinetics nonlinear effects become significant before the hydraulic nonlinear effects. This is the case because the reactivity oscillations required to induce large neutron flux response can be produced by relatively small coolant mass flow oscillation magnitude. In the idealized case of assumed linear thermal-hydraulics, with only the nonlinear effects of reactivity on the power response being allowed, a stabilizing effect has been observed which eventually leads to saturating the growth of the oscillation until a stable limit cycle is reached. The nonlinear stabilizing effect originates in the negative reactivity shift that is produced in response to the average power increases, the latter is due to the oscillating reactivity where the increase in reactivity during half a cycle increases power more than compensated for by an equal reactivity decrease in the subsequent half cycle. This asymmetric power response to reactivity oscillation is also responsible for generating high and sharp power peaks compared with the flat power minima.

The power drift under oscillatory reactivity results in an average power increase that is balanced by the negative reactivity due to the increased average void fraction. [

]

4.8 Large Amplitude Regional Mode Oscillations with Linearized Hydraulics

The power oscillation magnitude considered here is sufficiently large for the nonlinear neutron kinetics effects to manifest, but not high enough for the nonlinear effects of the hydraulics to become important. The regional oscillation of large amplitude differs in basic ways from a global oscillation (Reference 10). Most importantly, there is no reactivity bias associated with the first azimuthal harmonic excitation and growth, unlike the fundamental flux excitation and growth in the global mode oscillation. The only negative reactivity that reduces the first azimuthal mode growth is the subcriticality associated with its steady state eigenvalue being less than unity, and this subcriticality is not affected by the oscillation magnitude and therefore not a nonlinear effect. The main nonlinear effect of the growth of the first azimuthal mode is the emergence of a driven fundamental mode oscillation component with relative magnitude proportional to the square of the first harmonic magnitude at low oscillation magnitudes and at double its frequency (see References 11 and 12). The double frequency fundamental mode will grow until it becomes equal to the first harmonic in magnitude. A negative reactivity shift is generated, [

1

For growing regional oscillations, unlike the global mode, the nonlinear effects accelerate the rate of growth, and the oscillation magnitude is not self-limited (Reference 10). The eventual arrest of the regional mode oscillation growth is due to [] This is one reason why large amplitude regional oscillations are of special interest and can be considered limiting compared with the nonlinearly self-limiting global oscillations.

4.9 Large Amplitude Pure Thermal-Hydraulic Density Waves

Flow in a boiling channel includes highly nonlinear processes. For example, the frictional pressure drop is approximately proportional to the square of the flow rate, and the void fraction dependence on the steam quality is also nonlinear. When unstable

density waves in a boiling channel, without neutron kinetic feedback, are allowed to grow the oscillation magnitude may reach a limit cycle [

]

Detailed numerical models are needed to simulate the behavior of a boiling channel as an integral system whereas purely analytical models are of limited use for understanding the effects of various phenomena particularly for large amplitude oscillations. However, it is still possible to discern the role of these phenomena by observing the behavior of oscillating channels in test loops, and in simulations, and guided by knowledge of the fundamentals of flow dynamics. Using these tools, a qualitative description of the nonlinear effects and their influence on density wave oscillations growth is offered here.

[

]

[

]

The main nonlinearly destabilizing effect originates from the [

]

[

] The maximum oscillation amplitude at the channel inlet is negative, where the reverse flow magnitude [

] The inlet flow oscillation has broad peaks and sharp minima signifying the nonlinear processes involved in the generation of these high amplitude oscillations.

4.10 *Very Large Nonlinear Oscillations of Global and Regional Types*

For small amplitude oscillations, the system behavior is linear and the principle of superposition is applicable. Accordingly, all the possible unstable modes will be manifested without coupling to each other, for example in the case the decay ratios of the global and regional modes are comparable and greater than unity, both types of instabilities will be excited and the resultant oscillations will reflect a superposition mix.

This is not the case for large oscillations where nonlinear effects are significant. [

] An exception for this behavior is the case of two regional modes representing the excitation of a first azimuthal flux harmonic and a nearly degenerate mode where the corresponding neutral lines are orthogonal. The nonlinear effects of the growth of one of these modes will impact both modes, and simultaneous growth of the two modes would lead to oscillating or rotating neutral line, i.e. the mixed mode oscillation of the rotational type is not discouraged by nonlinear effects.

[

]

[

]

4.11 *Prompt-Criticality*

Very large power oscillations result from very large reactivity oscillations due to the severe flow oscillations. It is important to consider that reactivities in excess of the delayed neutron contribution may occur, i.e. prompt-super-criticality. The possibility of prompt-super-criticality requires the neutron kinetics models to be able to handle it properly with finite neutron velocity and Doppler reactivity feedback. However, from theoretical analysis (see References 9 and 10) and experience with numerical calculations (Reference 2), it has been found that prompt-criticality may be expected only under unrealistically rapid rate of oscillation growth, before the system has time to respond by increasing the average power and shift the average reactivity to a large negative value. Even in this case, the prompt criticality is exceeded by only a few cents, not dollars like in reactivity insertion accidents. No qualitatively distinct power pulses result from small super-prompt-critical reactivity.

[

]

4.12 *Effect of Bypass Flow with Possible Boiling*

Boiling is possible in the upper part of the core bypass at natural circulation under relatively high power (Reference 13). This effect is modeled in steady state simulators which provide the initial conditions and neutron cross sections to the transient codes used in this application. The main effect of the bypass boiling is a shift of the axial power shape to more bottom-peaking. The important question here is the transient response of the bypass, with or without boiling, in the presence of large regional mode oscillations. Under regional oscillations, the core pressure drop remains nearly invariant as the effects of flow in the two halves of the core oscillating out-of-phase tend to cancel out. [

]

4.13 *Cyclical Dryout and Rewetting*

Large oscillations of flow and power in a BWR bundle can result in conditions of degraded heat transfer and clad temperature excursions beyond the safe limits designated to maintain fuel coolability.

In steady state operation, the conditions of heat transfer degradation are associated with the inception of dryout. Dryout correlations based on critical heat flux or critical quality concepts are used to obtain the critical power ratio, which provide quantitative measure of allowable bundle power and define the safety margins to protect that limit. Quasi-steady state application of dryout correlations has been the basis for protecting the fuel against dryout. Steady state dryout correlations were extended for applications to DIVOM oscillatory transients (Reference 7), which are rather mild, compared with

power and flow oscillations accompanying anticipated transient without scram. [

]

With the detailed accounting of the phenomena governing the cyclical dryout and rewetting, the limiting consideration for fuel safety is shifted from dryout inception to failure to rewet. Accordingly, cyclical dryout and rewetting is not considered a threat to fuel integrity as long as high clad temperature excursion does not occur. [

]

A detailed [] model for cyclical dryout and rewetting with possible failure to rewet [

]

[

]

4.13.1 Impact of Cyclical Dryout and Rewetting on Very Large Oscillations

The phenomena of large density wave oscillations and cyclical dryout are interlinked.

The previous section addresses the cyclical dryout and rewetting, with possible failure to rewet, [

]

[

]

4.14 Vessel Considerations

Aside from the vessel impact on global oscillations as described in Section 4.3, there are several systems that can have a direct impact on the evolution of the ATWS-I event. One such category is the systems involved in pressure control. For a 2RPT, normal pressure control is maintained by the pressure control system through the positioning of the turbine control valves. Pressure change is gradual resulting in minimal effect on the system. For a turbine trip, the turbine is isolated and pressure is controlled by the bypass valves and Safety/Relief Valves (SRV). The fast opening and closing of the

SRVs cause pressure to oscillate in the vessel. [

]

The mitigating actions of the operators will also impact the progression of the ATWS-I event. There are two primary mitigating actions required to shut down the ATWS-I event: water level reduction and boron injection. The water level reduction begins by operator action at an assumed time following entry into the ATWS condition. Water level is reduced to a level that is typically near the top of the core. This reduction in water level to a point significantly below the feedwater spargers means that once water level control is re-established at the lower level, the cold feedwater is now sprayed through a steam environment. The large distance between the spargers and the water level means that the feedwater will be heated to near saturated conditions. This heated water will both reduce core power and stabilize the core terminating oscillations.

The boron injection process begins as soon as the ATWS condition is recognized (same time as the beginning of the water level reduction). However, system delays due to pump run up, the time required to pump boron from the holding tank to the vessel, and the time required for boron to accumulate in the core in sufficient concentration to suppress power mean that this action can be delayed relative to the water level reduction. As such, the water level reduction will mitigate the oscillation prior to boron injection. In this case, the boron injection serves to shut the core down and limit impact of high core power on the containment heat load. The RAMONA5-FA ATWS-I methodology will not include boron injection as the base analysis definition. If, in the unlikely scenario, the boron injection is needed to be modeled, it can be modeled

[]

4.15 *Phenomena Ranking*

A comprehensive phenomenon identification and ranking process has been performed to identify the dominant phenomena for the target scenario (ATWS leading to core instability). During the development process, this identification and ranking is the basis for determining which closure relations require development or enhancement for the intended application. The process aids in methodology development because it prioritizes the model development activities and defines the types of validation and sensitivity studies that are needed to support the methodology. The culmination of the process is a phenomenon identification and ranking table (PIRT) that summarizes all the phenomena and provides their importance ranking relative to selected figure of merit (FoM). This PIRT utilizes Framatome's extensive history and experience with analyzing and testing density wave phenomena including the core minimum critical power ratio (MCPR) response for both global and regional mode instabilities as a function of the power oscillation magnitude (Reference 7). In the approved EO-III TR (Reference 30) Framatome included [

]. In addition, Framatome has previously participated in industry efforts to develop a previous ATWS-I PIRT (Reference 31).

When developing the PIRT, it is important to note that the development of very large power and flow oscillations follows a progressive path from the initial inception of instability, exponential oscillation growth from noise level to mild amplitudes, and further growth to large amplitudes that can be prevented from further growth by nonlinear effects. Intuitively, the phenomena and parameters participating in all the stages of the evolution of the transient from inception to maximum oscillation amplitude are ranked such that any important phenomenon at any stage remains important for the ultimate maximum oscillation event under consideration. [

]

[
]

Acceptance criteria for the target scenario are derived from General Design Criteria 35:

“A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.”

For the ATWS-I event, maintaining the PCT below the 10CFR 50.46 limit of 2200 °F (1204 °C) ensures that the acceptance criteria of maintaining core coolability is met.

[
]

The first FoM is the oscillation inception (OI). Since the purpose of the evaluation is to demonstrate that operator actions occur in sufficient time to prevent severe overheating of the clad, the method must be able to accurately determine when oscillations would begin relative to the operator intervention.

The second FoM is the limit cycle amplitude (LCA). While not all events will reach the full limit cycle, this point determines the ultimate magnitude of the oscillations and defines the worst case oscillation.

The final FoM is post-dryout (PDO). This FoM encompasses the time between the initial prediction of dryout through to rewet or failure to rewet. The ability to accurately determine dryout and rewetting can directly determine the severity of the event.

The ranking of the phenomenon and processes are presented in Table 4-1.

Table 4-1: Ranking of Phenomena and Processes

H - High
M - Medium
L - Low
N - N/A

Table 4-1: Ranking of Phenomena and Processes (cont.)

H - High
M - Medium
L - Low
N - N/A

Table 4-1: Ranking of Phenomena and Processes (cont.)

H - High
M - Medium
L - Low
N - N/A

Table 4-1: Ranking of Phenomena and Processes (cont.)

H - High
M - Medium
L - Low
N - N/A

4.16 *Major Assumptions*

Assumptions are necessary measures and approximations needed to create any practical analytical or numerical tool such as done in this work. The listing of the key or major assumptions is desirable, at least in part, to put the accuracy and expectations of the model performance in the right perspective, enlighten the user as to the application limitations, and point to areas of future improvements.

The identification and justification of assumptions is often an exercise of engineering common sense more than a quantitative analysis with objective metrics. Fortunately in this particular case, the RAMONA5-FA ATWS-I model and code are based on a solid foundation of practice and experience with codes of similar nature, namely the previously approved RAMONA5-FA (Reference 22). The assumptions which represent simplifications or improvements or any deviation of significance from the experience base of the original RAMONA5-FA will be listed and discussed. Complementing assumptions in models [] will also be discussed depending on their particular significance to the correspondence between the particular model/assumption and the important ATWS-I phenomena which is the key application of the code.

The key assumptions are listed below along with the associated consequences and justifications. The neutron kinetics representation using []

[

]

New water property functions based on the IF97 formulation are used [

]. The use of the most up-to-date formulation is assumed to imply no significant changes to the nature of the oscillation transient, and any change no matter how small is an improvement. The density of liquid water at temperatures (or equivalently enthalpies) higher [

]

5.0 **CODE DESCRIPTION**

A detailed description of the theory is given in this section. Description of the various components of the model, the neutron kinetics, the fluid flow, pin heat conduction and heat transfer to the fluid, is given in separate subsections. Notice that the nomenclature is defined in each subsection as the model description is presented and the meaning of symbols may differ within each model. For example, ρ refers to reactivity in the description of the neutron kinetics, while the same symbol is used for density in the fluid flow model.

Model description is brought to the level of discretized formulation, with the aid of governing differential equations [

]

5.1 **Neutronics**

An adaptive 3-D neutron kinetics module has been developed for application to BWR transient codes. [

].

[

]

5.1.1 Adaptive Two-Group 3-D Neutron Kinetics

The adaptive kinetics theory is presented in this section along with a derivation of the 3-D governing equations in two-energy-groups. The two-group neutron diffusion equations in the steady state simulator MICROBURN-B2 are:

$$-\nabla \cdot (D_1(\mathbf{r}) \nabla \Psi_1(\mathbf{r})) + \Sigma_1(\mathbf{r}) \Psi_1(\mathbf{r}) = \frac{1}{k_0} (\nu \Sigma_{f1}(\mathbf{r}) \Psi_1(\mathbf{r}) + \nu \Sigma_{f2}(\mathbf{r}) \Psi_2(\mathbf{r})) \quad (5.1)$$

$$-\nabla \cdot (D_2(\mathbf{r}) \nabla \Psi_2(\mathbf{r})) + \Sigma_{a2}(\mathbf{r}) \Psi_2(\mathbf{r}) = \Sigma_{12}(\mathbf{r}) \Psi_1(\mathbf{r}) \quad (5.2)$$

where

D_1	Fast group diffusion coefficient
D_2	Thermal group diffusion coefficient
k_0	Effective multiplication factor (eigenvalue)
$\mathbf{r}$	Space vector
Σ_1	Fast neutron removal cross section (by absorption and slowing down)
Σ_{a2}	Thermal neutron absorption cross section
Σ_{12}	Slowing down cross section
$\nu \Sigma_{f1}$	Fast fission neutron production cross section
$\nu \Sigma_{f2}$	Thermal fission neutron production cross section
Ψ_1	Fast flux steady state distribution
Ψ_2	Thermal flux steady state distribution

The transient form is given by

$$\frac{1}{v_1} \frac{\partial \Phi_1(\mathbf{r}, t)}{\partial t} = \nabla \cdot (D_1(\mathbf{r}, t) \nabla \Phi_1(\mathbf{r}, t)) - \Sigma_1(\mathbf{r}, t) \Phi_1(\mathbf{r}, t) + (1 - \beta(\mathbf{r}, t)) \times$$

$$\frac{1}{k_0} (\nu \Sigma_{f1}(\mathbf{r}, t) \Phi_1(\mathbf{r}, t) + \nu \Sigma_{f2}(\mathbf{r}, t) \Phi_2(\mathbf{r}, t)) + \sum_{n=1}^N \lambda_n(\mathbf{r}, t) C_n(\mathbf{r}, t) \quad (5.3)$$

$$\frac{1}{v_2} \frac{\partial \Phi_2(\mathbf{r}, t)}{\partial t} = \nabla \cdot (D_2(\mathbf{r}, t) \nabla \Phi_2(\mathbf{r}, t)) - \Sigma_{a2}(\mathbf{r}, t) \Phi_2(\mathbf{r}, t) + \Sigma_{12}(\mathbf{r}, t) \Phi_1(\mathbf{r}, t) \quad (5.4)$$

$$\frac{\partial C_n(\mathbf{r}, t)}{\partial t} = \frac{\beta_n(\mathbf{r}, t)}{k_0} (\nu \Sigma_{f1}(\mathbf{r}, t) \Phi_1(\mathbf{r}, t) + \nu \Sigma_{f2}(\mathbf{r}, t) \Phi_2(\mathbf{r}, t)) - \lambda_n(\mathbf{r}, t) C_n(\mathbf{r}, t), \quad n = 1, \dots, N \quad (5.5)$$

where

t	Time
v_1	Fast neutron velocity
v_2	Thermal neutron velocity
N	Total number of delayed neutron energy groups
β_n	Delayed neutron fraction in the group n
λ_n	Decay constant for the delayed neutron precursor of the group n
C_n	Concentration of the delayed neutron precursor of the group n
Φ_1	Time- and space-dependent fast flux distribution
Φ_2	Time- and space-dependent thermal flux distribution

The total delayed neutron fraction is the sum of the group-wise fractions, thus

$$\beta(\mathbf{r}, t) = \sum_{n=1}^N \beta_n(\mathbf{r}, t) \quad (5.6)$$

The fast removal cross section is the sum of absorption and slowing down components, thus

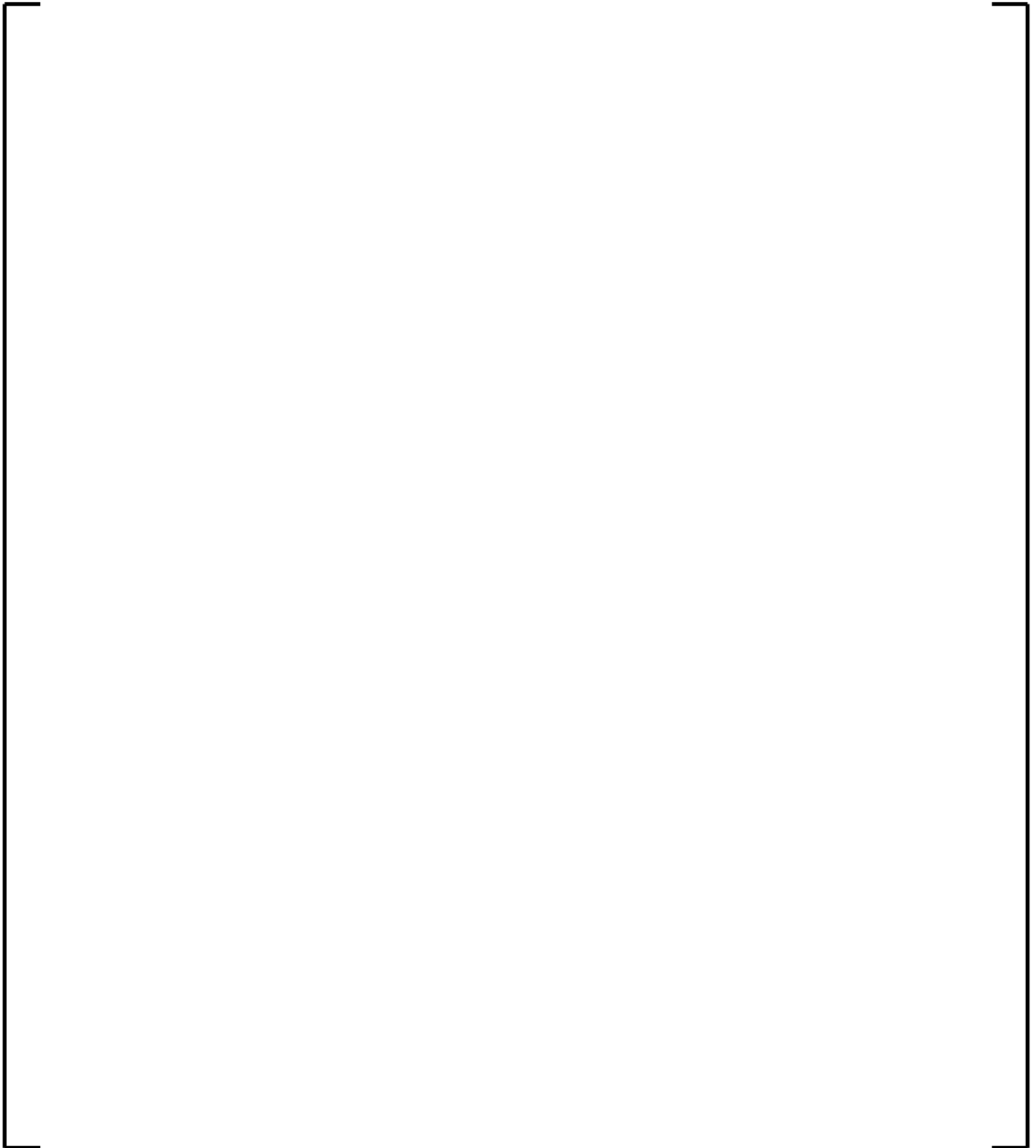
$$\Sigma_1(\mathbf{r}, t) = \Sigma_{a1}(\mathbf{r}, t) + \Sigma_{12}(\mathbf{r}, t) \quad (5.7)$$

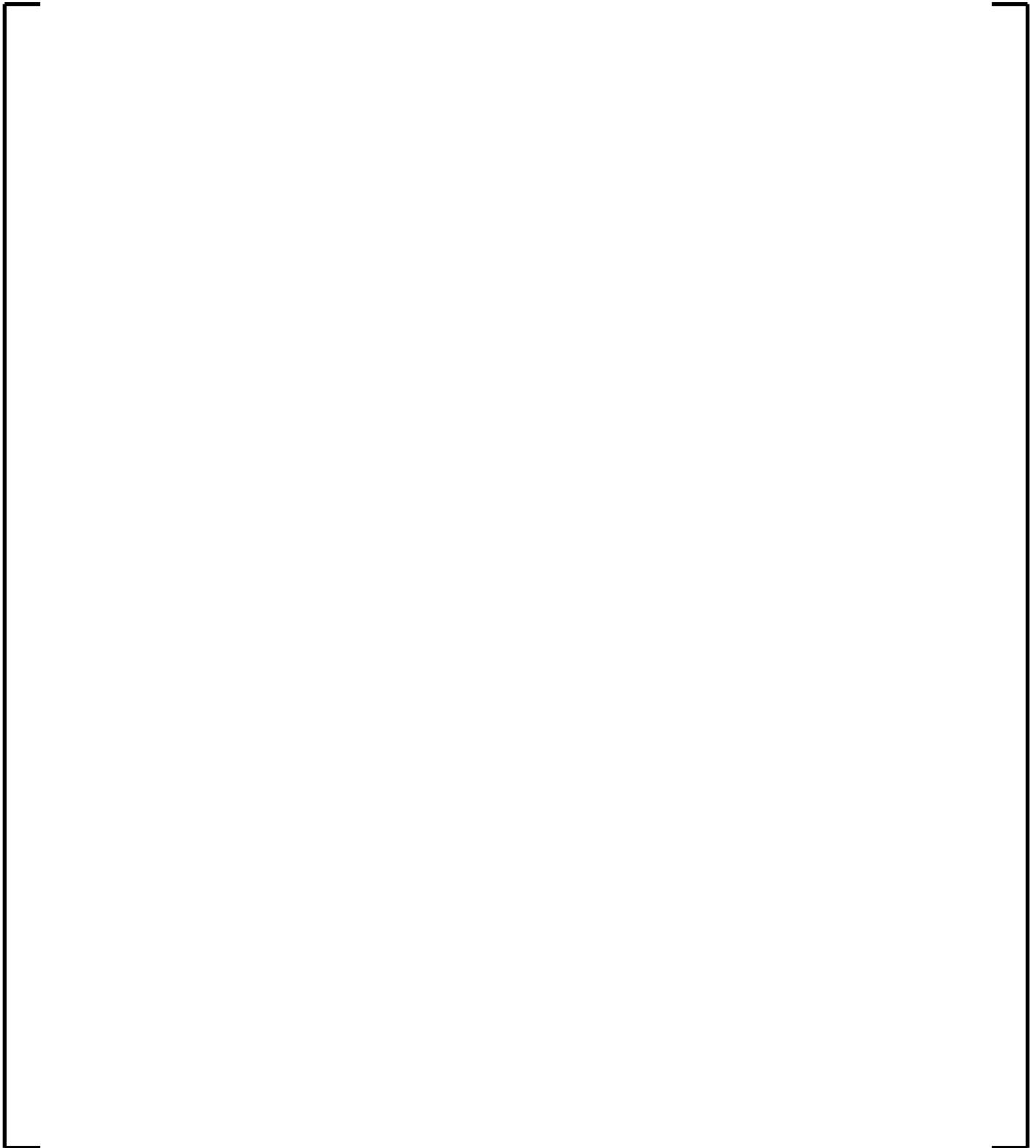
where

Σ_{a1} Fast absorption cross section.

Notice that the eigenvalue, k_0 , is retained to maintain consistency with the steady state cross sections and force the initial condition to exact criticality. [

]





5.1.2 Numerical Solution

The cross sections and fluxes are defined on the same 3-D mesh as MICROBURN-B2.

The x-coordinate is associated with the index i , the y-coordinate with j , and the vertical z-coordinate with k . For example

$$\Psi(\mathbf{r}) = \Psi(x, y, z) = \Psi_{i,j,k}$$

[

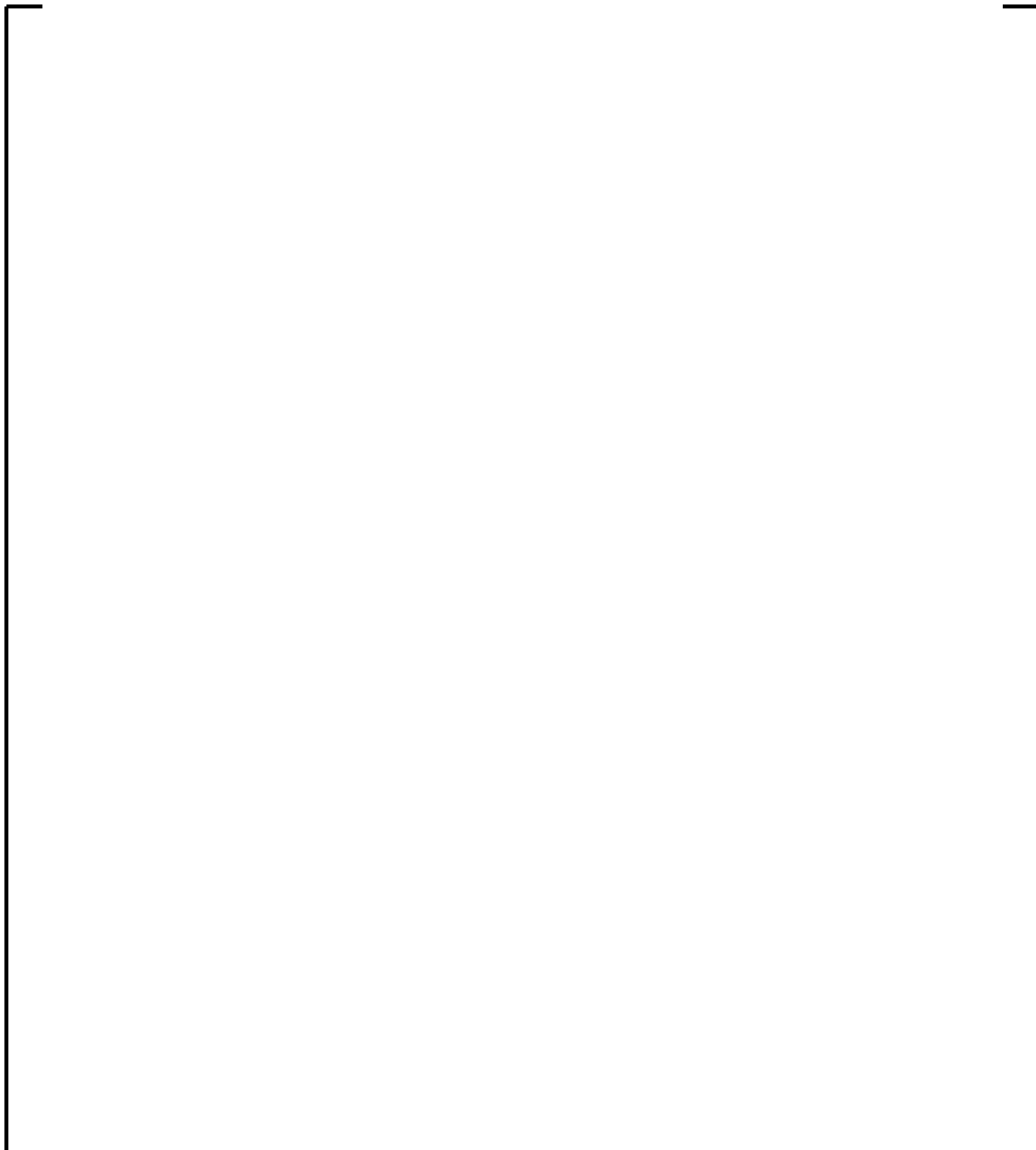
]

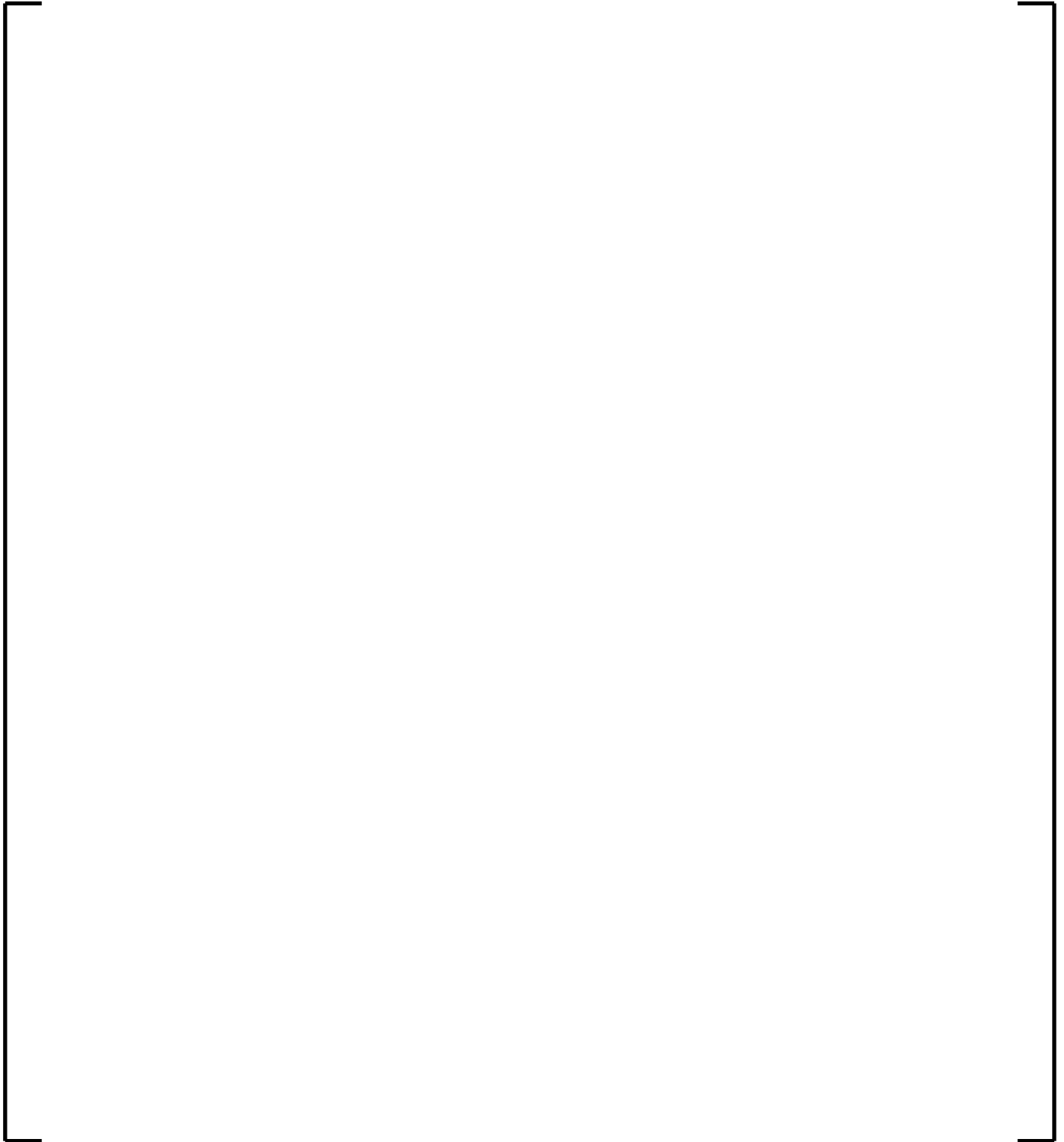
Finite differences are used to approximate the leakage term as

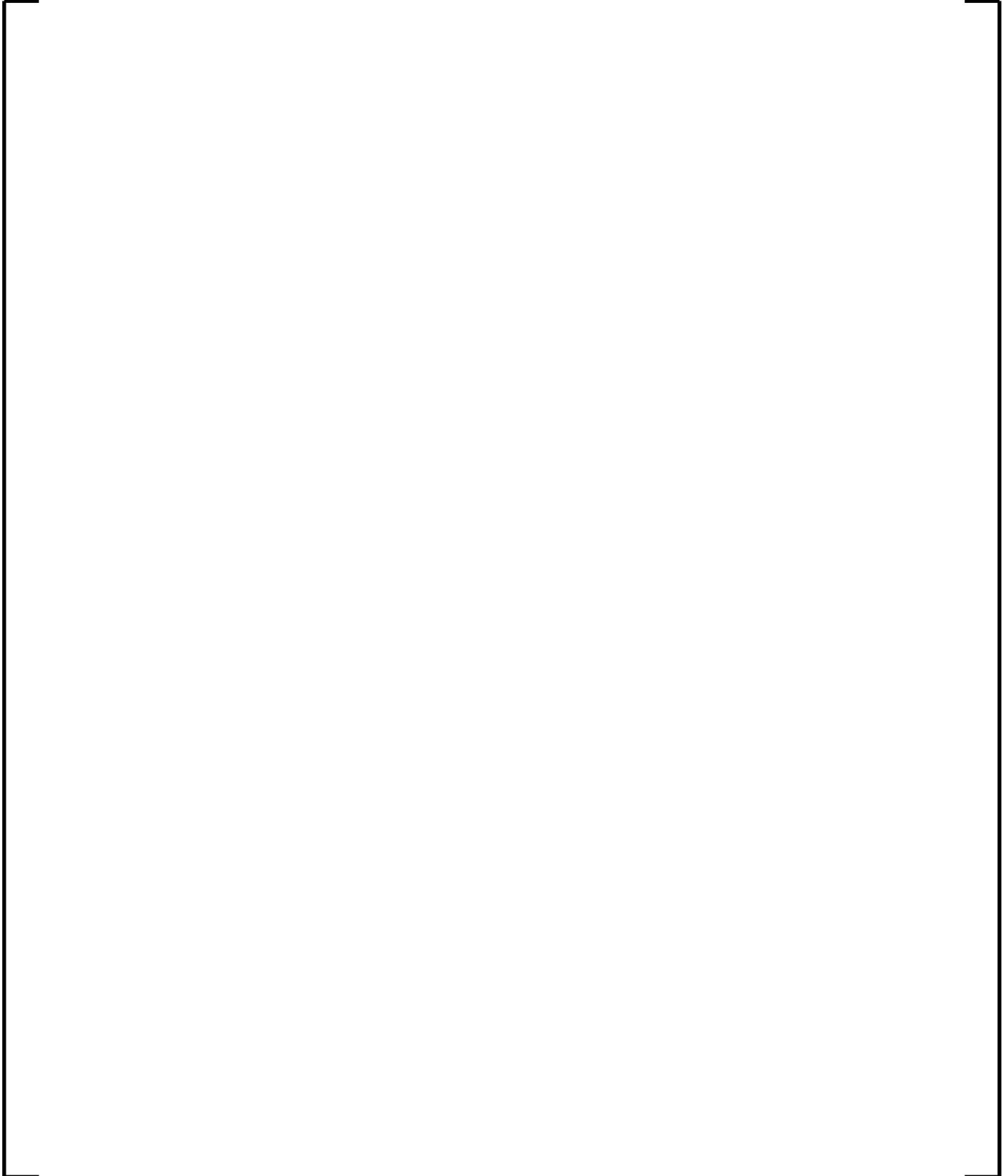
$$\begin{aligned} \nabla \cdot (D \nabla \Phi) \approx & \frac{1}{(\Delta x)^2} \left\{ D_{i+1/2,j,k} (\Phi_{i+1,j,k} - \Phi_{i,j,k}) - D_{i-1/2,j,k} (\Phi_{i,j,k} - \Phi_{i-1,j,k}) \right\} \\ & + \frac{1}{(\Delta y)^2} \left\{ D_{i,j+1/2,k} (\Phi_{i,j+1,k} - \Phi_{i,j,k}) - D_{i,j-1/2,k} (\Phi_{i,j,k} - \Phi_{i,j-1,k}) \right\} \\ & + \frac{1}{(\Delta z)^2} \left\{ D_{i,j,k+1/2} (\Phi_{i,j,k+1} - \Phi_{i,j,k}) - D_{i,j,k-1/2} (\Phi_{i,j,k} - \Phi_{i,j,k-1}) \right\} \end{aligned} \quad (5.26)$$

The interface values of the diffusion coefficient can be approximated by linear interpolation between the values in the two adjacent nodes. However, this linear interpolation approximation is not used in favor of a better leakage operator representation as derived in the next section.

5.1.2.1 Interfacial Diffusion Coefficient Approximation





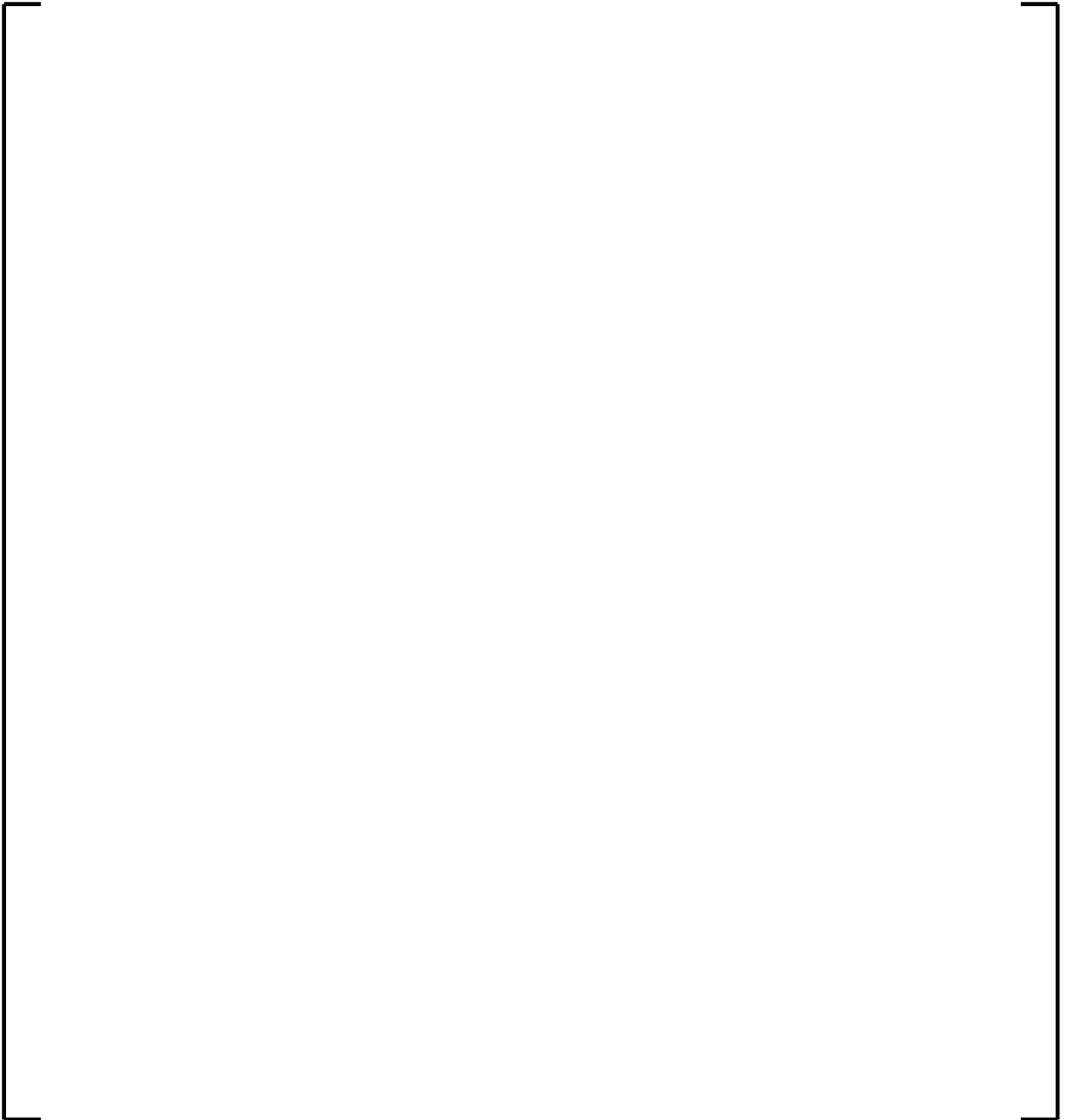


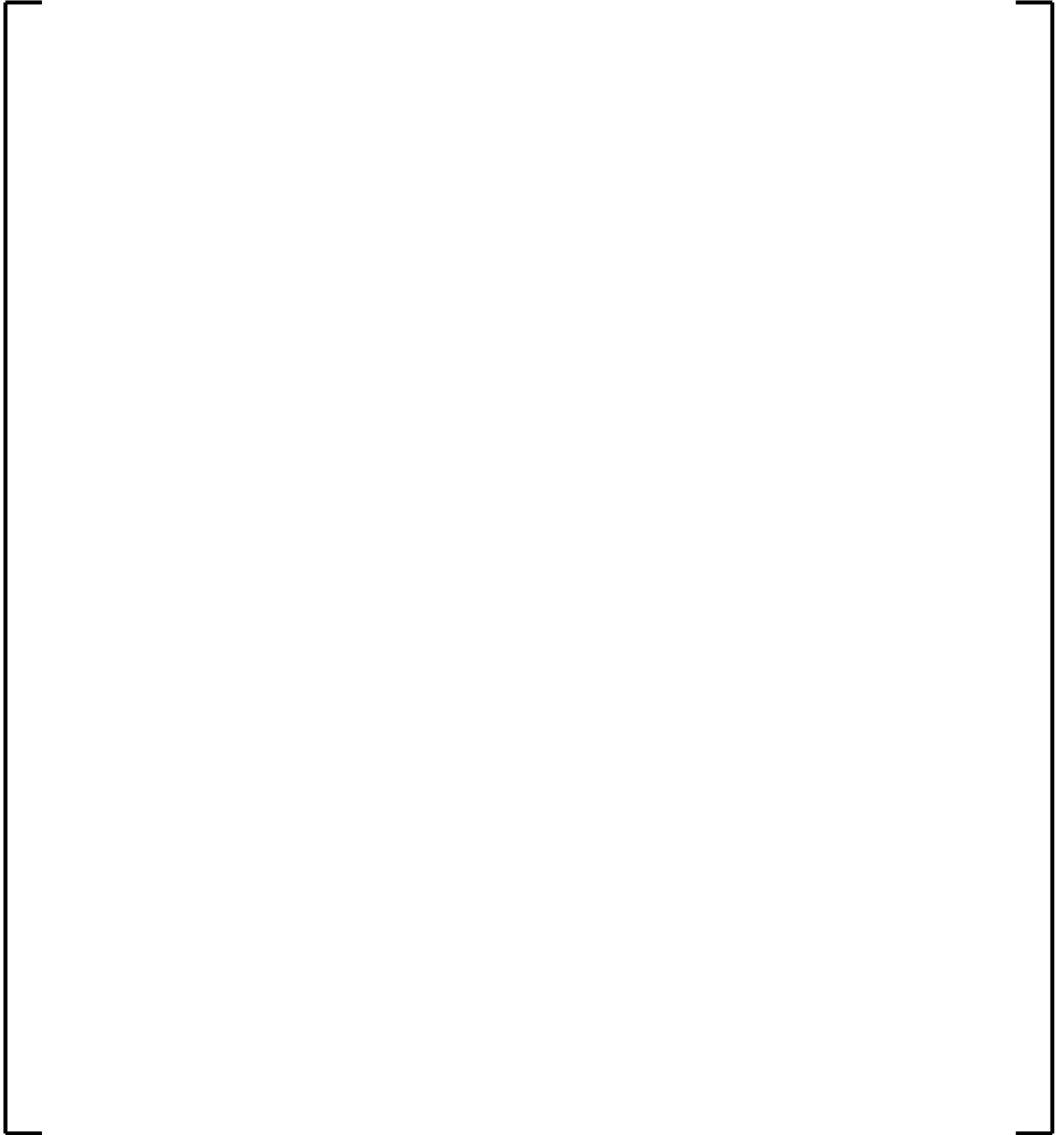
[

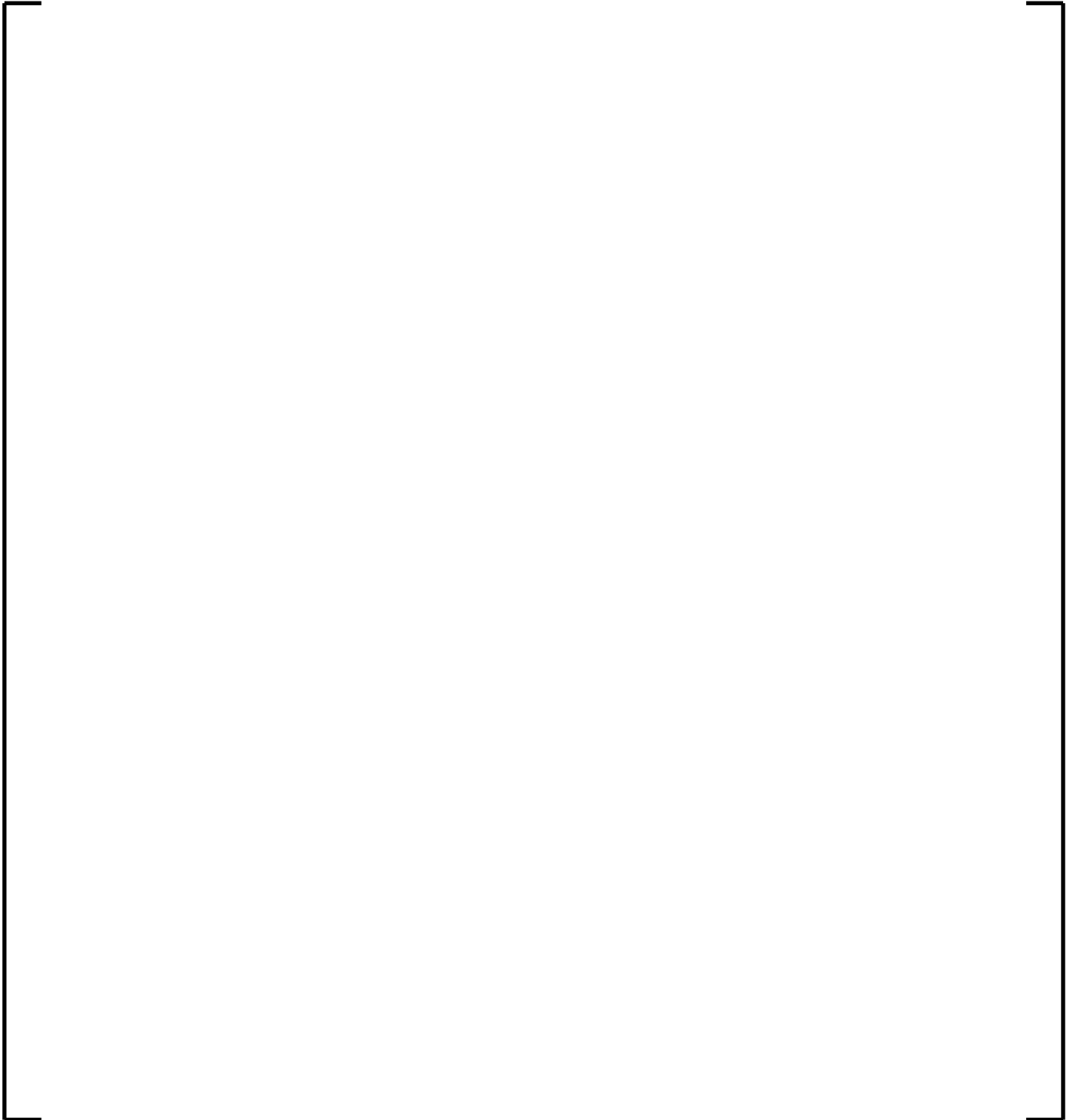
]

5.1.2.2 **Steady State and Initialization**

5.1.2.3 **Time Integration Procedure**







5.1.3 Cross Section Representation

5.1.4 Power Generation

The thermal-hydraulic calculations in RAMONA5-FA require the heat generation or power density in each computational cell. The power density at any point is the sum of two components, namely:

- Prompt fission heat: the amount of energy released promptly in the fission process, which is proportional to the fission rate.
- Decay heat: the amount of energy released by the decay fission products. It is delayed relative to the prompt fission heat and, hence, depends on the fission rate history.

The power density can be written as

$$q(\mathbf{r}, t) = q_p(\mathbf{r}, t) + q_D(\mathbf{r}, t) \quad (5.66)$$

where

- q total heat generation rate,
- q_p prompt component,
- q_D delayed component,
- t time,
- $\mathbf{r}$ spatial coordinate.

5.1.4.1 Prompt Fission Heat

5.1.4.2 Decay Heat

The amount of delayed energy released by the decay of the fission products following the shutdown of a reactor is fitted with a series of decay heat groups. Thus, the model is similar to the handling of delayed neutrons. The concentration of decay heat precursors in a decay group can be expressed in each neutronic node by the following differential equation

$$\frac{dD_i}{dt} = \alpha_i \left(\kappa \Sigma_{f1} \Phi_1 + \kappa \Sigma_{f2} \Phi_2 \right) - \lambda_i D_i = \alpha_i \kappa F(\mathbf{r}, t) - \lambda_i D_i \quad (5.69)$$

where

- D_i concentration of decay heat precursors
 α_i fraction of the total energy appearing as decay heat in decay group
 λ_i decay constant [1/sec]
 i decay group number

The decay heat model is based on the American National Standard for Decay Heat Power in Light Water Reactors [Reference 23]. This standard uses 23 groups to fit the decay heat power t seconds after a fission pulse from a fissionable nuclide with a series of exponential terms. Each group is characterized by the fraction of the total fission energy appearing as decay heat in the group, α_i , and by a decay constant, λ_i .

The decay heat component can be written for RAMONA5-FA as:

$$q_D(\mathbf{r}, t) = \sum_{i=1}^{23} \lambda_i D_{H,i} \quad (5.70)$$

The concentration of the decay heat precursors, $D_{H,i}$, for the group i is given by the following differential equation, which is very similar to (5.69)

$$\frac{\partial D_{H,i}}{\partial t} = \gamma_i \kappa F(\mathbf{r}, t) - \varepsilon_i D_{H,i} \quad (5.71)$$

If we assume that $F(\mathbf{r}, t)$ is a pulse at time zero, then the solution of (5.71) is given by

$$D_{H,i} = \gamma_i \kappa \exp(-\varepsilon_i t) \quad (5.72)$$

However, the ANS Standard gives the expression and the values of the coefficients for the function $f(t)$ which represents the decay heat power t seconds after a fission pulse,

$$f(t) = \sum_{i=1}^{23} \alpha_i \exp(-\lambda_i t) \quad (5.73)$$

Combining Equation (5.72) with (5.70), we obtain for a fission pulse

$$q_D(\mathbf{r}, t) = \sum_{i=1}^{23} \gamma_i \varepsilon_i \kappa \exp(-\varepsilon_i t) \quad (5.74)$$

Comparing Equations (5.73) and (5.74), expressions for the coefficient set (γ, ε) are obtained in terms of the coefficients of the ANS standard (α, λ) . Thus,

$$\begin{aligned} \varepsilon_i &= \lambda_i \\ \gamma_i &= \frac{\alpha_i}{\kappa \lambda_i} \end{aligned} \quad (5.75)$$

The coefficients γ_i must be corrected to take into account two effects. First, if the fuel has been irradiated for a finite period of time, T , the coefficients are redefined as

$$\gamma_i = \frac{\alpha_i}{\kappa \lambda_i} [1 - \exp(-\lambda_i T)] \quad (5.76)$$

The second correction takes into account for the fact [

].

The total fraction of fission energy appearing as decay heat is obtained from

$$\gamma_T = \sum_{i=1}^{23} \gamma_i \quad (5.77)$$

which is used in the prompt power density calculation in Equation (5.67).

5.1.5 Power Deposition

RAMONA5-FA takes into account the fact that the fission energy is deposited as thermal energy both inside the fuel pellet, where the fission takes place, and outside the pellet due to neutron slowing down and gamma attenuation. [

]

5.2 *Fuel Thermodynamics*

In this section, the modeling of heat conduction in the heating elements is presented. The transient heat conduction serves as a link between the energy deposition from nuclear fission and the dynamics of the fluid flow in the fuel assemblies. The heat conduction in fuel rods consisting of pellet and cladding and pellet-clad gap is needed for the dynamic modeling of the reactor core, while modeling of heat conduction in electrically heated pins is needed for performing benchmarking calculations for comparison with test loop data. For either fuel or heater rods, the models for heat transfer between the rod surface and the coolant covering different heat transfer regimes are presented. For the analysis of fuel rods, [

].

5.2.1 ATWS-I Fuel Pin Heat Conduction

Heat conduction in the fuel pin is assumed to be azimuthally symmetric with no axial component. The transient heat conduction equation is thus

$$\rho C \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(k r \frac{\partial T}{\partial r} \right) + q''' \quad (5.82)$$

where

r	radial coordinate from the fuel pin center
t	time
$T(r, t)$	temperature
$q'''(r, t)$	volumetric heat generation rate
ρ	density
C	specific heat at constant pressure
k	thermal conductivity

The fuel rod is made of 3 components, fuel pellet, clad and pellet-clad gap. [

]

The boundary condition at the pellet center is

$$\frac{\partial T}{\partial r} = 0 \quad \text{at} \quad r = 0 \quad (5.83)$$

The boundary condition at the outer clad surface is obtained as heat flux continuity, thus

$$-k_c \left. \frac{\partial T}{\partial r} \right|_{r=R} = h(T_{wall} - T_{ref}) \quad (5.84)$$

where

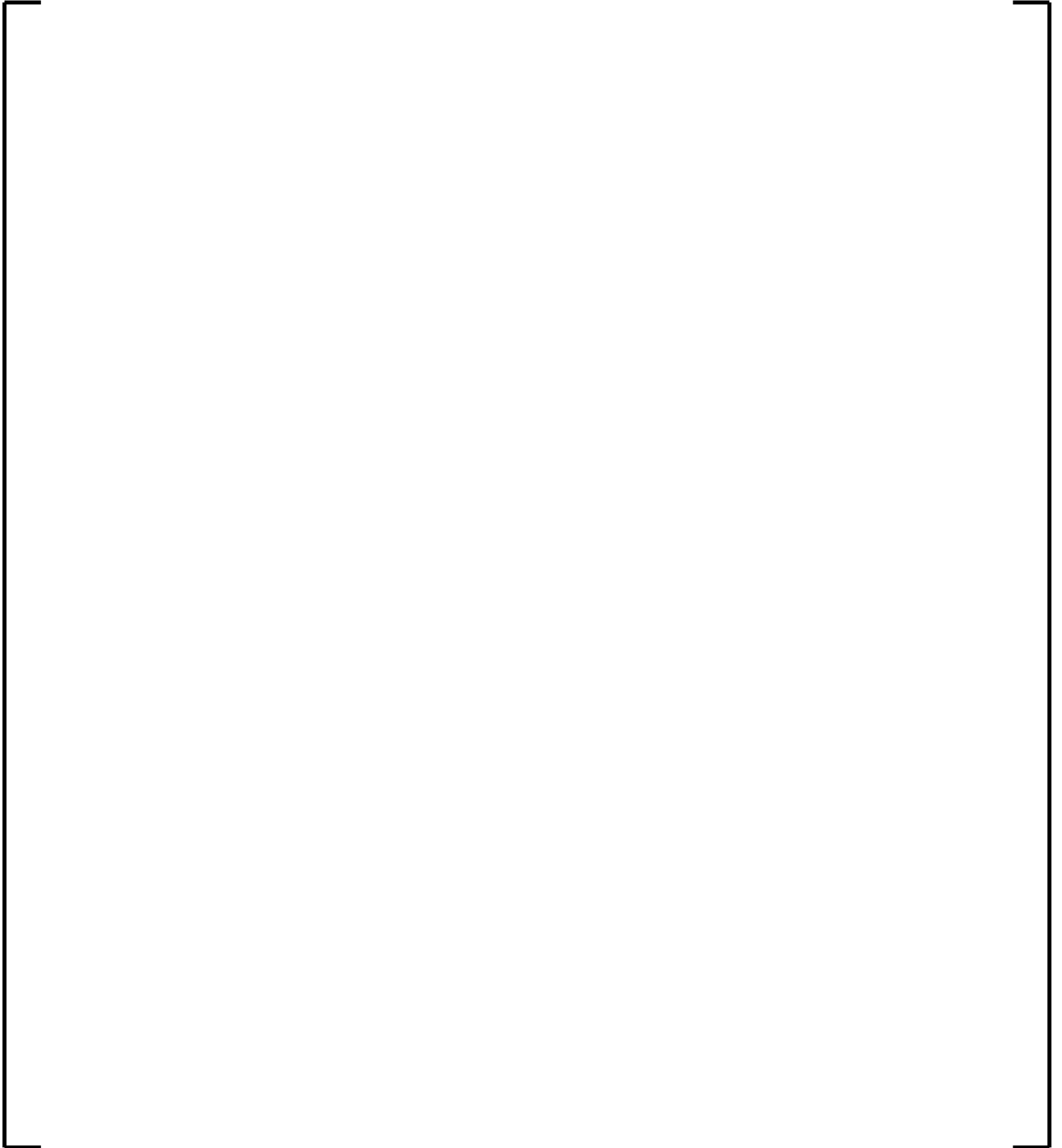
T_{ref}	heat sink (coolant) temperature
R	outer clad radius
T_{wall}	outer clad surface temperature
h	heat transfer coefficient
k_c	clad thermal conductivity

The pellet-clad gap is modeled as a thin layer with no thermal inertia but finite thermal resistance. Thus the inner clad radius is approximated as equal to the outer pellet radius, R_f . The heat flux across the gap is obtained from

$$-k_c \frac{\partial T}{\partial r} \bigg|_{r=R_f+} = -k_f \frac{\partial T}{\partial r} \bigg|_{r=R_f-} = h_{gap} (T_f - T_{ci}) \quad (5.85)$$

where

- h_{gap} gap heat conductance
- T_f temperature at fuel pellet outer radius
- T_{ci} temperature at clad inner radius
- k_c clad thermal conductivity
- k_f pellet thermal conductivity
- R_f pellet outer radius (R_{f-} and R_{f+} refer to the pellet and clad sides of the gap respectively)



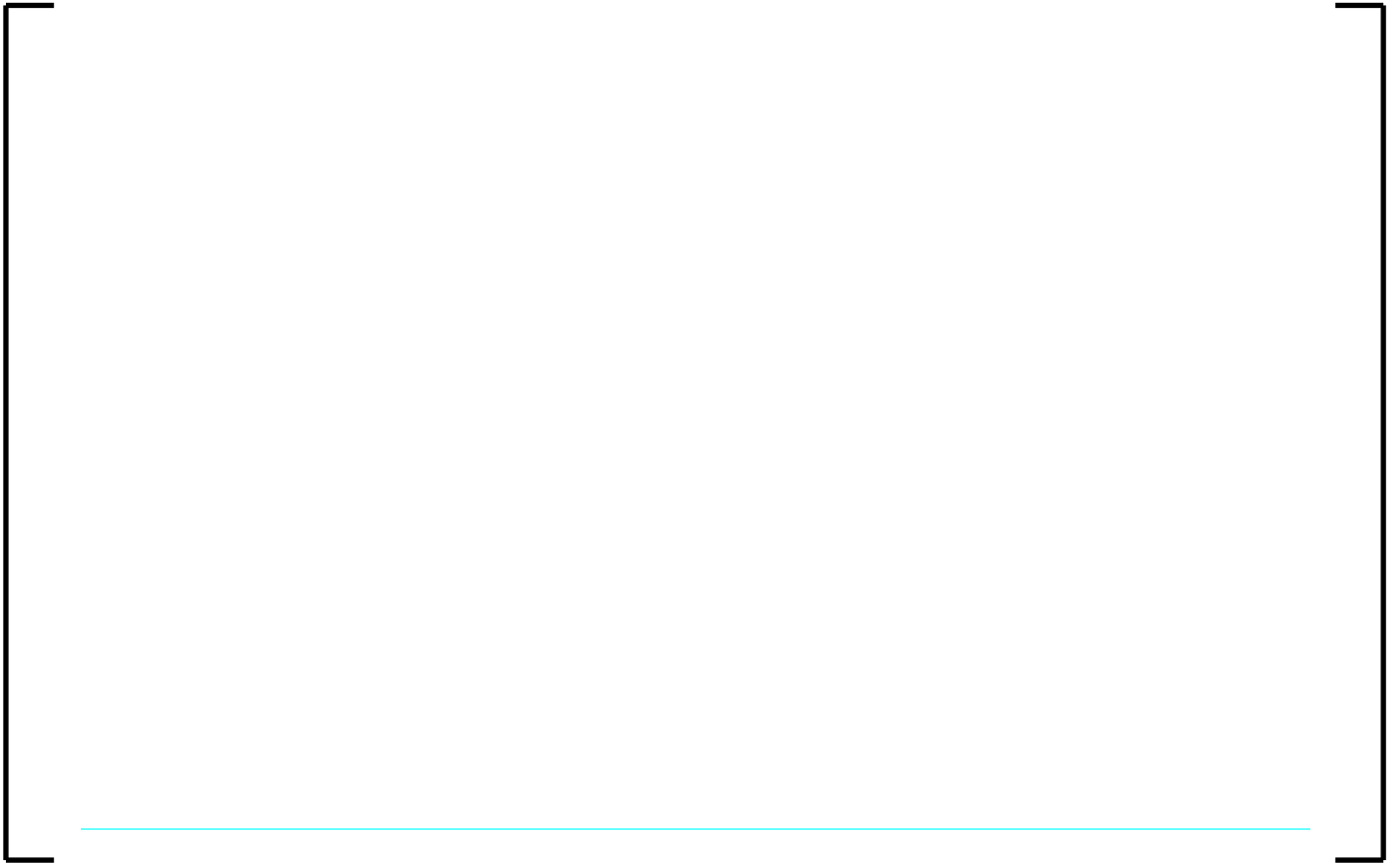
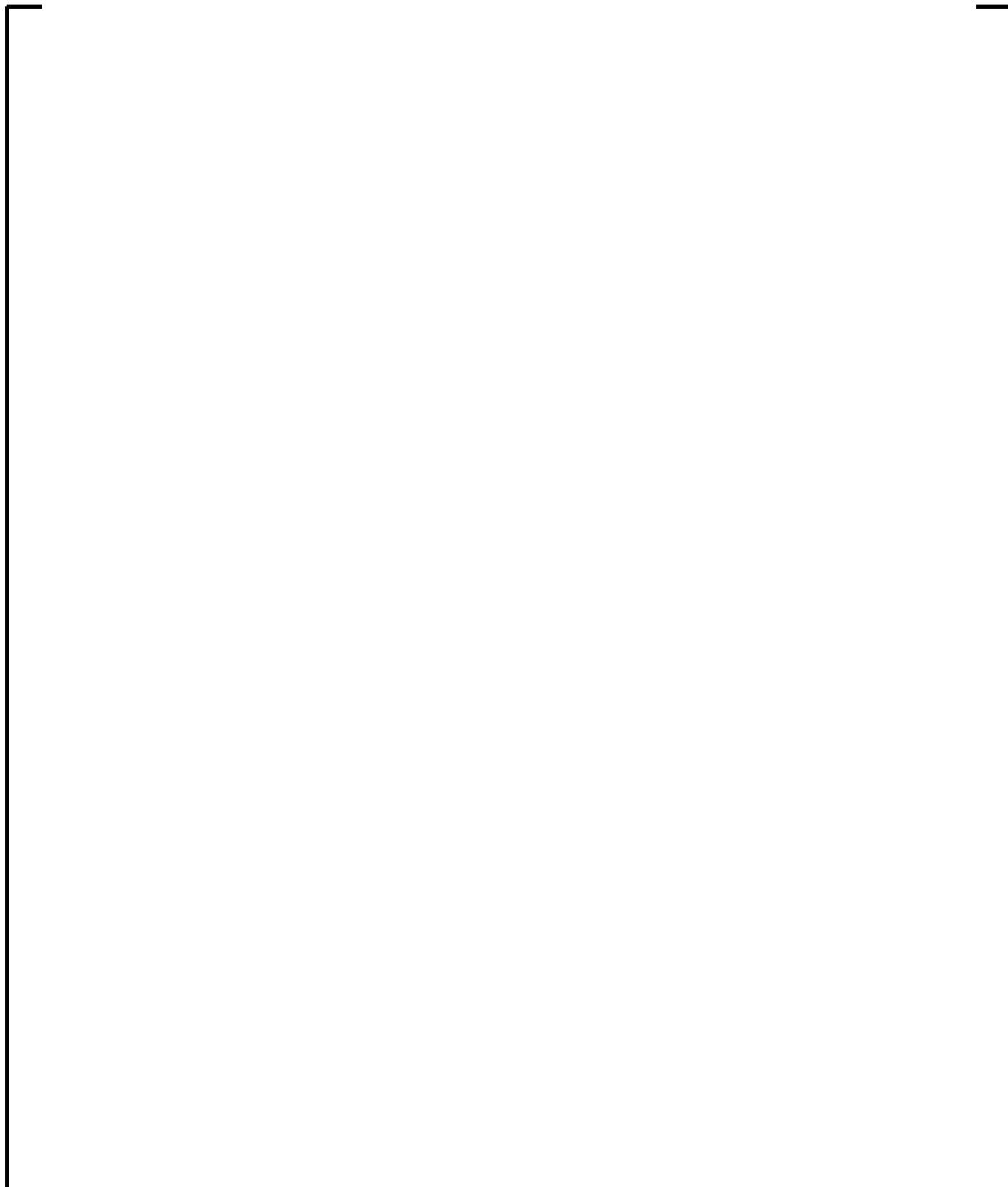
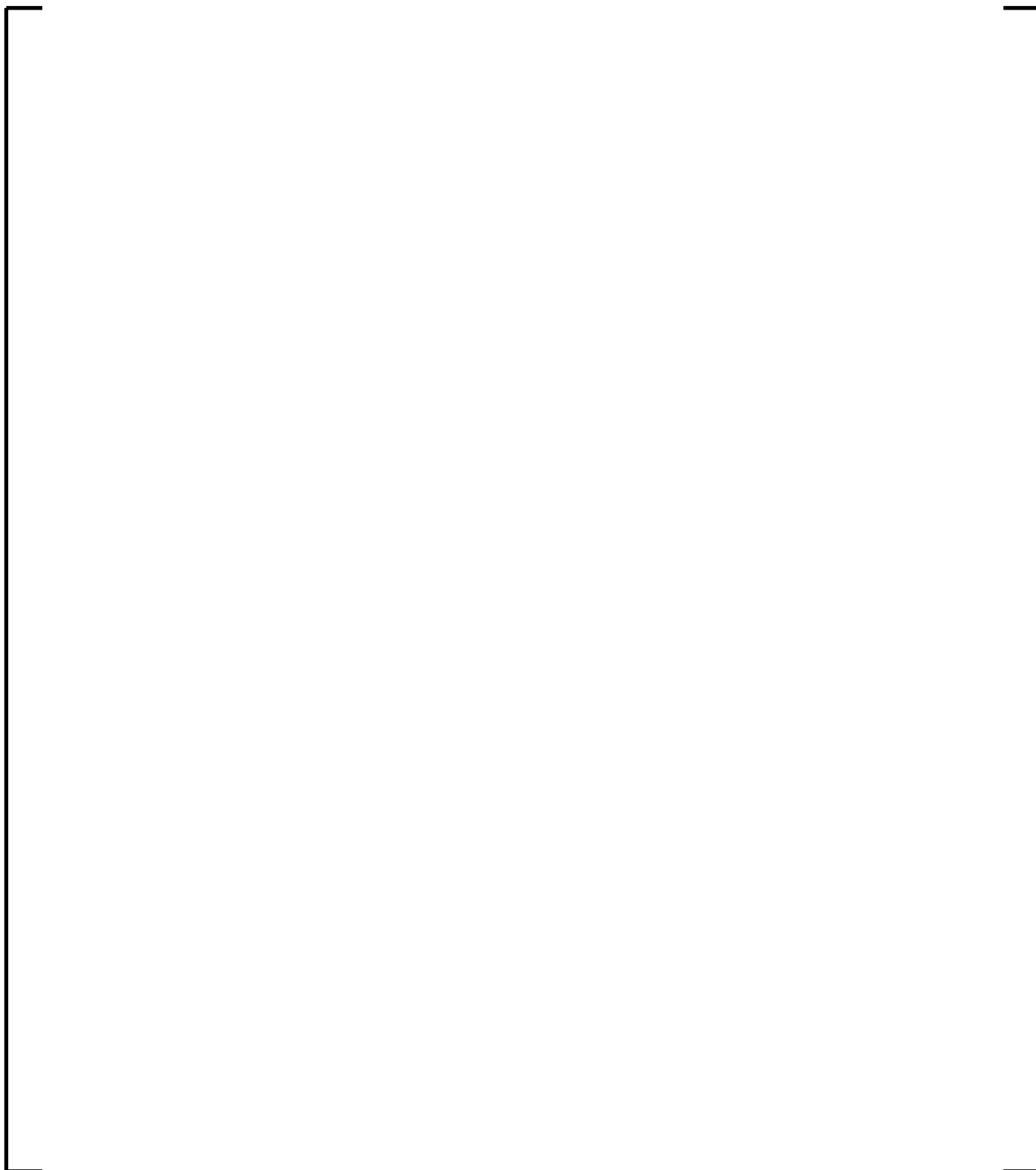
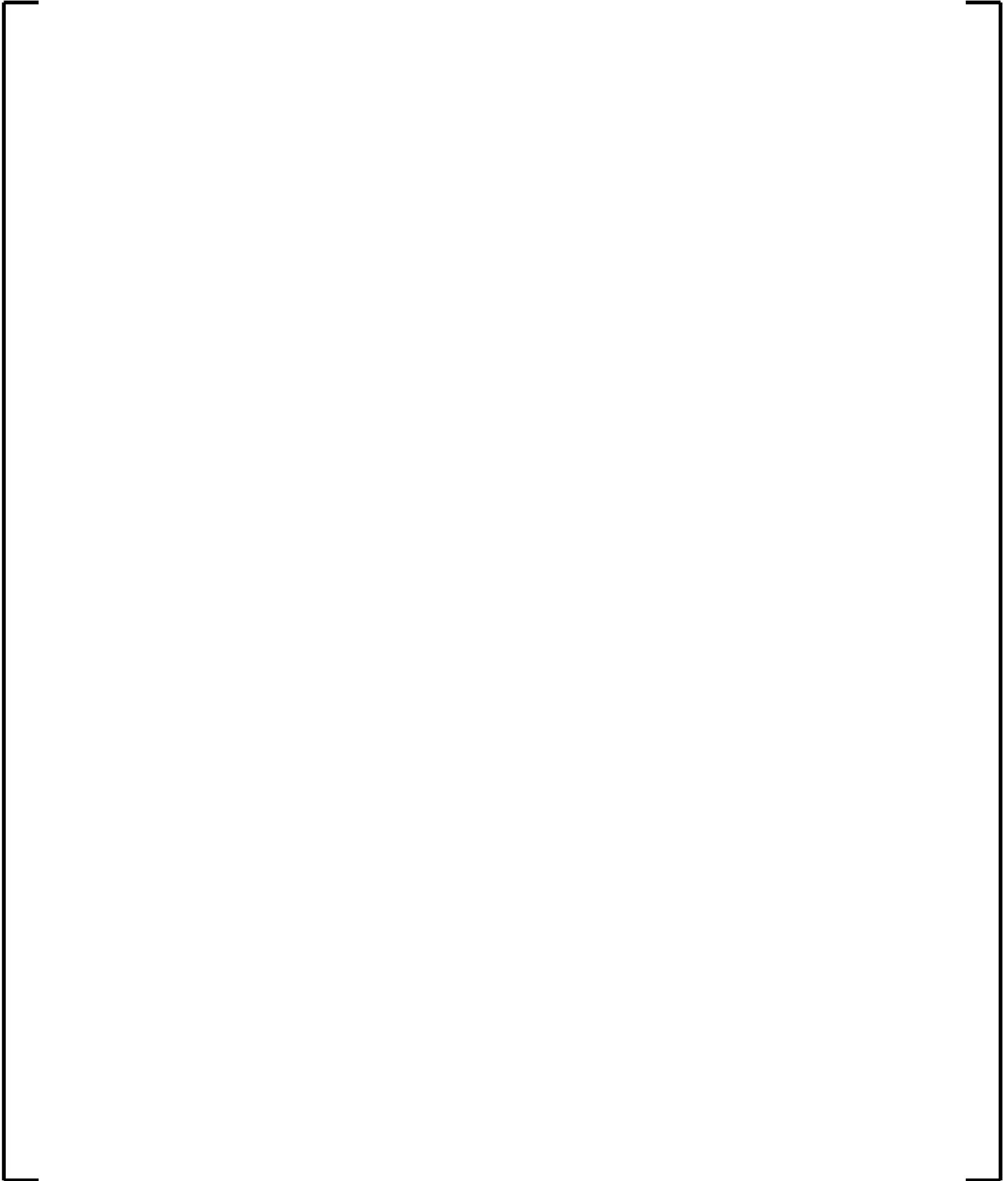


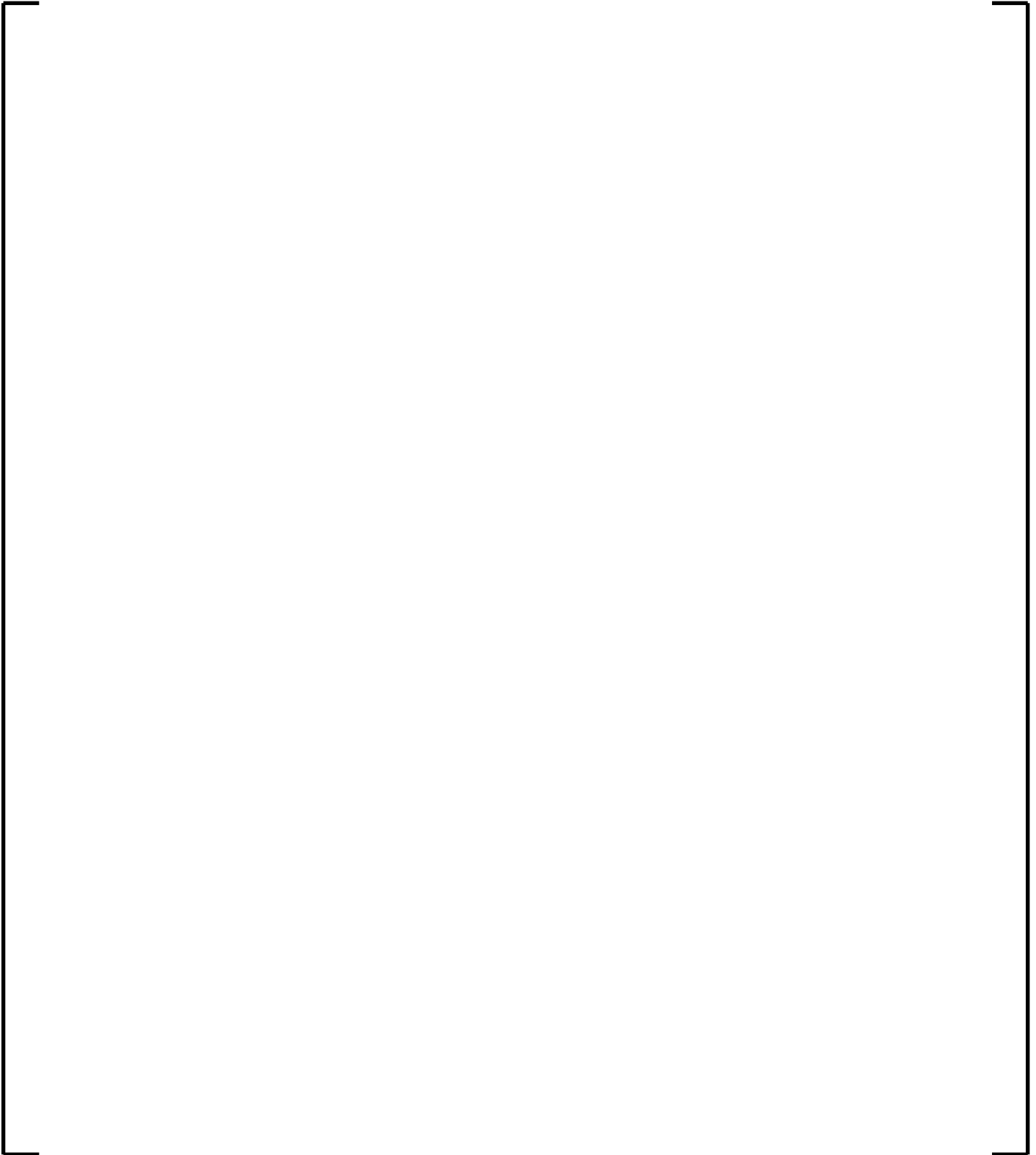
Figure 5-1: Fuel rod discretization







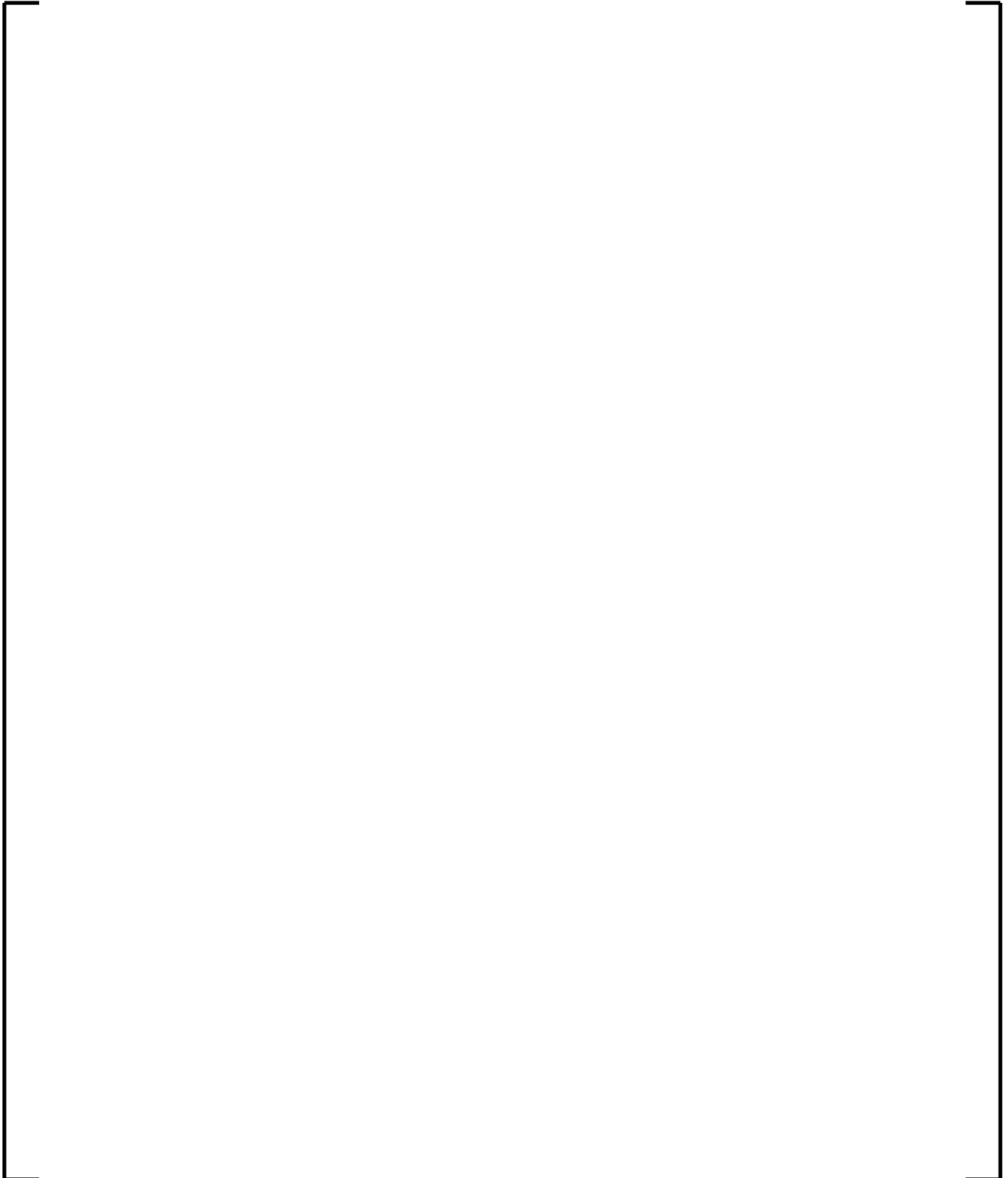




5.2.2 ATWS-I Heater Rod Heat Conduction

In order to properly model the KATHY test facility, [

]



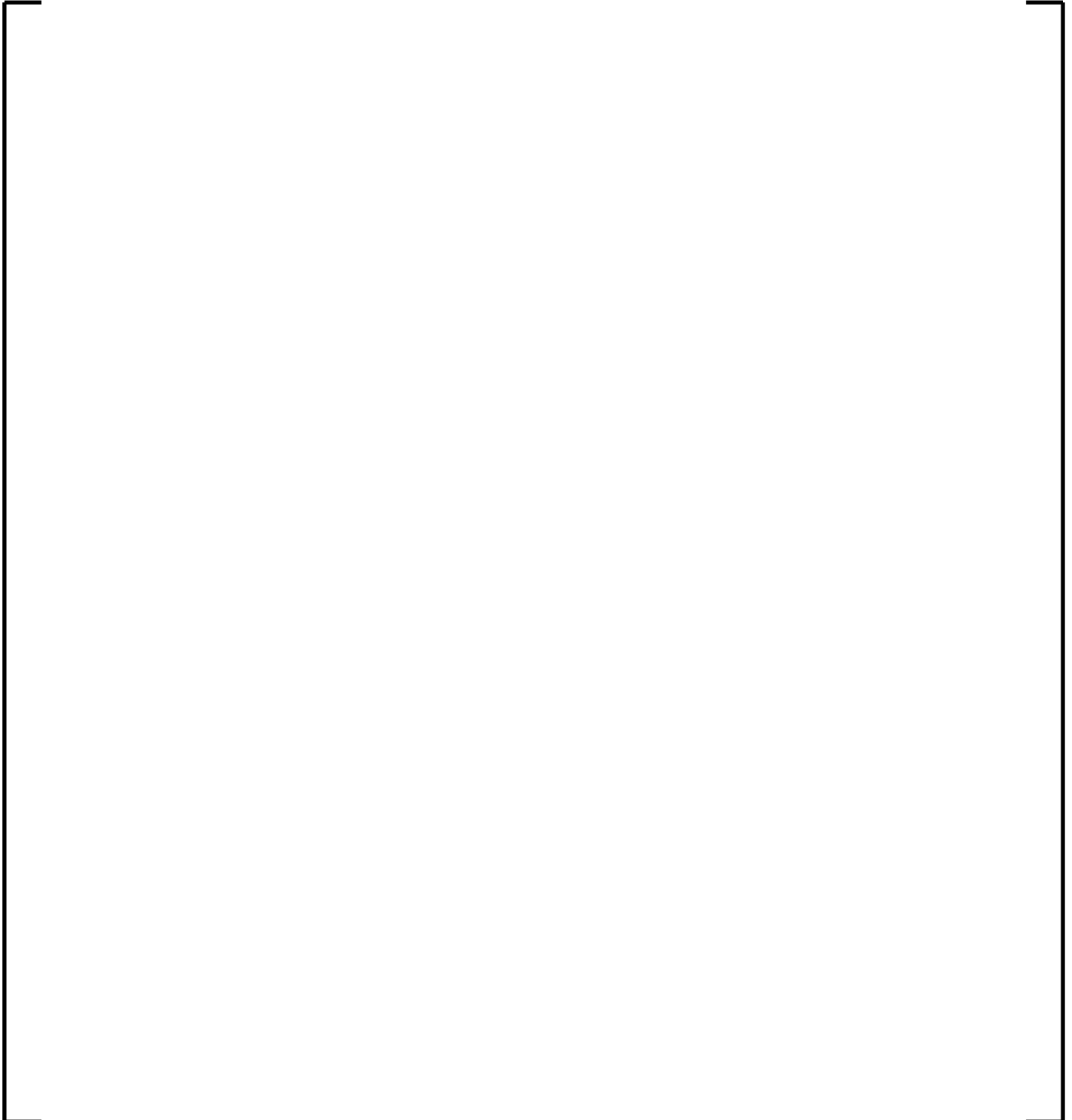
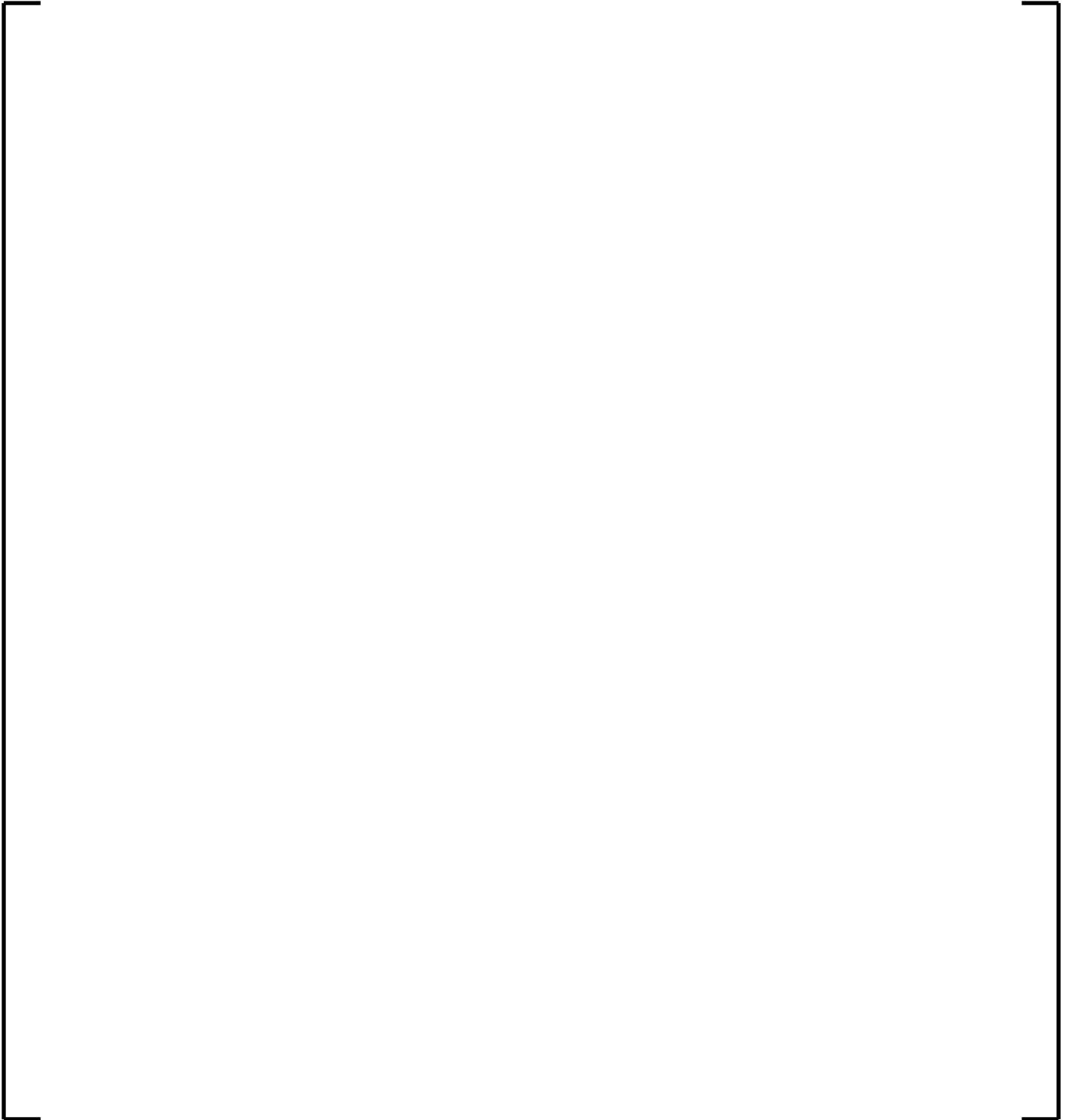
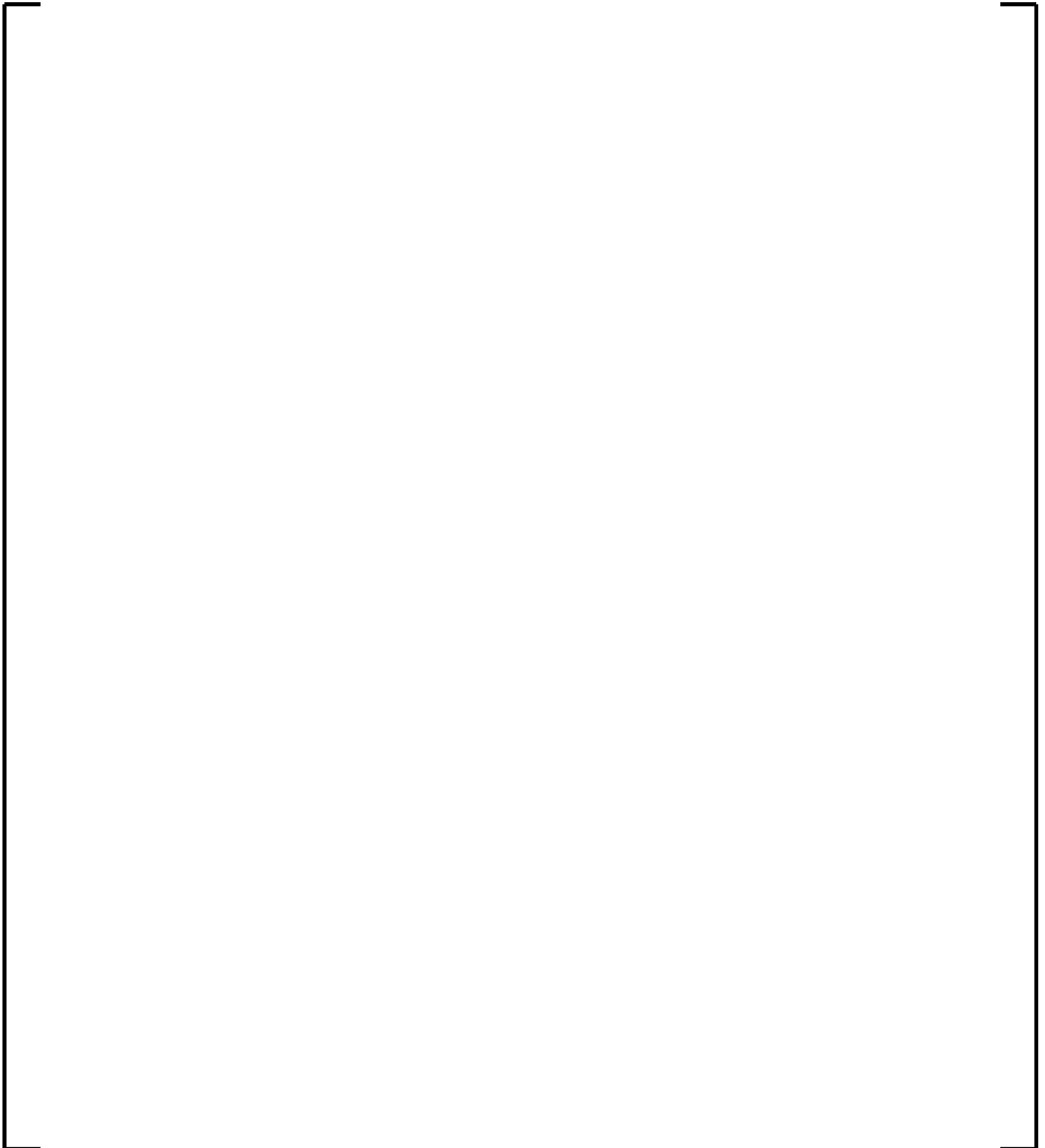
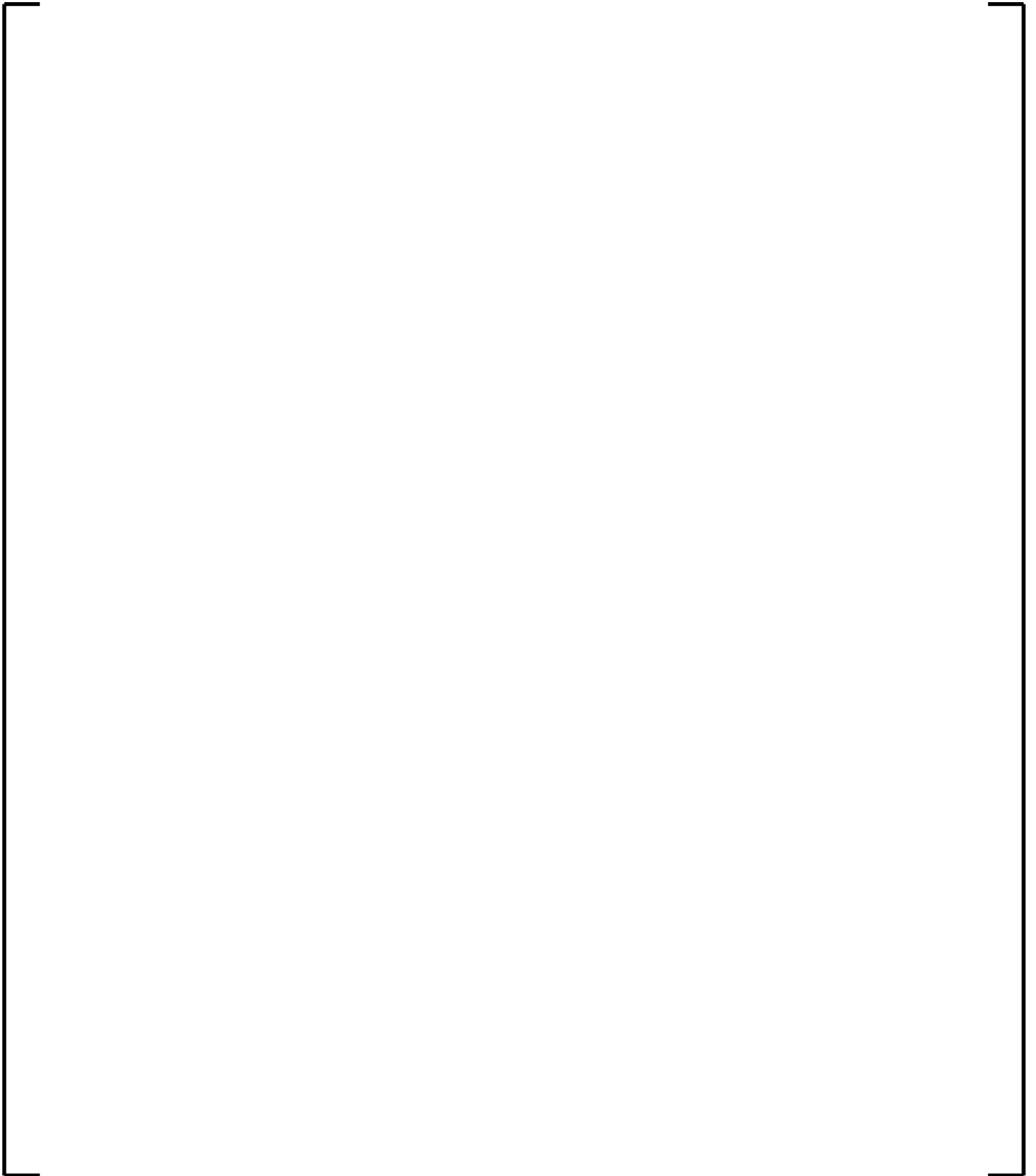
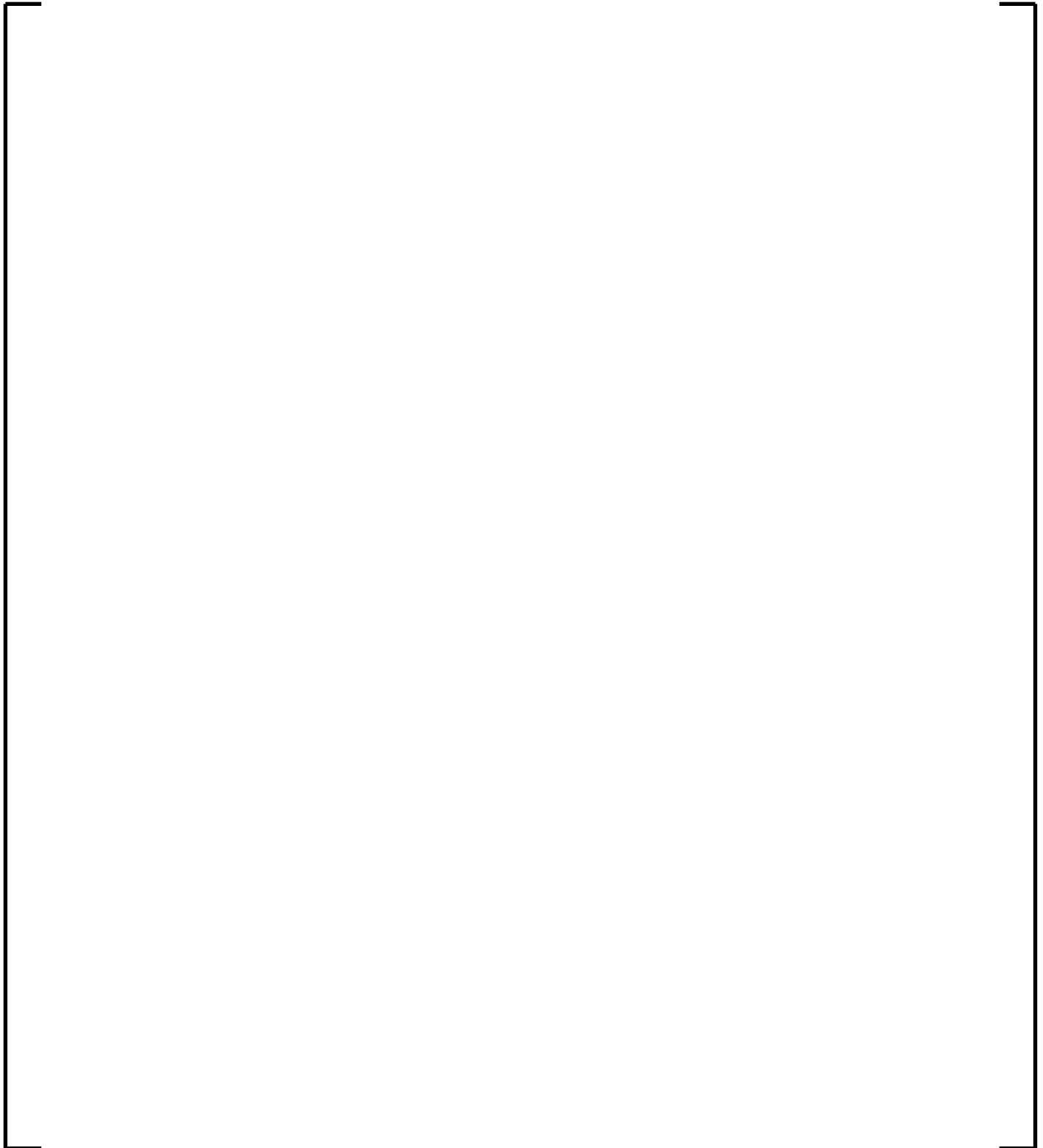


Figure 5-2: Heater rod discretization







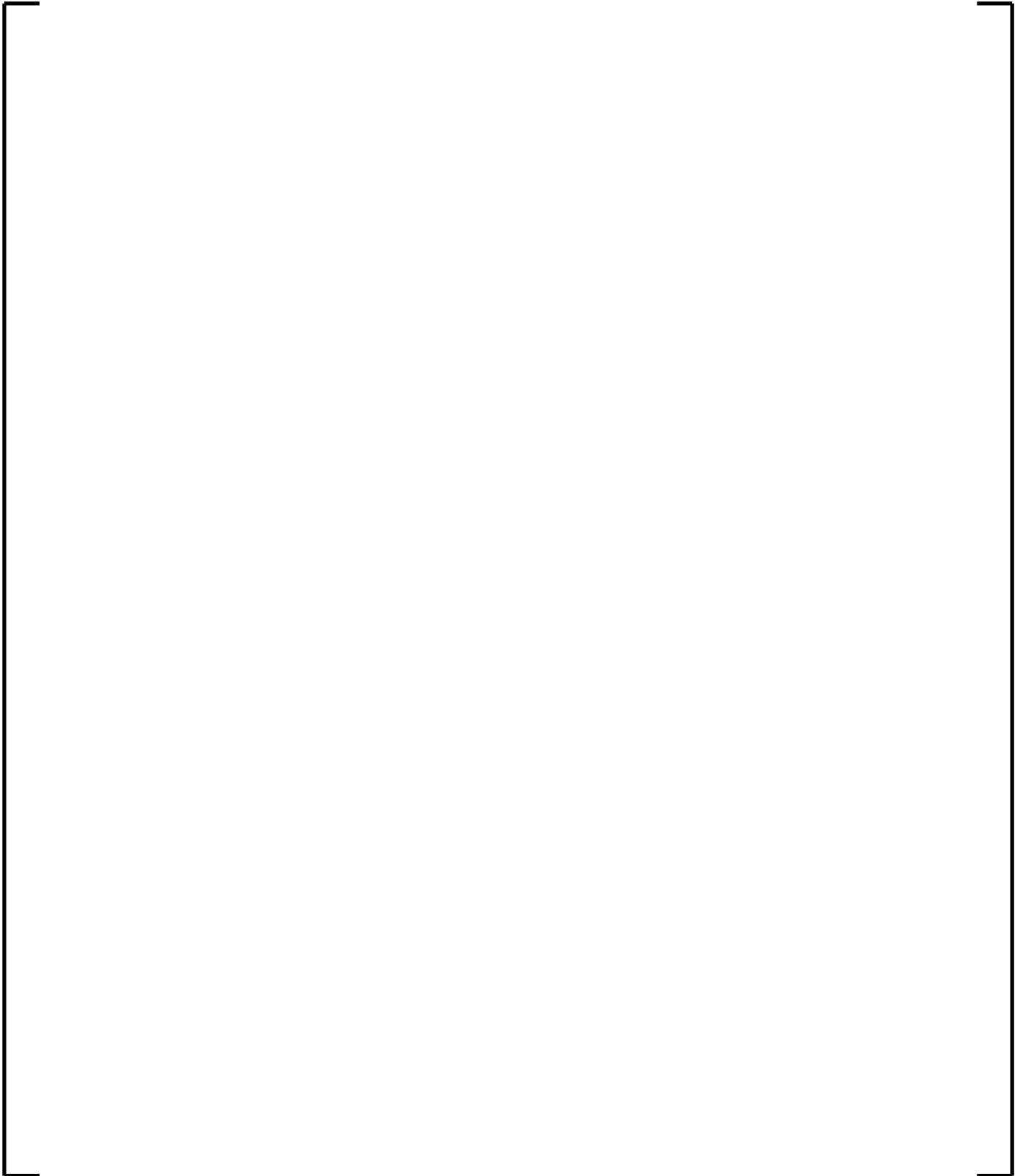


[
]

5.2.3 Heat Transfer Coefficient

The heat transfer coefficient calculations include wetted conditions under single- or two-phase flow, partially or fully dry conditions, and the transitions between these different regimes. With possible heat transfer from pin surface to liquid and/or vapor [

]

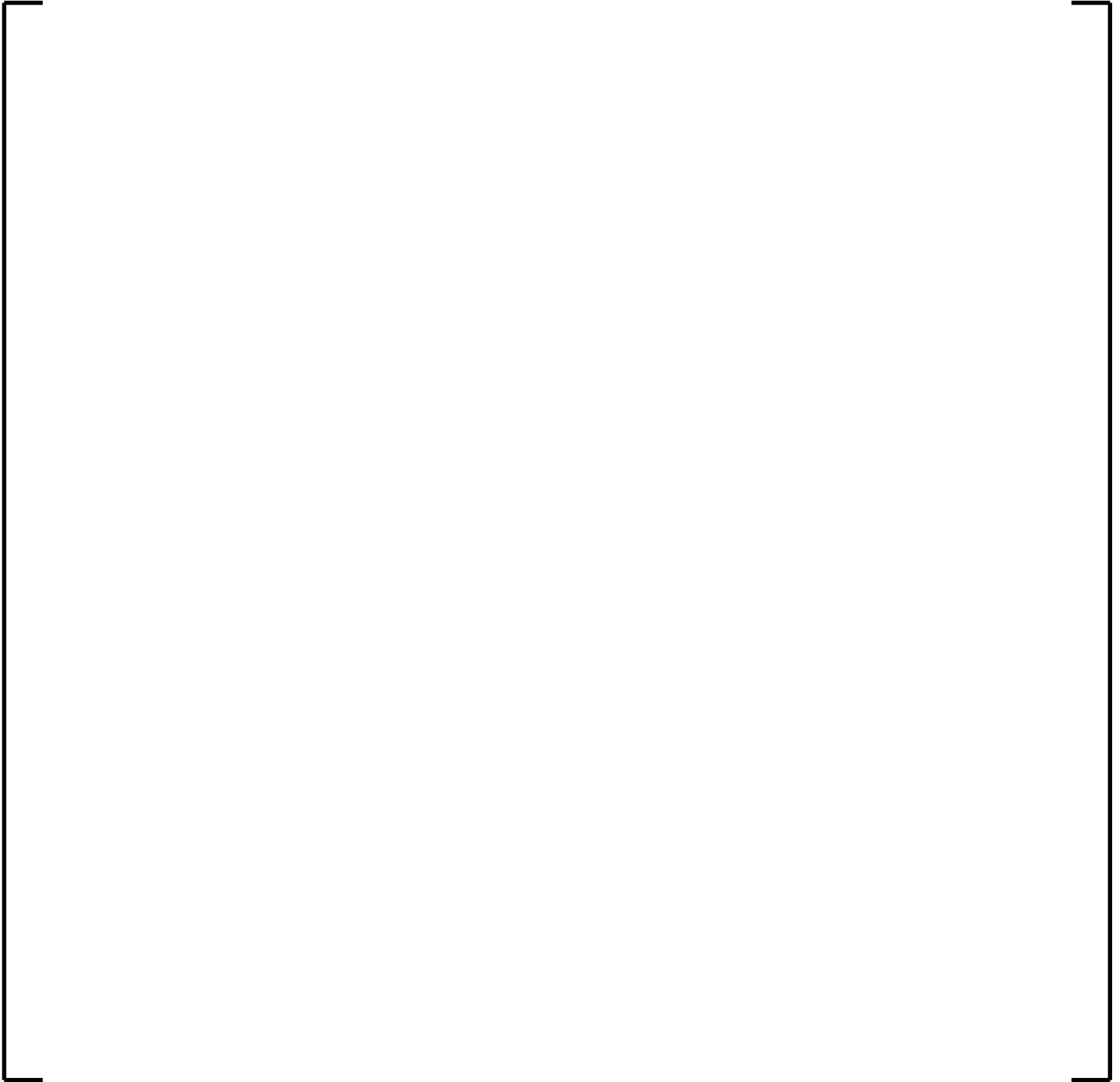


Dry heat transfer coefficient

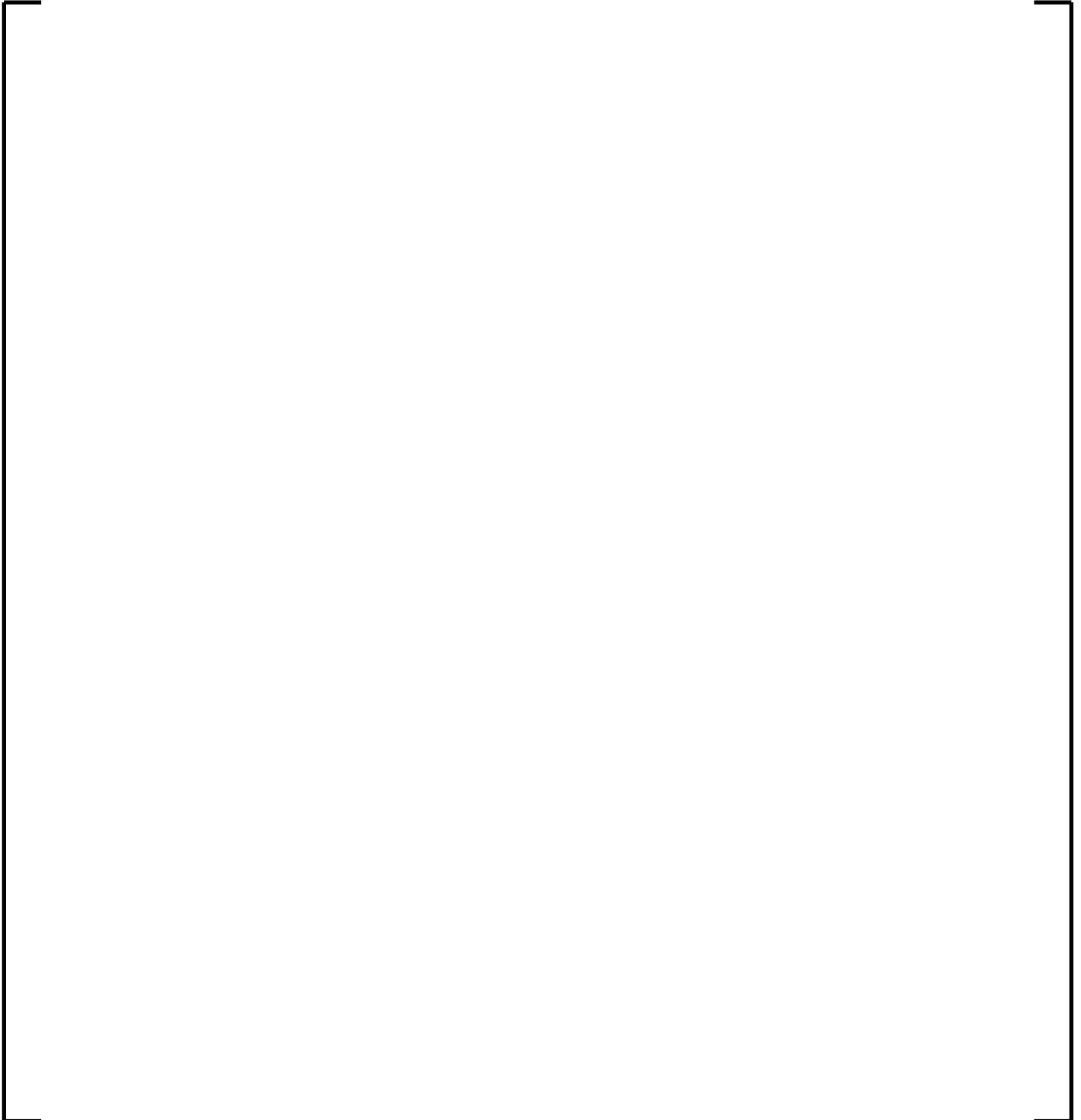
Reference temperature

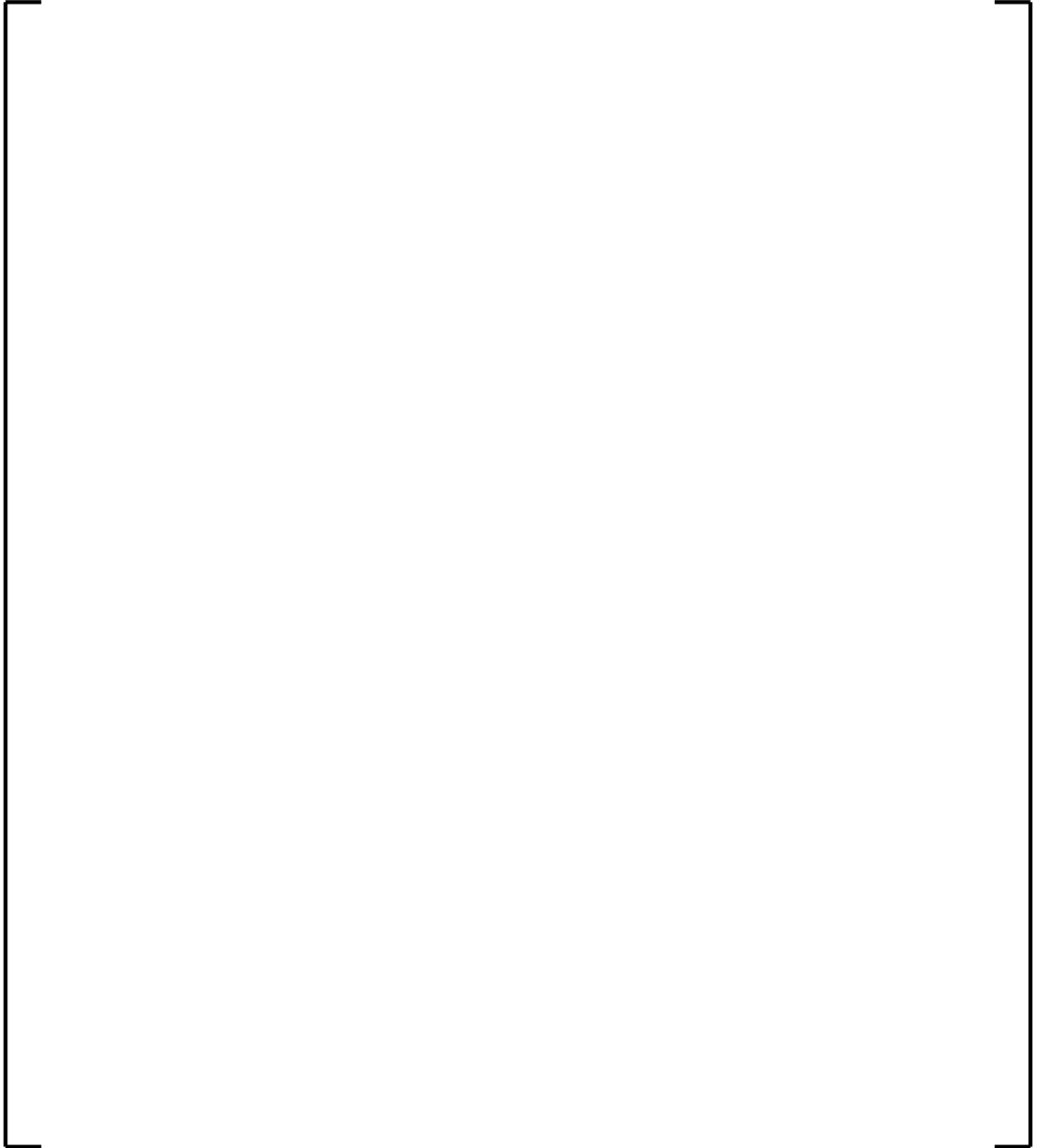
Average rod heat transfer coefficient

5.2.4 Hot Fuel Pin Model

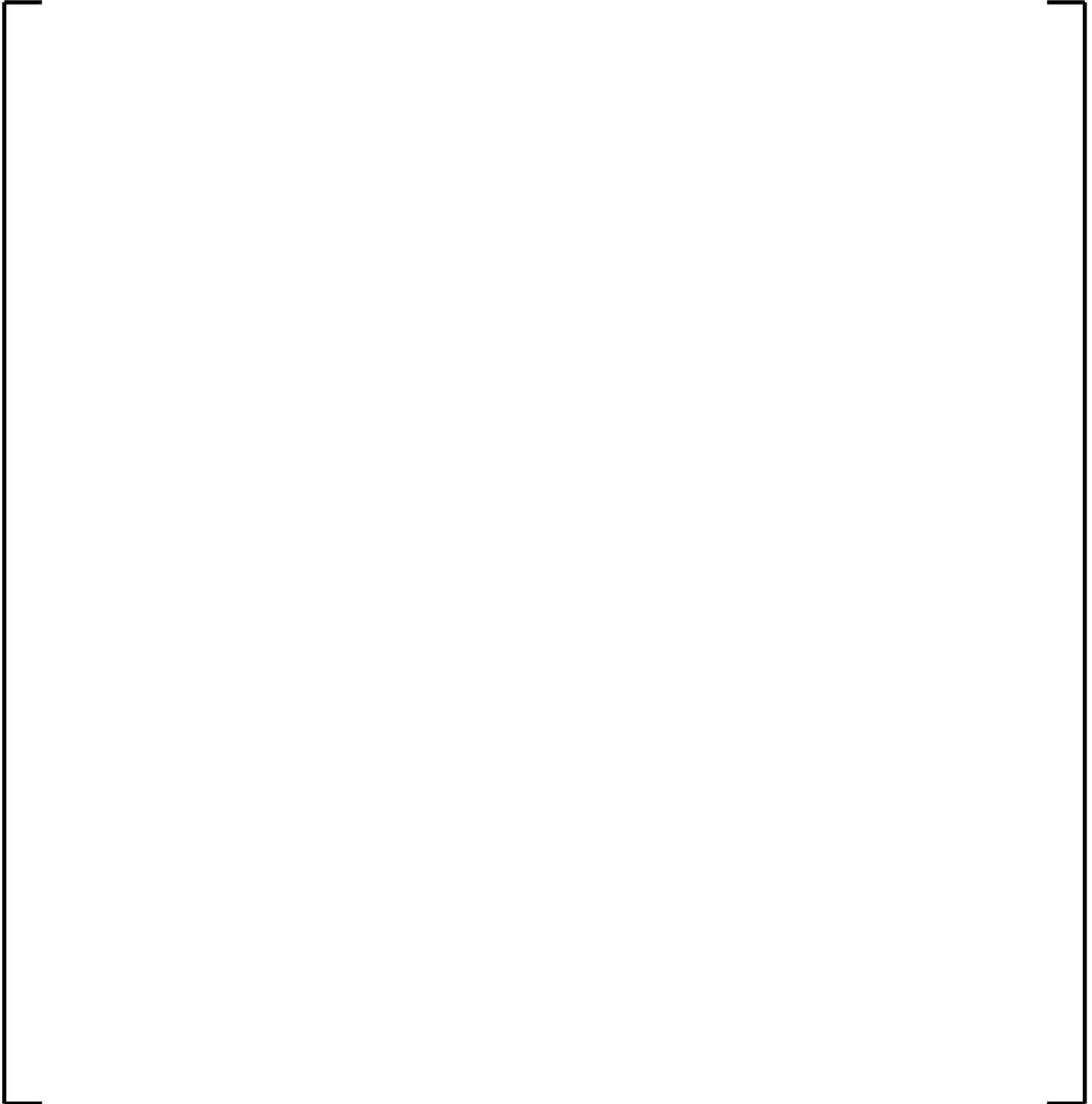


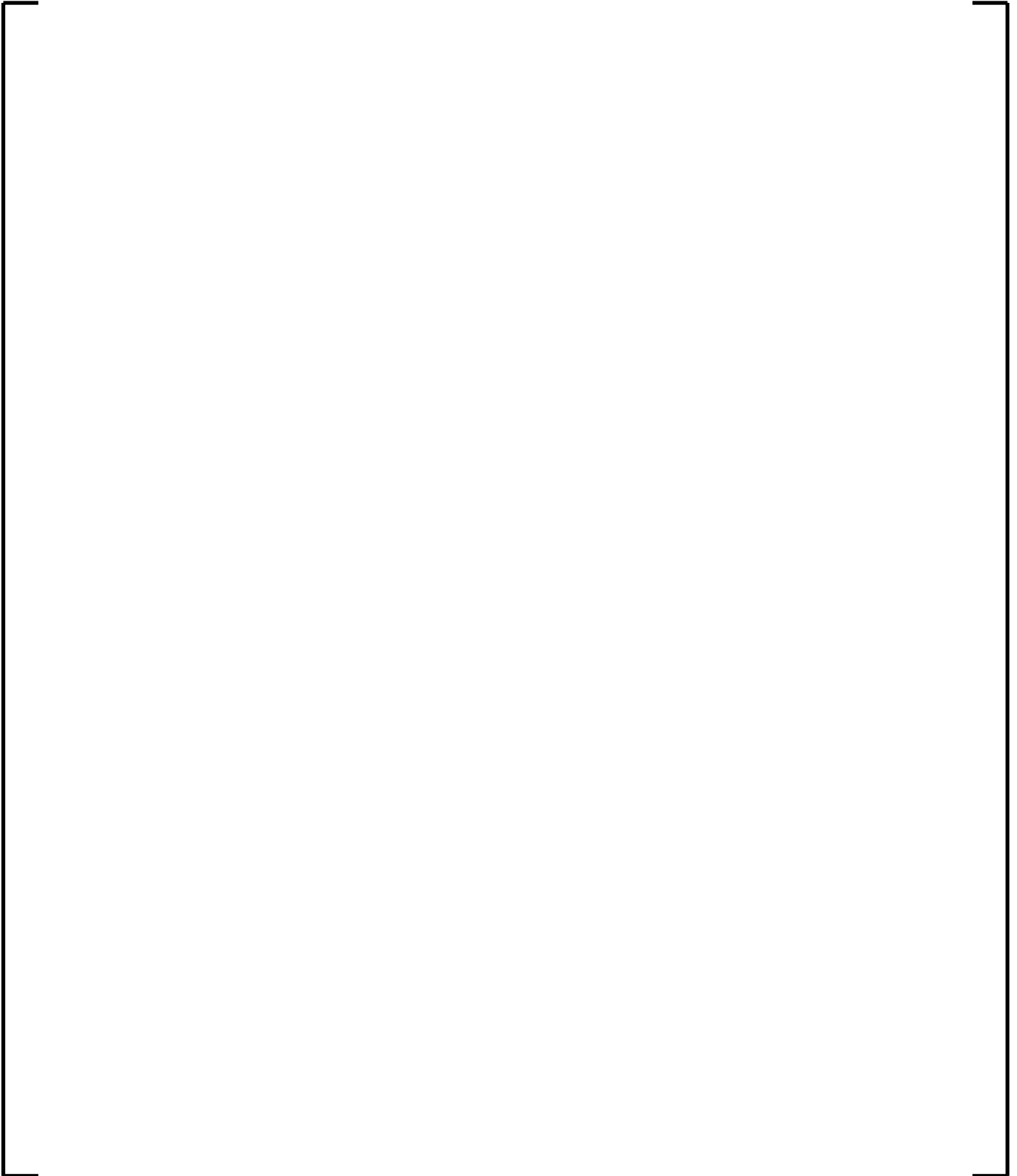
5.2.5 Material Properties

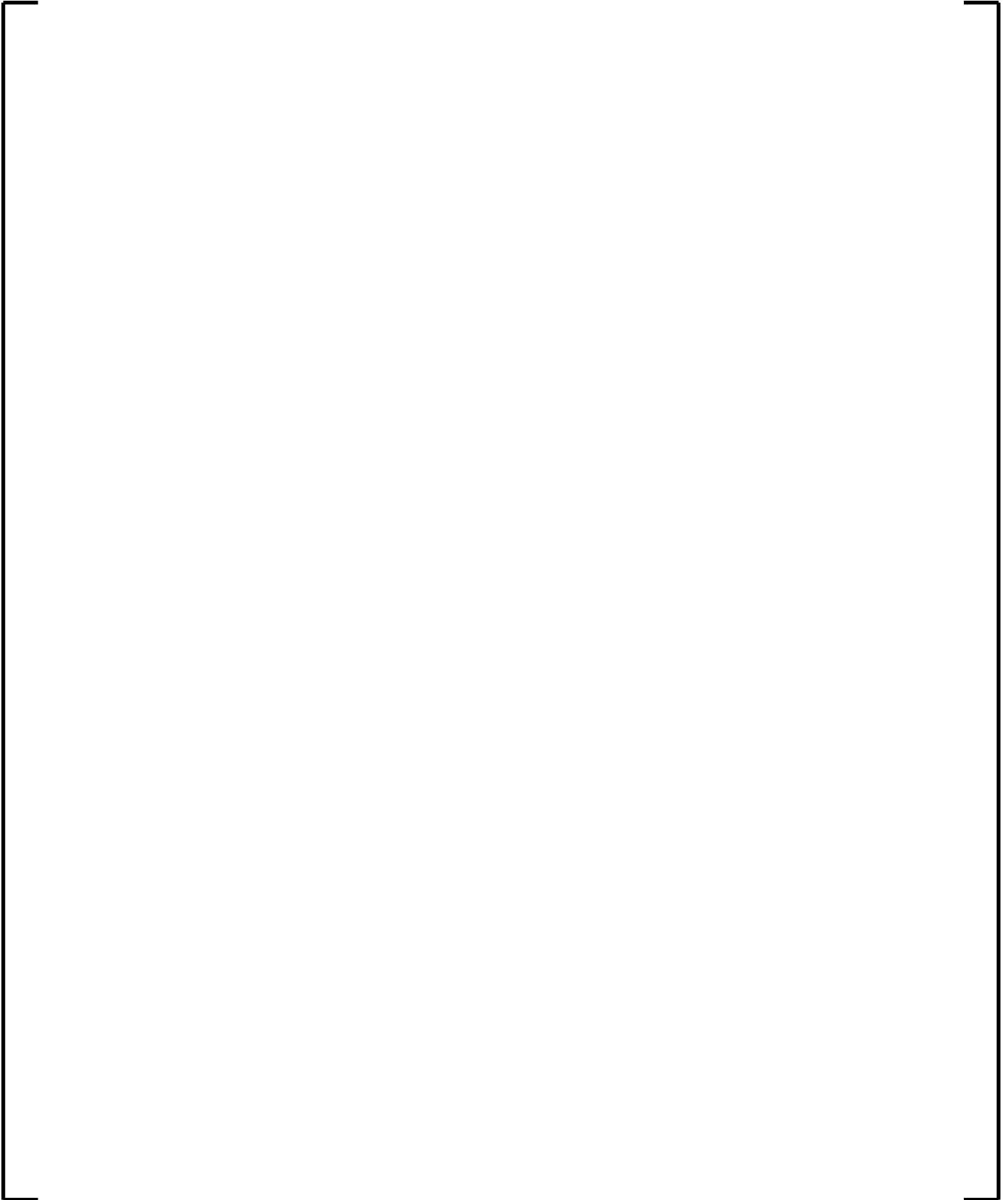


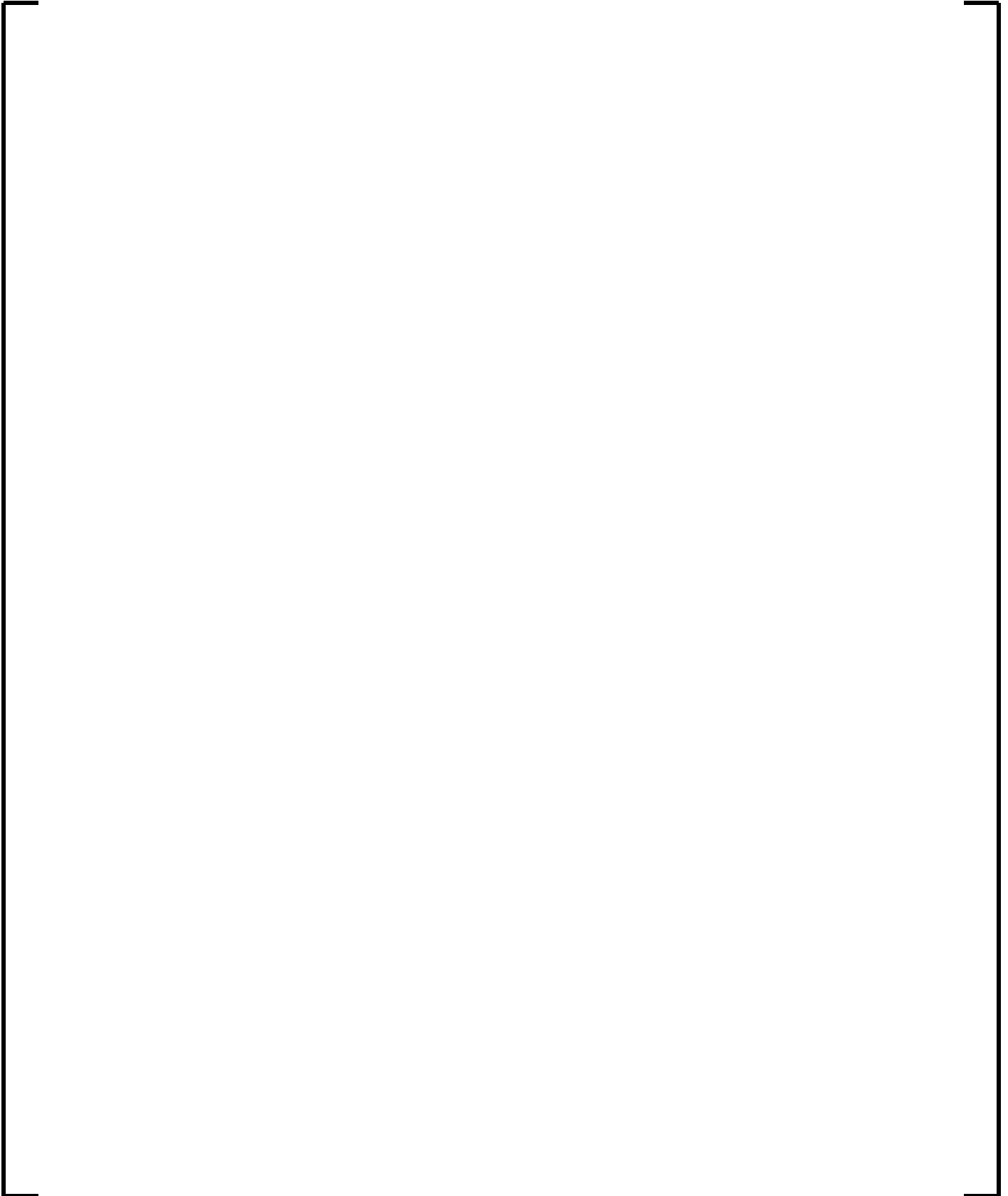


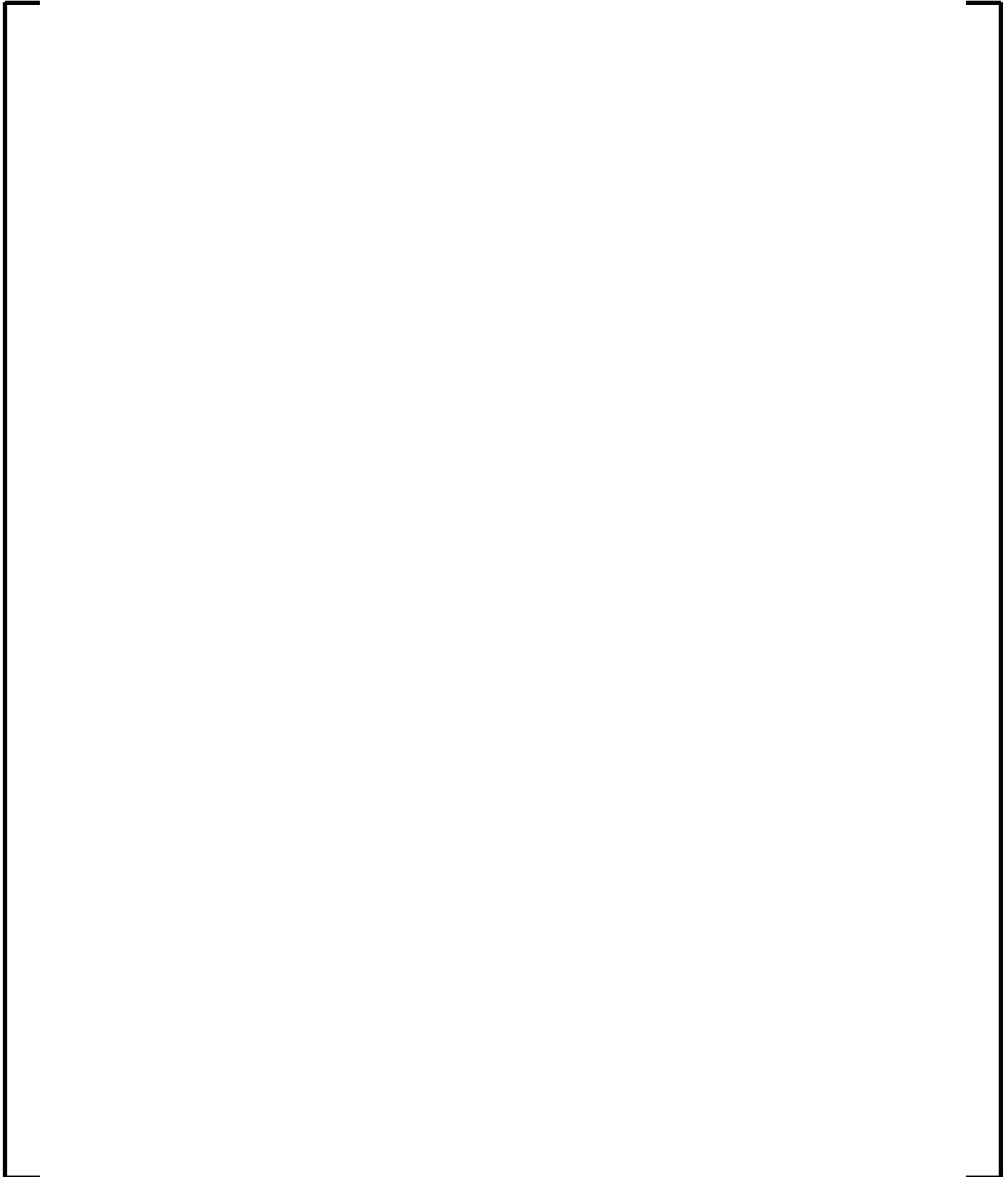
5.2.6 Pellet-Clad Gap Heat Transfer Coefficient

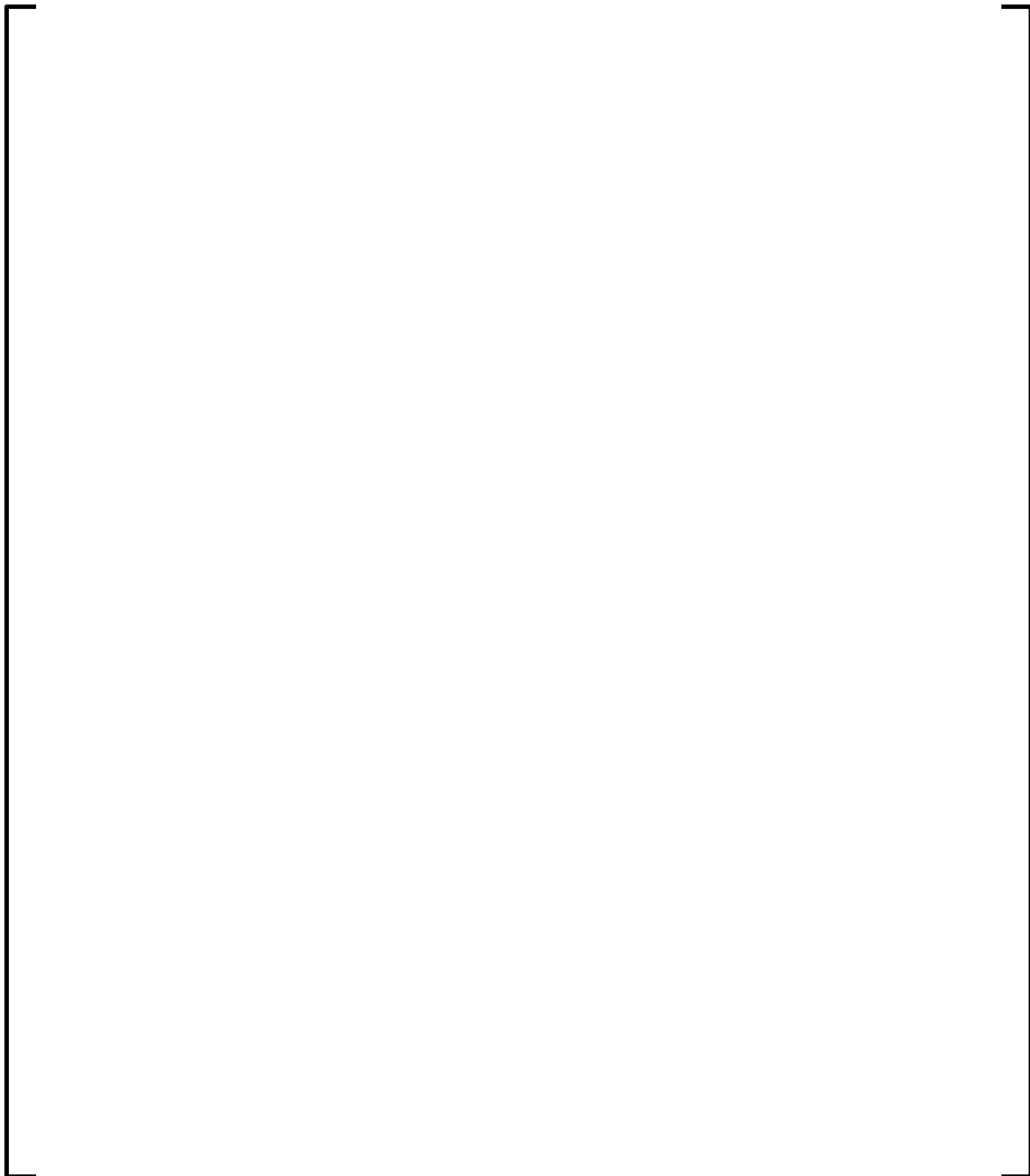












5.2.7 Radial Power Deposition Distributions in Fuel Pellets

5.3 *Thermal-hydraulic Model*

The RAMONA5-FA ATWS-I thermal-hydraulics model is a [] equation, non-homogeneous, non-equilibrium, one-dimensional two-phase flow model with constitutive equations for thermodynamic state variables, as well as heat transfer and vapor generation/condensation. Thermal non-equilibrium between the phases is accounted for by allowing the liquid in a two-phase mixture to depart from saturated conditions. Similarly, [

]. A description of the hydraulics is given in this section.

The channel is divided into N nodes, which are control volumes [

]. The flow area and hydraulic diameter for each node is allowed to vary in order to account for specific bundle design features such as part-length fuel rods. The 1-D formulation [

]

[

] These equations are written directly for control volumes which directly correspond to the as programmed model. The control volume

formulation is straightforward, and there is no need to follow the customary style of first writing the partial differential equation set and applying finite differencing over the control volume as approximations.

It is important to note that a volume conservation equation is not an independent equation with physical significance like the mass, momentum, and energy equations. However, the fact that the volume of the fluid species in a node sum up to the volume of that node, is useful in arranging the information content of the physical balance equations.

5.3.1 General Description of the System Considered

The hydraulic loop is divided into nine main parts as shown in Figure 5-3, namely:

Downcomer 1
Downcomer 2, with NDC2 parallel paths
Lower Plenum 1
Lower Plenum 2
Core, with NPC parallel paths
Core Upper Plenum
Standpipes
Steam Separators
Steam Dome

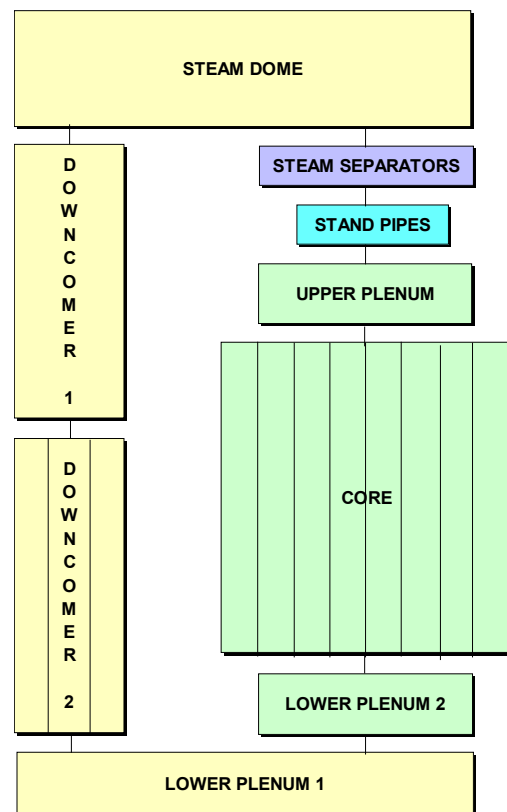


**Figure 5-3: Loop Parts in the
Vessel Hydraulics Model**

All the loop parts are vertical except for Lower Plenum 1, which is horizontal. As indicated in Figure 5-3, Downcomer 2 is divided into NDC2 parallel paths, and the core is divided into NPC parallel channels consisting of NCC coolant channels and one moderator or bypass channel. The bypass channel accounts for the inter-channel flow as well as the internal water structures in the assemblies.

The parallel paths of Downcomer 2 (DC2) are hydraulically coupled at the Downcomer 1 (DC1) and at the Lower Plenum 1 (LP1). The core channels are also hydraulically coupled at the Lower Plenum 2 (LP2) and core Upper Plenum (UP). The Upper Plenum

(UP), Standpipes (SP), and Steam Separators (SS) can be modeled separately or lumped into one volume (riser component).

[

]

The position of the feedwater inlet is limited to Downcomer 1 (DC1) and the pump may be anywhere in Downcomer 1 or Downcomer 2 (DC2). Systems with multiple pumps can be explicitly modeled.

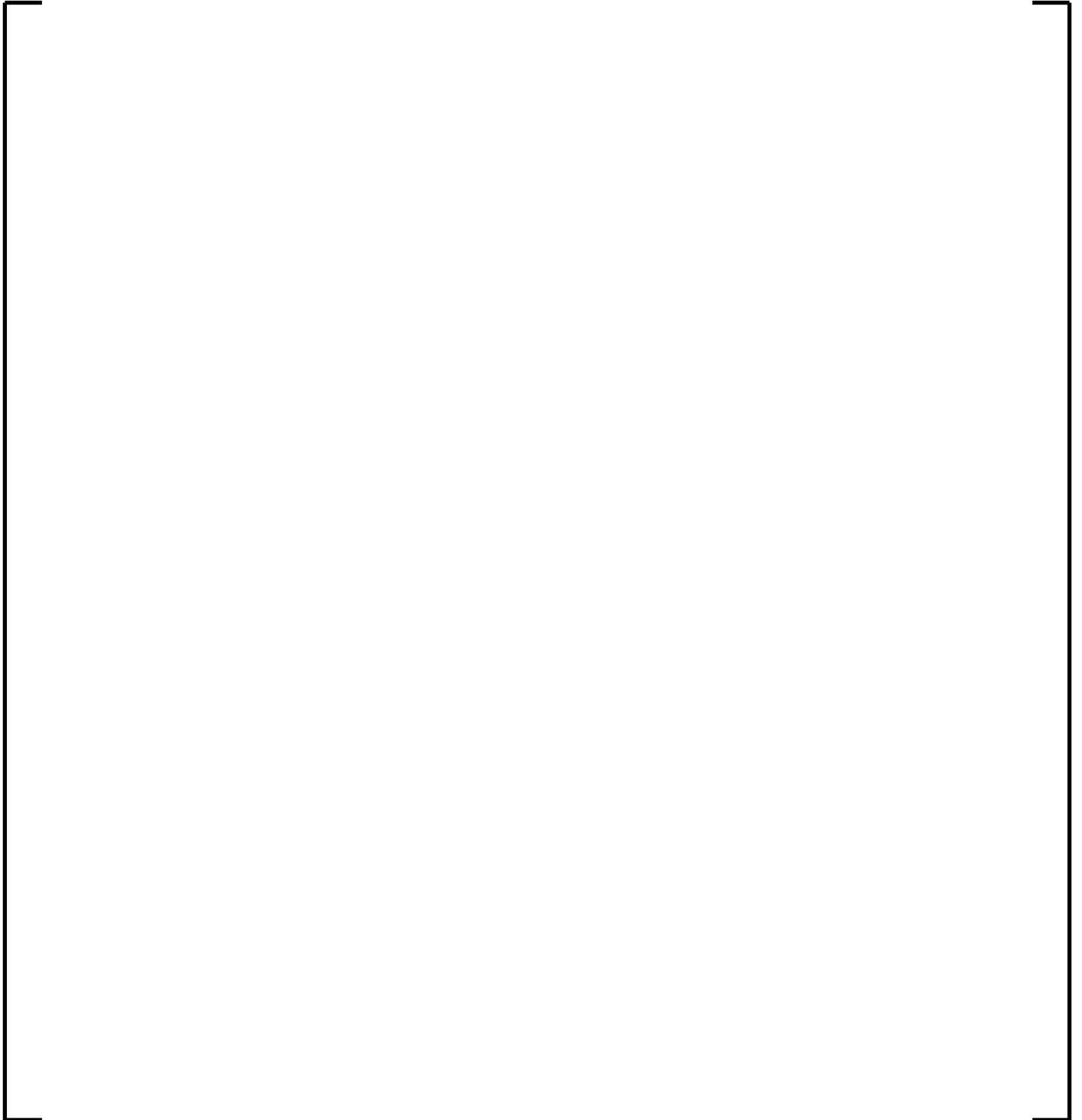
[

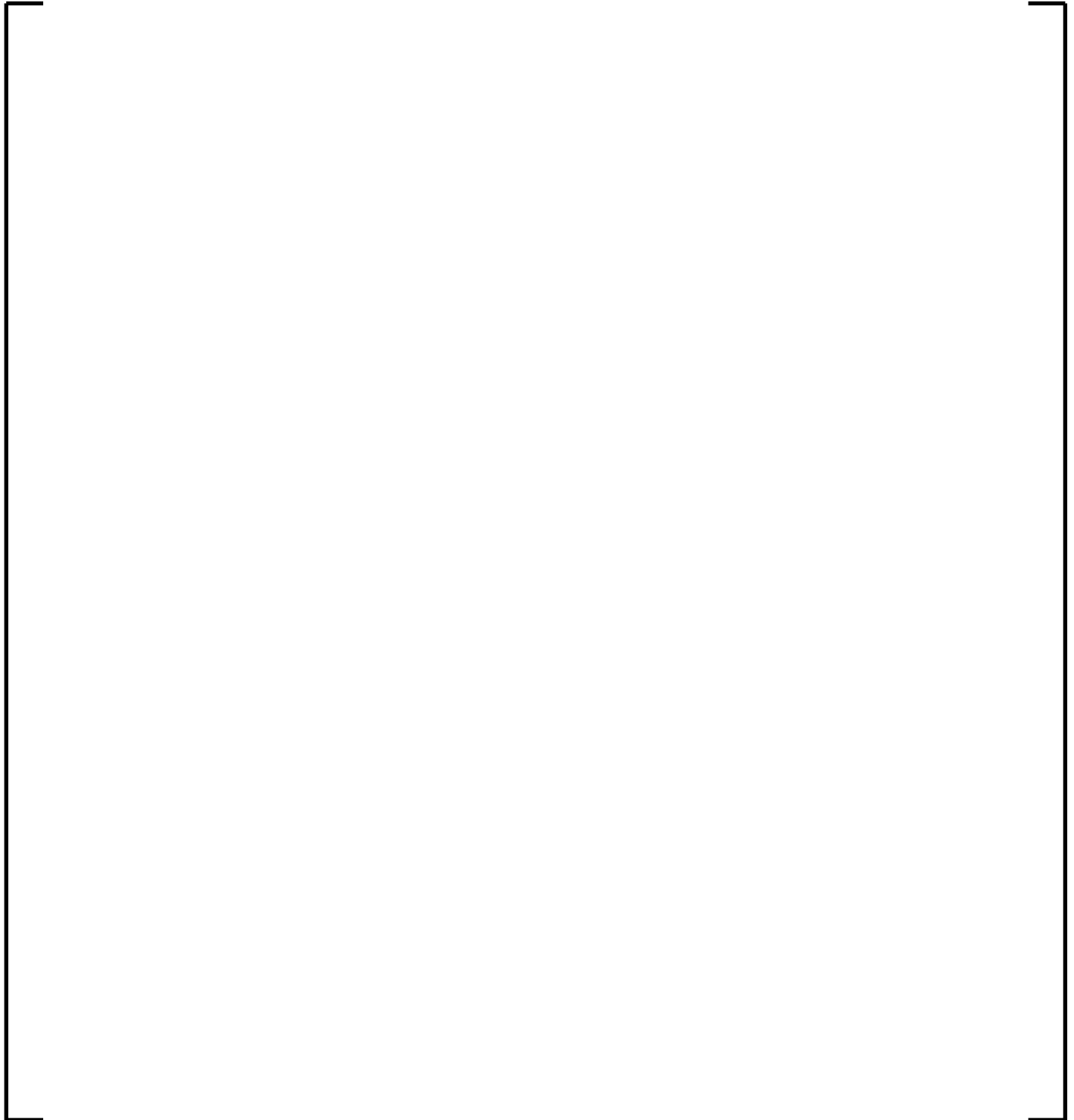
]

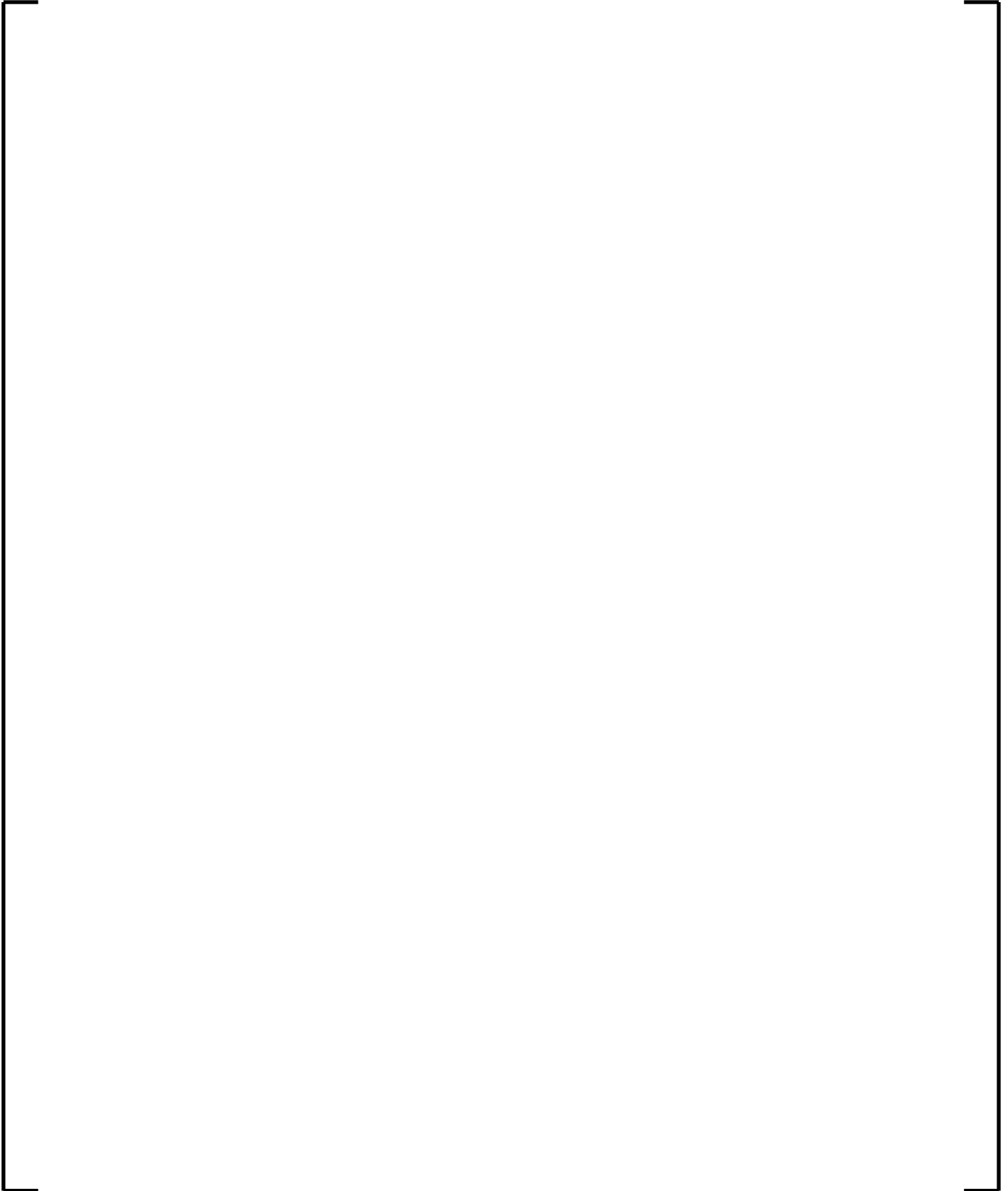
Power is supplied to the loop in two different ways:

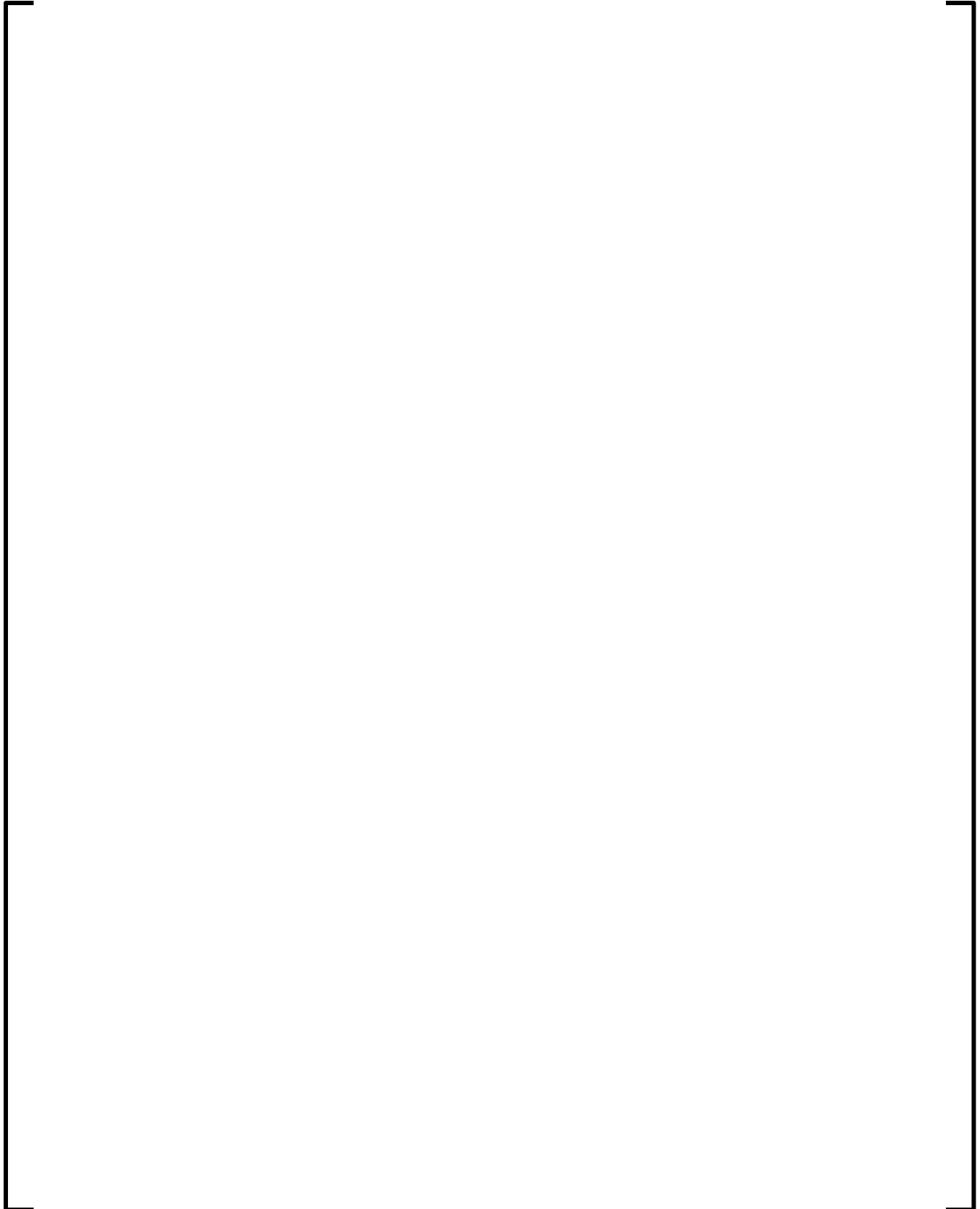
- Heat transfer from the surfaces of the fuel rods to the coolant (see Section 5.2.1)
- A fraction of the nuclear power is directly generated in the coolant and moderator (see Section 5.1.5 above)

5.3.2 []









[

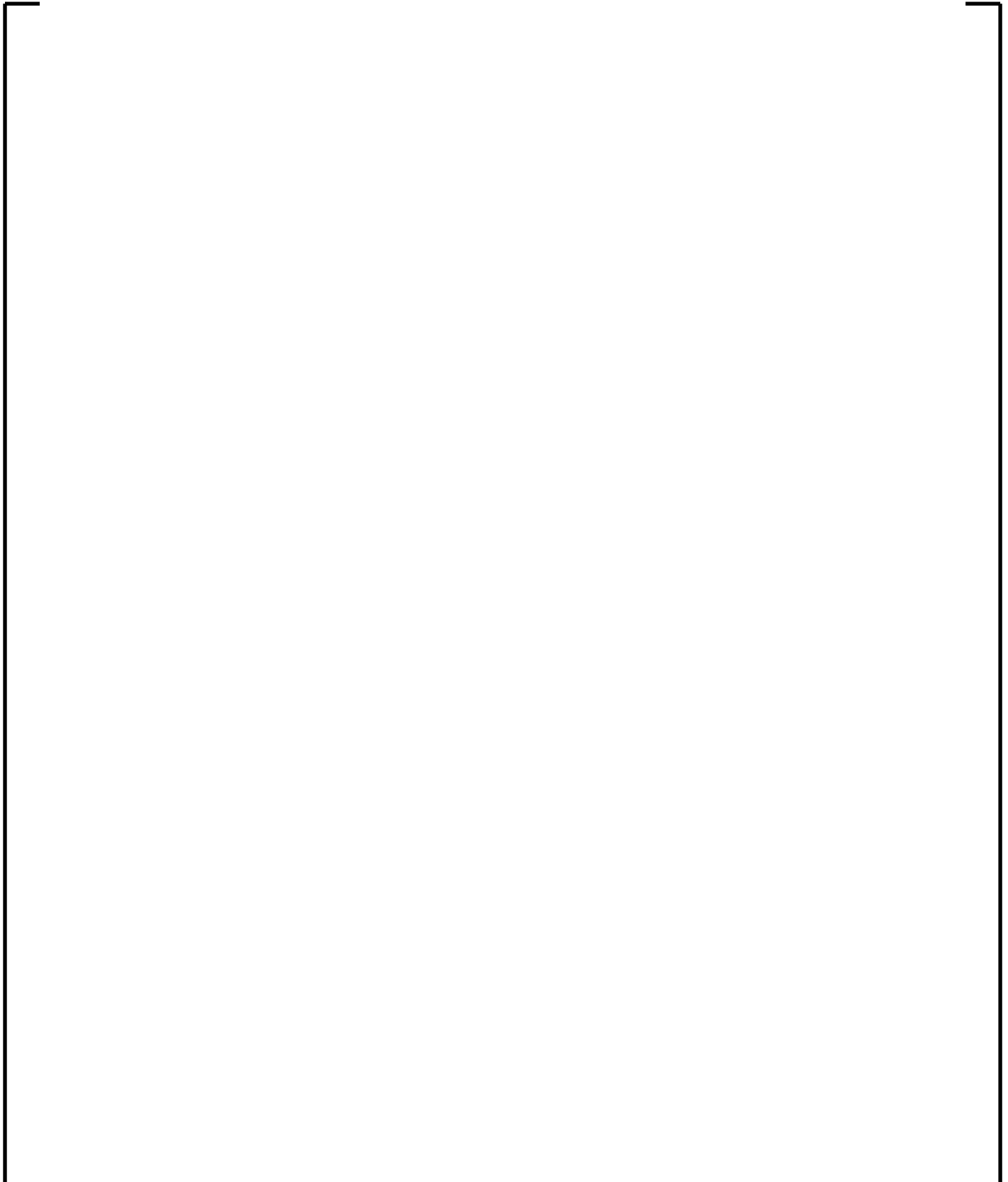
]

5.3.3 Vapor generation rate

The vapor generation rate is modeled [

]

[



5.3.4 Mass conservation

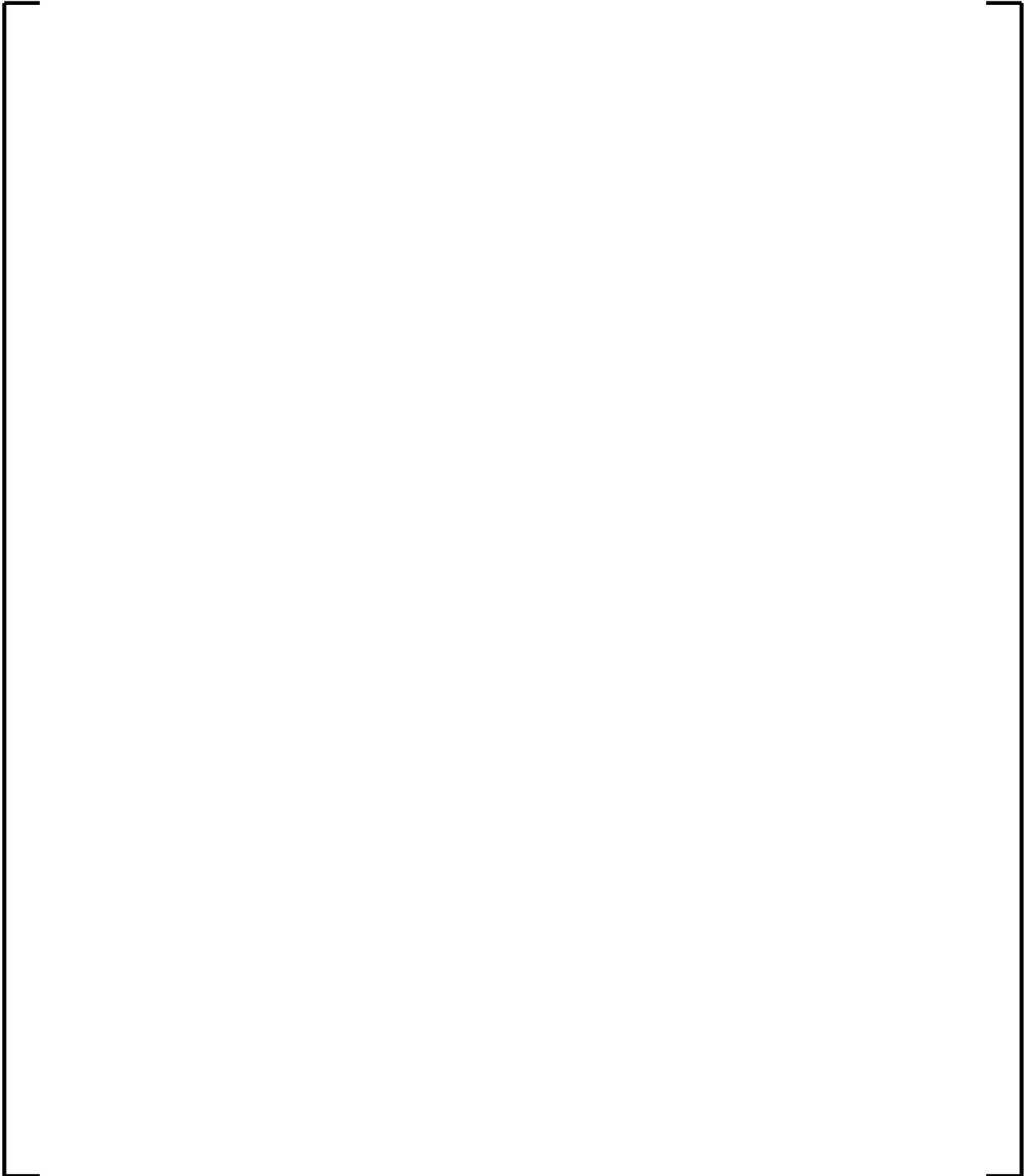
The mass conservation equation is solved for the liquid and vapor phases. [

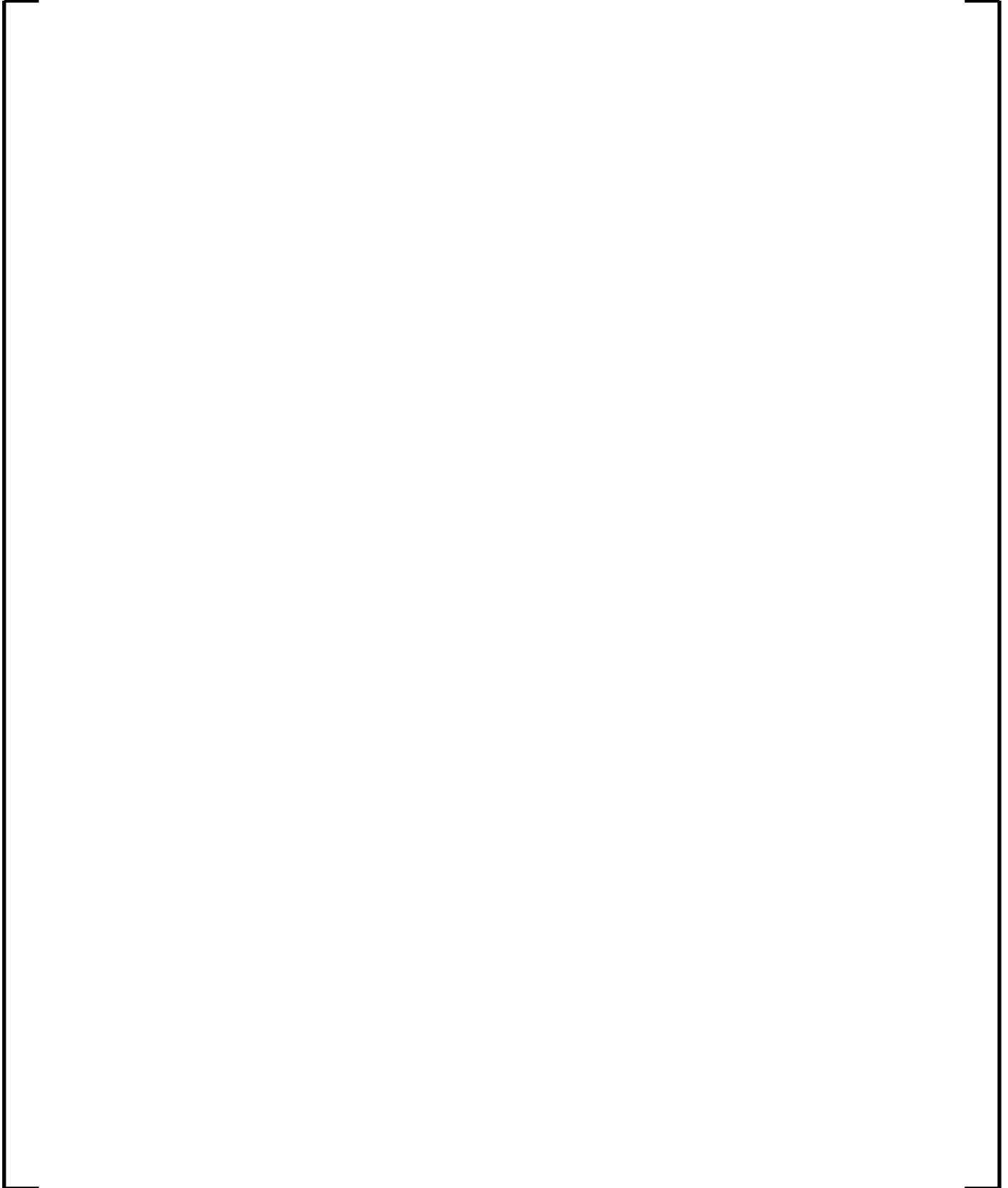
]

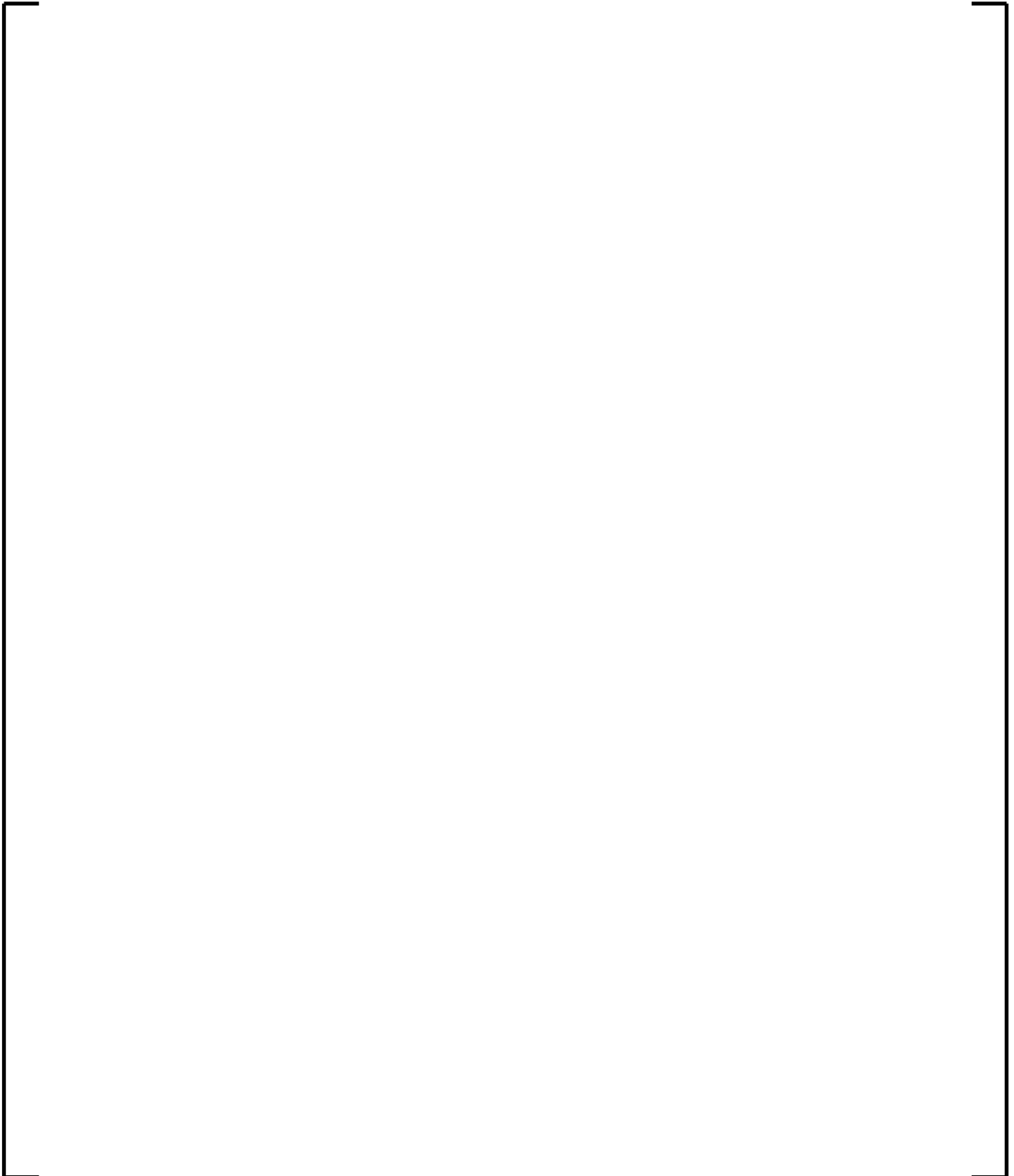
5.3.5 Energy Conservation

Energy conservation, in the ATWS-I formulation, requires solving [

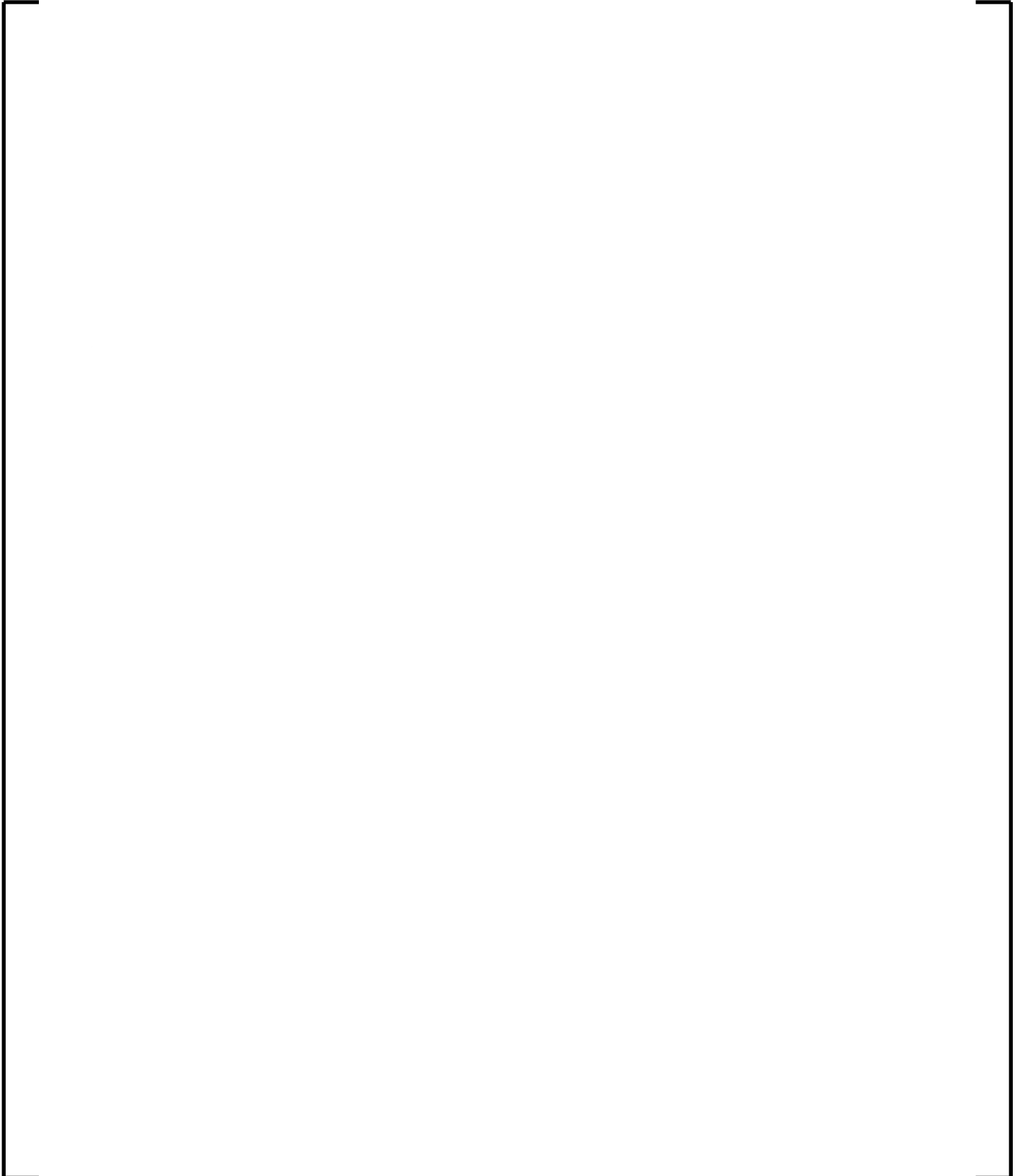
]





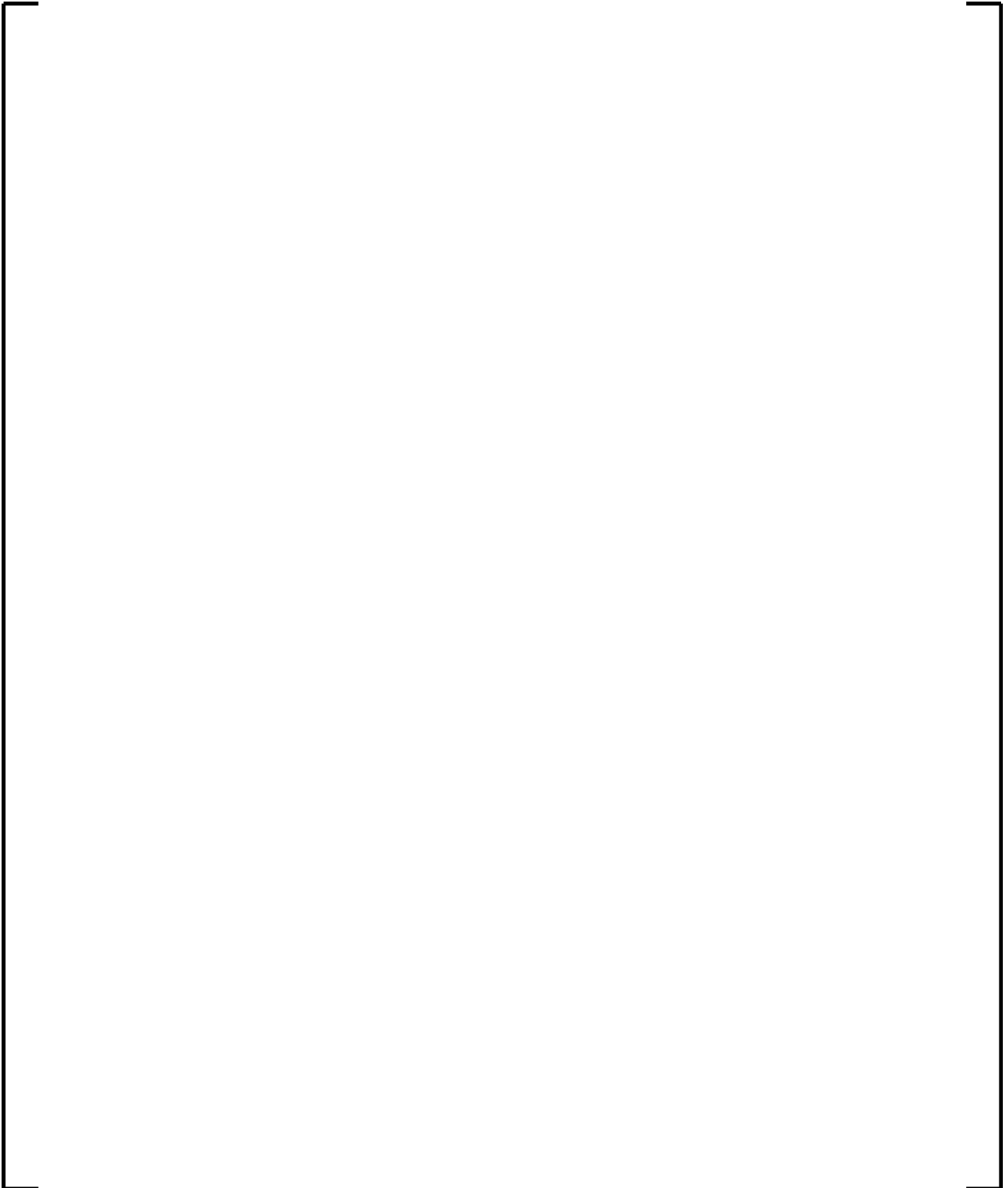


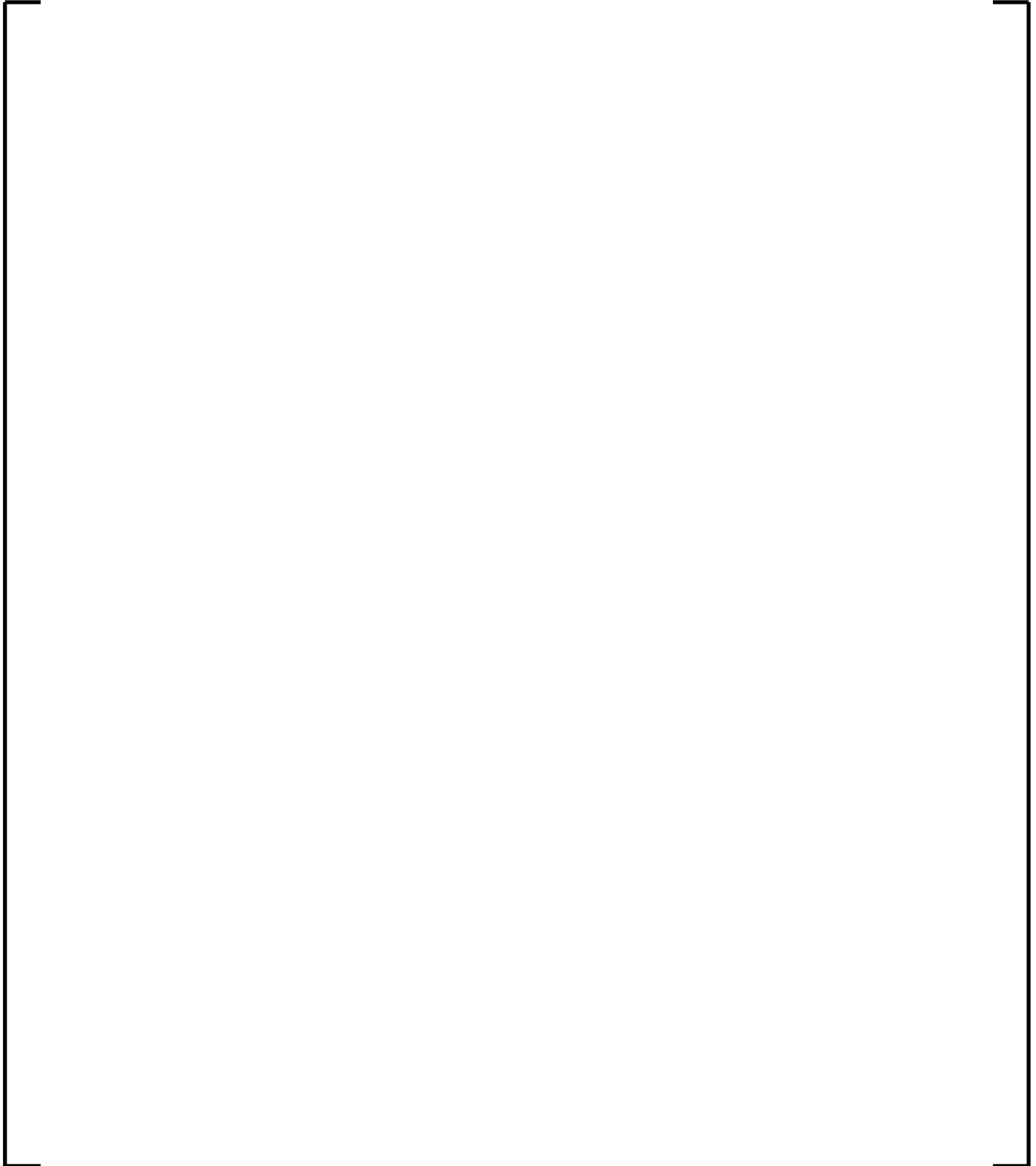
5.3.6 []

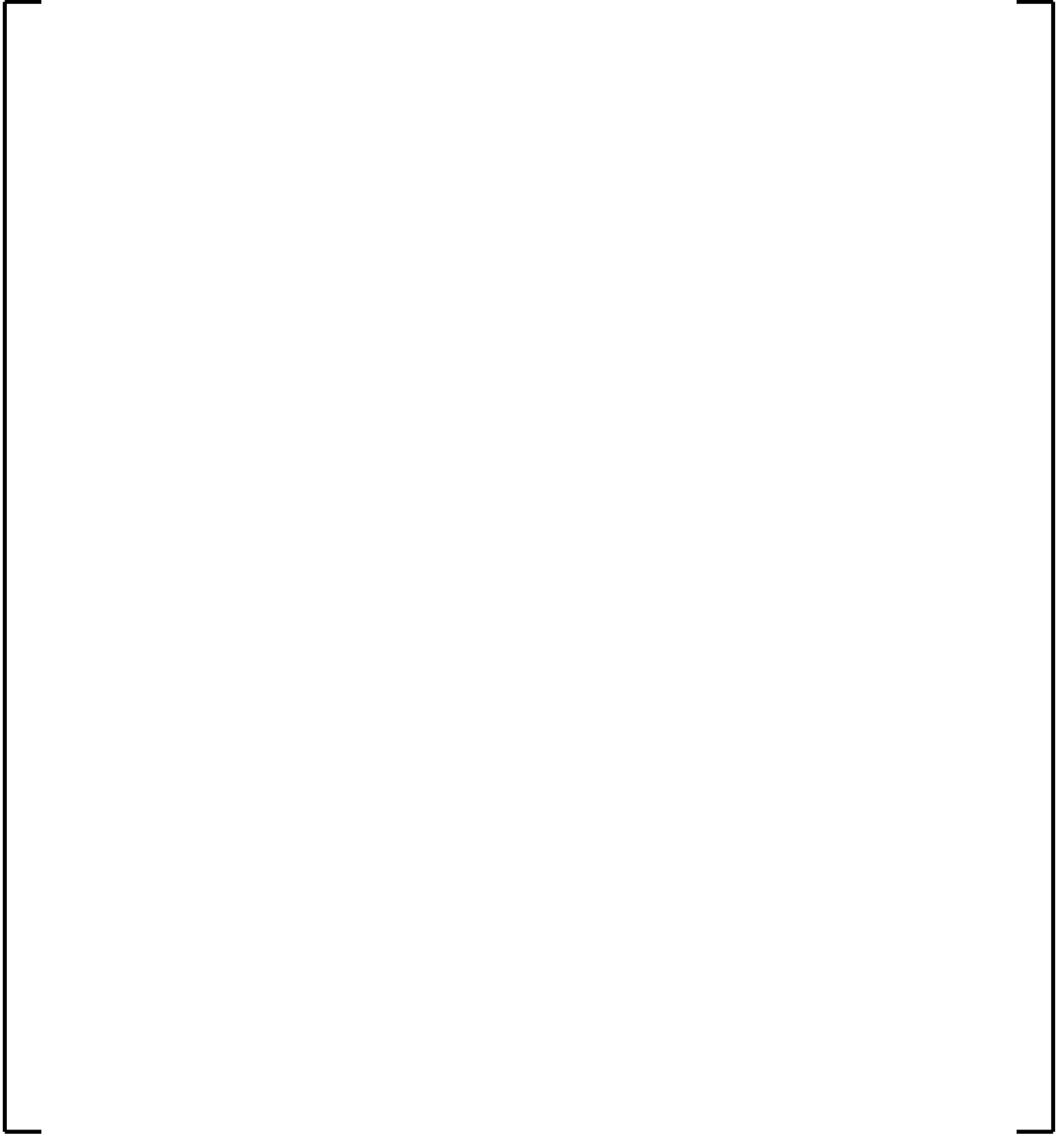


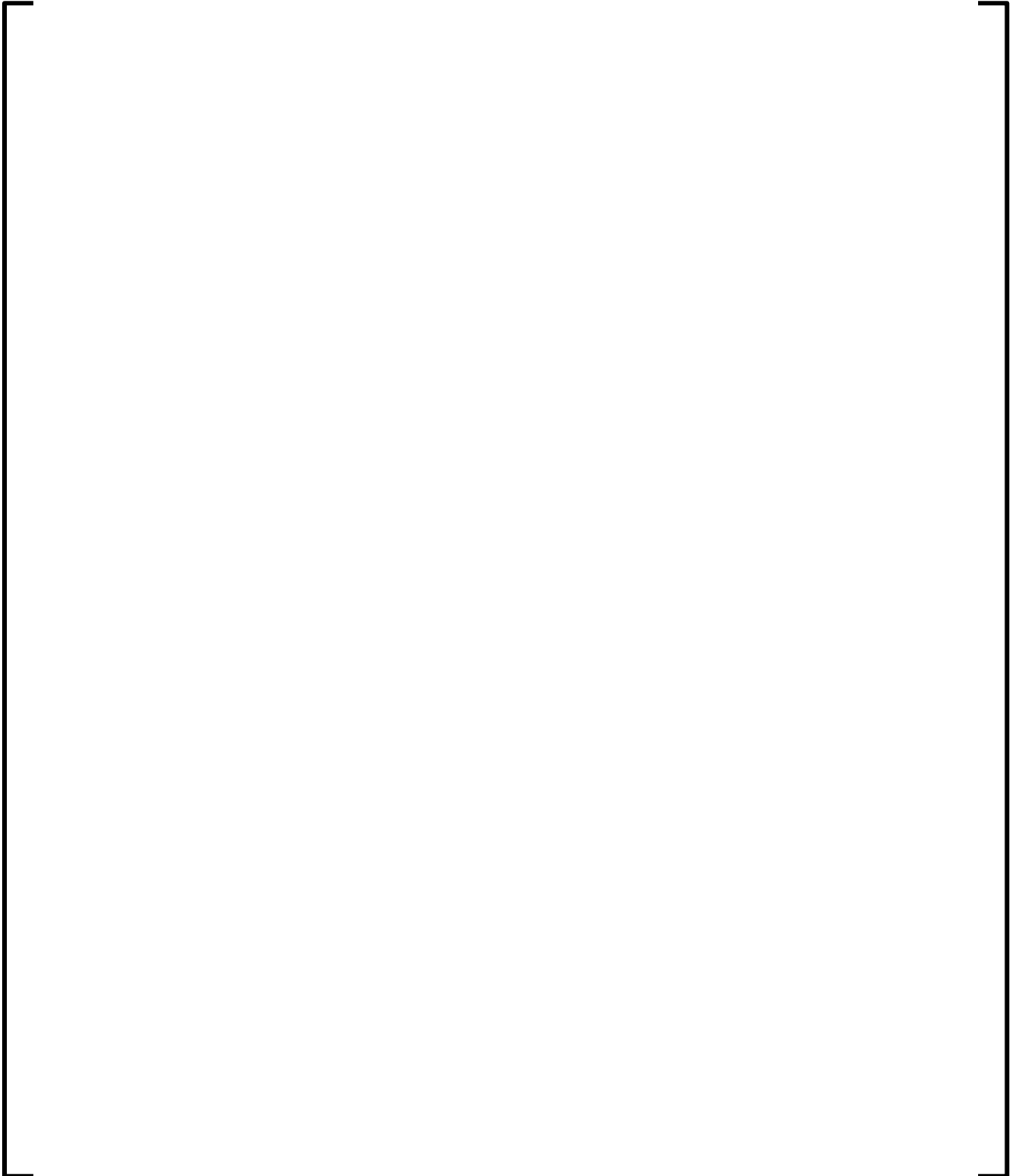
The wall surface temperature is obtained by solving the heat conduction equation for the fuel rod, which is presented in Section 5.2.4.

5.3.7 [] Momentum Conservation

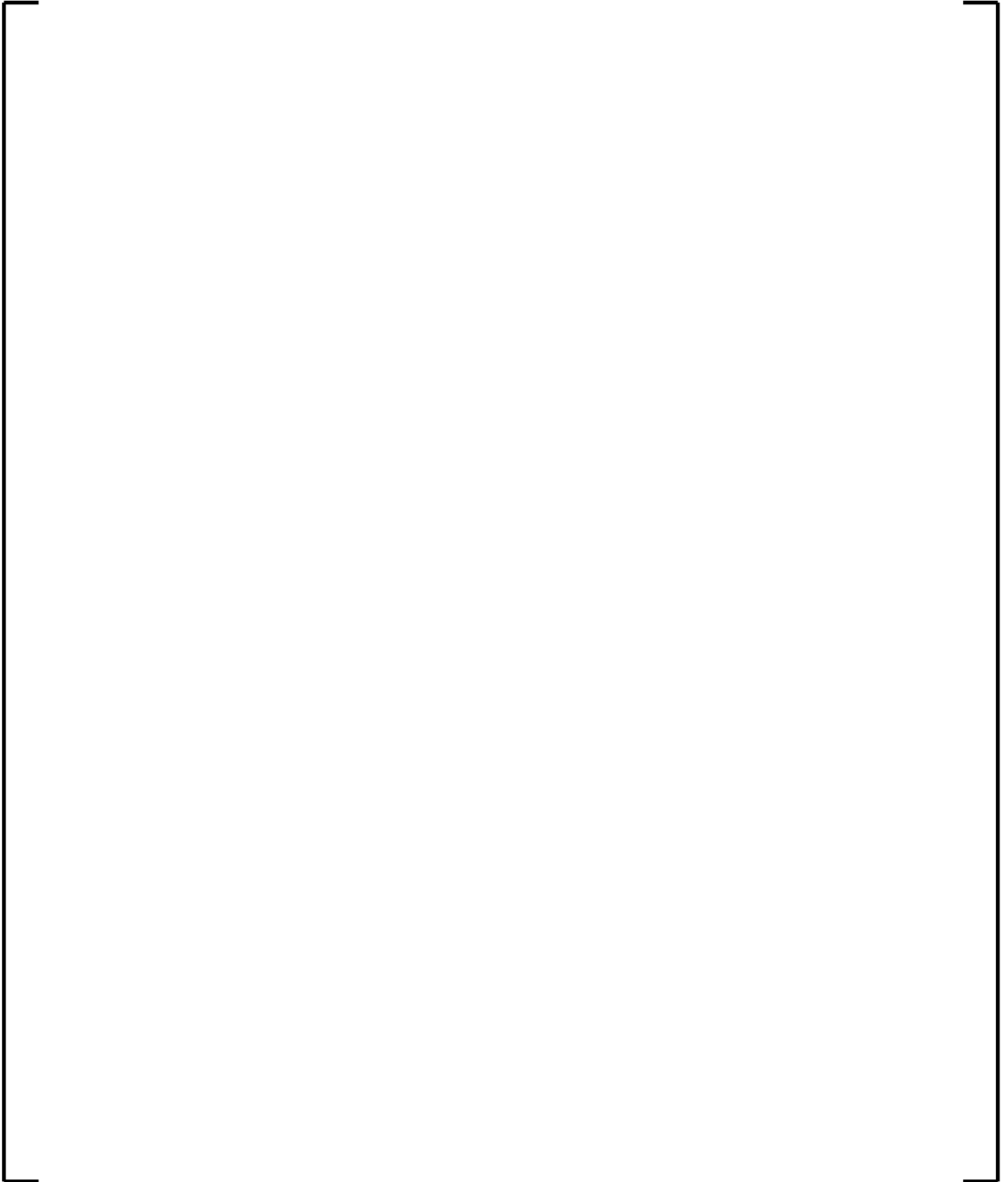




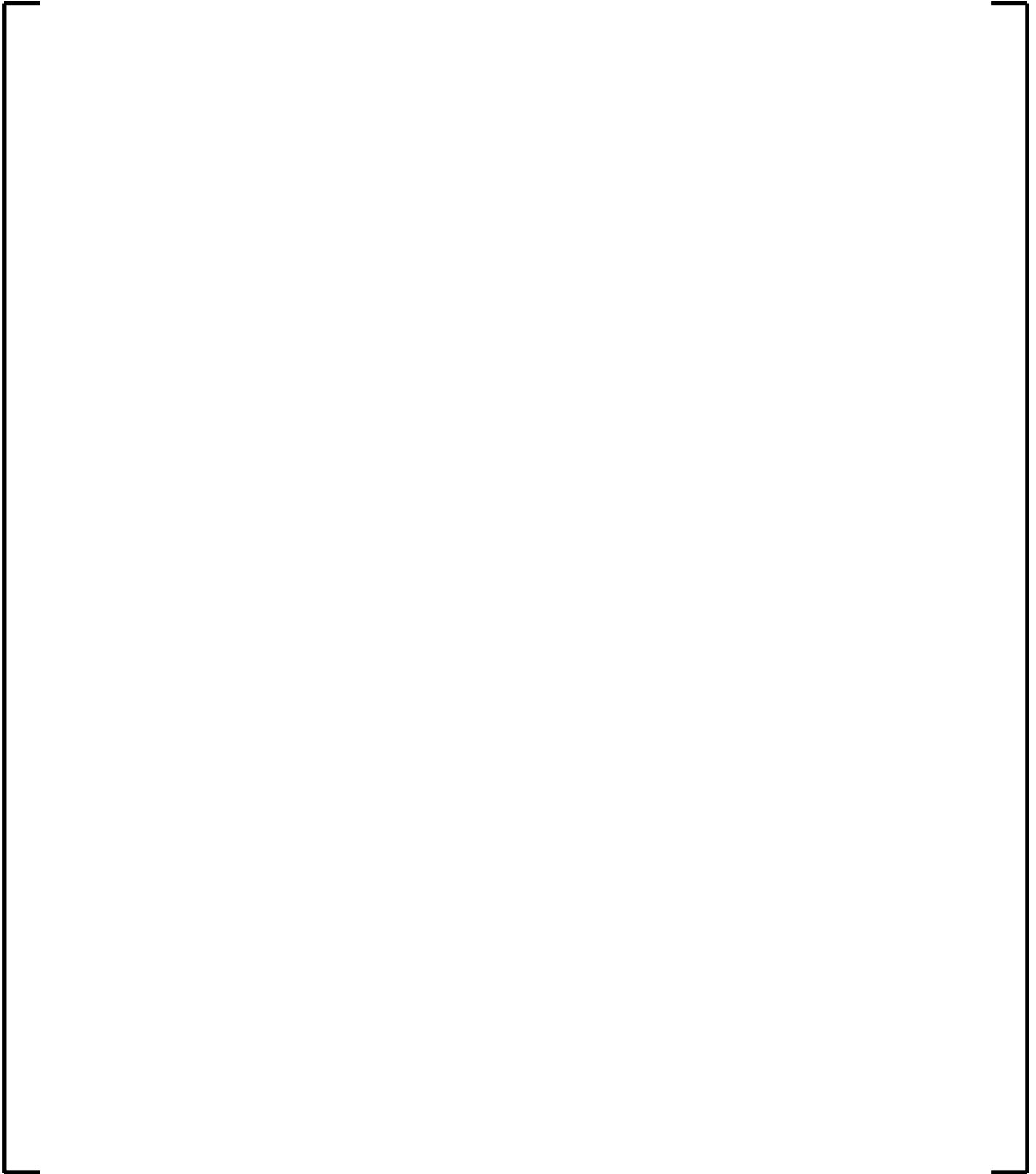




5.3.7.1 [] **Formulation in the Vessel Components**



5.3.7.2 [] Formulation in the Core



[

]

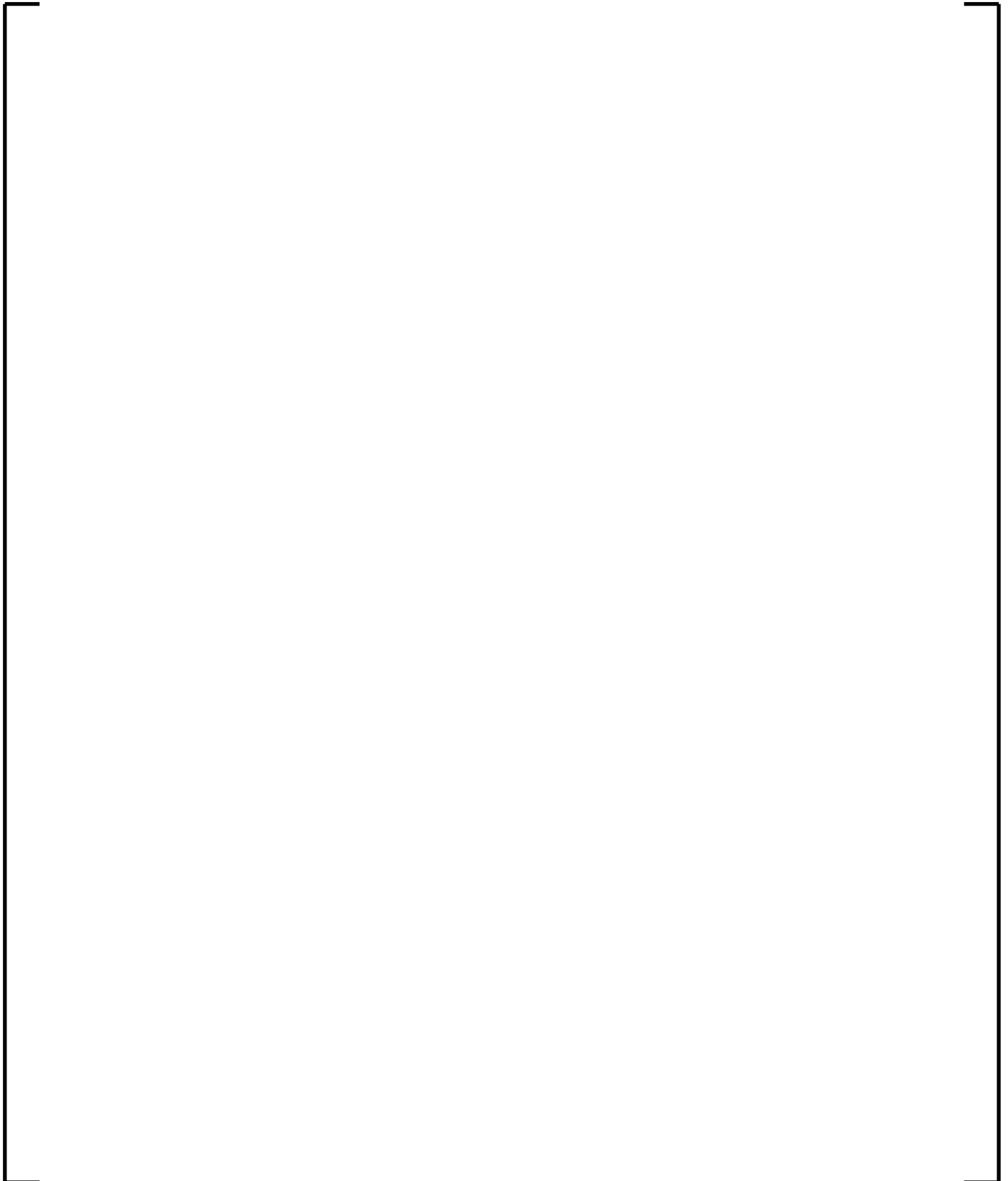
5.3.8 Pressure Calculation

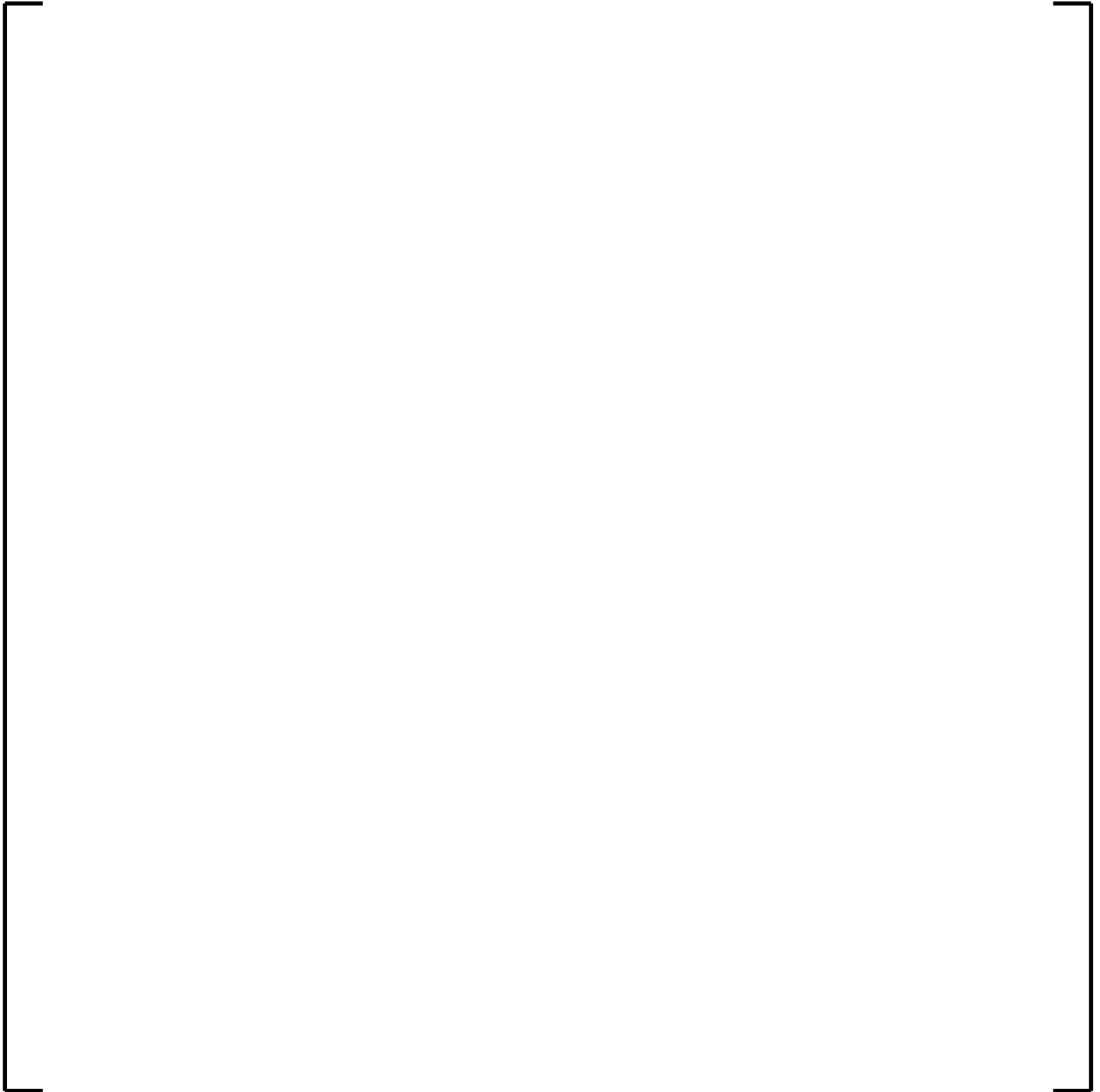
[

] The equations describing the transient pressure calculation are presented in this section.

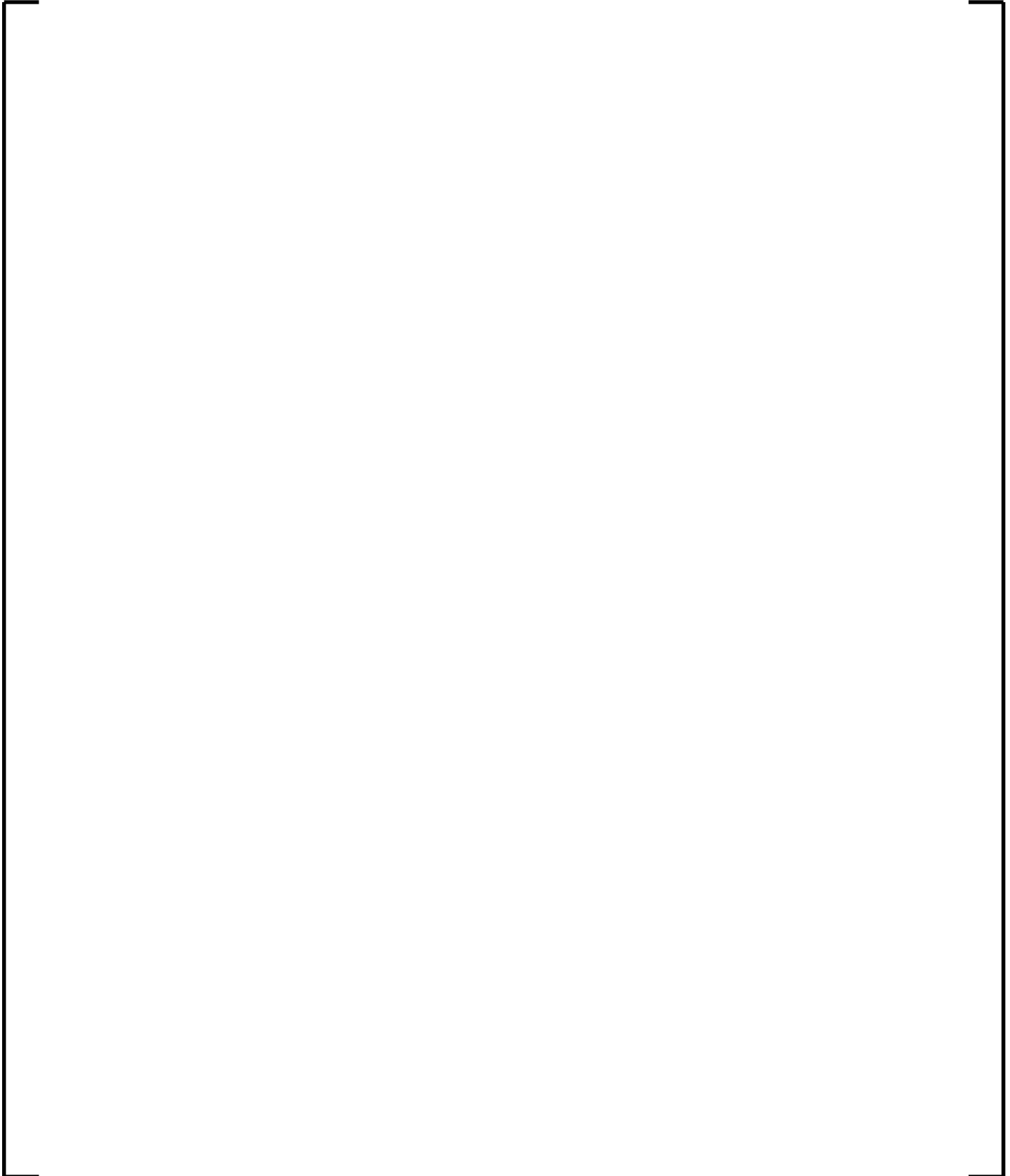
The mass balance equations for the vapor and liquid phases respectively are

[





5.3.9 Steam Dome Equations



5.3.10 Recirculation Flow

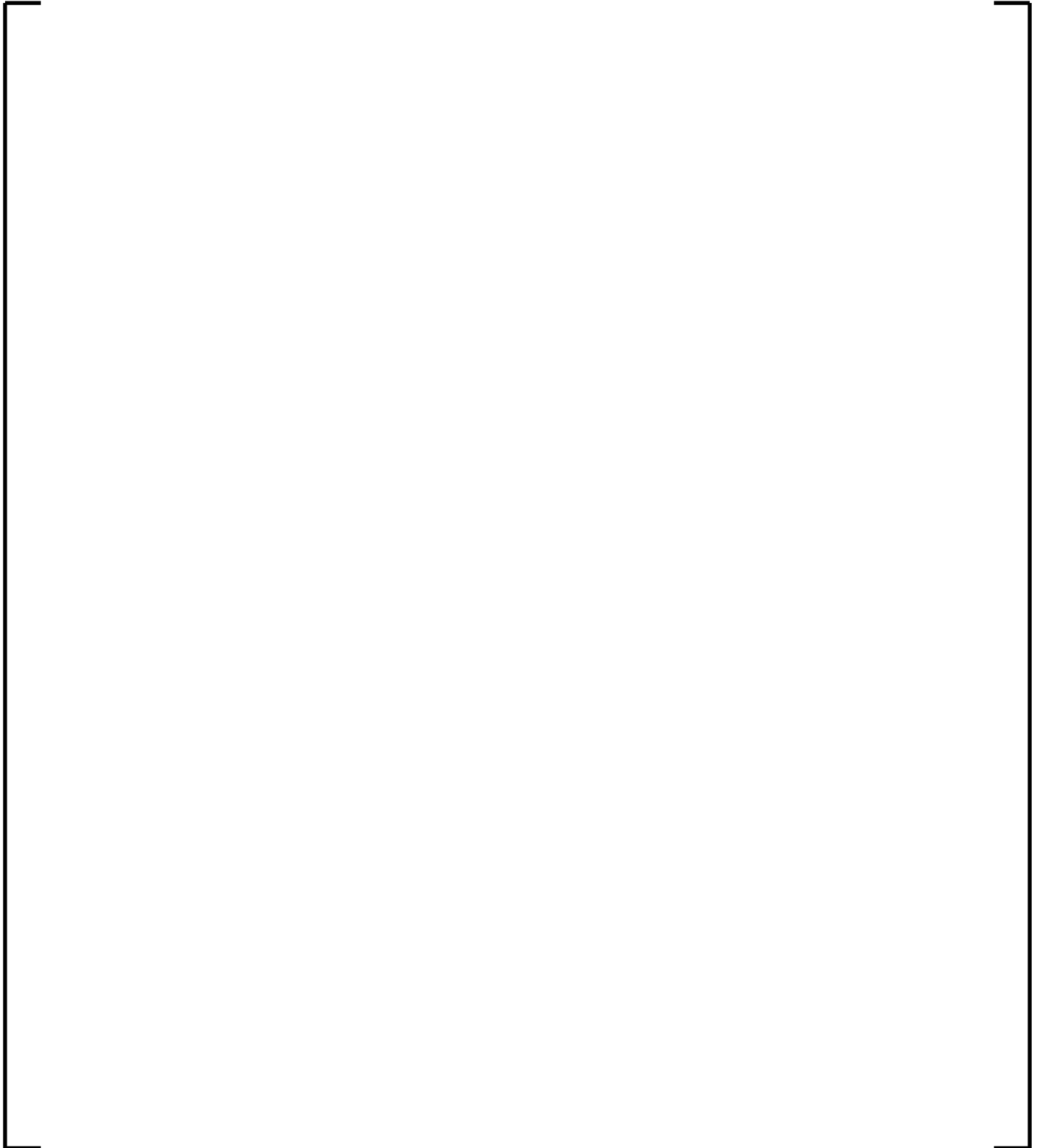
The recirculation flow calculation is based on [

]

[
]



Figure 5-4: Recirculation Loop



5.3.11 Constitutive Equations

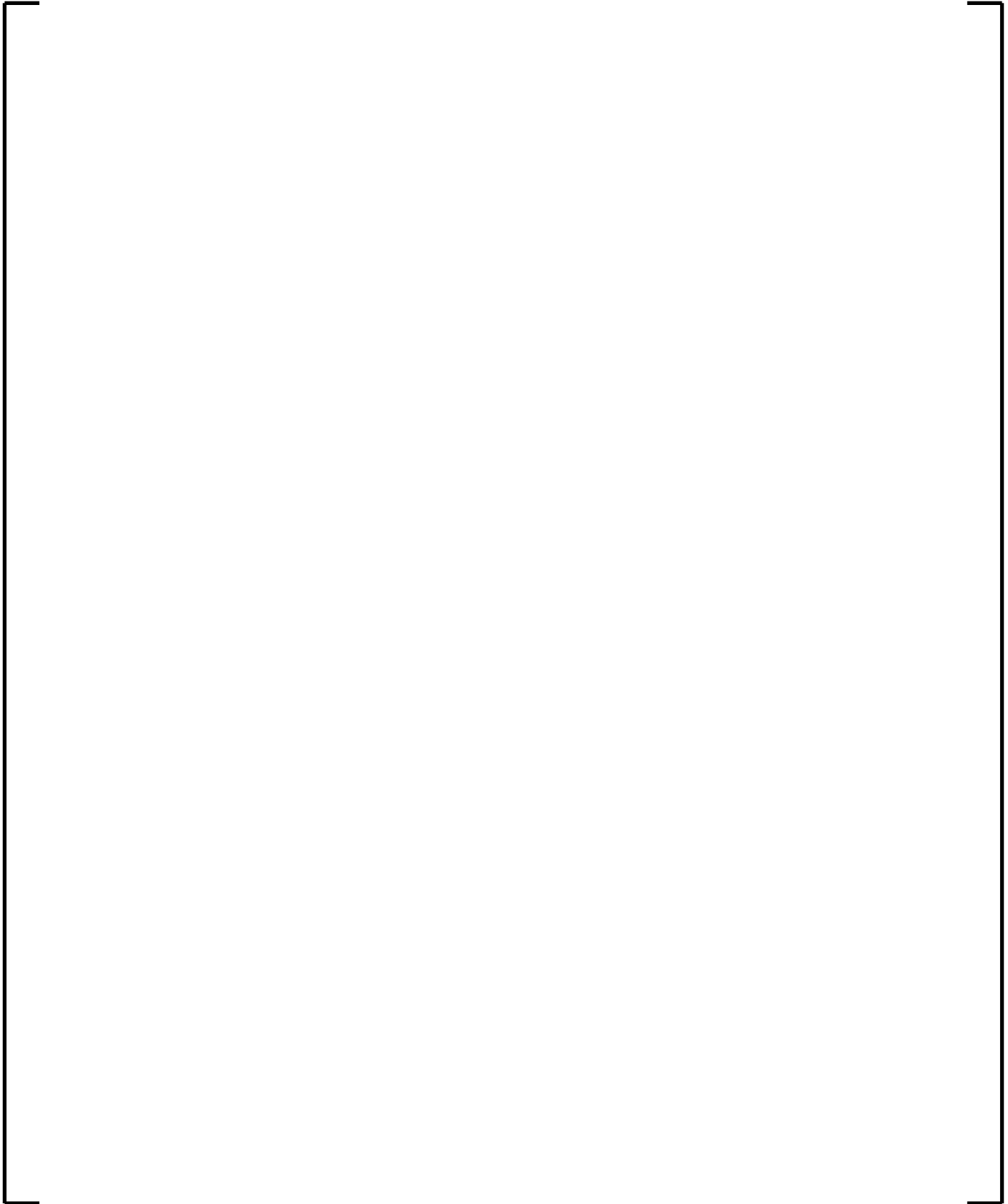
The most important constitutive equations used in the standard thermal-hydraulics are

- Friction and two phase friction multiplier
- Local pressure loss models
- Abrupt contraction/expansion pressure change models
- []
- Thermodynamic steam-water properties
- []
- Heat transfer correlations
- Evaporation rate correlation

5.3.11.1 Friction and Two Phase Friction Multiplier

Two options are available in RAMONA5-FA to specify the single-phase friction factor.

The first option is of the form:



5.3.11.2 Local Pressure Loss Models

Local pressure loss models are available in RAMONA5-FA to predict the local pressure loss effect of spacer grids, tie plates, etc. contained in the BWR core and vessel. Local pressure losses are captured in the Δp_{loc} term of Equation (5.244).

[

]

5.3.11.3 **Abrupt Contraction/Expansion Pressure Change Model**

In addition to pressure losses related to loss coefficients, the local pressure drop is affected by models for treating the pressure change resulting from abrupt contractions and expansions that occur at the inlet and outlet of core component hydraulic channels.

[

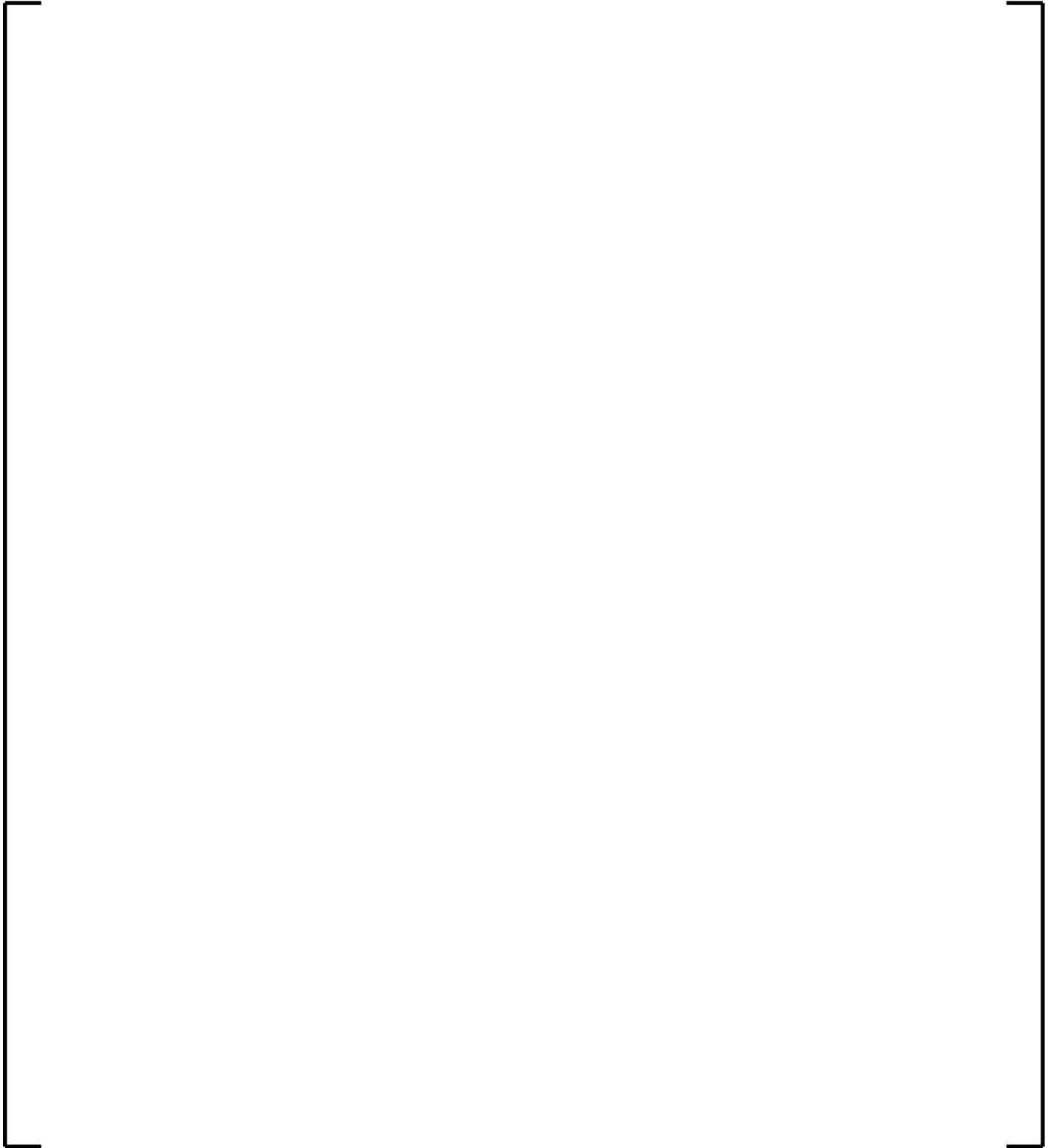
]

5.3.11.4 []

5.3.11.5 Thermodynamic Steam-Water Properties

Thermodynamic variables are determined corresponding to the system pressure and liquid or vapor enthalpy. The water properties in RAMONA5-FA utilize the new IF97 formulation [Reference 29].

5.3.11.6 []



5.3.12 Numerical Integration Techniques



Table 5-1: Summary of State Equations

5.4 *Steam Line Flow Dynamics*

RAMONA5-FA has a steam line model to make it capable of simulating acoustic effects in the steam line due to sudden valve closures or openings, leading to pressure waves traveling back and forth in the steam line. Strong pressure pulses in the steam line will in turn induce pressure pulses in the steam dome and core, thus causing a void collapse in the core and a sudden increase in reactivity.

As the time-scale of these phenomena is much shorter than the time scale of the dominating phenomena inside the reactor vessel, the need for a separate model to be able to resolve these effects is obvious.

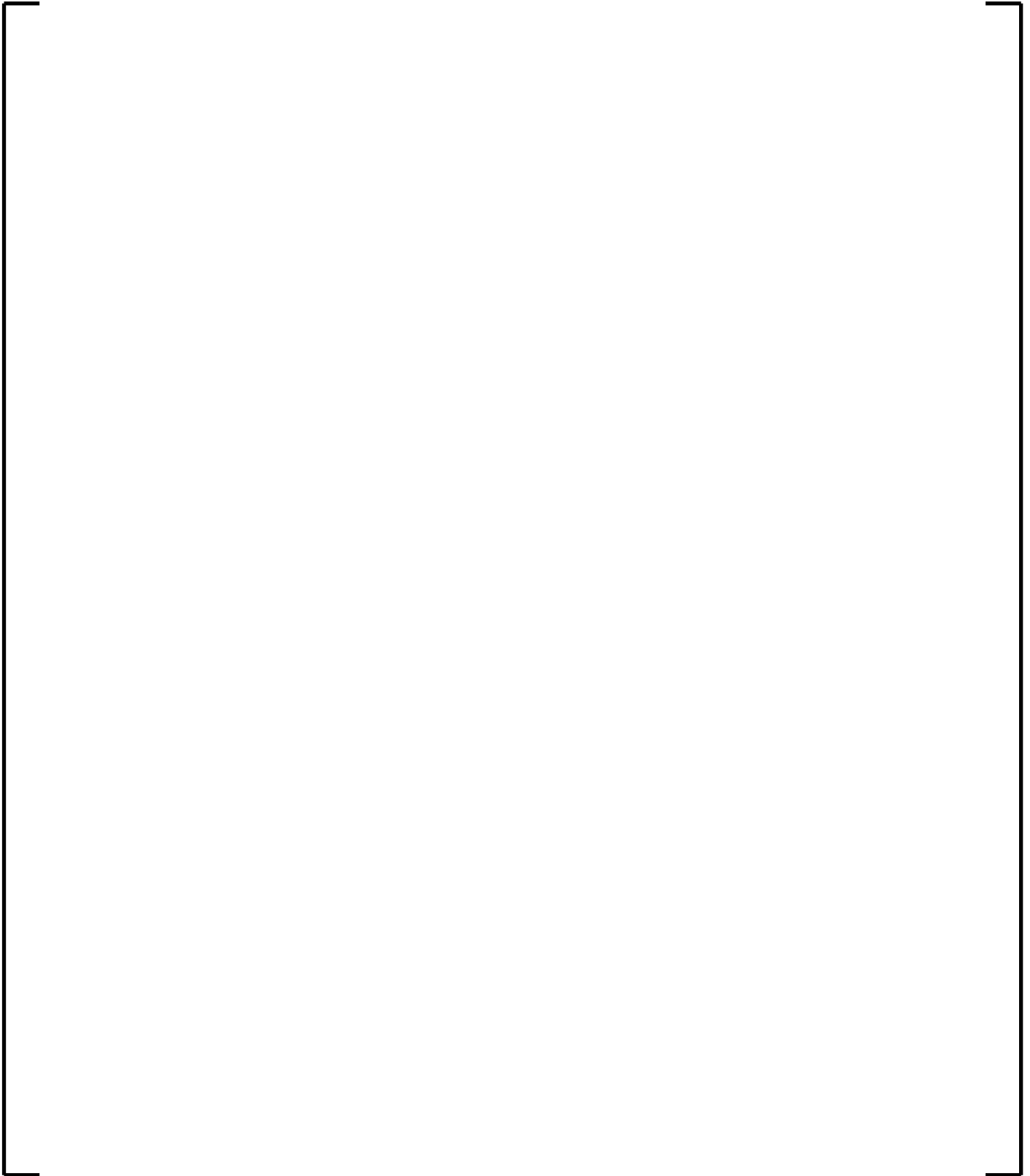
[

]



Figure 5-5: Steam Line Model





[

]

5.5 SPECIAL MODELS

Special models are included in RAMONA5-FA to simulate specific flow conditions.

They include at present:

- Recirculation flow pumps
- Jet pump model
- Feedwater sparger
- Steam separators
- Dryout/rewet model

5.5.1 Recirculation Pump Model

The recirculation pumps, one in each recirculation loop, drive the recirculation flow through the recirculation loops into the jet pumps or drive the core flow in the plants with internal pumps. The recirculation pumps are used to control the core flow, consequently the inlet subcooling temperature, the non-boiling heat and, thereby, the vapor void fraction, moderator density and fission power. The purpose of the recirculation pump model is to predict the pressure rise (Δp_{pump}) used in the drive force (Equation (5.242)). This pressure rise depends not only on the flow rate in the pump but also in the angular speed (N_{pump}) of the recirculation pump. The angular speed is computed from the equation of motion for the pump, the motion being governed by the balance between the electrical torque, the friction torque and the hydraulic torque.

There are three different recirculation pump types implemented in RAMONA5-FA.

[

]

5.5.1.1 **Pump Model 1**



5.5.1.2 **Pump Model 2**



5.5.1.3 **Pump Model 3**

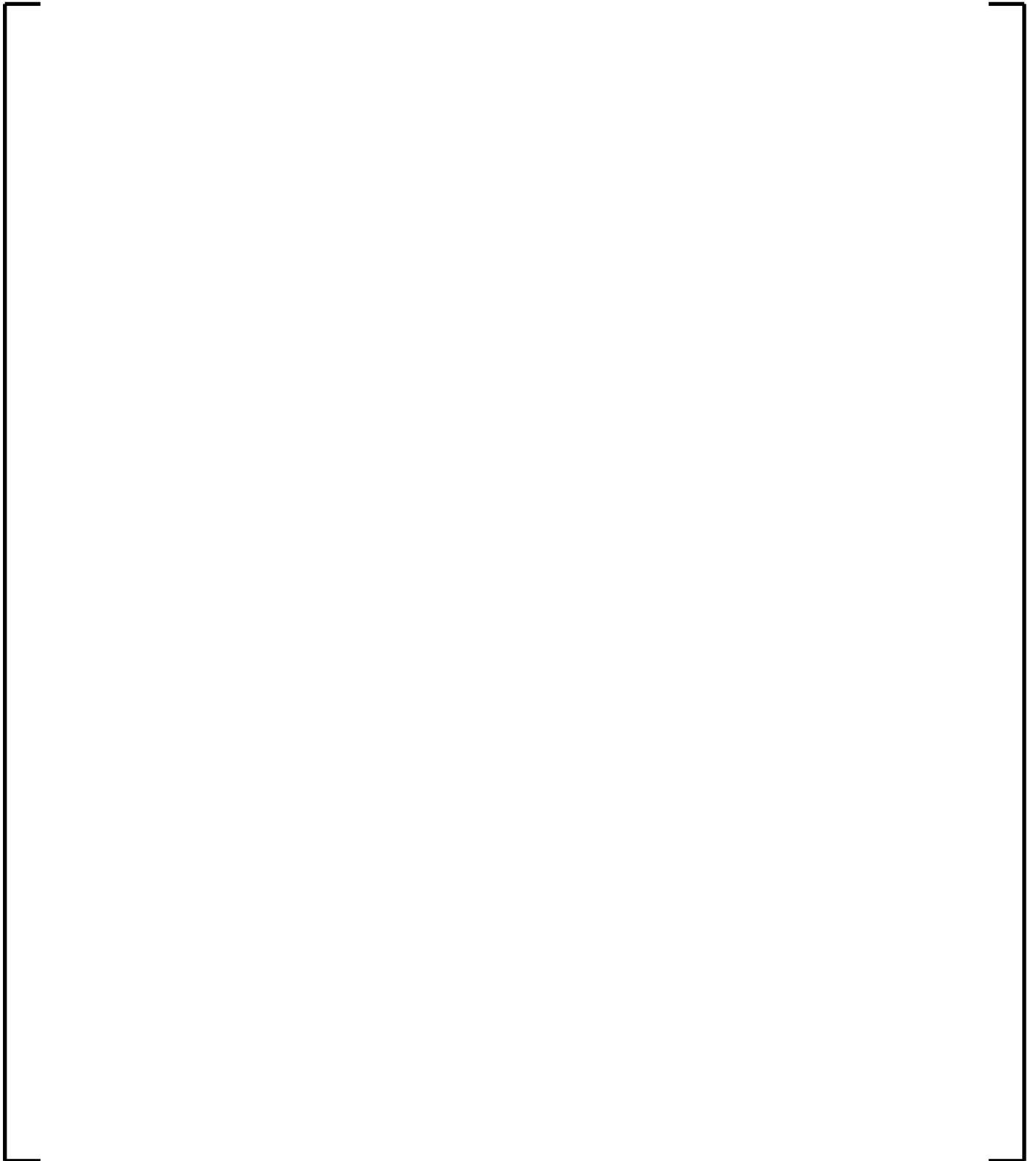
[

]

Table 5-2: Homologous Pump Curves Definition**5.5.2 Jet Pump Model**

The jet pump model calculates the pump head of the internal jet pumps. [

]



5.5.3 Steam Separator Model

When modeling the steam separators, there are two main effects which will be accounted for in this section:

- the flow inertia in the spiral path of the separators
- the volumetric flow of saturated vapor leaving the circulation loops and entering the steam dome above the coolant level (entrainment of vapor or carry under)

The effect of the form loss is taken into consideration in the same manner as other flow components.

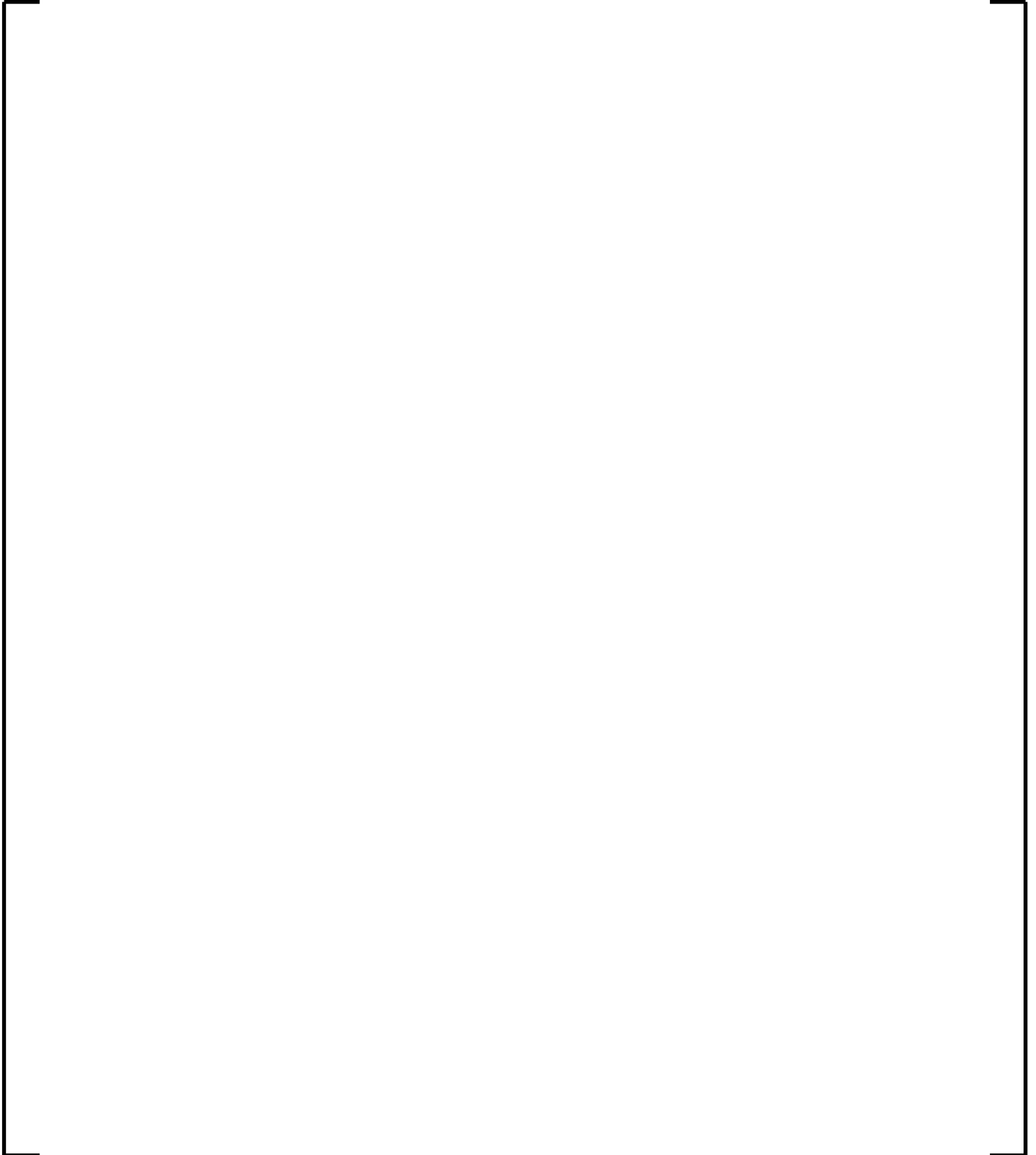
5.5.3.1 **Flow Inertia**

5.5.3.2 **Carry under Flow**





Figure 5-6: The Loop Parts of the Vessel Hydraulics



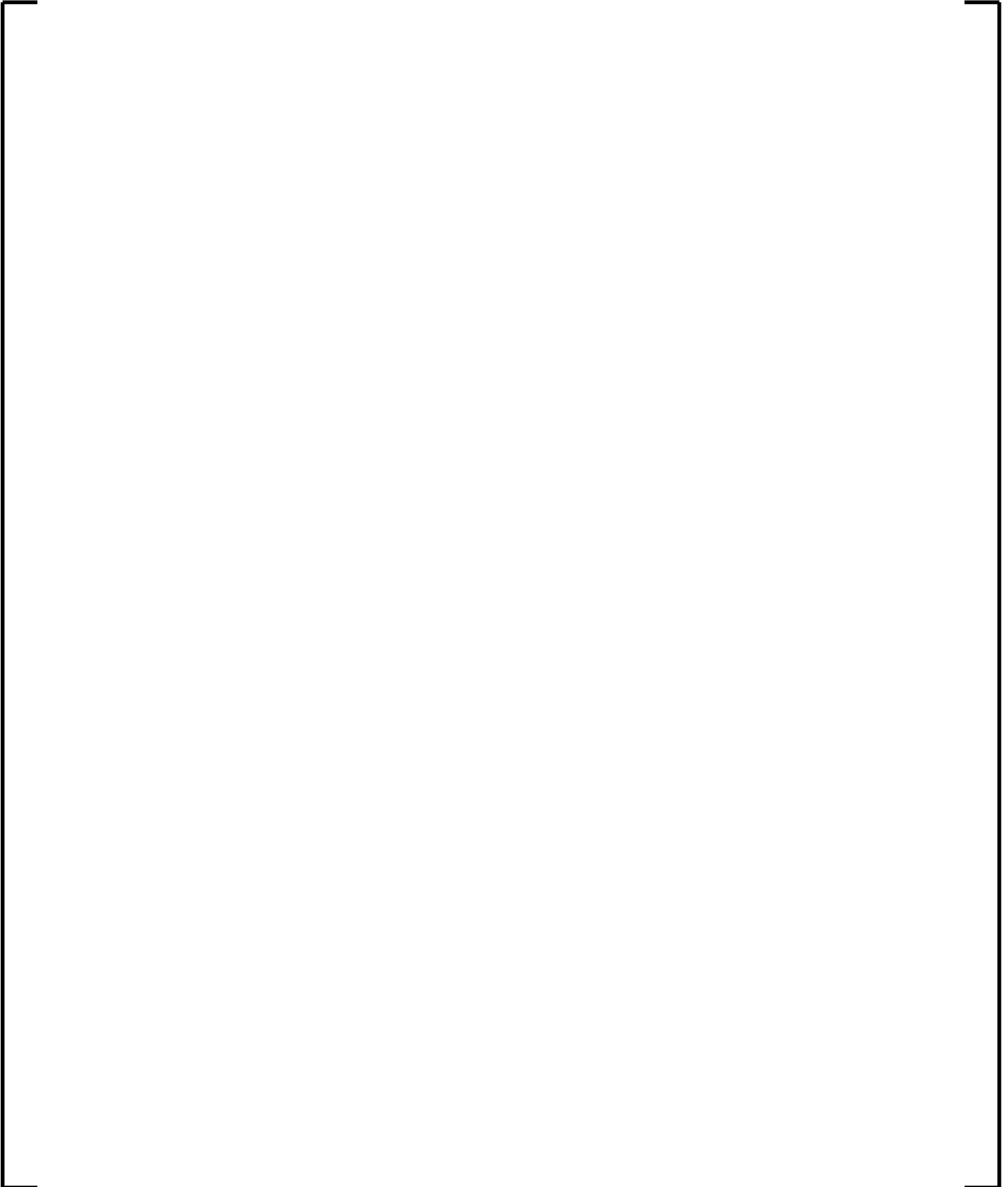
5.5.4 Feedwater Sparger Condensation Model

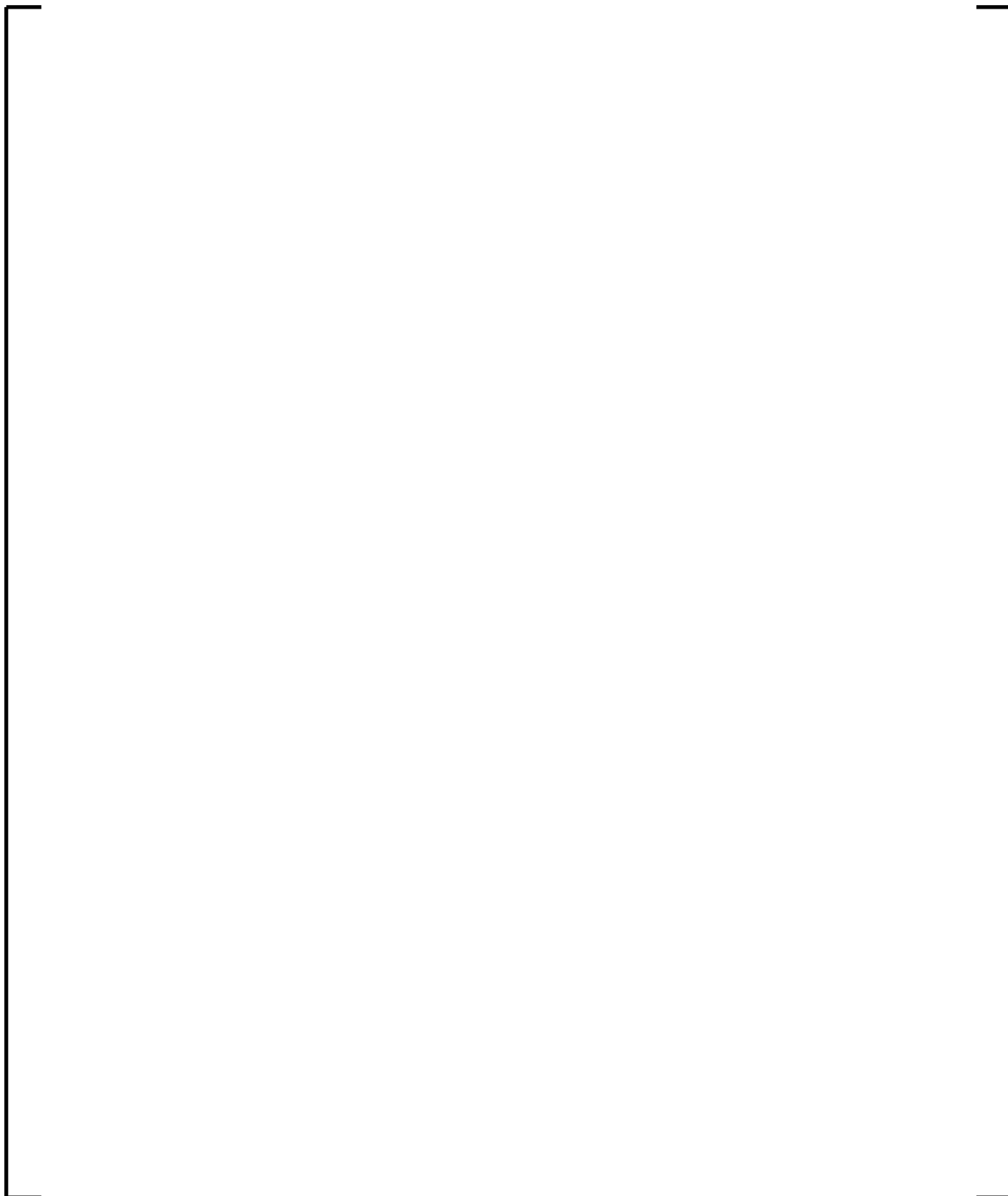
When the water level falls below the feedwater inlet, a special model takes into account the condensation due to the sub-cooled water injected into the saturated steam. This term is added to the vapor generation rate from Section 5.3.3 to determine the total evaporation/condensation in the downcomer. This condensation rate is calculated according to the following expression

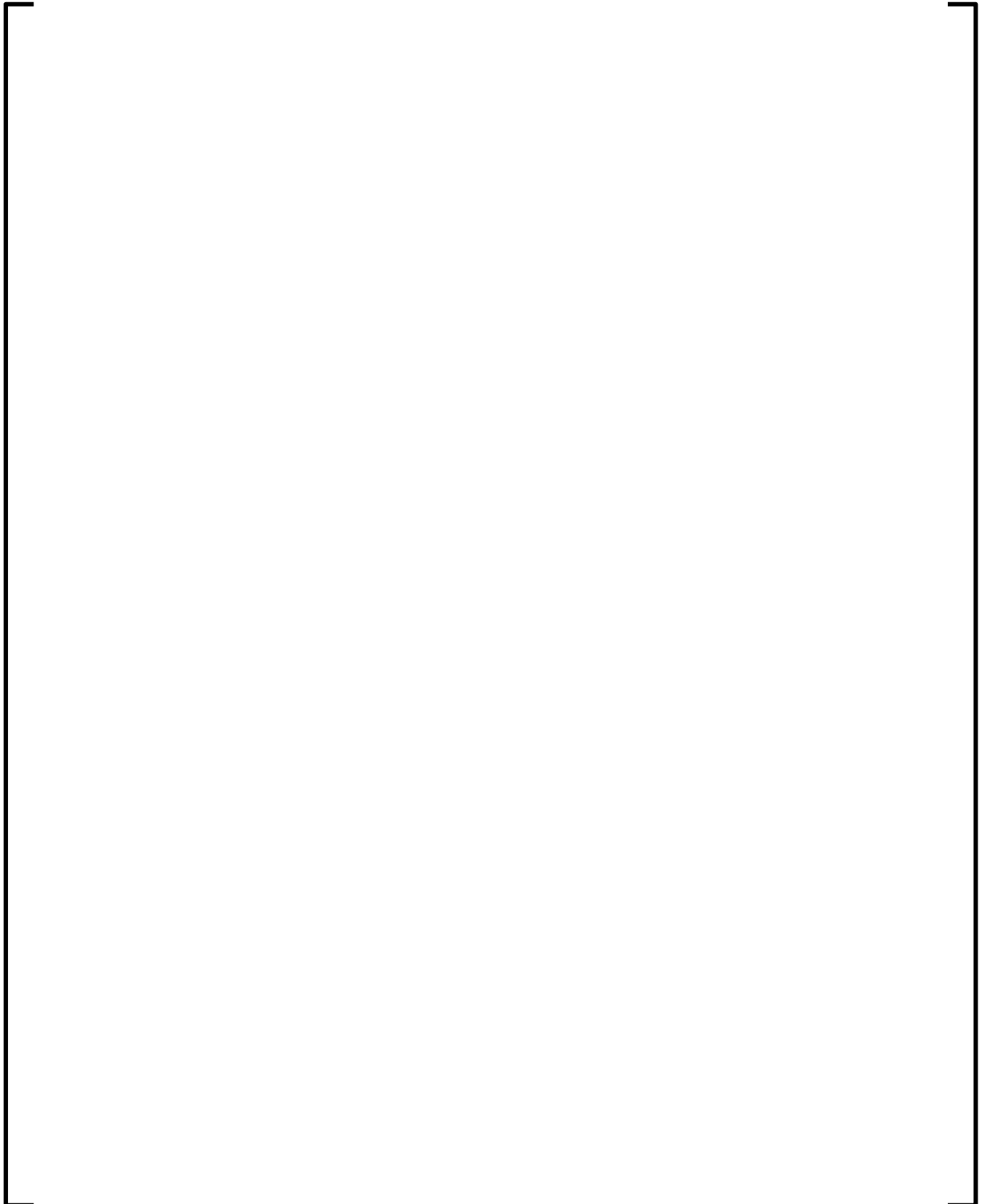
5.5.5 Dryout and Rewetting Model

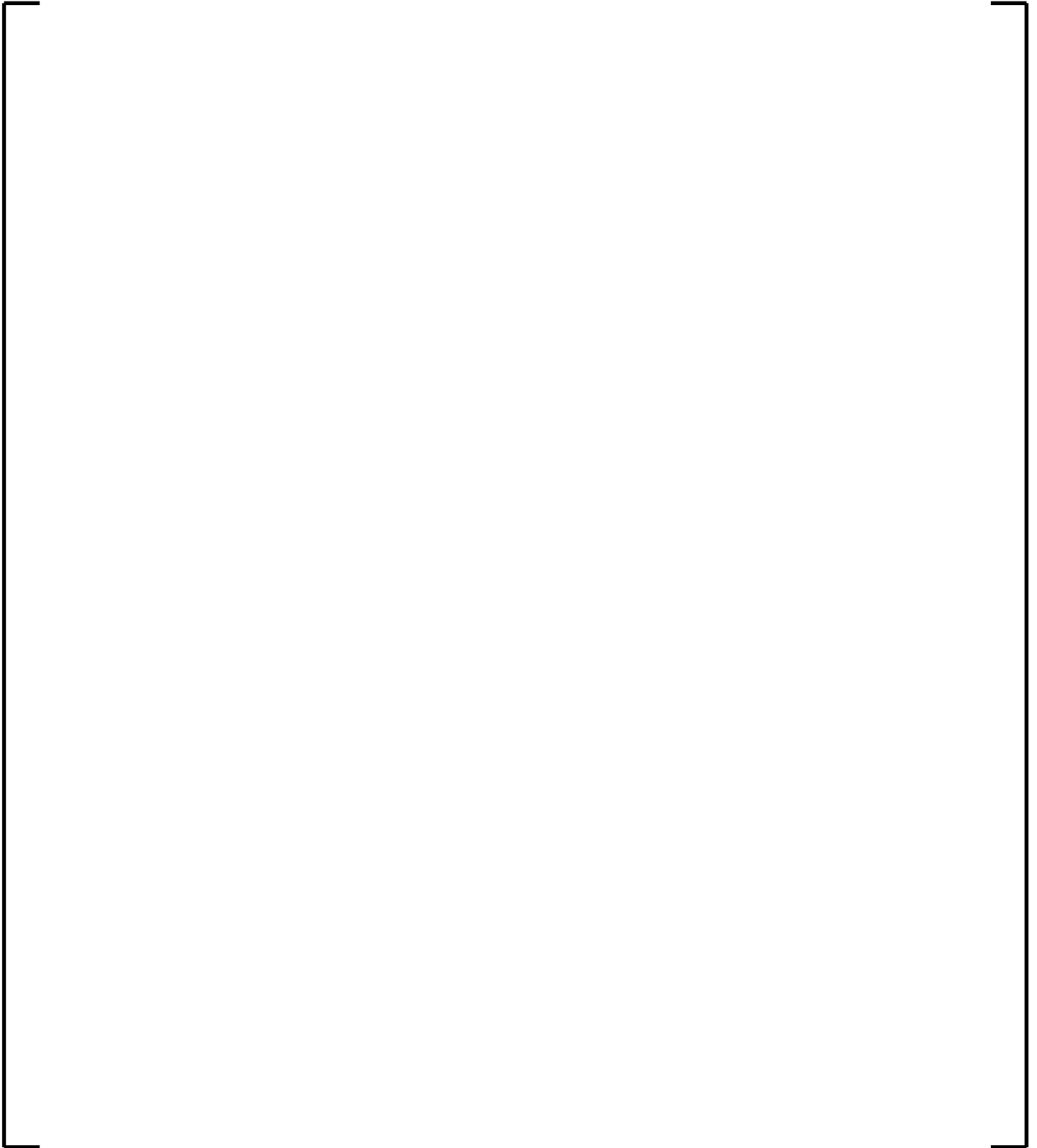
The Critical Power Reduced Order Model (CPRM) for dryout and rewetting is based on [

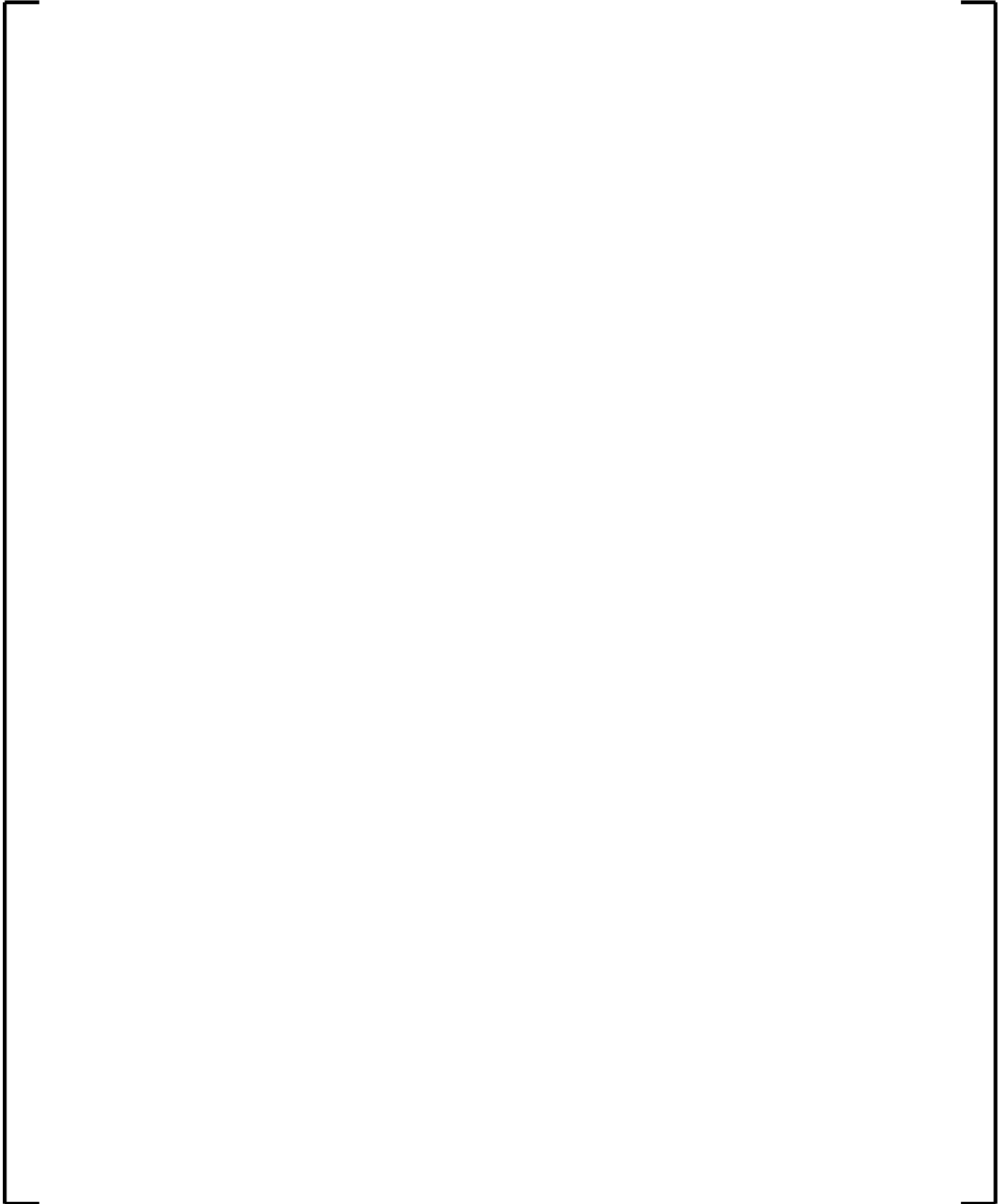
]

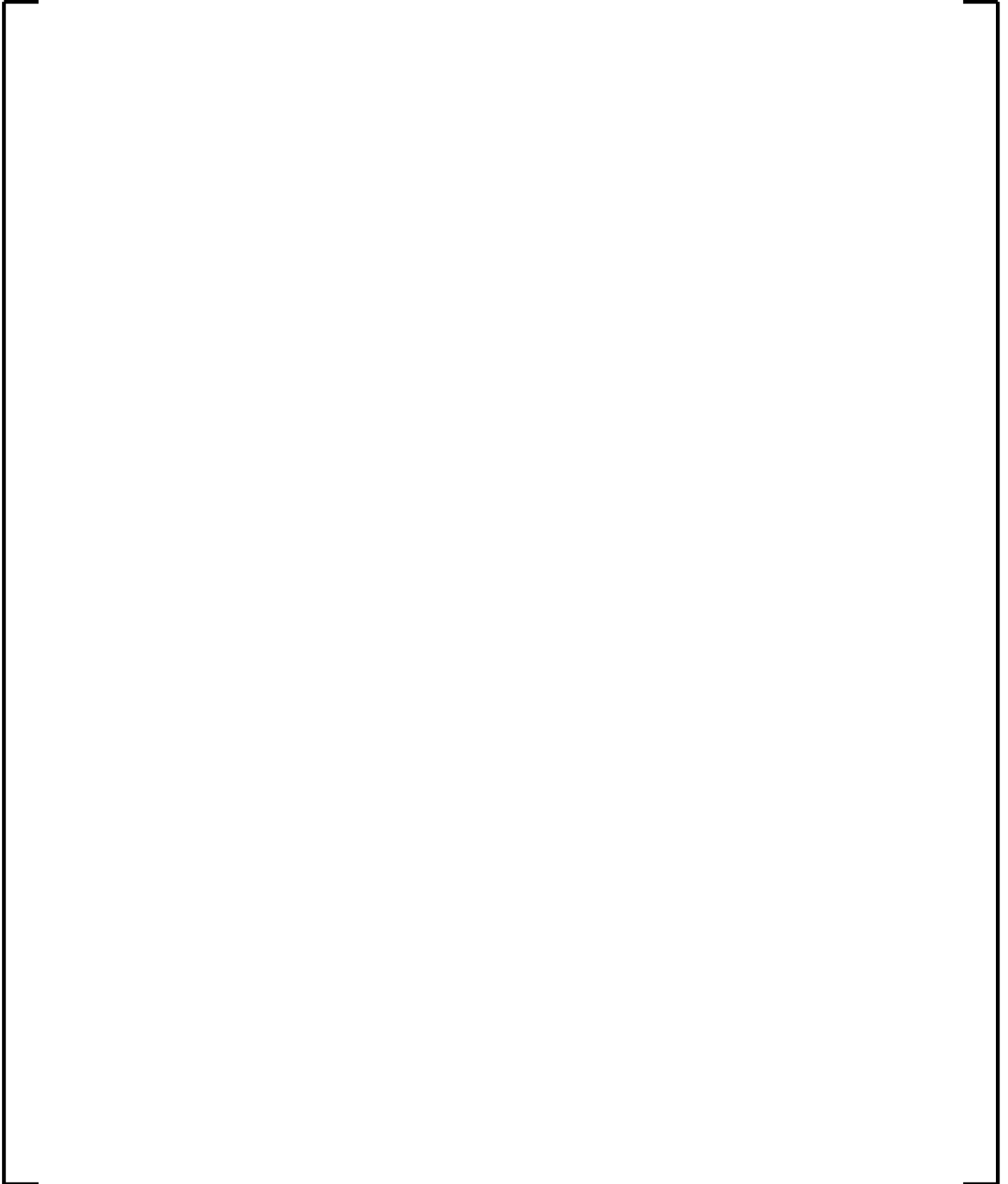


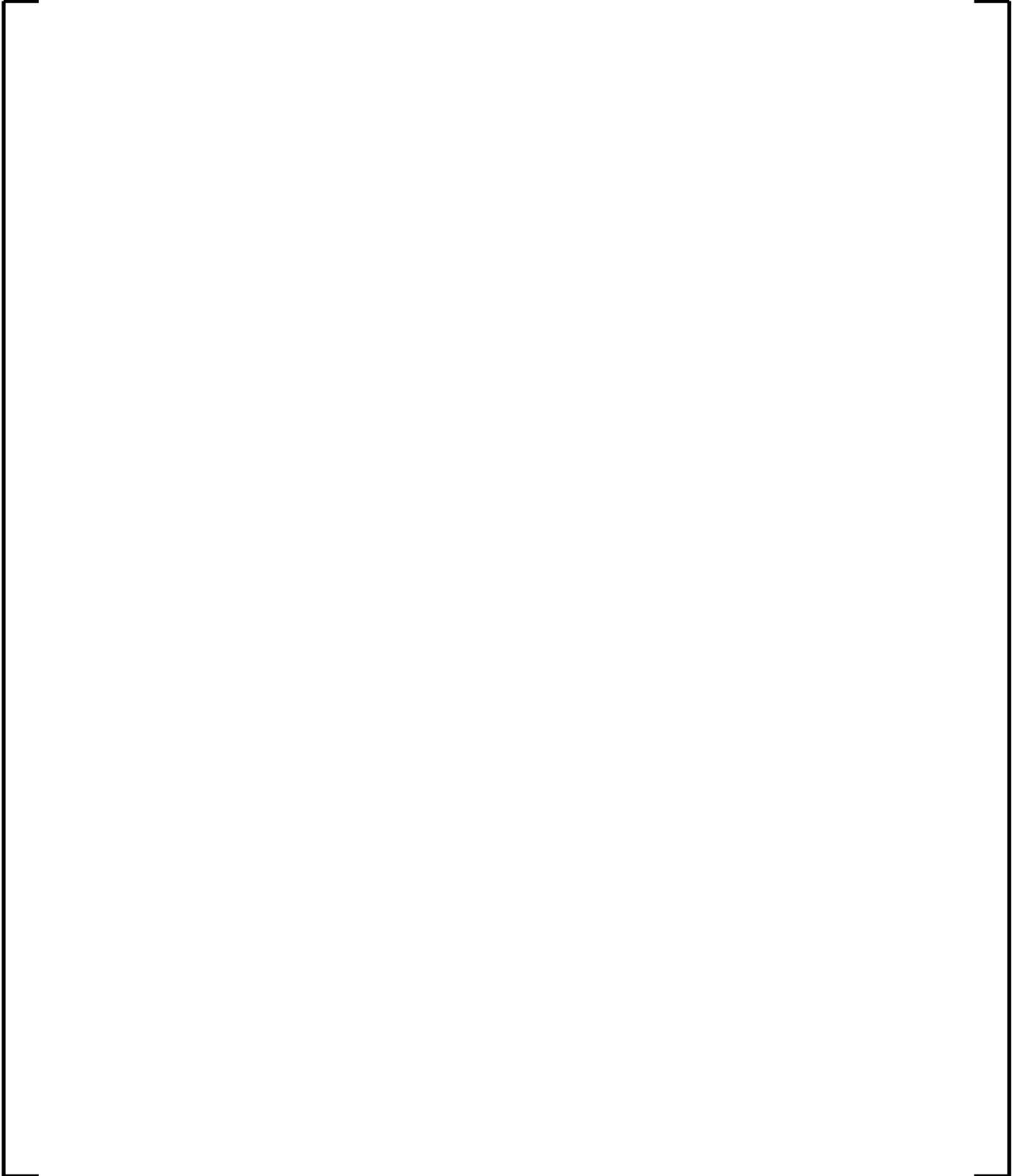












5.6 PLANT CONTROL AND PROTECTION SYSTEMS

Below follows a short summary of the plant control and protection system models implemented in RAMONA5-FA:

- Pressure control system consisting of turbine control, bypass valve and safety and relief valve (SRV).
- Plant protection systems (PPS) including high-pressure coolant injection system (HPCI), control rod, main steam isolation valve (MSIV) and recirculation pump trips.
- Reactor core isolation cooling system (RCIC)
- Feedwater control system, for water level control
- Feedwater trip.

5.6.1 Pressure Control System

In a BWR, an increase in the vessel steam pressure results in an increase in steam flow through the steam line and the collapse of steam void in the reactor. The latter means that the water density increases and, hence, there is an increase in neutron moderation. This in turn leads to an increase in power, which has the effect of increasing pressure. In order to deal with this positive feedback a pressure regulator is provided. To maintain an approximately constant system pressure, a turbine control valve is provided. The bypass valve also directs the excess steam flow to the primary heat sink during load rejection events. Since the turbine and bypass flow controllers will influence the system response during many transients, it is important to have them properly represented in RAMONA5-FA.

5.6.2 Turbine Valve Regulator

The pressure regulator is composed of a pressure sensor transmitter, comparator, PID element, lag element, and a valve actuator. This model allows RAMONA5-FA to reasonably simulate the actual plant pressure control system.

5.6.3 Bypass Valve Regulator

The turbine bypass valve is not operative during normal plant operation. It opens to dump the excess steam to the condenser during abnormal transients such as turbine trip, load rejection. The bypass valve regulator is identical to the turbine control valve regulator. However, the operational characteristics may be quite different than the turbine control valve.

5.6.4 Feedwater Controller

The purpose of the feedwater controller is to determine the proper feedwater flow rate by comparing water level demand with level set point. If the error in the water level combined with the imbalance between steam and feedwater flow rates exceeds operational tolerance, proper action will be taken by the feedwater controller to correct this deficiency. The feedwater controller model employed in RAMONA5-FA is similar to the ones suggested in the literature with some adjustments and simplifications. In addition, RAMONA5-FA allows for an operator initiated reduction in water level in order to properly model the mitigation actions during an ATWS-I event.

5.6.5 Safety and Relief Valves

In a BWR, there are valves in the steam lines, which serve as safety and relief valves to maintain the system pressure below prescribed limits. RAMONA5-FA represents up to five different banks; each bank representing one or more safety or relief valves. Each bank can be activated on either steam line or dome pressure or at a user defined time.

5.6.6 Main Steam Isolation Valve (MSIV)

The purpose of the MSIV model is to predict the mass flow rate of steam through the valve during its closure. [

]

5.6.7 Plant Protection System (PPS)

The BWR plant protection system (PPS) is to assure that the consequences of all postulated conditions do not exceed the specified safety limit in the reactor system. It should provide the required protection by sensing the necessity and implementation of reactor scrams, pump trips, and turbine trip.

In RAMONA5-FA, the PPS functions include both manual and automatic modes. In the manual mode, the operator's action is simulated through a user specified "trip time", at which the desired shutdown system is activated. In the automatic mode, important system variables are processed through appropriate PPS subsystem trip functions for possible protective action in response to selected instrumentation signals. Following the PPS signal, a user specified trip time delay must be exceeded before PPS action is initiated.

5.6.8 Manual Operator Actions

Manual operator actions to reduce water level during an ATWS-I event are simulated in RAMONA5-FA through the feedwater control system. The time at which operator actions begin is specified by input, and is simulated by a reduction in the water level setpoint to a user specified value. [

] The feedwater pumps coast down until the feedwater controller takes control to maintain the water level at the new lower level.

5.7 NUMERICAL TIME INTEGRATION

This section summarizes the different time-integration techniques used to integrate the RAMONA5-FA differential equations and the intertwining of the numerical integration of the neutronics with that of the main hydraulics and the steam line integration.

5.7.1 Neutron Kinetics

[

]

5.7.2 Fuel Thermodynamics

[

]

5.7.3 Vessel Hydraulics

[

]

[

]

5.7.4 Coupling of the Neutronics and Hydraulics Integration

[

]

6.0 CODE VALIDATION

The RAMONA5-FA ATWS-I code theory is described in Section 5.0. The code calculates the transient thermal-hydraulic response of a BWR with a detailed core representation of one channel per fuel assembly. It applies a [

] There are no limitations with respect to flow direction, and the severe flow oscillations accompanied with inlet flow reversal can be simulated.

RAMONA5-FA ATWS-I applies [

] The steady state simulator provides automated input coupling for the hydraulic and neutron cross section parameters. [

] The dynamic functionality of the algorithms which is important in stability and oscillation calculations is verified by benchmarking to stability specific data.

The benchmarking of RAMONA5-FA ATWS-I is divided into two parts. The first part is focused on the pure thermal-hydraulic modeling and is accomplished by comparing the code results with the stability tests of various fuel designs performed at the KATHY loop as well as other publically available data. Both steady-state and transient benchmarks will be performed. The steady-state benchmarking includes measurement for void fraction in ATRIUM-10 and ATRIUM 10XM as well as FRIGG3. KATHY steady state pressure drop data will also be benchmarked. The measured decay ratio and frequency

for a large number of test points for ATRIUM-10 and ATRIUM 10XM are compared with the RAMONA5-FA ATWS-I calculated values. The agreement provides the needed evidence of the validity of the RAMONA5-FA ATWS-I thermal-hydraulic models.

The second part of the benchmarking is an integral exercise where both the thermal-hydraulic and the neutron kinetics are coupled in the simulation of oscillations that occurred in actual BWR plants. These benchmarks will be separated into linear stability and non-linear stability benchmarks. The linear stability benchmarks are the same used to benchmark the NRC-approved frequency domain stability code STAIF (Reference 21), and the original time-domain code RAMONA5-FA (Reference 7).

6.1 *Test Suite and Acceptance Criteria*

The RAMONA5-FA ATWS-I code validation includes the following cases:

- Comparison to KATHY void fraction tests for:
 - ATRIUM-10
 - ATRIUM 10XM
 - FRIGG3
- Comparison to steady state pressure drop tests for:
 - KATHY ATRIUM-10
 - KATHY ATRIUM 10XM
- Comparison to KATHY loop stability tests. Comparisons include the decay ratio and frequency for all the runs in the test suite for the following fuel designs
 - ATRIUM-10
 - ATRIUM 10XM
- Comparison to KATHY dryout/rewet tests for ATRIUM 10XM and [].

- Benchmarking to all the linear instability tests in actual BWR plants included in the RAMONA5-FA test suite (Reference 7). These are:

- Benchmarking to the non-linear stability events in actual BWR plants. These include:
 - Oskarshamn turbine trip with non-linear oscillation
 - BWR A feedwater temperature transient with non-linear oscillation

The acceptance criteria are satisfied if the RAMONA5-FA ATWS-I code results agree with the experimental results. The criteria are chosen to be consistent with how this data is used in other approved methodologies. Quantitatively, the criteria are

- Calculated void fractions are within [] of the measured value.
- Calculated pressure drops are within [] of the measured value.
- Calculated decay ratios are within [] of the measured value. Conservative trends [] are acceptable.
- Calculated frequencies are within [] Hz of the measured values.
- For dryout/rewet cases, []

]

- For non-linear oscillations, []

]

6.2 *Benchmarking to Void Fraction Tests*

The FRIGG experiments, Reference 32 have been included in the validating database because of the broad industry use of these experiments in benchmarking activities, including TRAC, RETRAN, and S-RELAP5. The experiments include a wide range of pressure, subcooling, and quality from which to validate the general applicability of a void correlation. However, the experiments do not contain features found in modern rod bundles such as part length fuel rods and mixing vane grids. The lack of such features makes the data less useful in validating correlations for modern fuel designs.

Because of its prototypical geometry, the ATRIUM-10 and ATRIUM 10XM void data collected at KATHY was useful in validating void correlation performance in modern rod bundles that include part length fuel rods, mixing vane grids, and prototypic axial/radial power distributions. The characteristics of the void fraction validation database are listed in Table 6-1. . For ATWS-I benchmarking the range of data [

]

Figure 6-1 provides comparisons of predicted versus measured void fractions for the Framatome multi-rod void fraction validation database using the [] correlation. This figure shows reasonable predictions versus the measured data. The mean predictions fall within [] (predicted – measured) error with a mean error of [] and a standard deviation of [].

Table 6-1: Summary of Void Fraction Test Conditions

	FRIGG (Reference 32)	ATRIUM-10 KATHY	ATRIUM 10XM KATHY
Axial Power Shape	uniform	[]	[]
Radial Power Peaking	mild peaking	[]	[]
Bundle Design	circular array with 36 rods + central thimble	[]	[]
Pressure (psi)	435, 725, 1000, and 1260	[]	[]
Inlet Subcooling (°F)	4.1 to 54.7	[]	[]
Mass Flow Rate (lbm/s) <i>(Based on mass flux assuming ATRIUM-10 inlet area)</i>	10.1 to 42.5	[]	[]
Max Void at Measurement Plane (fraction)	0.848	[]	[]
Number of Data	66 tests, 331 points	[]	[]



**Figure 6-1: Validation of [] using FRIGG,
ATRIUM-10 and ATRIUM 10XM Void Data**

6.3 *Benchmarking to KATHY Pressure Drop Tests*

Steady state pressure drop measurements have been performed for the ATRIUM-10 and ATRIUM 10XM at KATHY. The geometry was prototypic and includes all necessary features such as []

[]. Pressure measurements were made at several elevations in the bundles. In addition measurements include both single phase and two phase statepoints. The characteristics of the pressure drop validation database are listed in Table 6-2.

Figure 6-2 provides comparisons of predicted versus measured pressure drops for the Framatome ATRIUM-10 multi-rod pressure drop validation. This figure shows that the majority of the predictions fall within [] (predicted – measured) error bands. The mean and standard deviation of the error were calculated using the method used in Reference 35. The single phase ATRIUM-10 data showed a mean relative error of [] and a standard deviation of []. The two phase ATRIUM-10 data showed a mean relative error of [] and a standard deviation of []. These statistics meet the NRC criteria for both average error and standard deviation.

Figure 6-3 provides comparisons of predicted versus measured pressure drops for the Framatome ATRIUM 10XM multi-rod pressure drop validation. This figure shows that the majority of the predictions fall within [] (predicted – measured) error bands. The mean and standard deviation of the error were calculated using the method used in Reference 35. The single phase ATRIUM 10XM data showed a mean relative error of [] and a standard deviation of []. The two phase ATRIUM 10XM data showed a mean relative error of [] and a standard deviation of [].

Table 6-2: Summary of Pressure Drop Test Conditions

	ATRIUM-10 KATHY	ATRIUM 10XM KATHY
Axial Power Shape	[]	[]
Bundle Design	[]	[]
Pressure (bar)	[]	[]
Inlet Temperature (^o C)	[]	[]
Mass Flow Rate (kg/s)	[]	[]
Number of Two Phase Data Points	[]	[]
Number of Single Phase Data Points	[]	[]



**Figure 6-2: Validation of Pressure Drop Prediction versus KATHY ATRIUM-10
Measured Data**



**Figure 6-3: Validation of Pressure Drop Prediction versus KATHY ATRIUM 10XM
Measured Data**

6.4 ***Benchmarking to KATHY Stability Tests***

Several measurement campaigns were performed in the KATHY loop under natural circulation configuration to quantify the stability characteristics of ATRIUM-9, ATRIUM-10, and ATRIUM 10XM BWR fuel designs. The results of these measurements were used for developing and validating Framatome's stability methodologies. Of particular interest here is the ATRIUM-10 stability test series (Bundle ID STS-49.1) and the ATRIUM 10XM test series (Bundle ID STS115.1). [

]

The ATRIUM-10 tests were performed during the period May 31-June 17, 1999. The test bundle STS-49.1 was characterized by a down-skew power profile with [

] From this

data, decay ratios and frequencies were calculated.

The ATRIUM 10XM tests were performed during the period October 15-October 23, 2009. The test bundle STS-115.1 was characterized by a down-skew power profile with [

] From this

data, decay ratios and frequencies were calculated.

The data collected from the stability testing of the ATRIUM-10 and ATRIUM 10XM bundles in the KATHY loop are used for benchmarking RAMONA5-FA ATWS-I. The operating conditions of power and inlet subcooling were varied and data were collected for each operating point. [

]

The number of ATRIUM-10 data points used in this benchmarking is [] while the number of ATRIUM 10XM data points used in this benchmarking is []. The measured operating parameters for each test point are used as input to RAMONA5-FA ATWS-I. The decay ratio and frequency for each test point are compared with the corresponding measured values.

The following figures depict good agreement between the measured and calculated decay ratios and frequencies.



Figure 6-4: Validation of Decay Ratio Prediction versus KATHY Measured Data



Figure 6-5: Validation of Frequency Prediction versus KATHY Measured Data

6.5 ***Benchmarking to KATHY Dryout/Rewet Tests***

For stability and severe oscillation testing of ATRIUM 10XM, a full scale electrically heated test section is used. The axial power shape is bottom-peaked [

]. The heated rods include full-length and part-length rods. [

]

The procedure in the pure thermal-hydraulic testing is similar to the previous stability testing campaigns with ATRIUM-9 and ATRIUM-10. [

]

Information about dryout behavior is extracted from the pure thermal-hydraulic stability testing by simply allowing the flow oscillations to increase, and apply additional power increase steps as needed. Cyclical dryout and rewetting were observed in these tests by recording the responses of the many thermocouples attached to the heater rods at different elevations. [

]

It is well-known from numerical and theoretical studies of density waves in BWRs that the reactivity-to-power feedback has a destabilizing effect. By implementing such feedback in the KATHY test loop, the loop is operated at conditions closely resembling the actual conditions in an unstable BWR. With the power feedback turned on, [

] oscillations of the flow and now power to reach high amplitudes with significant inlet flow reversal [

]

[

]

The test results were studied and important data were extracted. These data allowed the transient extraction of [

] The measured and extracted information from the tests were essential in developing the post-dryout models, and serve to benchmark it.

The entire test run database was reviewed with regard to dryout occurrence under oscillation. All the test runs that were identified as experiencing dryout at any spacer, with or without failure to rewet, are processed and used for the benchmarking of post-dryout models. [

]

The post-dryout models were originally developed and validated using the SINANO code, Reference 34. These models have been further improved as described in Section 5.9.5, and were validated with the SINANO code. The models from the SINANO code have been integrated within the RAMONA code system, and the same benchmarks were performed with RAMONA to ensure the models were properly integrated.

Figure 6-6 through Figure 6-20 show the results of the benchmarking using CPROM coefficients consistent with the ATRIUM 10XM design discussed in Appendix A. All plots compare predicted temperatures at the spacer to the measured temperatures. In some instances nodes above and below are shown to better highlight the model behavior.

Figure 6-6 through Figure 6-20 provide a qualitative evaluation of the accuracy of the post-dryout models. In order to provide a quantitative evaluation of model accuracy, the benchmarks were re-analyzed with [

] and demonstrates that models can accurately reproduce the data.

In order to validate the post-dryout models for fuel designs besides ATRIUM 10XM, [

] Results of these cases are plotted in Figure 6-22 and Figure 6-23.

Table 6-3: Dryout and rewetting ATRIUM 10XM KATHY test runs



Figure 6-6: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-7: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-8: Limiting Temperature for KATHY ATRIUM 10XM [

]



Figure 6-9: Limiting Temperature for KATHY ATRIUM 10XM [

]



Figure 6-10: Limiting Temperature for KATHY ATRIUM 10XM test []



Figure 6-11: Limiting Temperature for KATHY ATRIUM 10XM []

Figure 6-12: Limiting Temperature for KATHY ATRIUM 10XM []

Figure 6-13: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-14: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-15: Limiting Temperature for KATHY ATRIUM 10XM []

Figure 6-16: Limiting Temperature for KATHY ATRIUM 10XM []

Figure 6-17: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-18: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-19: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-20: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-21: Limiting Temperature for KATHY ATRIUM 10XM []



Figure 6-22: Limiting Temperature for KATHY [

]



Figure 6-23: Limiting Temperature for KATHY [

]

6.6 *Benchmarking to Linear Reactor Stability Benchmarks*

In order to validate the functions and additions to the RAMONA5-FA ATWS-I code, several sets of linear stability reactor benchmarks were performed. [

]

utilize neutronic input taken from the benchmark material used to qualify the frequency domain code STAIF (Reference 21).

6.6.1 []

[

]

*

[

]

1

[

1

[

1

1

6.6.4 []

[

]

6.7 ***Benchmarking to Non-Linear Reactor Benchmarks***

In order to validate the functions and additions to the RAMONA5-FA ATWS-I code, several sets of non-linear stability reactor benchmarks were performed. These benchmarks include:

- Oskarshamn Non-Linear Instability
- BWR A Feedwater Transient with Non-Linear Instability

A description of the benchmark analyses is given in the following sections along with the RAMONA5-FA ATWS-I calculated decay ratios and frequencies.

6.7.1 **Oskarshamn Nonlinear Instability**

On February 25, 1999 as maintenance work was being performed on a switchyard outside of Oskarshamn Unit 2, the power supply to a bus bar was interrupted for 150 ms. A load rejection signal was sent to the main breaker that connects the unit to the grid. This signal caused the turbine to trip, however due to a failure in the relay circuit, this signal was not transmitted to the reactor protection system. The system continued at power until operators initiated a partial scram. Following the partial scram, power and flow were decreased. The feedwater temperature continued to decrease causing reactor power to further increase until the system crossed the stability boundary. The reactor continued to oscillate until a high power scram was reached.

The Oskarshamn-2 non-linear stability was analyzed with RAMONA5-FA ATWS-I. Two separate scenarios were evaluated. In the first scenario, the measured pump speed was imposed and the recirculation flow was calculated based on the specified pump performance curves. The plots of relevant parameters to actual measured data for this scenario are given in Figure 6-24, Figure 6-25, and Figure 6-26. The results show good agreement with measured values with a small overestimation of the event growth rate. However, Figure 6-26 shows that the code overestimates the final recirculation flow during the final portion of the event. A second scenario was then run in which the pump speed versus time was modified to produce a recirculation flow approximately equal to the measured value. The results of this evaluation are given in Figure 6-27, Figure 6-28, and Figure 6-29. The results of this scenario show a slightly greater overestimation with the measured power results.

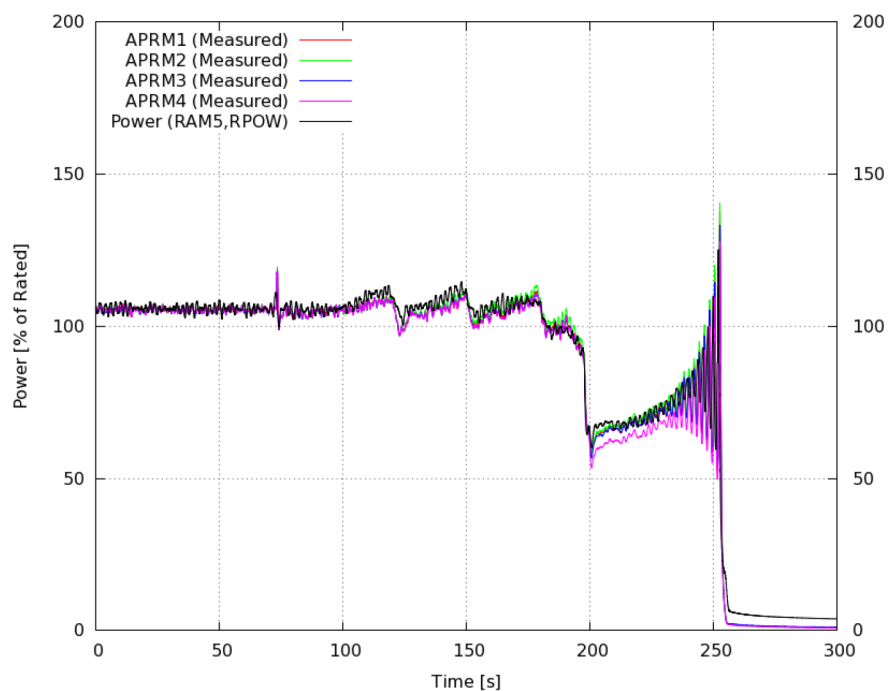


**Figure 6-24: Oskarshamn-2 Non-Linear Stability Simulation
Core Power, Imposed Pump Speed**

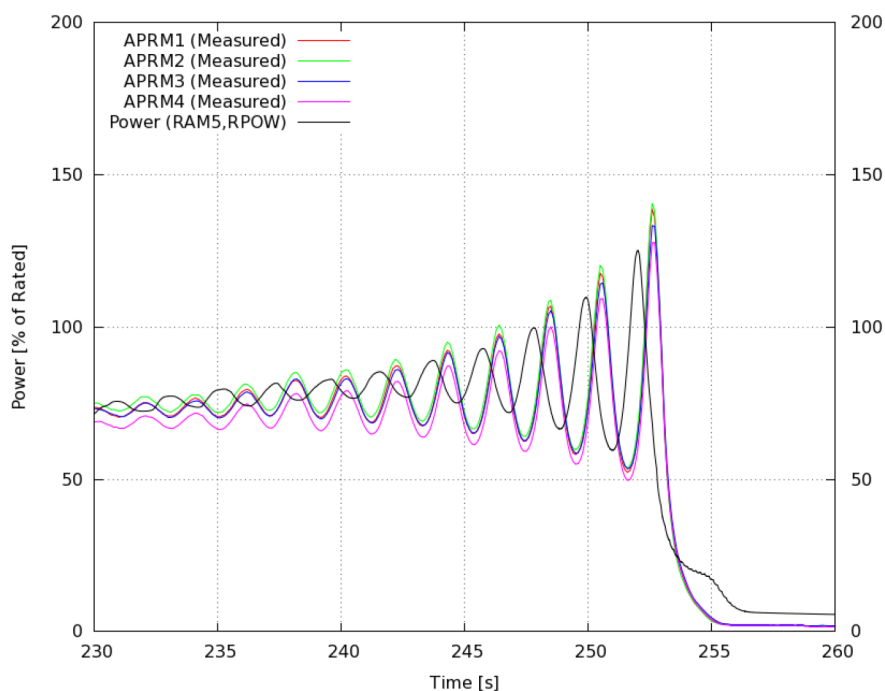


**Figure 6-25: Oskarshamn-2 Non-Linear Stability Simulation
Core Power - Zoom, Imposed Pump Speed**

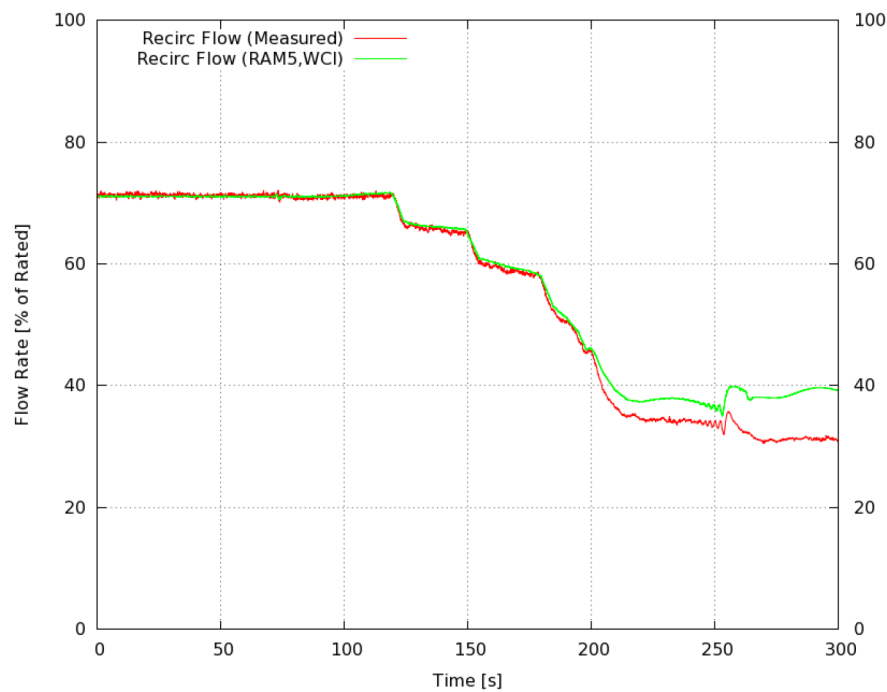


**Figure 6-26: Oskarshamn-2 Non-Linear Stability Simulation
Recirculation Flow, Imposed Pump Speed**

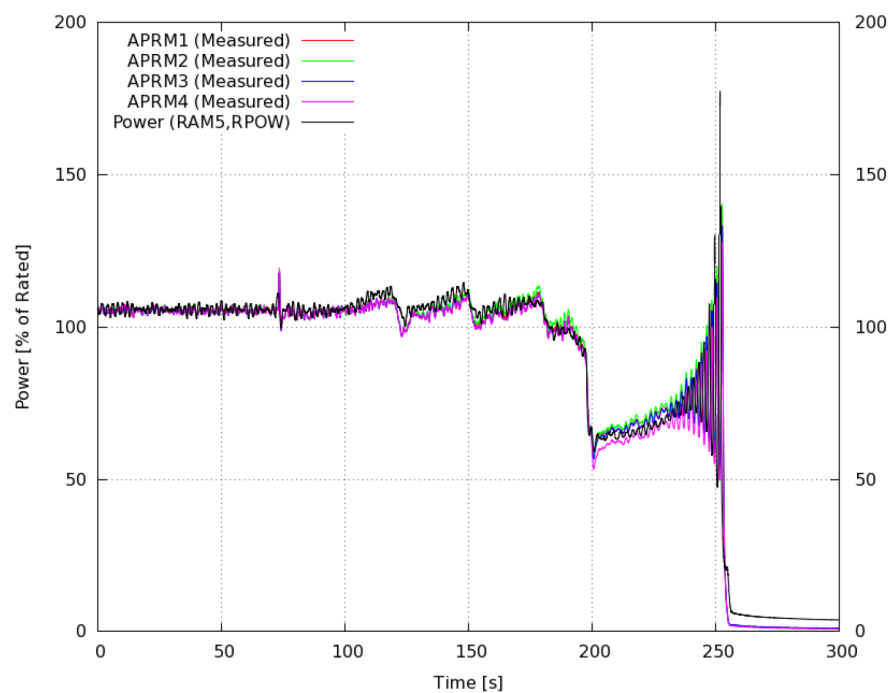


**Figure 6-27: Oskarshamn-2 Non-Linear Stability Simulation
Core Power, Match Recirculation Flow**

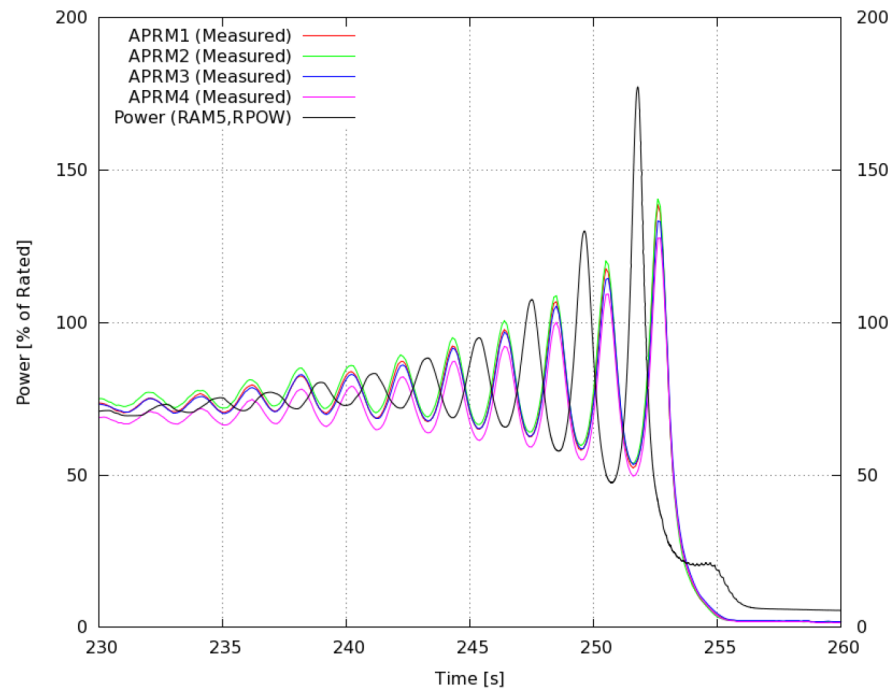


**Figure 6-28: Oskarshamn-2 Non-Linear Stability Simulation
Core Power - Zoom, Match Recirculation Flow**

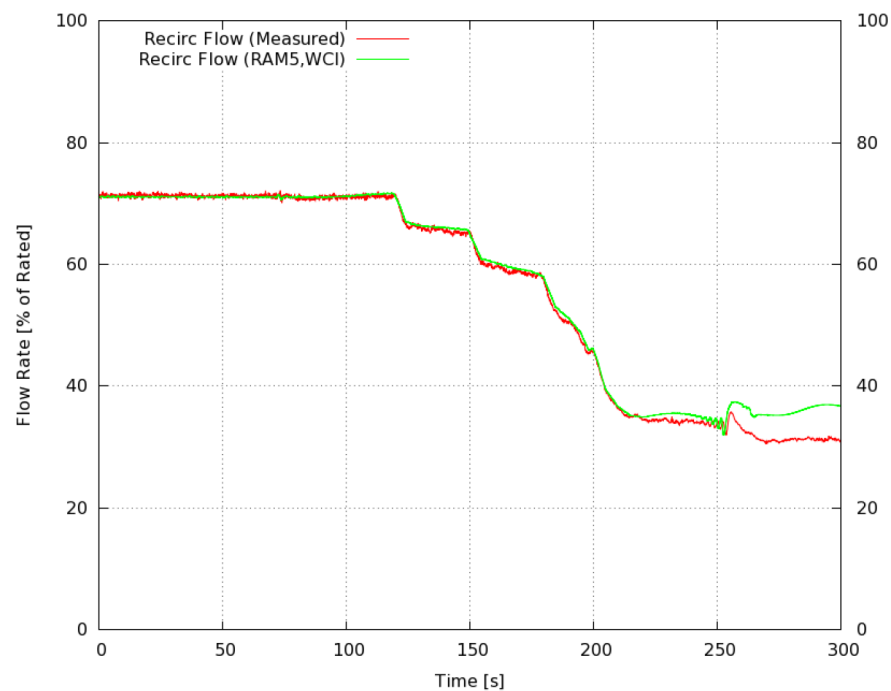


**Figure 6-29: Oskarshamn-2 Non-Linear Stability Simulation
Recirculation Flow, Match Recirculation Flow**

6.7.2 BWR A Feedwater Transient with Non-Linear Instability

[

] was analyzed with RAMONA5-FA ATWS-I. The plots of relevant parameters to actual measured data for this scenario are given in

Figure 6-30. The results show very good agreement between the measured and calculated []



Figure 6-30: BWR [] Transient Non-Linear Stability Simulation

7.0 **SAMPLE PROBLEMS**

In addition to the benchmarking described in the previous section, the general code performance against theoretically predicted trends was also investigated. This is accomplished by running a sample ATWS-I transient and performing checks to demonstrate the ability of the code to generate very large oscillations in power and flow and demonstrate large amplitude inlet flow reversal in some bundles. Sensitivity calculations for key parameters are examined.

The sample problem is based on the Brunswick BWR4 reactor. A full core of ATRIUM 10XM was modeled, and both TTWB and 2RPT transients were simulated. [

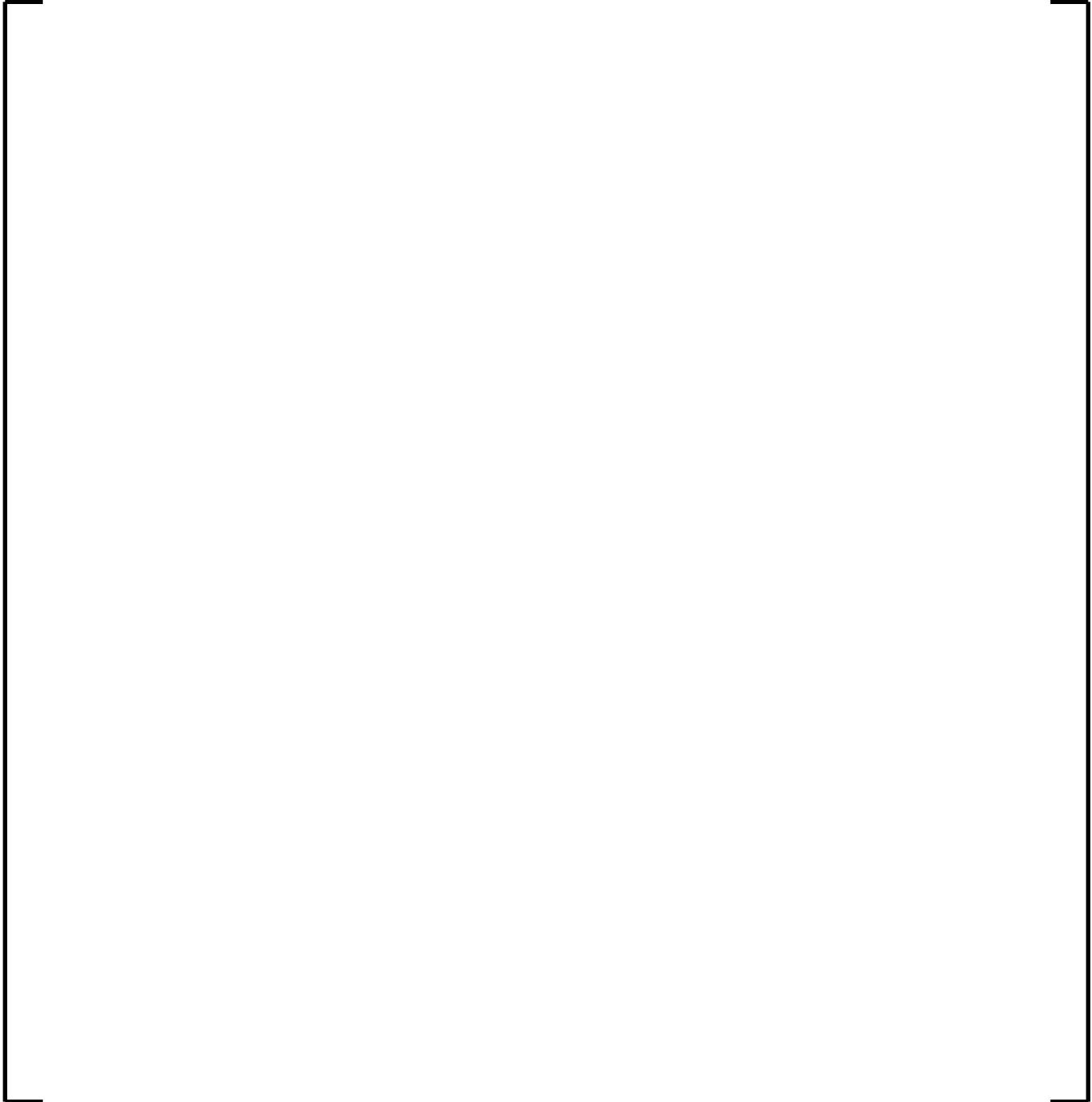
]

7.1 ***Turbine Trip***

A turbine trip with bypass was simulated [

]

Numerous sensitivity studies have also been performed to examine the sensitivity of the models to various operational variables, as well as modeling variables. The sensitivity to operational variables includes:



To examine the effect of model variations, the following sensitivity studies were performed.

The results for the [] sensitivity studies are presented in Table 7-1.

Table 7-1: TTWB Sensitivity Study Results





Figure 7-1: TTWB Base Case Core Power



Figure 7-2: TTWB Base Case Core Inlet Flow



Figure 7-3: TTWB Base Case Core Inlet Subcooling



Figure 7-4: TTWB Base Case Limiting Channel Inlet Flow



Figure 7-5: TTWB Base Case Vessel Water Level



Figure 7-6: TTWB Base Case Limiting Channel PCT

7.2 *Two Recirculation Pump Trip*

A 2RPT was simulated [

]

Table 7-2: 2RPT Sensitivity Study Results



Figure 7-7: 2RPT Base Case Core Power



Figure 7-8: 2RPT Base Case Core Inlet Flow



Figure 7-9: 2RPT Base Case Limiting Channel Inlet Flow



Figure 7-10: 2RPT Base Case Core Inlet Subcooling



Figure 7-11: 2RPT Base Case Vessel Water Level

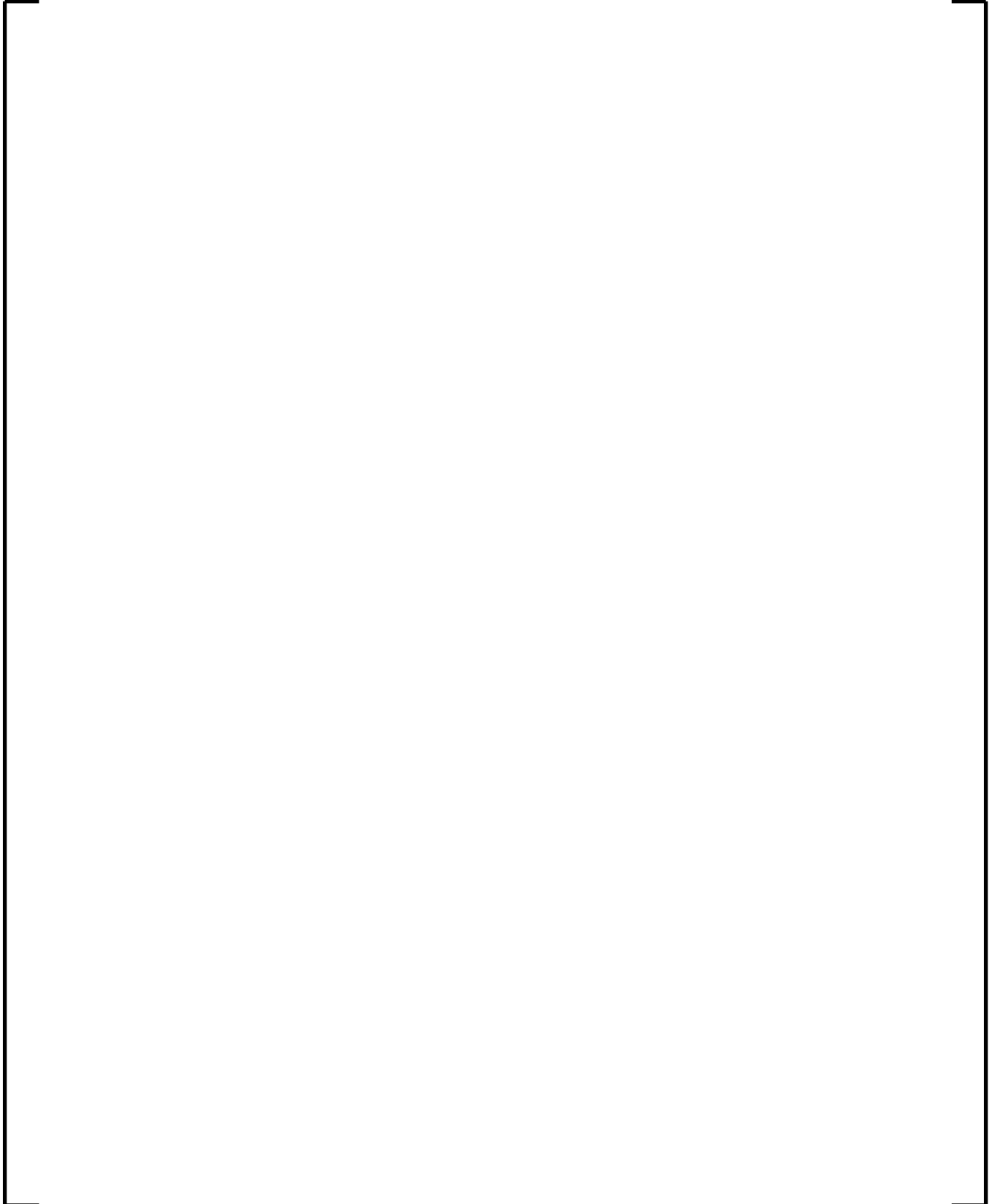


Figure 7-12: 2RPT Base Case Limiting Channel PCT

8.0 **CALCULATION PROCEDURE**

The RAMONA5-FA ATWS-I evaluation entails the analysis of simulated ATWS events at several state points throughout that cycle. This section is devoted to the general description of the methodology, the procedure for performing this calculation, and the limitation and conditions of the methodology which is presented in Table 8-1. In summary, the application procedure includes the following elements:





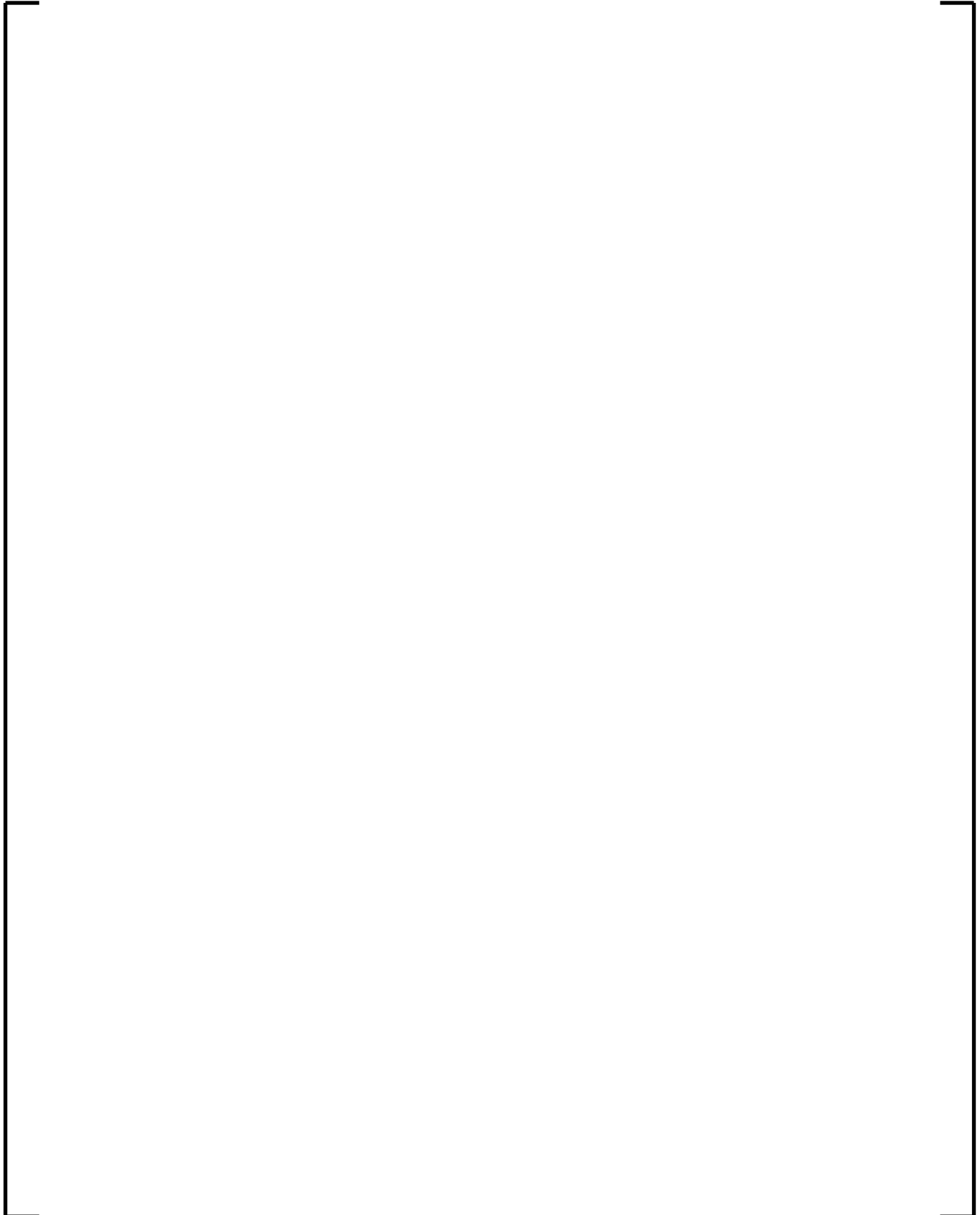


Table 8-1: ATWS-I Limitation and Conditions

9.0 REFERENCES

1. "ATWS Rule Issues Relative to BWR Core Thermal-Hydraulic Stability," NEDO-32047-A, Class I June 1995.
2. W. Wulff et al., "BWR Stability Analysis with the BNL Engineering Plant Analyzer," NUREG/CR 5816, BNL/NUREG-52312, October 1992.
3. USNRC Standard Review Plan, *15.8 Anticipated Transient Without Scram*, NUREG-0800, Revision 2, March 2007.
4. FQM, Revision 3, *AREVA NP Fuel Sector Quality Management Manual*, AREVA NP, June 2008.
5. J. March-Leuba, "Density-Wave Instabilities in Boiling Water Reactors," NUREG/CR-6003, ORNL/TM-12130, September 1992.
6. Carsten Lange et al., "Comments on local power oscillation phenomenon at BWRs," *Progress in Nuclear Energy* 60 (2012) 73-88.
7. BAW-10255(P)(A) Revision 2, "Cycle-Specific DIVOM Methodology Using the RAMONA5-FA Code," AREVA NP, May 2008.
8. A. Wysocki, J. March-Leuba, T. Downar, and A. Manera, "TRACE/PARCS Analysis of Out-of-Phase Power Oscillations With a Rotating Line of Symmetry," The 15th International Topical Meeting on Nuclear Reactor Thermal- Hydraulics, NURETH-15, paper 457, Pisa, Italy, May 12-17, 2013.
9. Y. M. Farawila and D. W. Pruitt, "A Study of Nonlinear Oscillation and Limit Cycles in Boiling Water Reactors – I: The Global Mode," *Nuclear Science and Engineering*: 154, 302-315 (2006).
10. Y. M. Farawila and D. W. Pruitt, "A Study of Nonlinear Oscillation and Limit Cycles in Boiling Water Reactors – II: The Regional Mode," *Nuclear Science and Engineering*: 154, 316-327 (2006).
11. Y. M. Farawila, "Application of Modal Neutron Kinetics to Boiling Water Reactor Oscillation Problems," *Nuclear Science and Engineering*: 129, 261 (1998).

12. Hideaki IKEDA et al., "Nonlinear Behavior under Regional Neutron Flux Oscillations in BWR Cores," J. Nuclear Science and Technology, Vol. 38, No. 5, p. 312-323 (May 2001).
13. D. W. Pruitt, D. R. Tinkler, and Y. M. Farawila, "Considerations for Bypass Boiling during BWR Power Oscillations," Trans. Am. Nucl. Soc., Vol. 99, pp. 739-740 (Nov. 2008).
14. D. W. Pruitt, K. R. Greene, F. Wehle, R. Velten, J. Kronenberg, A. Beisiegel, and Y. M. Farawila, " Stability and Void Fraction Measurements for the ATRIUM 10XM BWR Fuel Bundle," Proceedings of 2010 LWR Fuel Performance Top Fuel WRFPM, Orlando, Florida, Sept. 26-29, 2010.
15. F. Wehle, R. Velten, J. Kronenberg, A. Beisiegel, D. Pruitt, K. Greene, and Y. Farawila, "Full Scale Stability and Void Fraction Measurements for the ATRIUM 10XM BWR Fuel Bundle," 2011 Jahrestagung Kerntechnik, Berlin, Germany, May 17-19 2011.
16. [
-]
17. W. Wulff, "Simulation of Two-Phase Flow in Complex Systems," Nuclear Technology Vol. 159, September 2007.
18. ANF-88-101(P), *MICROBURN-B: A Two-Group, Three Dimensional BWR Nodal Simulator Code*, Advanced Nuclear Fuels, July 1988.
19. Byung-Oh Cho, "Nodal Methods for Calculating Nuclear Reactor Transients, Control Rod Patterns, and Fuel Pin Powers," Ph.D. Thesis, Oregon State University, OSU-NE-9108, June 1991.
20. EMF-2158(P)(A) Revision 0, "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2," Siemens Power Corporation, October 1999.
21. EMF-CC-074(P)(A) Volume 4 Revision 0, *BWR Stability Analysis – Assessment of STAIF with Input from MICROBURN-B2*, Siemens Power Corporation, August 2000.

-
22. EMF-3028P-A Volume 2 Revision 4, "RAMONA5-FA: A Computer Program for BWR Transient Analysis in the Time Domain Volume 2 -- Theory Manual," AREVA NP Inc., March 2013.
 23. American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1979.
 24. W. Wulff, et al., "A Description and Assessment of RAMONA-3B Mod. 0 Cycle 4 A Computer Code with Three-Dimensional Neutron Kinetics for BWR System Transients," BNL-NUREG-51748, January 1984.
 25. []
 26. Moody, L. F., "An Approximate Formula for Pipe Friction Factors," *Mechanical Eng.* 69, pp 1005-1006, December 1947.
 27. []
 28. []
 29. W. Wagner and H.-J. Kretzschmar, "International Steam Tables – Properties of Water and Steam Based on the Industrial Formulation IAPWS-IF97," second edition 2008 Springer-Verlag Berlin Heidelberg.
 30. ANP-10262PA Revision 0, "Enhanced Option III Long Term Stability Solution", AREVA NP, May 2008.
 31. NUREG/CR-6743, LA-UR-00-3122, "Phenomenon Identification and Ranking Tables (PIRTS) for Power Oscillations Without Scram in Boiling Water Reactors Containing High Burnup Fuel," September 2001.
 32. O. Nylund et al., "Hydrodynamic and Heat Transfer Measurements on A Full-Scale Simulated 36-Rod Marviken Fuel Element with Non-Uniform Radial Heat Flux Distribution," FRIGG-3, R-494/RL-1154, November 1969.

33. BAW-10247PA Revision 0, *Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors*, AREVA NP, February 2008.
34. ANP-3274P Revision 3, *Analytical Methods for Monticello ATWS-I*, February 2017.
35. XN-NF-79-59(P)(A), *Methodology for Calculations of Pressure Drop in BWR Fuel Assemblies*, October 1983.

APPENDIX A STEADY STATE DRYOUT CORRELATION CPROM**Abstract**

A new dryout correlation is presented. This correlation, named Critical Power Reduced Order Model (CPROM), has been developed based on Framatome correlation development guidelines similar to dryout licensing correlations such as ACE. The CPROM correlation range of applicability is wide [

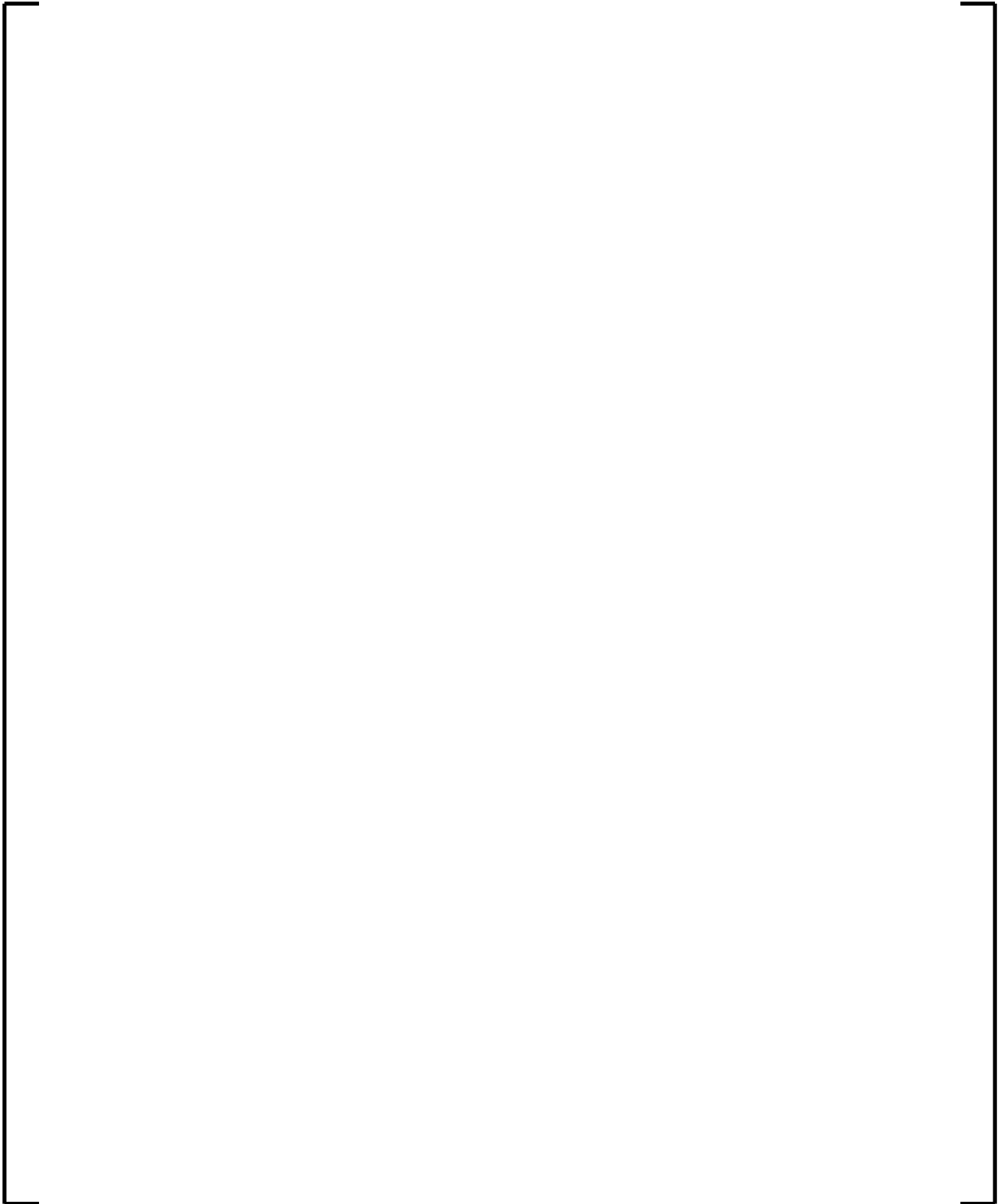
] making it well-suited to fitting into transient models of post-dryout that include cyclical dryout and rewetting with possible failure to rewet. CPROM is an integral part of the RAMONA5-FA transient model described in Section 5.5.5.

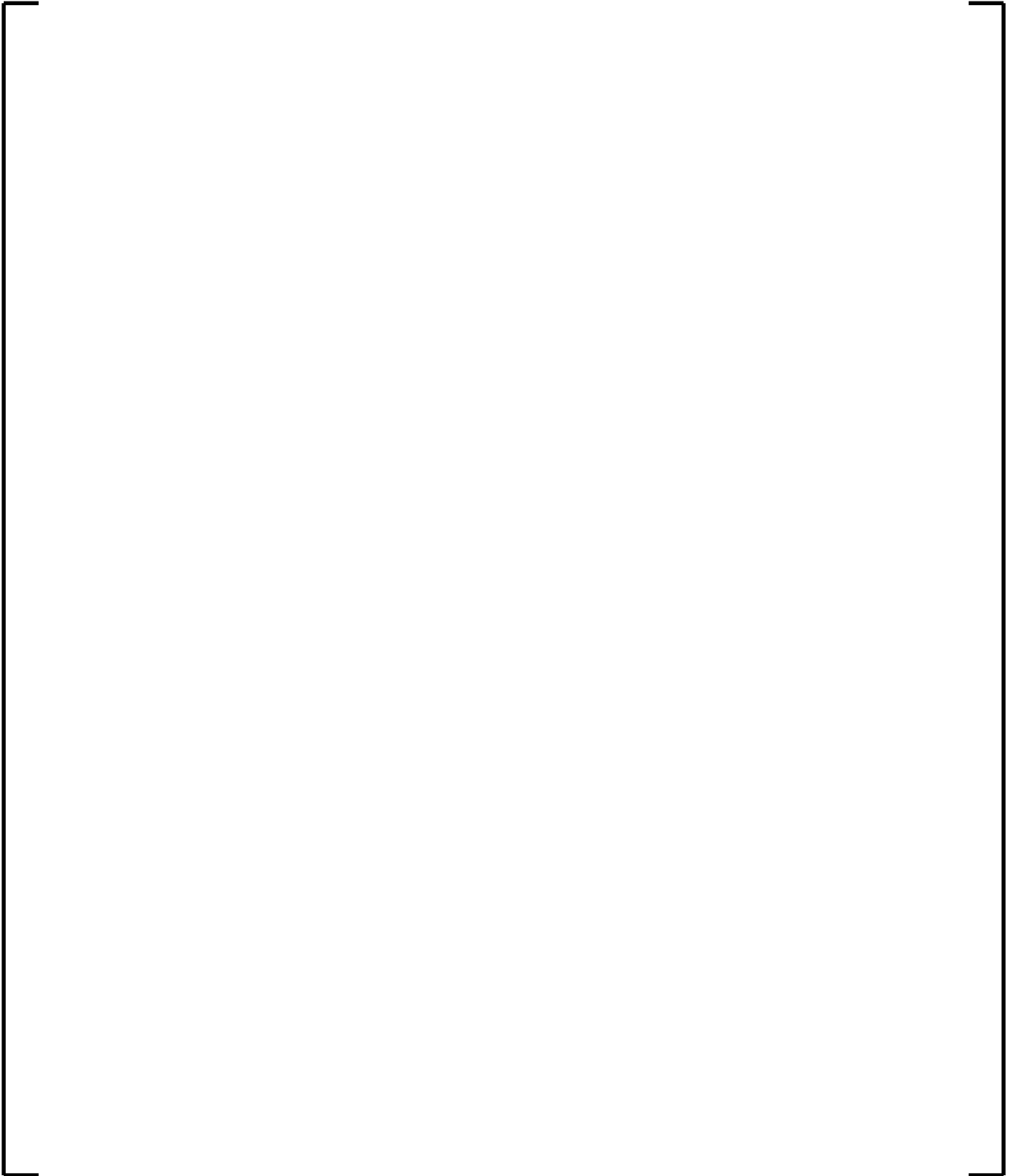
A.1 *Description of CPROM Correlation*

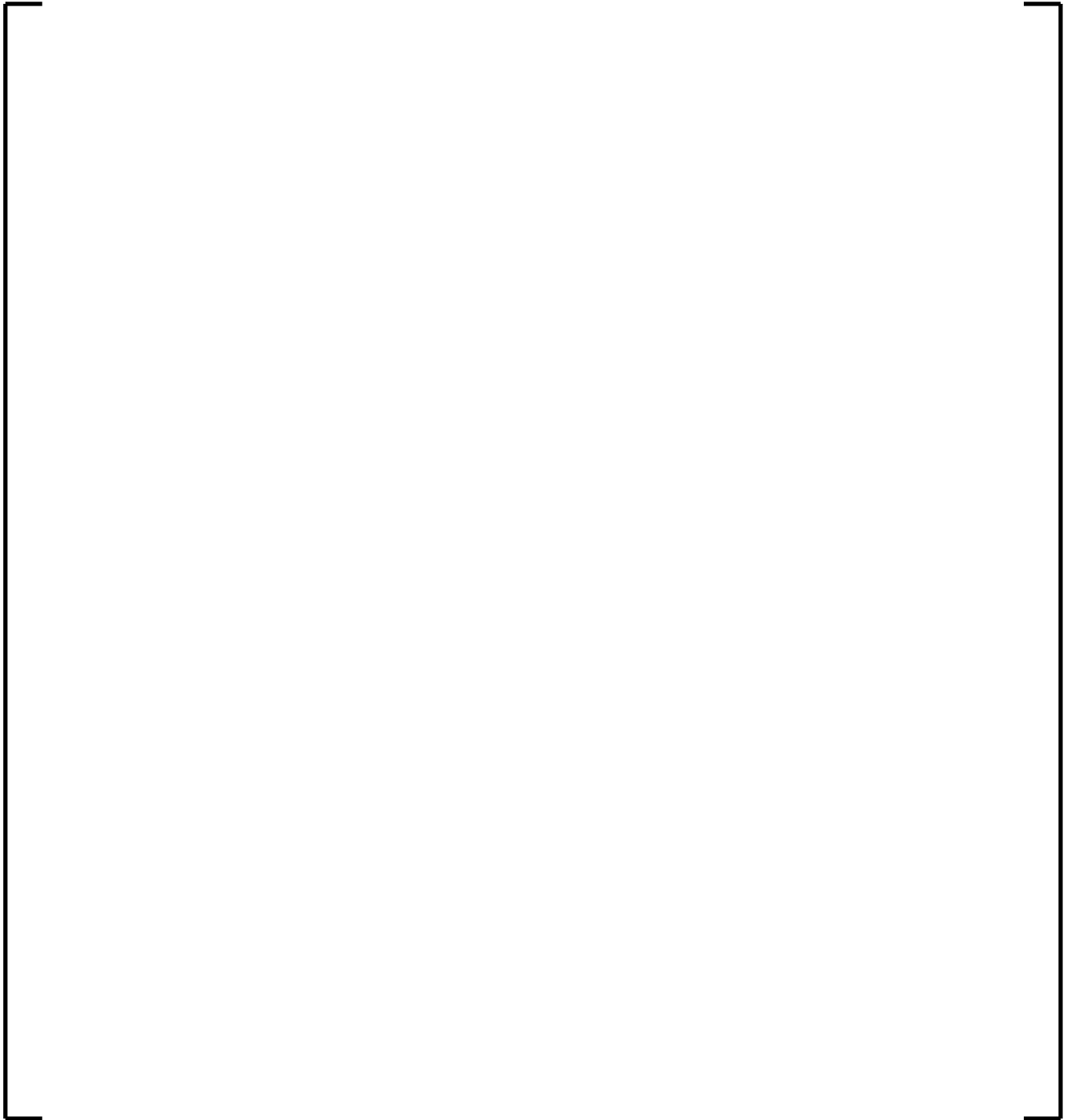
A dryout correlation of the critical heat flux type is developed. [

]









A.2 ***CPRM Correlation for ATRIUM 10XM***



Table A-1: [

]

[

]

[

]



Figure A-1: Calculated versus measured critical power,
[]



Figure A-2: []



Figure A-3: []



Figure A-4: []



Figure A-5: []



Figure A-6: []

Table A-2: Statistics [

Table A-3: Statistics [

Table A-4: Statistics [

1

Table A-5: Statistics [

1

[

1



Figure A-7: Calculated versus measured critical power,
[]



Figure A-8: []



Figure A-9: []



Figure A-10: []



Figure A-11: []



Figure A-12: []

Table A-6: Statistics []



Table A-7: Statistics [

Table A-8: Statistics [

Table A-9: Statistics [

The figure below shows comparison of the calculated and measured critical power for the combined data set. The mean critical power ratio is [] and the standard deviation of the calculated versus measured critical power for the entire database is [] and the number of data points is [].



Figure A-13: Calculated versus measured critical power

A.3 *CFROM BOUNDS OF APPLICABILITY*

The bounds of applicability are determined by the data available to benchmark the correlation. For ATRIUM 10XM, the [

]

A.4 *CPRM COEFFICIENT GENERATION FOR NEW FUEL DESIGNS*

In order to properly generate CPRM coefficients for new fuel designs, the following requirements must be met.



APPENDIX B HEAT TRANSFER DATA FROM KATHY LOOP STABILITY TESTING OF ATRIUM 10XM

Abstract

Essential elements of the RAMONA5-FA model pertaining to the heat transfer coefficient behavior under wetted and dry conditions are extracted from measured data. The data set used for this purpose is the stability testing of the ATRIUM 10XM BWR bundle represented in full scale electrically heated module in the KATHY test facility. The testing conditions include steady state where the flow rate fluctuates only at the noise level. They also include very large unstable oscillations where significant inlet flow reversal occurs. The power level was kept constant under manual control for some tests. For other test runs, a feedback loop (SINAN module) determined the power input to the bundle and the resulting coherent power and flow oscillations of large amplitude provided a close simulation of the realistic conditions under ATWS-I transient.

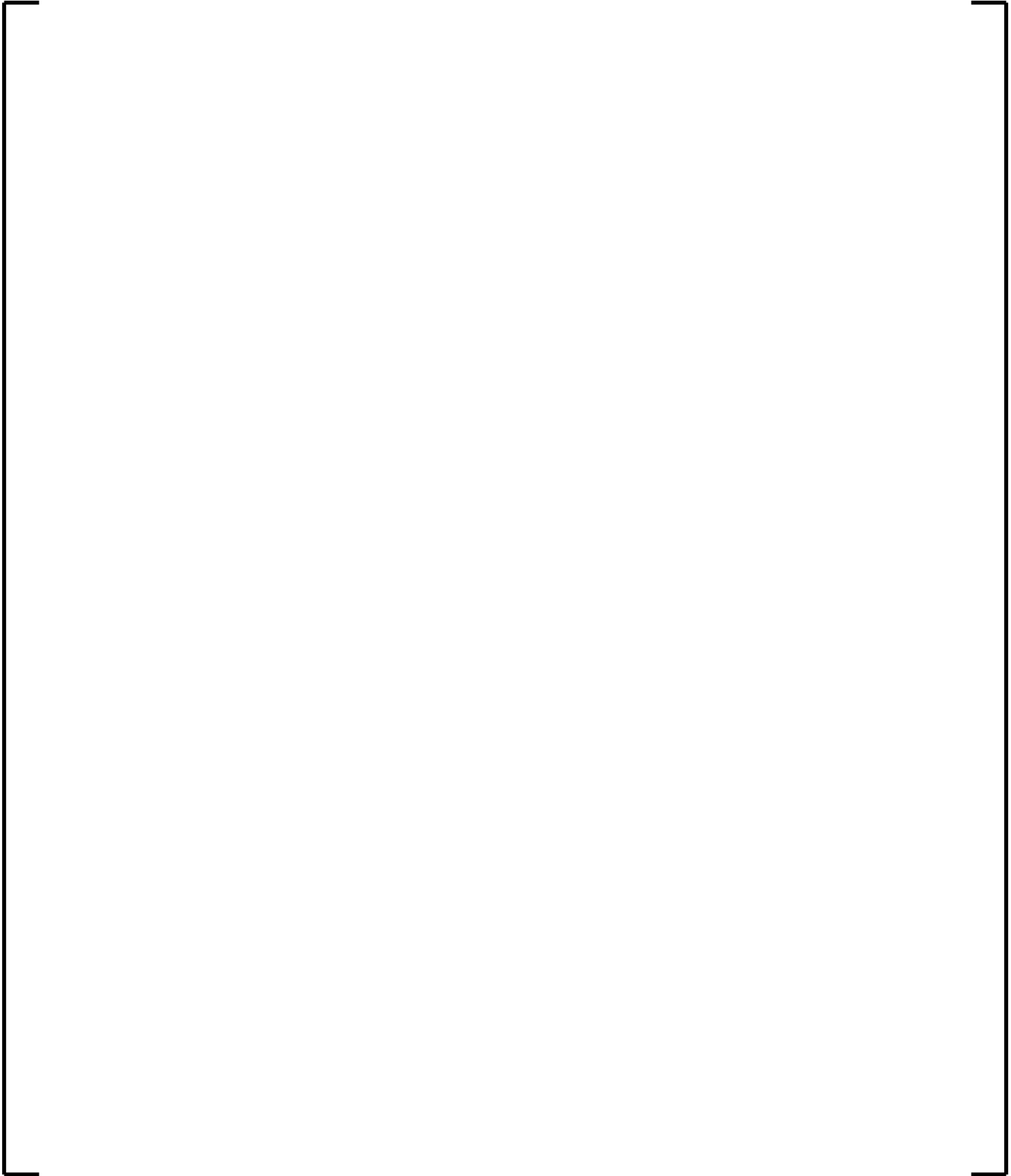
The following sections provide the heat transfer parameters determining the wet and dry conditions and [

]

B.1 *Summary of Heat Transfer Coefficient Data and Observations*

The needed measured data include the test section power, pressure, inlet flow rate, inlet subcooling and the temperature of the heater rods. [

]



B.2 Heat Transfer Coefficient under Wetted Conditions

The heat transfer extracted at the initial testing time, where wet conditions are guaranteed, are fit to the [].

B.3 []

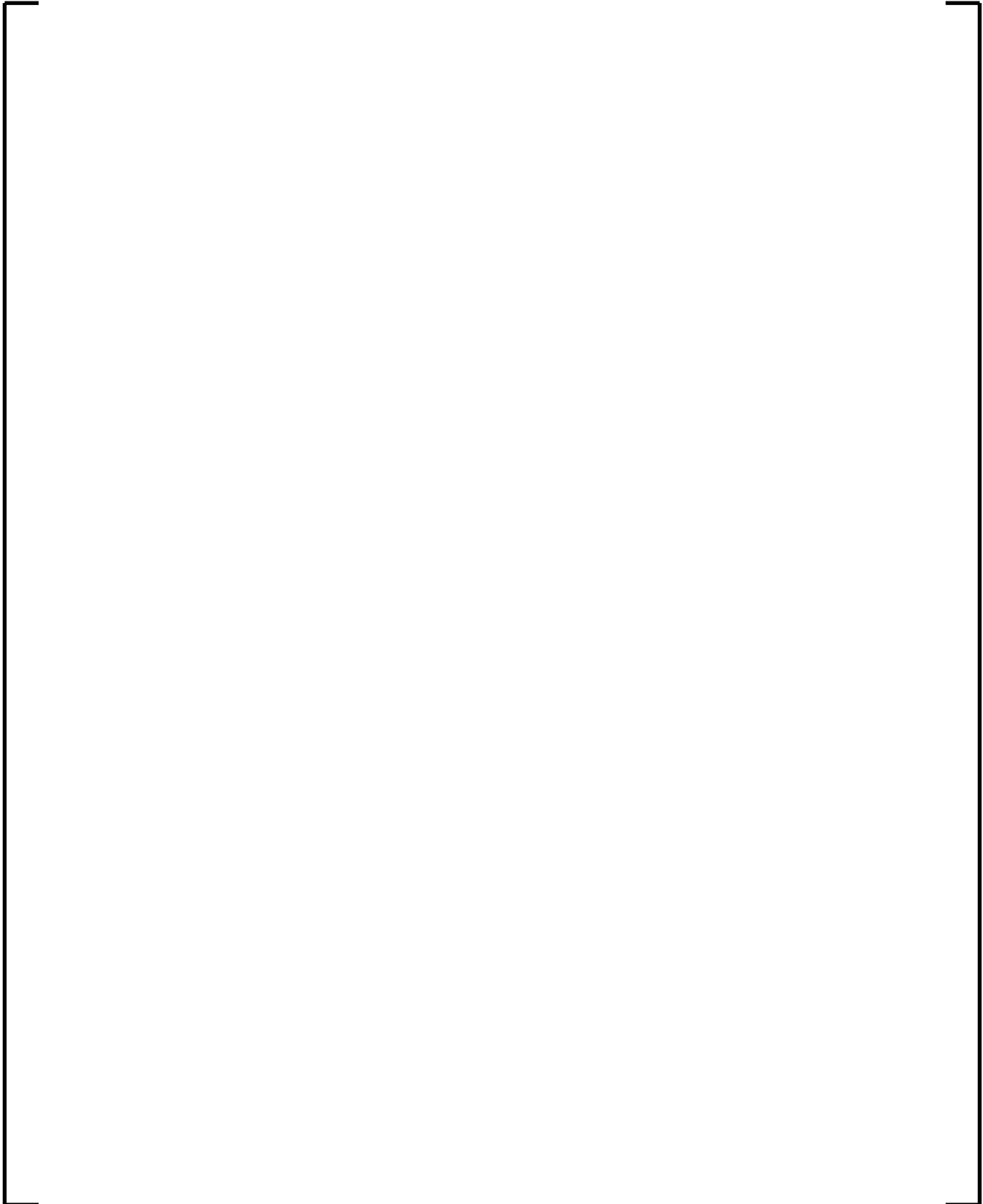




Figure B-1: [

]

B.4 *References*

B.1. [

]

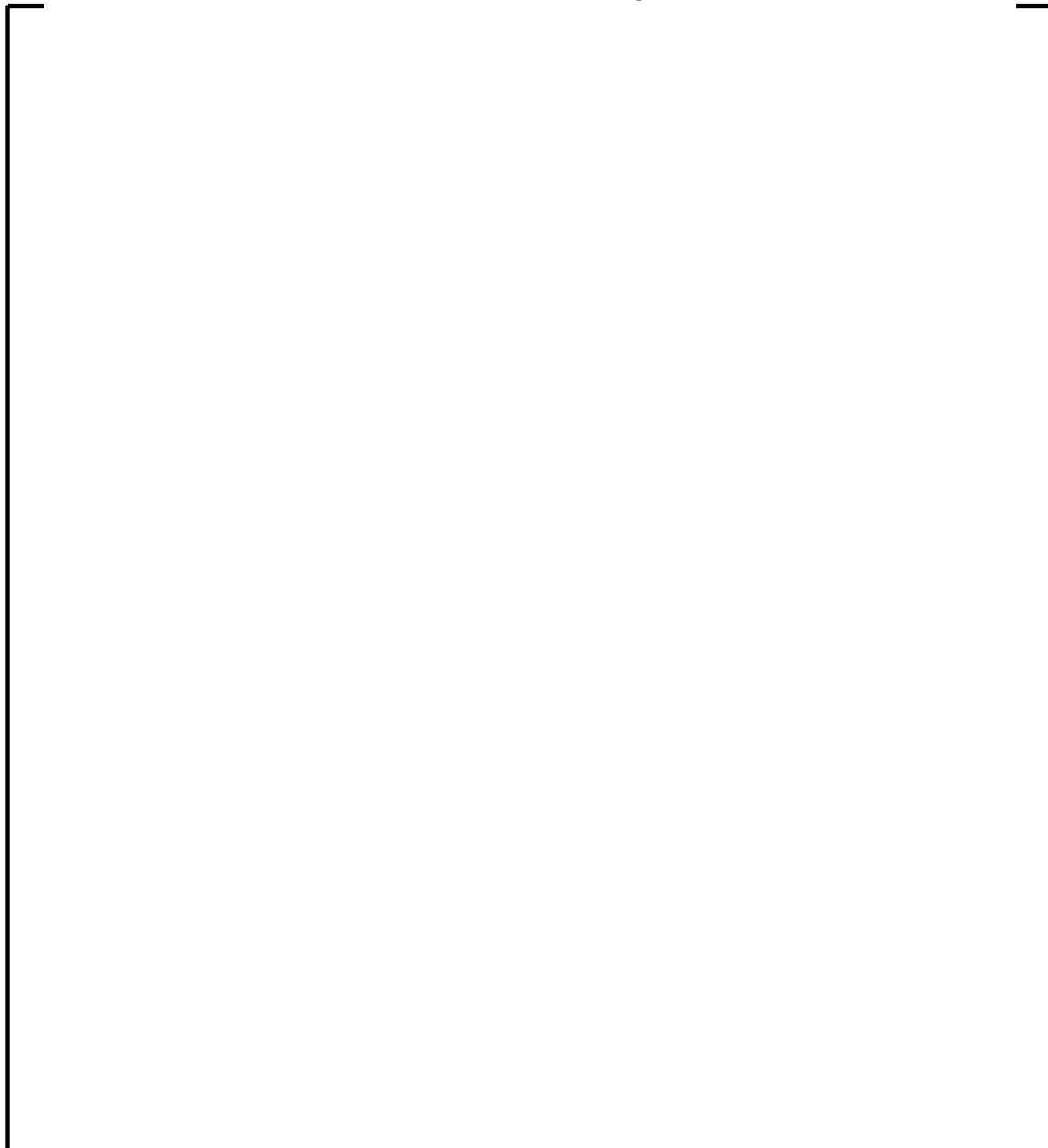
B.2. [

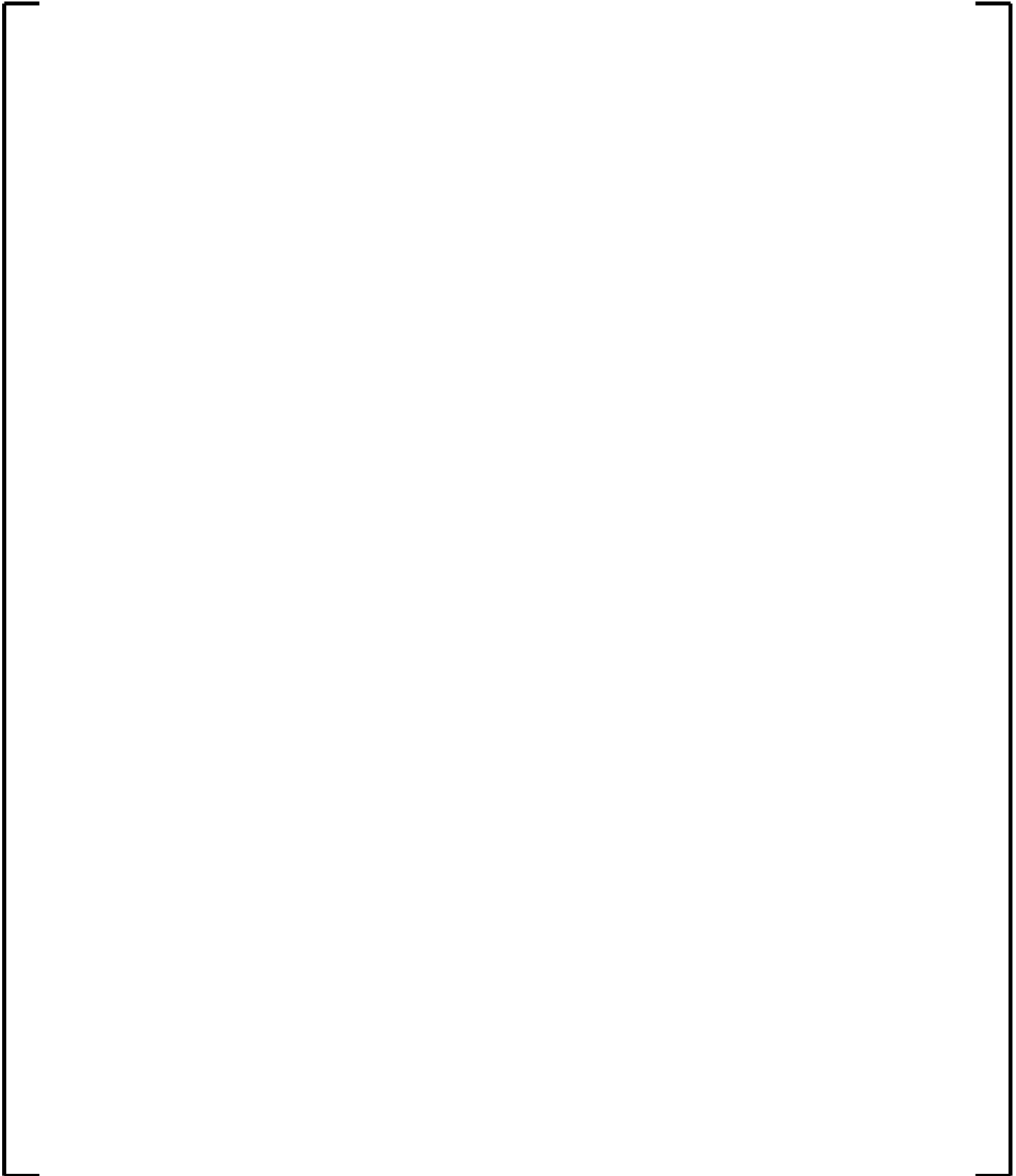
]

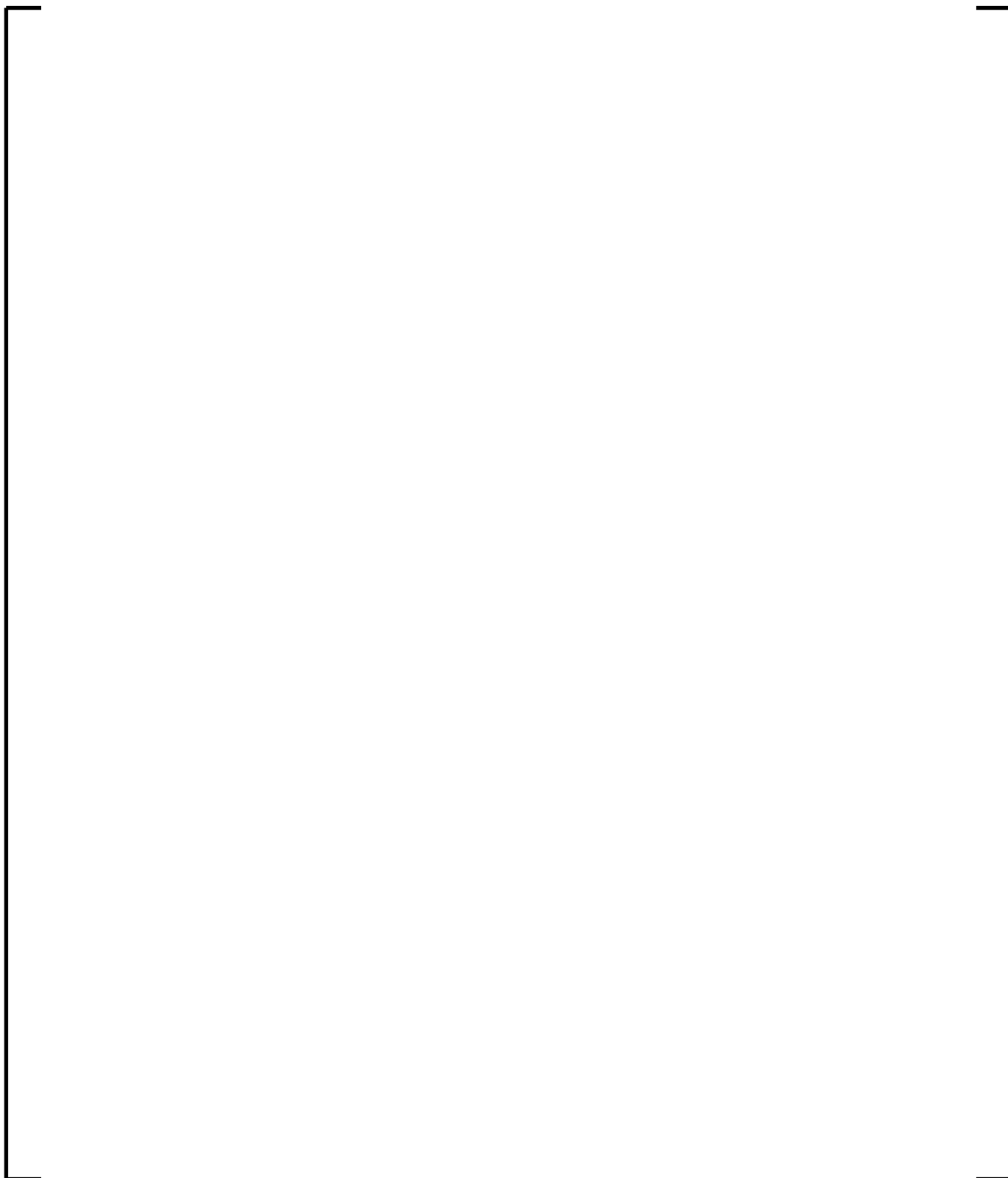
B.3. [

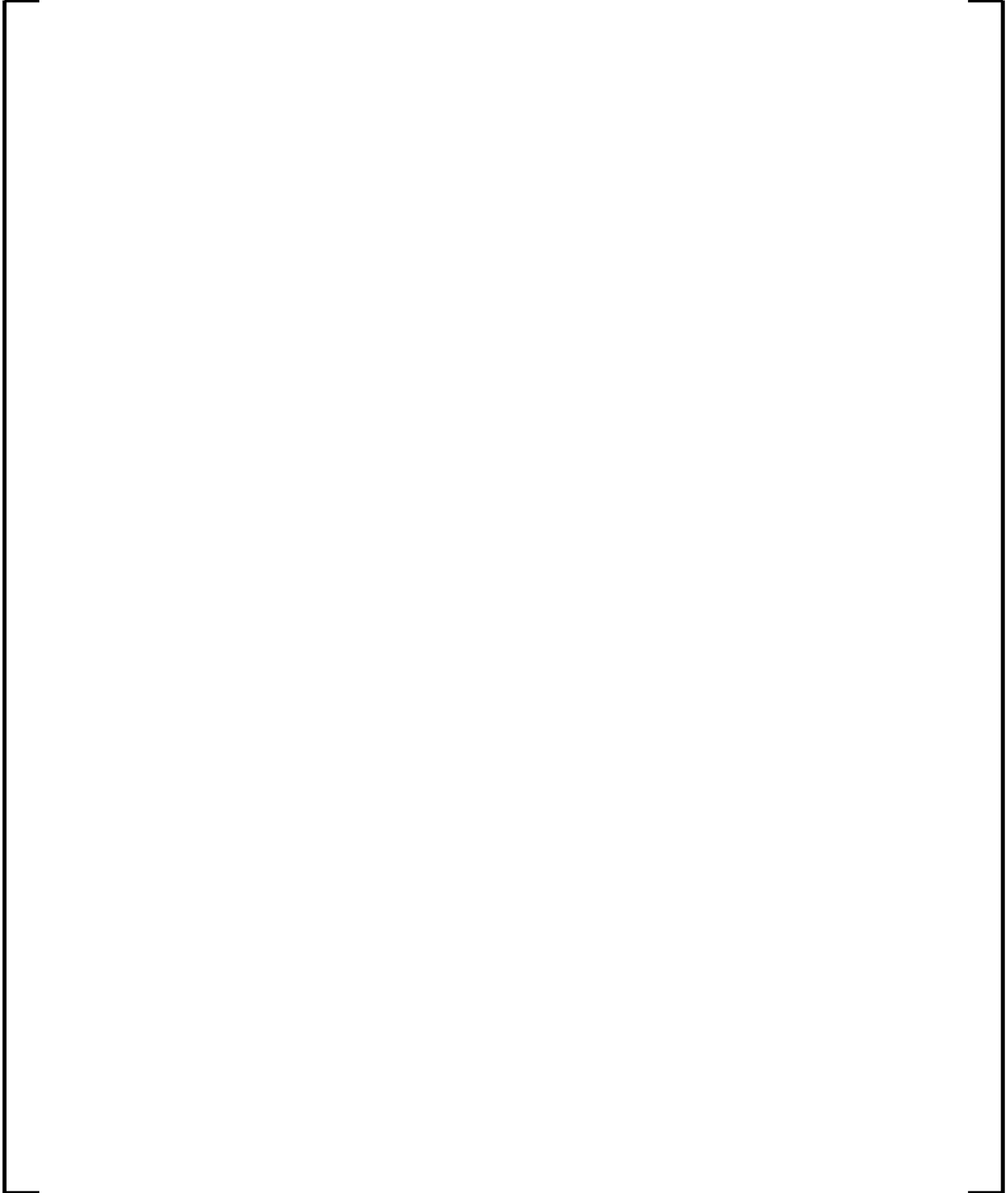
]

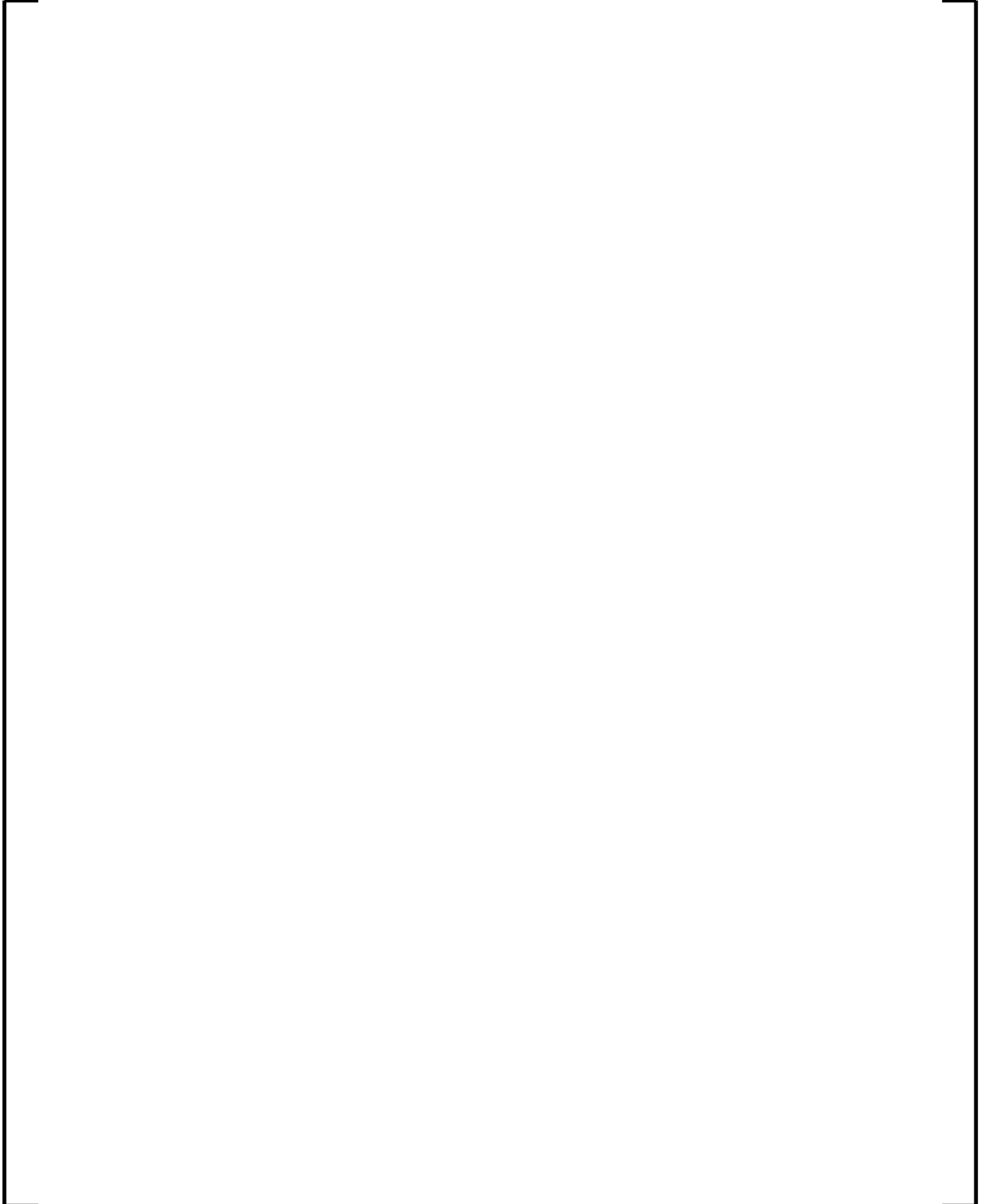
**Appendix C INVESTIGATION OF THE DYNAMIC EFFECTS OF
INTERFACIAL FRICTION**

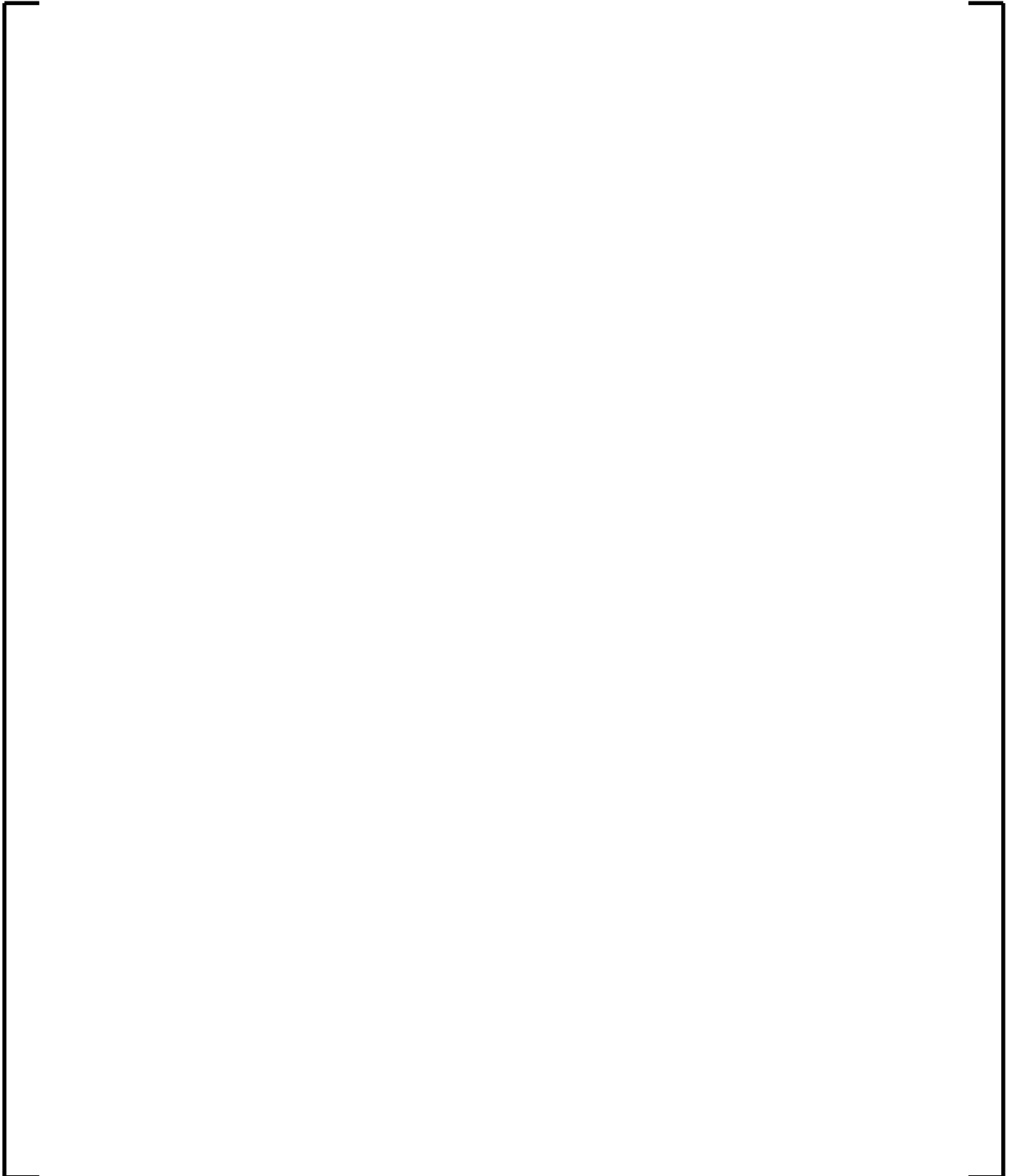


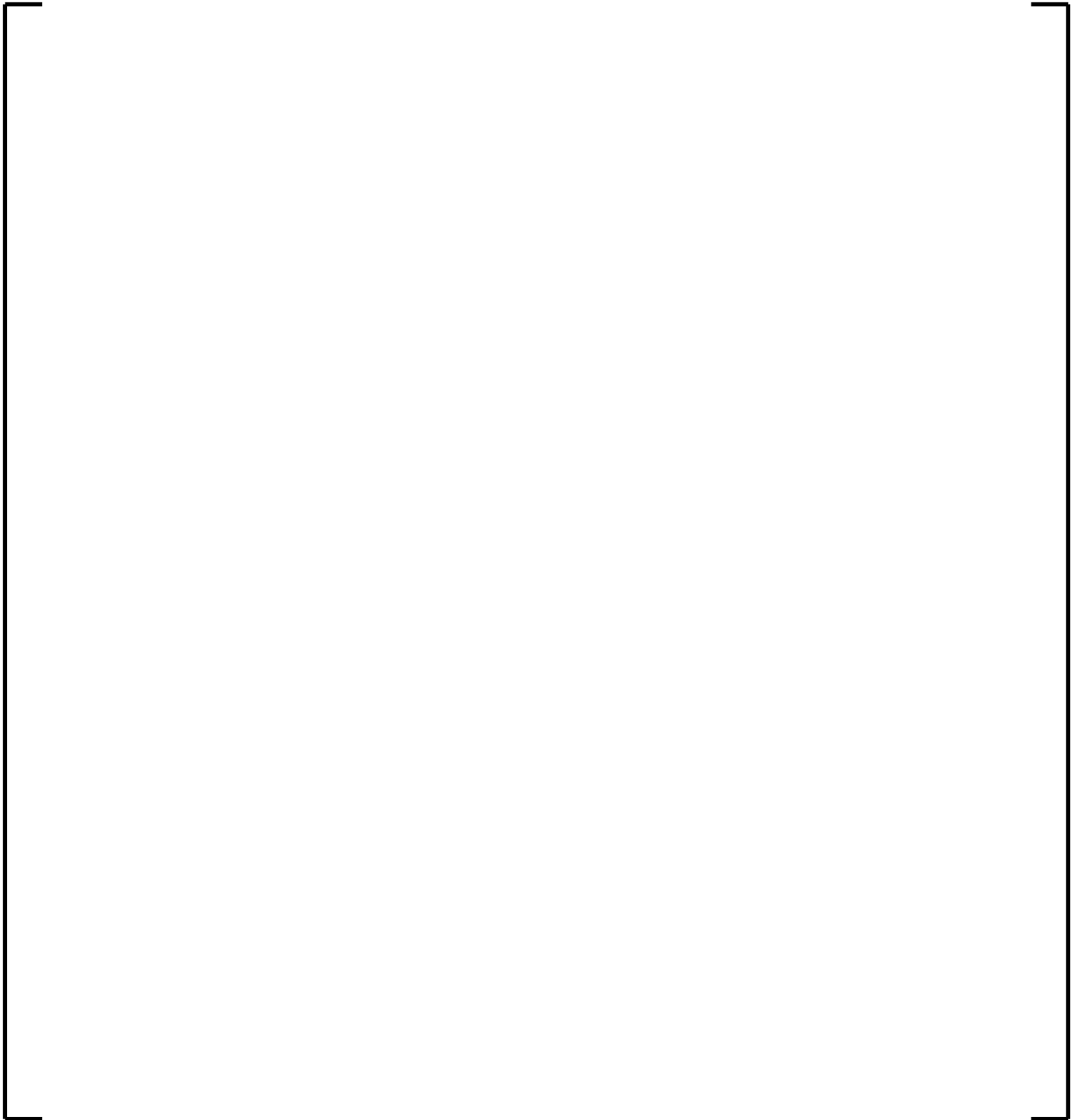


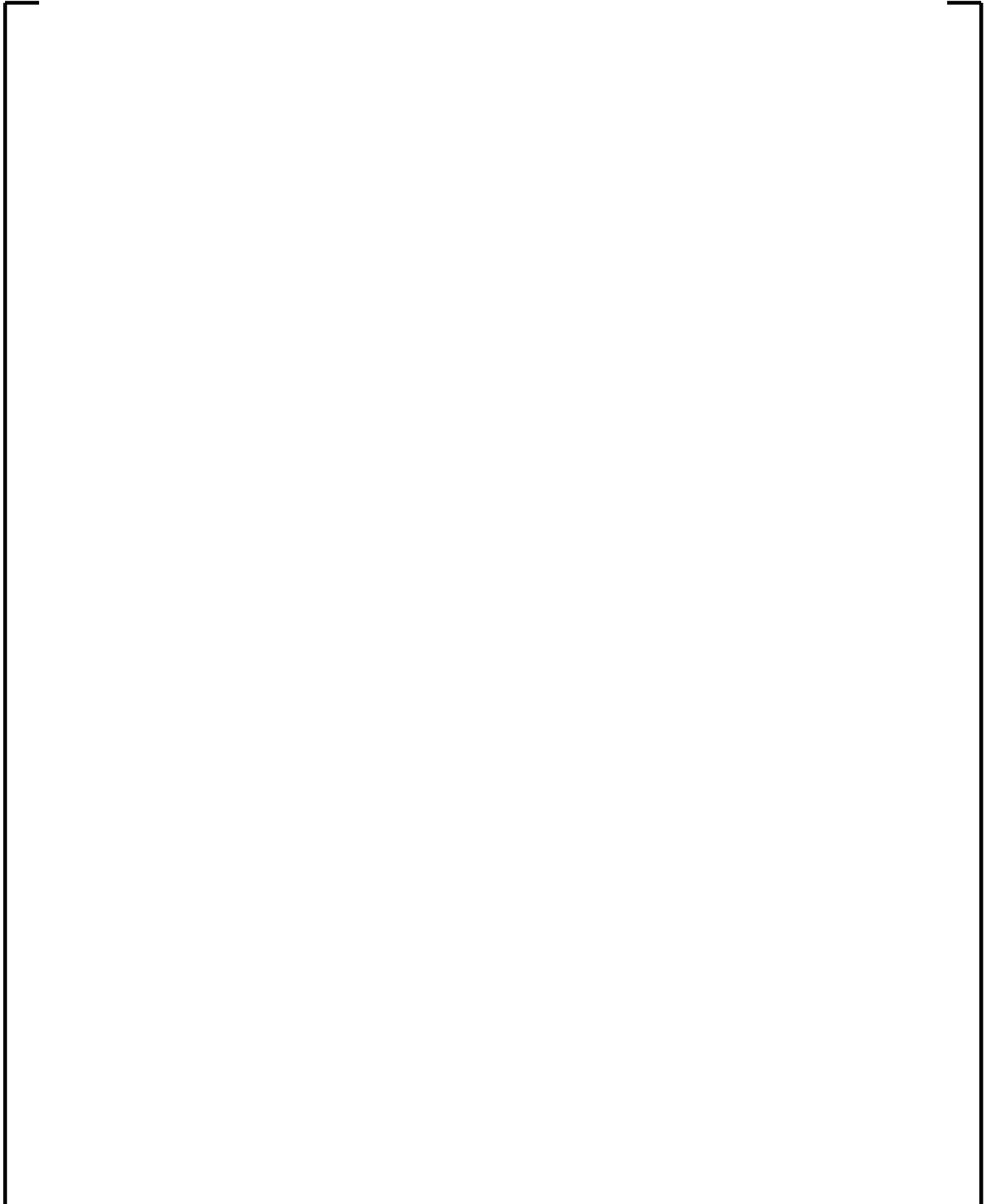


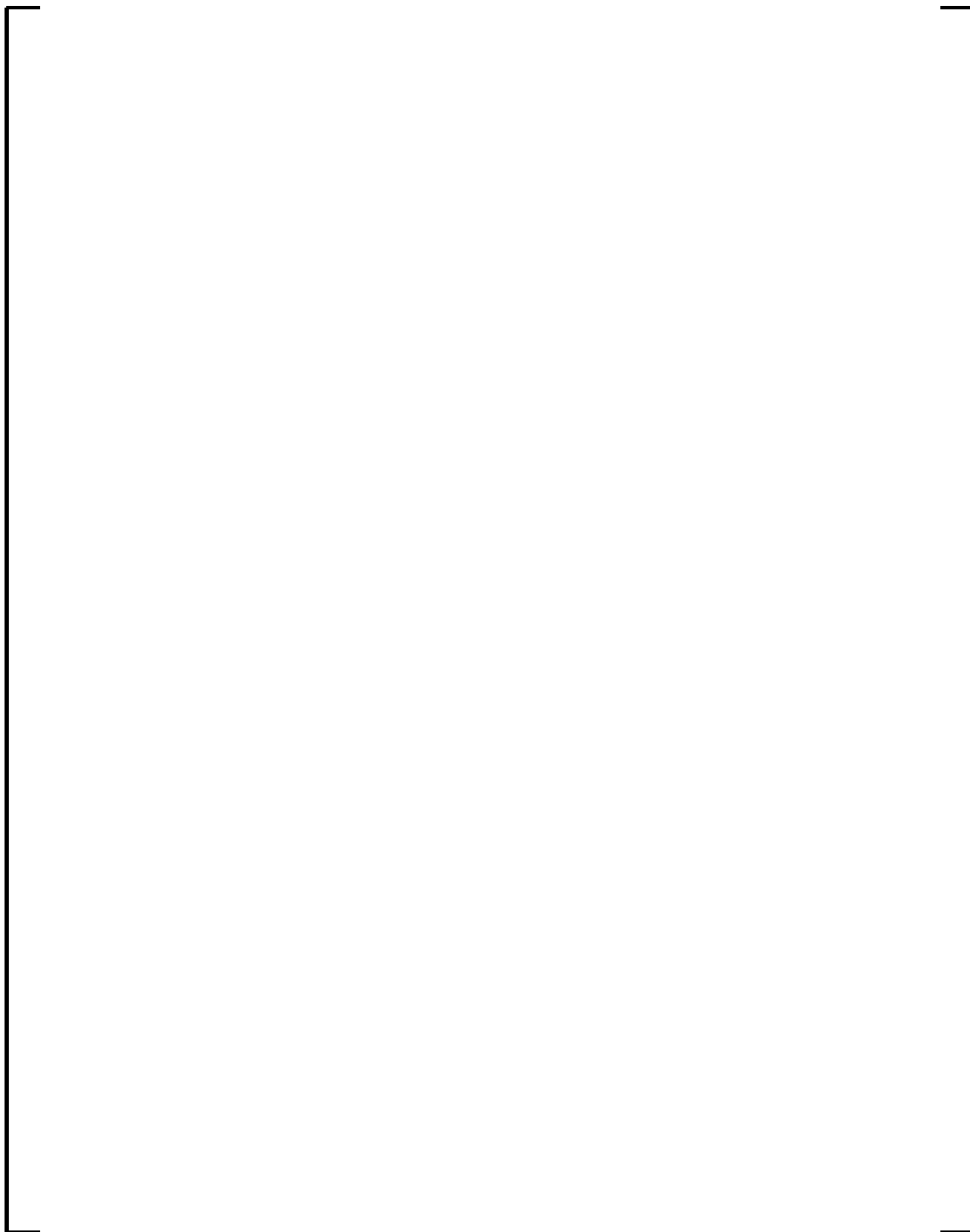


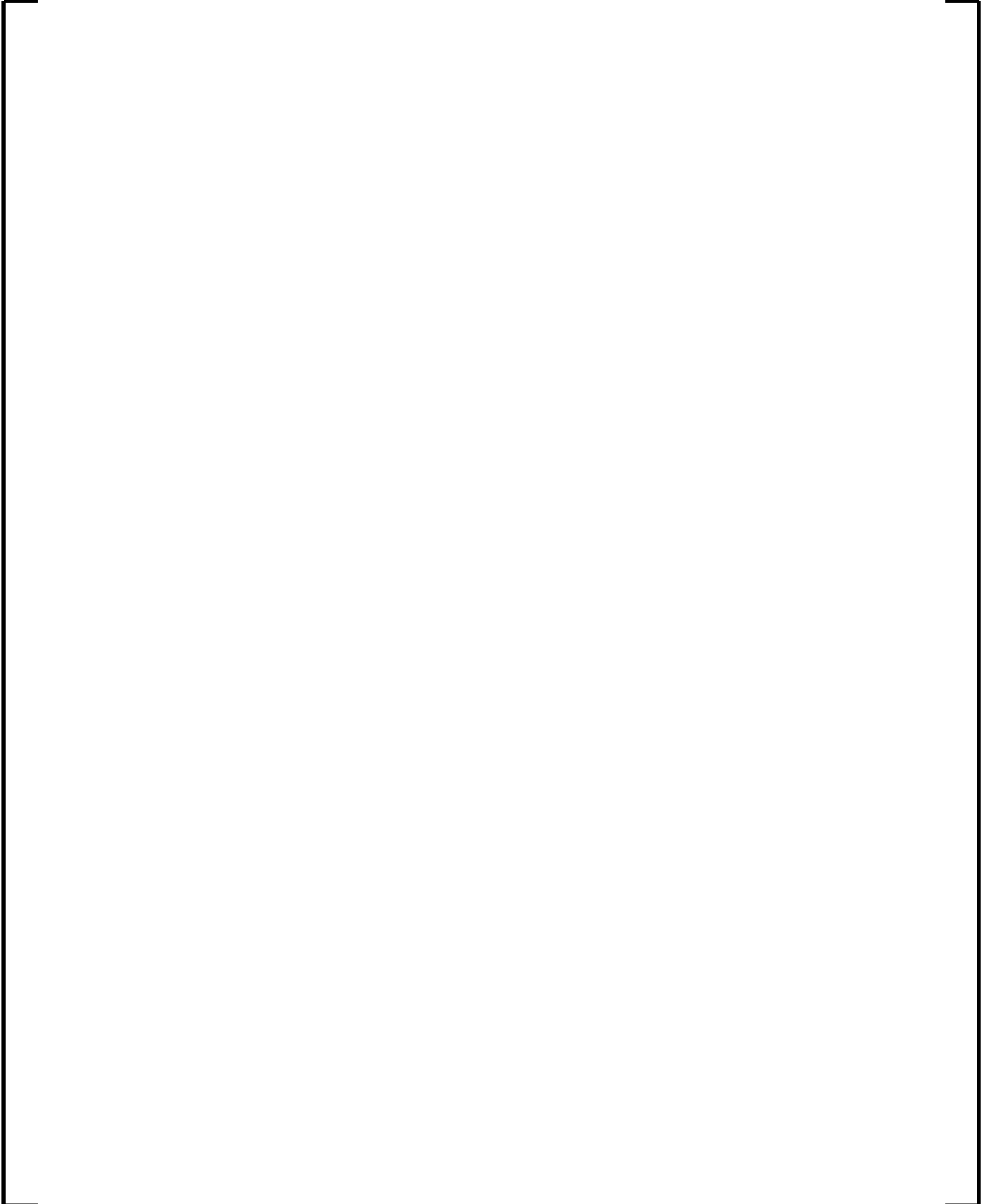














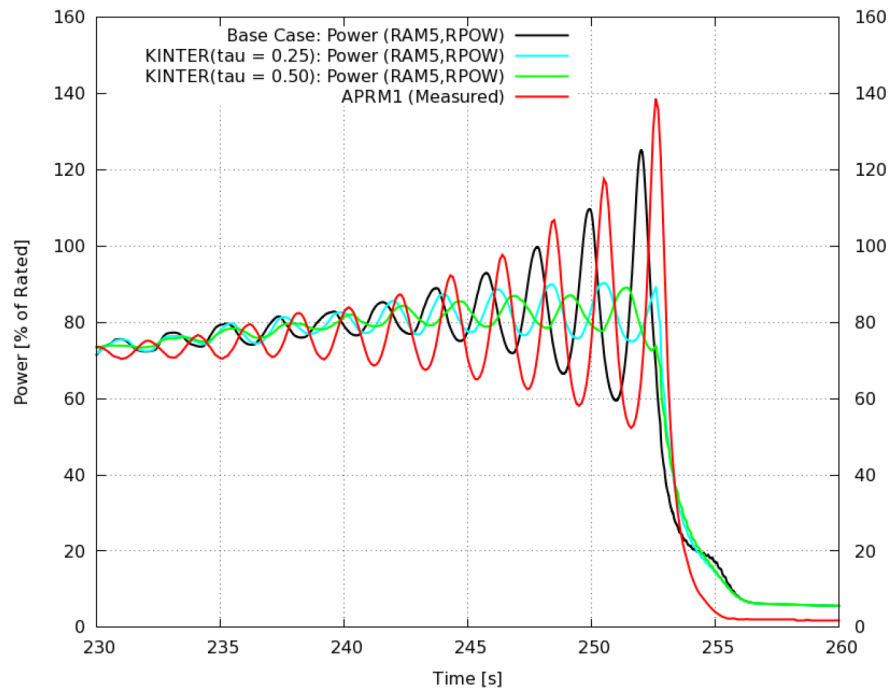


Figure C-1: Oskarshamn Core Power, Interfacial Friction Sensitivity



Figure C-2: BWR A Core Power, Interfacial Friction Sensitivity

APPENDIX D ATRIUM 11 CPROM CORRELATION

Abstract

A new dryout correlation was presented in Appendix A. This correlation, named Critical Power Reduced Order Model (CPROM), has been developed based on Framatome correlation development guidelines similar to dryout licensing correlations such as ACE. The CPROM correlation range of applicability is wide [

] making it well-suited to fitting into transient models of post-dryout that include cyclical dryout and rewetting with possible failure to rewet. CPROM is an integral part of the RAMONA5-FA transient model described in Section 5.5.5.

D.1 CPROM CORRELATION FOR ATRIUM 11



Table D-1: []

[

1

[

]



Figure D-1: Calculated versus measured critical power, []



Figure D-2: []



Figure D-3: []



Figure D-4: []



Figure D-5: []



Figure D-6: []

Table D-2: Statistics [

Table D-3: Statistics [

Table D-4: Statistics [

]

Table D-5: Statistics [

]

[

]



Figure D-7: Calculated versus measured critical power,
[]



Figure D-8: []



Figure D-9: []



Figure D-10: []



Figure D-11: []



Figure D-12: []

Table D-6: Statistics []



Table D-7: Statistics [

Table D-8: Statistics []

Table D-9: Statistics [

The figure below shows comparison of the calculated and measured critical power for the combined data set. The mean critical power ratio is [] and the standard deviation of the calculated versus measured critical power for the entire database is [] and the number of data points is [].



Figure D-13: Calculated versus measured critical power

D.2 ATRIUM 11 CPROM BOUNDS OF APPLICABILITY

The bounds of applicability are determined by the data available to benchmark the correlation. For ATRIUM 11, the [

]

[

]

APPENDIX E CHROMIA FUEL ROD PROPERTIES

New RODEX4 based fuel rod properties models are described in Section 5.2.5. These models are intended for use with standard UO_2 pellets. For Chromia doped pellets, modifications to the fuel thermal conductivity and [] models will be needed to account for the effects of the Chromia doping. The Chromia doped pellet specific models presented here will be based on the RODEX4 Chromia models described in Reference E.1.

E.1 Fuel Conductivity

The fuel thermal conductivity model for Chromia doped fuel is given in Section 7.1.1 of Reference E.1. [

] As such, this correlation forms the basis of the fit for the model shown.

- Fuel conductivity (W/m-K)



where

E.2 []

where

E.3 *References*

- E.1 ANP-10340P-A Revision 0, "Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods," May 2018.

APPENDIX F BRUNSWICK ATRIUM 11 ATWS-I ANALYSES

In order to demonstrate that ATRIUM 11 will be able to maintain core coolability following an ATWS-I event, the methodology described in this document was applied using the calculation procedure described in Section 8.0. An equilibrium ATRIUM 11 core in Brunswick Unit 1 was analyzed. The primary difference between Unit 1 and 2 that directly affects this event is the inlet pressure drop. Since Brunswick Unit 1 has a much lower inlet pressure drop due to larger inlet orificing, oscillations are expected to develop sooner and grow faster than a comparable Unit 2 event. As such, Unit 1 ATWS-I events are expected to bound an event in Unit 2. [

], consistent with Section 8.0.

In general, [

]

Additional analyses were performed to determine the margin available to the acceptance criteria. These sensitivities examined [

] The base case analysis assumes a feedwater temperature reduction rate of 1.3 °F/s and an operator intervention time of 120 seconds. Additional sensitivities using [

]

[

]

and

as such core coolability will be maintained.

Table F-1: Brunswick ATRIUM 11 ATWS-I Results

[illegible]

★ **[**

1



Figure F-1: TTWB Base Case Core Power



Figure F-2: TTWB Base Case Core Inlet Flow



Figure F-3: TTWB Base Case Core Inlet Subcooling



Figure F-4: TTWB Base Case Limiting Channel Inlet Flow



Figure F-5: TTWB Base Case Vessel Water Level



Figure F-6: TTWB Base Case Limiting Channel PCT

Affidavit for ANP-3694P, ATWS-I Analysis Methodology for
Brunswick Using RAMONA5-FA

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3694P, Revision 0, "ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA," dated June 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(a), 6(b), 6(c), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

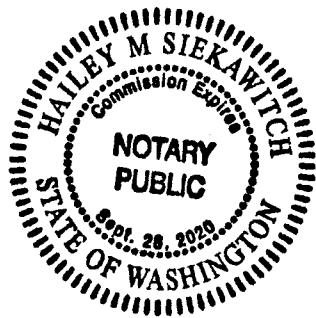
Alan E. Mag...

SUBSCRIBED before me this 27th

day of June, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3703NP, BEO-III Analysis Methodology for Brunswick
Using RAMONA5-FA



BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA

ANP-3703NP
Revision 0

August 2018

Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

ATRIUM is a trademark or registered trademark of Framatome (formerly known as AREVA Inc.) or its affiliates, in the USA or other countries.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

		Page
1.0	SUMMARY	1-1
2.0	REGULATORY REQUIREMENTS SUMMARY	2-1
2.1	Regulatory Requirements	2-1
2.2	Compliance with NUREG-0800 Chapter 15.0.2.....	2-1
3.0	SCENARIO IDENTIFICATION	3-1
4.0	EVALUATION MODEL REQUIREMENTS	4-1
4.1	Regulatory Basis.....	4-1
4.2	PIRT Summary	4-1
4.3	PIRT Impact on Model Development	4-3
5.0	METHOD ADAPTATIONS FOR BEO-III	5-1
5.1	[] Fuel Rod Models	5-1
5.1.1	Material Properties	5-1
5.1.2	Pellet-Clad Gap Heat Transfer Coefficient	5-4
5.2	Radial Power Deposition Distributions in Fuel Pellets	5-10
5.3	Period-Based Detection Algorithm Model	5-11
5.3.1	Relative OPRM Signal	5-11
5.3.2	PBDA Reactor Trip.....	5-12
5.4	Multi-stage Analysis	5-14
6.0	CODE VALIDATION AND MODEL UNCERTAINTIES	6-1
6.1	Void Fraction Assessments	6-2
6.1.1	[]	6-3
6.1.2	[]	6-4
6.2	Pressure Drop Assessments	6-14
6.3	Benchmarking to KATHY Stability Tests.....	6-19
6.3.1	[]	6-20
6.4	Benchmarking to KATHY Dryout/Rewet Tests.....	6-23
6.5	[]	6-32
6.6	[]	6-32
6.7	[]	6-32
6.8	Benchmarking Reactor Instabilities.....	6-33

6.8.1	[	]		6-34
6.8.2	[	]		6-35
6.8.3	[	]		6-35
6.8.4	[	]		6-36
6.8.5	Oskarshamn Nonlinear Instability.....			6-36
6.9	STAIF Reactor Benchmarks Using New Fuel Rod Property Models			6-39
7.0	BEO-III CYCLE ANALYSES			7-1
7.1	Statistical Methodology			7-1
7.1.1	Sampled Parameters for Non-Parametric Analysis			7-2
7.1.2	Sampling Range Applicability.....			7-3
7.1.3	Statistical Independence of Sampled Variables			7-3
7.1.4	Sampling Methods for Non-Parametric Process			7-4
7.1.5	Truncation of Sampled Parameter Distributions.....			7-4
7.1.6	Application of Statistical Analysis			7-5
7.2	BEO-III Calculation Procedure			7-5
7.3	Backup Stability Protection Calculation Procedure			7-12
8.0	BRUNSWICK ATRIUM 11 EQUILIBRIUM CYCLE ANALYSES			8-1
9.0	REFERENCES			9-1

List of Tables

Table 4-1	Ranking of Phenomena and Processes.....	4-4
Table 6-1	Summary of Void Fraction Test Conditions.....	6-6
Table 6-2	Nominal Benchmarking Statistics [.....].....	6-7
Table 6-3	Summary of KATHY Pressure Drop Test Conditions.....	6-15
Table 6-4	Summary of RAMONA5-FA Pressure Drop Relative Errors	6-15
Table 6-5	Onset of dryout and rewetting KATHY test runs	6-24
Table 6-6	[.....]	6-40
Table 6-7	[.....]	6-41
Table 6-8	[.....]	6-42
Table 6-9	[.....]	6-42
Table 6-10	[.....]	6-43
Table 7-1	[.....]	7-8
Table 7-2	Disposition of Highly Ranked Phenomena.....	7-10
Table 7-3	Sampled Parameters for BEO-III ATRIUM 11 Statistical Analyses	7-11
Table 7-4	BSP Region Calculation Procedure	7-13
Table 8-1	Brunswick OPRM and PBDA Parameters.....	8-3

List of Figures

Figure 5-1	Core Instrumentation	5-17
Figure 5-2	[]	5-17
Figure 5-3	Sensitivities to Least Stable Channel Growth Ratio	5-18
Figure 6-1	Validation of [] using FRIGG, ATRIUM-10 and ATRIUM 10XM Void Data	6-8
Figure 6-2	Void Fraction []	6-9
Figure 6-3	Void Fraction []	6-10
Figure 6-4	[]	6-11
Figure 6-5	Subcooled Void Fraction []	6-12
Figure 6-6	Subcooled Void Fraction []	6-12
Figure 6-7	[]	6-13
Figure 6-8	Validation of Pressure Drop Prediction versus KATHY Measured Data (ATRIUM-10, ATRIUM 10XM, ATRIUM 11)	6-16
Figure 6-9	[]	6-17
Figure 6-10	[]	6-18
Figure 6-11	Validation of Decay Ratio Prediction versus KATHY Data	6-21
Figure 6-12	Validation of Frequency Prediction versus KATHY Data	6-21
Figure 6-13	[]	6-22
Figure 6-14	[]	6-22
Figure 6-15	Dryout Results for ATRIUM-10 Karlstein []	6-25
Figure 6-16	Dryout Results for ATRIUM-10 Karlstein []	6-26
Figure 6-17	Dryout Results for ATRIUM-10 Karlstein []	6-27
Figure 6-18	Dryout Results for ATRIUM XM Karlstein []	6-28
Figure 6-19	Dryout Results for ATRIUM XM Karlstein []	6-29
Figure 6-20	Dryout Results for ATRIUM XM Karlstein Case []	6-30
Figure 6-21	Dryout Results for ATRIUM XM Karlstein []	6-31

Figure 6-22	Oskarshamn-2 Simulation Core Power	6-37
Figure 6-23	Oskarshamn-2 Simulation Core Power - Zoom	6-37
Figure 6-24	Oskarshamn-2 Simulation Recirculation Flow	6-38
Figure 7-1	[.....]	7-9
Figure 8-1	Limiting MELLLA+ MCPR	8-4
Figure 8-2	Limiting MELLLA+ [.....]	8-4
Figure 8-3	Limiting MELLLA with FWHOOS MCPR	8-5
Figure 8-4	Limiting MELLLA with FWHOOS [.....]	8-5
Figure 8-5	Limiting SLO MCPR	8-6
Figure 8-6	Limiting SLO [.....]	8-6

Nomenclature

Acronym	Definition
2RPT	Two Recirculation Pump Trip
BEO-III	Best-estimate Enhanced Option III
BSP	Backup Stability Protection
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners' Group
CDA	Confirmation Density Algorithm
CFR	Code of Federal Regulations
CHF	Critical Heat Flux
CPR	Critical Power Ratio
DIVOM	Delta over Initial critical power Versus Oscillation Magnitude
D&S	Detect and Suppress
EO-III	Enhanced Option III
FoM	Figure(s) of Merit
FWHOOS	Feedwater heater out-of-service
GDC	General Design Criteria
ICO	Independent Channel Oscillations
KATHY	Karlstein thermal-hydraulic loop test facility
LPRM	Local Power Range Monitor
LTSS	Long-Term Stability Solution(s)
MCPR	Minimum Critical Power Ratio
MELLLA	Maximum Extended Load Line Limit Analysis
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
OLMCPR	Operating Limit MCPR
OPRM	Oscillation Power Range Monitor
PBDA	Period-based Detection Algorithm
PIRT	Phenomena Identification and Ranking Table
SLMCPR	Safety Limit MCPR
SLO	Single Loop Operation
USNRC	United States Nuclear Regulatory Commission

ABSTRACT

This report presents a plant-specific best-estimate methodology for licensing of approved long-term stability solutions (LTSS) for operation under the approved MELLLA+ operating domain. The method aims at establishing the cycle-specific operating limit Minimum Critical Power Ratio (OLMCPR) based on statistical analyses of pump trip scenarios and evaluation of the time dependent local power range monitors (LPRMs) and core minimum critical power ratio (MCPR) to determine the most limiting event based on the plant-specific detect and suppress (D&S) hardware response. A description of the method for backup stability protection is also provided.

Section 2.0 identifies the regulatory requirements and Section 3.0 identifies the potential limiting pump trip scenarios. Section 4.0 is devoted to a detailed assessment of the phenomena associated with the limiting scenarios and provides a ranking of importance of the phenomena on the analysis Figures of Merit (FoM). The modifications to the approved RAMONA5-FA code (Reference 1) utilized in the previously approved DIVOM methodology (Reference 2) and Enhanced Option-III methodology (Reference 3) are presented in Section 5.0. The validation of the code capabilities and derivation of the model uncertainties are presented in Section 6.0. This includes validation against both steady state and transient hydraulic test loop measurements and reactor instabilities. Having demonstrated the capability of the code and uncertainties, Section 7.0 presents the licensing basis procedure and Section 8.0 presents a sample application of the methodology to an equilibrium ATRIUM 11 cycle design for the Brunswick Unit 1 reactor.

1.0 SUMMARY

A plant-specific best-estimate methodology for the evaluation of the long-term stability solution (LTSS) Enhanced Option-III (EO-III) is presented. This report documents a RAMONA5-FA based method for determining the core operating limit MCPR (OLMCPR) based on the Option III period-based detection algorithm (PBDA). In addition, the methodology demonstrates that the conservative channel instability exclusion region required by EO-III is not required to protect the safety limit MCPR (SLMCPR).

A key improvement over EO-III is the use of cycle-specific best-estimate evaluations of pump trip scenarios from the initial operating state point through the simulation termination due to limit cycle conditions or reactor trip due to the PBDA. This realistic evaluation of the pump trip scenarios eliminates the piece-meal compounding of conservatisms inherent in EO-III and the original boiling water reactor owners' group (BWROG) LTSS Option III.

The original LTSS employs a statistical treatment for the hot channel analysis which includes probability distribution functions for the decay ratio and frequency of oscillations which was accepted as conservative. One advantage of this best estimate methodology is that the statistical treatment is rigorous and realistic as it is based on detailed parametric variations of a best estimate code.

RAMONA5-FA has been benchmarked against steady-state data and both linear and non-linear stability transients. These benchmarks include evaluation of the highly ranked phenomena and associated uncertainties for the RAMONA5-FA computer code and assessment of those uncertainties against hydraulic-only oscillations at the KATHY test facility and full core reactor instabilities. These benchmarks demonstrate the overall conservatism of the Best-estimate Enhanced Option III (BEO-III) methodology.

New fuel rod property models implemented in RAMONA5-FA have also been added to the STAIF frequency domain stability code. These new models have been applied to the approved linear reactor stability benchmark suite. These benchmarks demonstrate that the models can accurately reproduce the measured plant stability performance.

The application of the BEO-III analyses methodology to the Brunswick Unit 1 BWR4 reactor is also presented.

2.0 REGULATORY REQUIREMENTS SUMMARY

2.1 *Regulatory Requirements*

The regulatory requirements for these events are compliance with General Design Criteria (GDC) 10 and 12 in Appendix A to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50). Specifically, GDC 12 states:

“The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.”

Based on the approved RAMONA5-FA DIVOM methodology and EO-III LTSS (References 2 and 3), the figures of merit (FoM) for the event analyses are the minimum critical power ratio (MCPR) at the time of oscillation suppression by the PBDA and verification that independent channel oscillations (ICO) do not invalidate the assumption that the reactor protection system can detect and suppress the oscillations prior to violation of the fuel design limits.

2.2 *Compliance with NUREG-0800 Chapter 15.0.2*

This NUREG-0800 Chapter 15, Section 15.0.2 provides guidance to the Nuclear Regulatory Commission (USNRC) reviewer with respect to reviewing the technical contents of a submittal, typically a Topical Report pertinent to transient and accident analysis methodology. To accomplish this task, the USNRC provided the reviewer a list of criteria in Chapter 15.0.2 of the Standard Review Plan as a means of arriving at a sound technical conclusion. The areas of considerations listed in Chapter 15.0.2 are provided below:

- Item 1. Documentation. This document satisfies this requirement.
- Item 2. Evaluation Model. Refer to Section 5.0 for Modifications to the approved RAMONA5-FA code version.

- Item 3. Accident Scenario Identification Process. Refer to Section 3.0.
- Item 4. Code Assessment Database. Refer to Section 6.0.
- Item 5. Uncertainty Analysis. Refer to Section 7.1.
- Item 6. Quality Assurance Plan. Refer to Reference 4. Reference 4 is the basis for quality assurance in both the development and application of RAMONA5-FA for BEO-III.

3.0 SCENARIO IDENTIFICATION

Based on approved applications of best-estimate methodologies for the licensing of LTSS, the limiting event is the two recirculation pump trip (2RPT) from the minimum flow condition at rated power. This is based primarily on the rationale that reactor maneuvers near the high power / low flow portion of the operating map that would lead to the onset of instabilities would be limited in nature (e.g. single control rod pulls) and easily reversed prior to any significant change in thermal margin. For MELLLA+ operation the limiting condition is the lowest core flow rate at rated core power. Other initial conditions that are considered are the lowest core flow at rated core power within the MELLLA domain with the minimum allowed feedwater temperature allowed by the licensee for the feedwater heater out-of-service (FWHOOS) scenario and the highest core power under the single loop operation (SLO) scenario.

4.0 EVALUATION MODEL REQUIREMENTS

4.1 *Regulatory Basis*

The RAMONA5-FA code is currently approved by the NRC for DIVOM analyses and support of Enhanced Option-III applications. The modeling capabilities for application as a best-estimate methodology supporting the original PBDA or other instability algorithms when utilized as the licensing basis (e.g. the confirmation density algorithm, CDA) are presented in the following subsections.

4.2 *PIRT Summary*

A comprehensive phenomenon identification and ranking process was performed to identify the dominant phenomena for the target scenario (2RPT leading to reactor instabilities). During the development of the BEO-III statistical methodology, this identification and ranking is the basis for determining which of the model uncertainties are important in determining the figures of merit (FoM) for the cycle design and defined the model development validation and sensitivity studies that are needed to support the methodology. The culmination of the process is a phenomenon identification and ranking table (PIRT) that summarizes all the relevant phenomena and provides their importance ranking relative to the selected FoM.

This PIRT utilizes Framatome's extensive history and experience with analyzing and testing density wave phenomena including the core MCPR response for both global and regional mode instabilities as a function of the power oscillation magnitude (Reference 2). In the approved EO-III Topical Report (Reference 3) Framatome included

[

]. In addition,

Framatome has previously participated in industry efforts to develop a previous ATWS-I PIRT (Reference 5).

When developing the BEO-III PIRT, it is important to note that the terminal state-point of the reactor may be stable, marginally unstable such that the magnitude of the oscillation is below the PBDA trip setpoint, or unstable such that the event is terminated by the PBDA initiated trip. Independent of the coupled neutronic/hydraulic stability of the terminal conditions, the stability of individual fuel channels can also be stable, slightly unstable or hypothetically highly unstable such that ICO develop where the flow magnitude and MCPR response are no longer correlated to the local power response.

The first FoM is the change in the core MCPR due to the pump trip and subsequent oscillatory behavior at natural circulation conditions. The statistical evaluation determines the maximum reduction in the core MCPR which is bound by the plant-specific PBDA trip setpoints.

The second FoM is the assessment of the least stable channels in the core to demonstrate that the core design and PBDA trip setpoints do not result in ICO that would prevent the D&S hardware from readily detecting and suppressing oscillations prior to reaching the SLMCPR. The PIRT ranking for this FoM is associated with the relative separation of the coupled neutronic/hydraulic oscillation mode and the single channel instability mode.

The ranking of the phenomena and processes is presented in Table 4-1.

4.3 *PIRT Impact on Model Development*

In addition to the ability to sample on the highly ranked phenomena or impose conservative assumptions, the two FoM presented in Section 4.2 require that the RAMONA5-FA model be able to statistically evaluate the coupled reactor response to the 2RPT, determine the terminal operating conditions, evaluate the state of each fuel channel in the core at those terminal conditions and determine whether the least stable channel could lead to ICO. As described in Section 5, the adaptation of the approved RAMONA5-FA model includes introduction of [] based material properties and pellet-clad heat transfer coefficient model to allow statistical sampling on independent phenomena responsible for the transient thermal time constant, the determination of the PBDA trip to establish the terminal event condition and implementation of an analytical approach to evaluate the potential for ICO at the time of the oscillation suppression.

Table 4-1
Ranking of Phenomena and Processes

H - High
M - Medium
L - Low
N - Not Applicable

Table 4-1
Ranking of Phenomena and Processes, (continued)

H - High
M - Medium
L - Low
N - Not Applicable

Table 4-1
Ranking of Phenomena and Processes, (continued)

H	- High
M	- Medium
L	- Low
N	- Not Applicable

Table 4-1
Ranking of Phenomena and Processes, (continued)

H	- High
M	- Medium
L	- Low
N	- Not Applicable

5.0 METHOD ADAPTATIONS FOR BEO-III

A detailed description of the method adaptations for BEO-III from the approved DIVOM and EO-III RAMONA5-FA code version (Reference 1) are presented in this section.

These adaptations include the implementation of an improved pellet-clad gap heat transfer coefficient model to accommodate sampling of important thermal-mechanical phenomena and to address the ATRIUM 11 fuel design with Cr-Doped fuel, inclusion of the PBDA algorithm to assess oscillation suppression times and the multi-stage analysis capability. Description of each of these modifications is given in separate subsections.

5.1 [] *Fuel Rod Models*

For the BEO-III methodology [

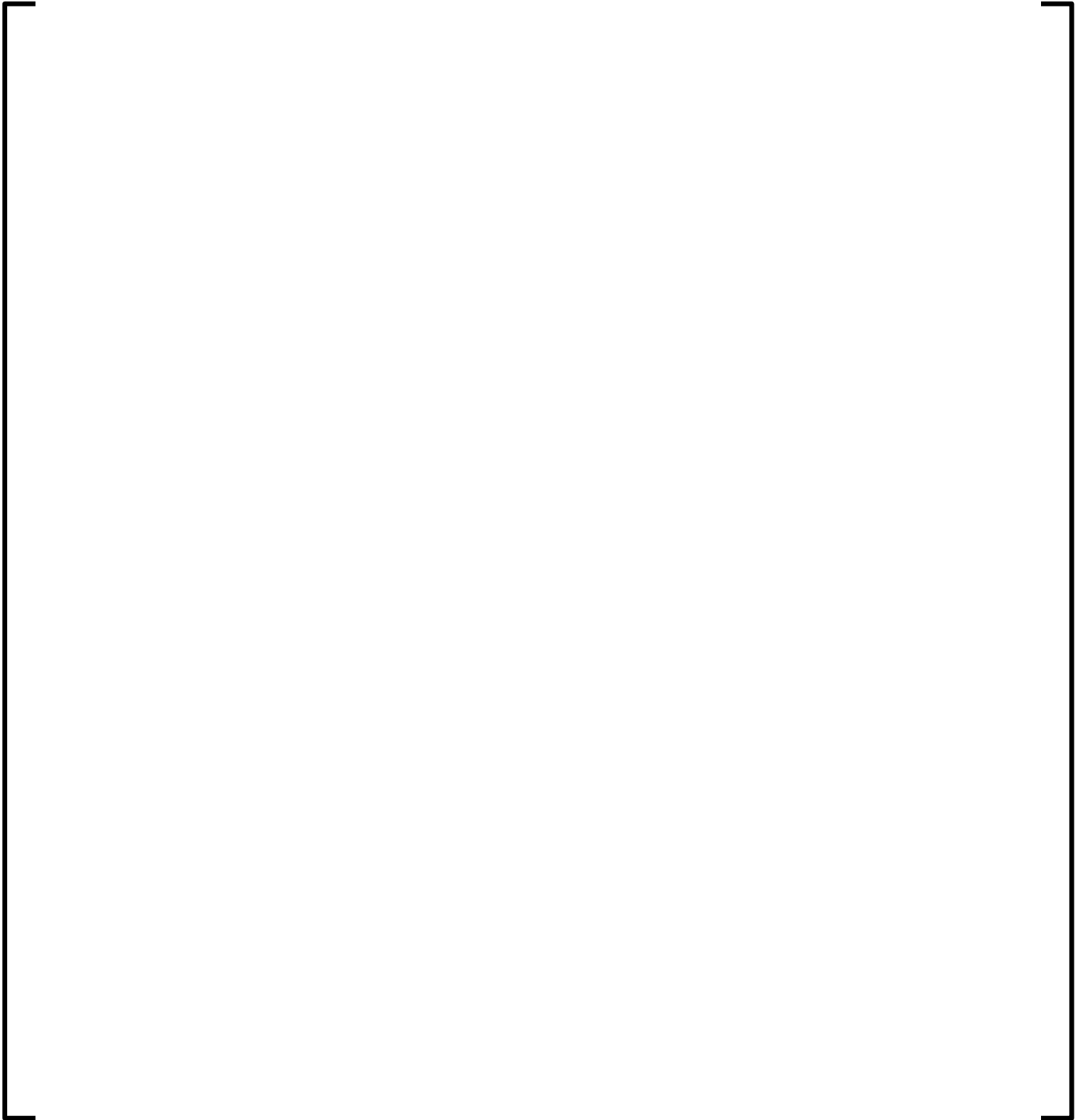
]. For Chromia-doped pellets, modifications to the standard UO_2 thermal conductivity and [] models were necessary to account for the effects of the Chromia doping. The Chromia-doped pellet specific models presented here are [].

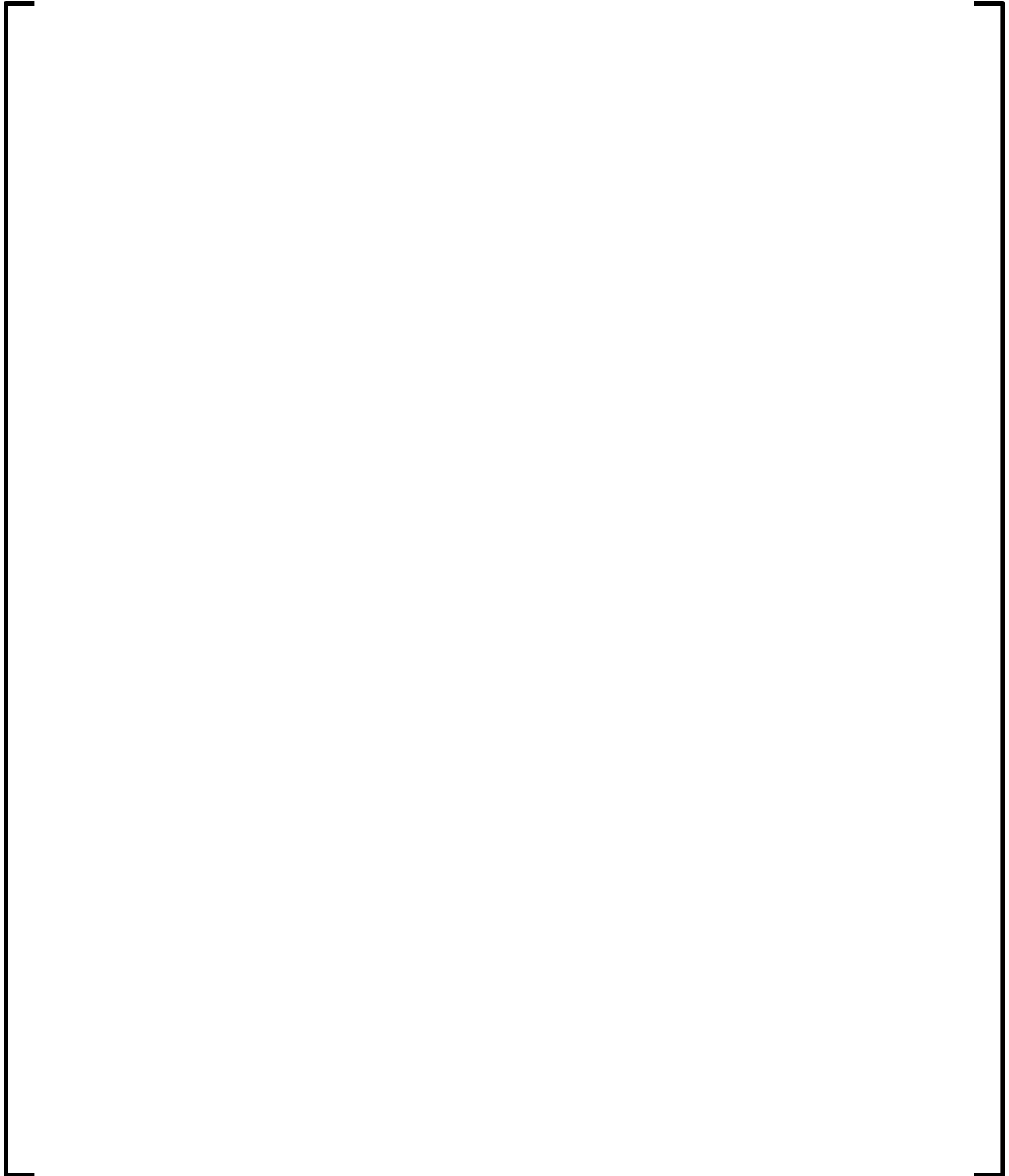
The subsections that follow present the fuel rod material properties and the pellet-clad gap heat transfer coefficient model used in the BEO-III methodology.

5.1.1 Material Properties

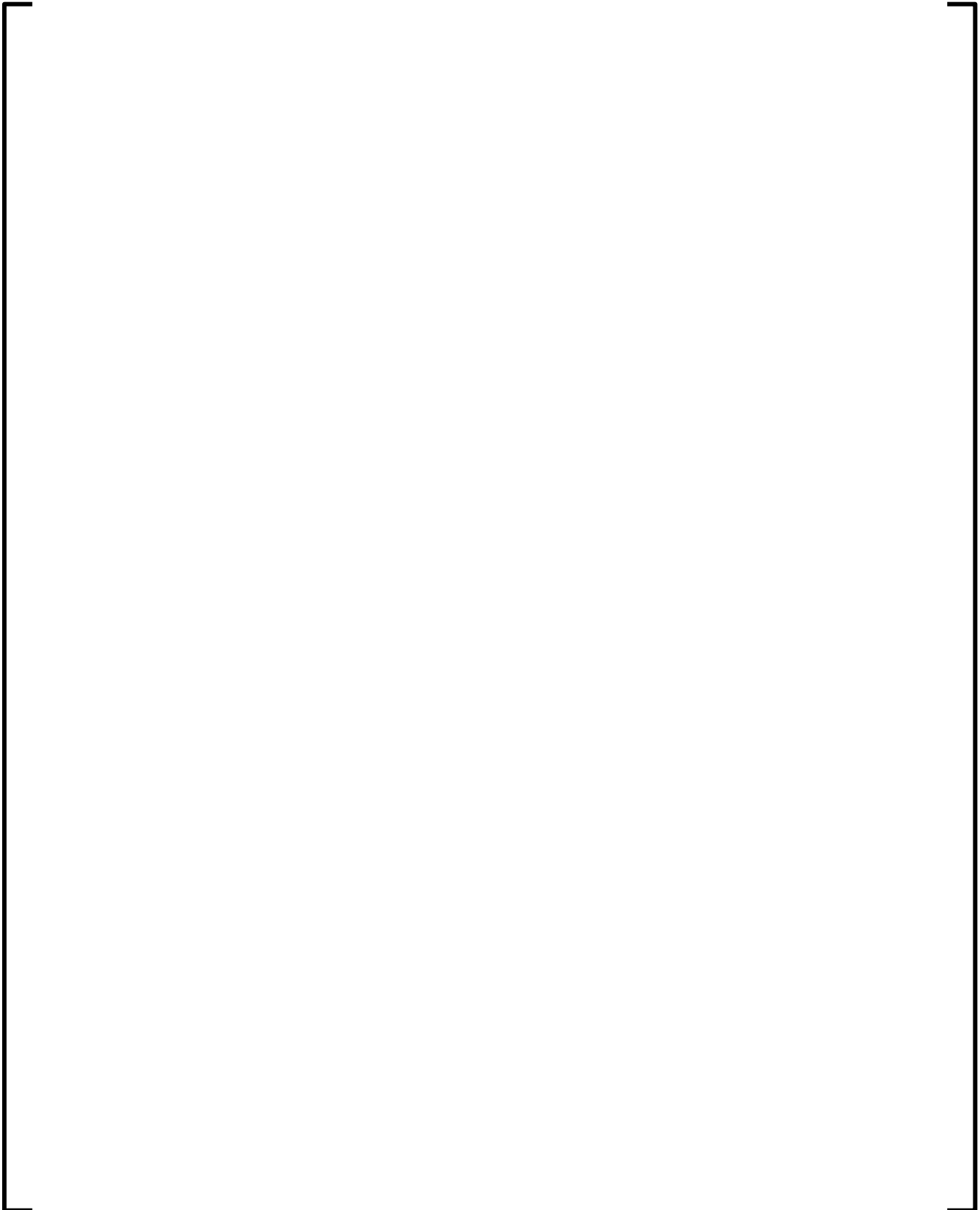
[

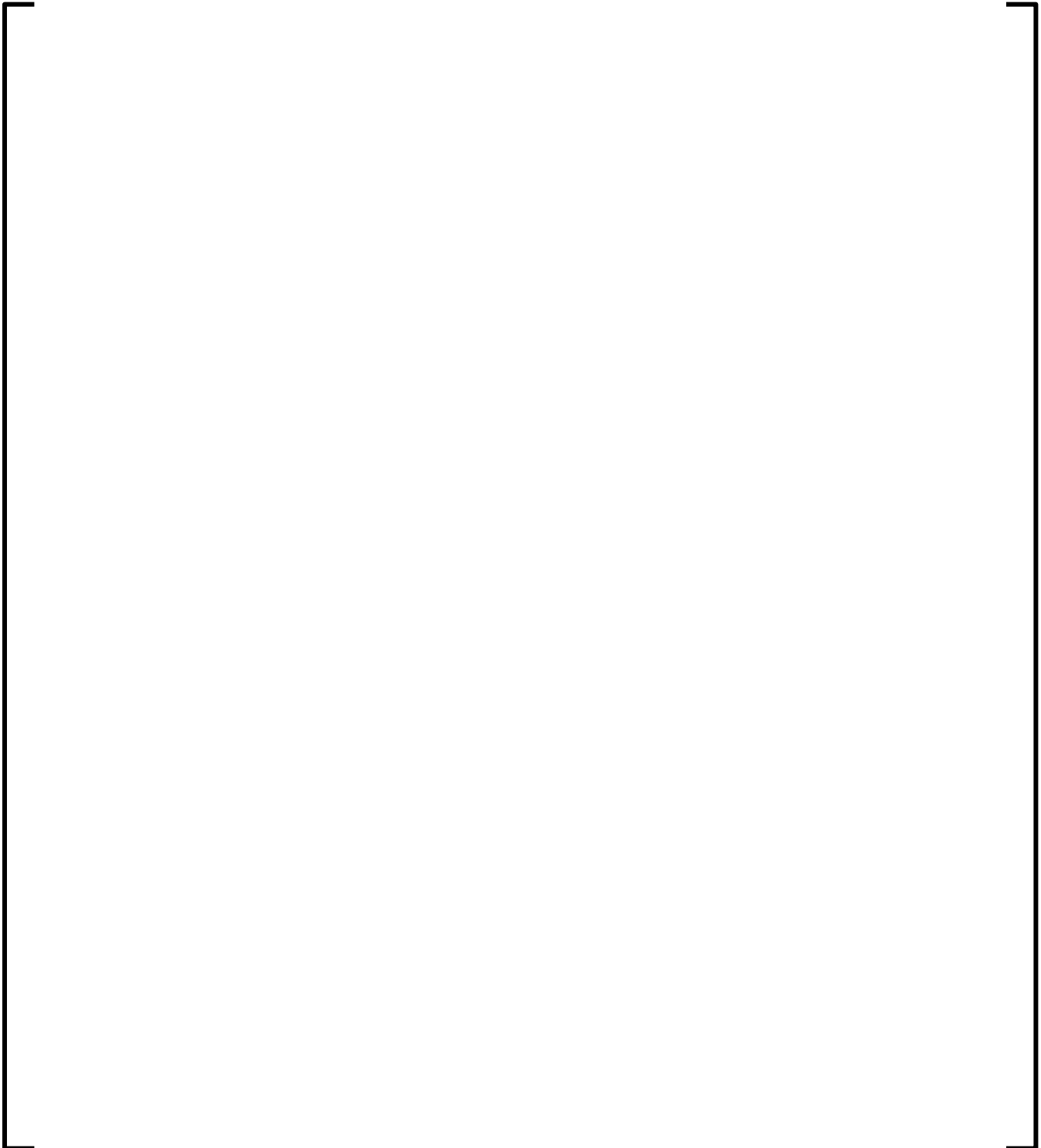
]

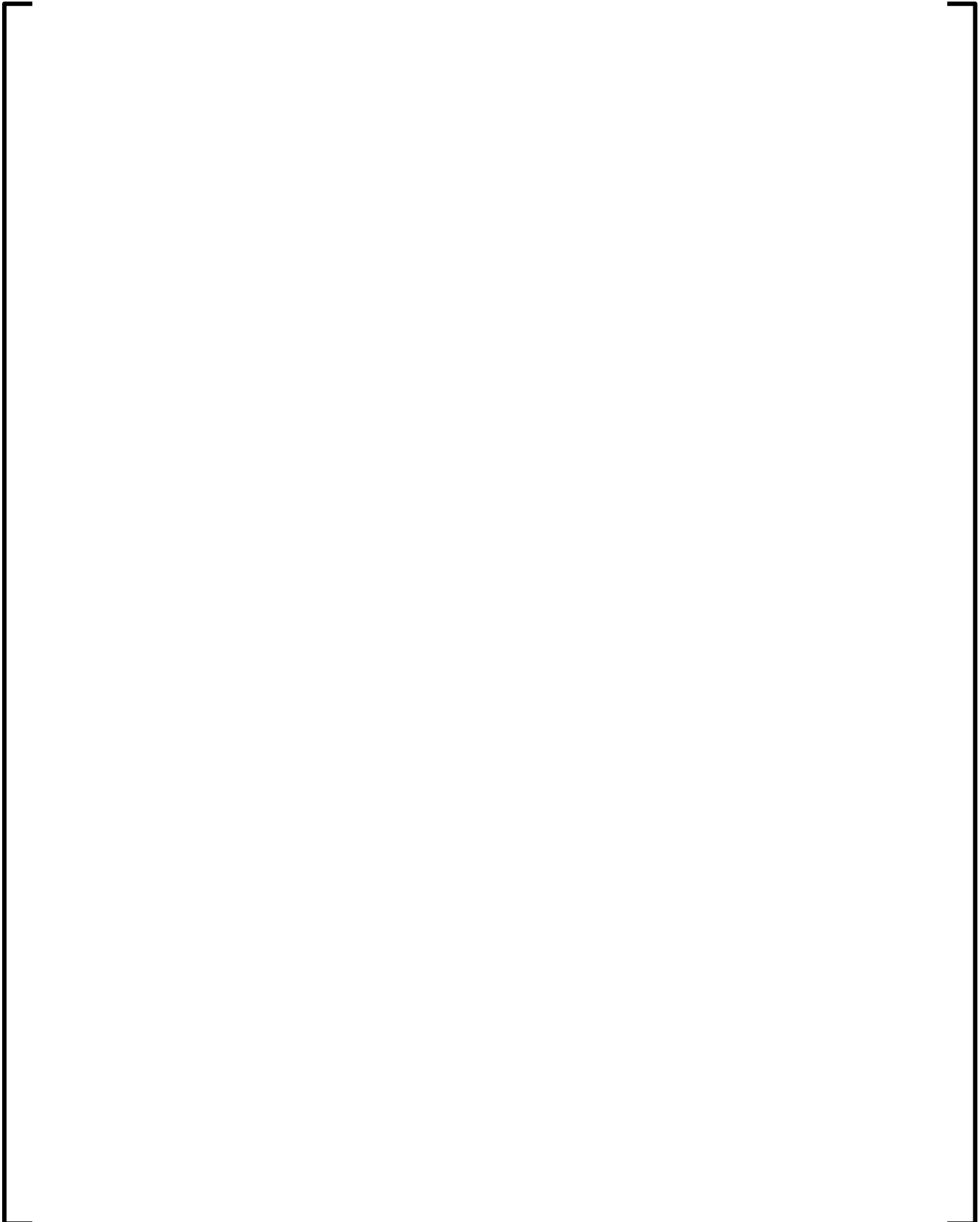


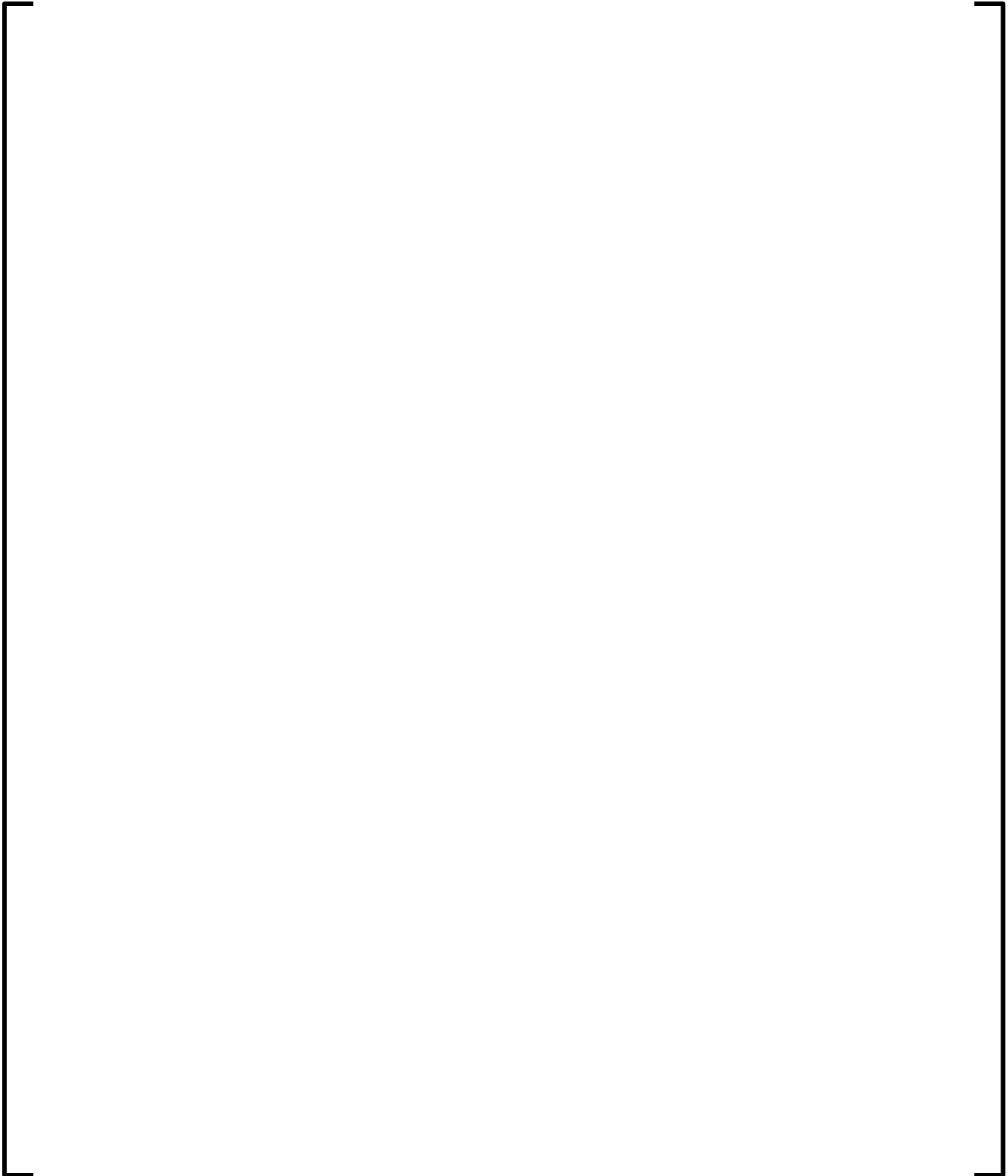


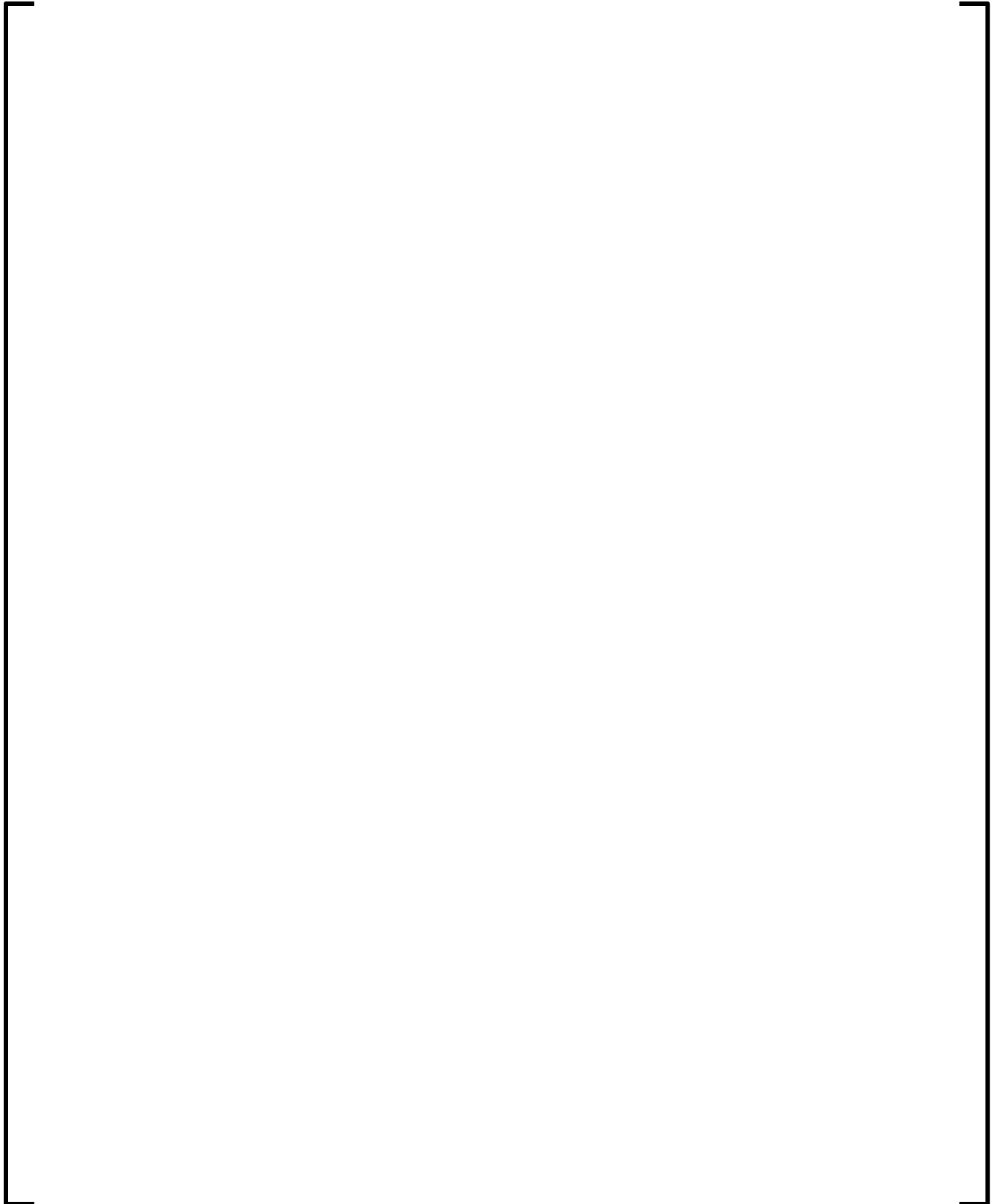
5.1.2 Pellet-Clad Gap Heat Transfer Coefficient











5.2 *Radial Power Deposition Distributions in Fuel Pellets*

5.3 *Period-Based Detection Algorithm Model*

The period-based detection algorithm used within the BWROG LTSS Option III solution was implemented within RAMONA5-FA to assess the consequences on the FoM on a cycle specific basis at the 95 percent probability and 95 percent confidence (95/95). The software requirements were derived from information in the approved BWROG Topical Reports.

5.3.1 Relative OPRM Signal

The filtering that is applied to the raw OPRM signal is based on the BWROG Topical Report NEDO-31960, Appendix B, Reference 9.

1. LPRM or OPRM signals are filtered to remove high frequency noise components relative to the oscillation frequency (>5 Hz) to create the “conditioned signal.” NEDO-31960 Supplement 1 clarifies that the frequency range for the conditioning filter is in the range of 1.0 to 5.0 Hz.

2. The conditioned signal is then filtered (with approximately a six second time constant) to produce a moving average trace indicative of the thermal power in the region where the signal measurement is taken. NEDO-31960 Supplement 1 clarifies that the time constant for the time-averaging filter is in the range of 5.0 to 7.0 seconds.
3. A relative signal value is then determined by dividing the conditioned signal value by the moving average value. This relative signal is then used in the PBDA algorithm.
4. NEDO-31960 Supplement 1 also states that the Butterworth filter model order for both the conditioning filter and the time-averaging filter is typically chosen as 2.

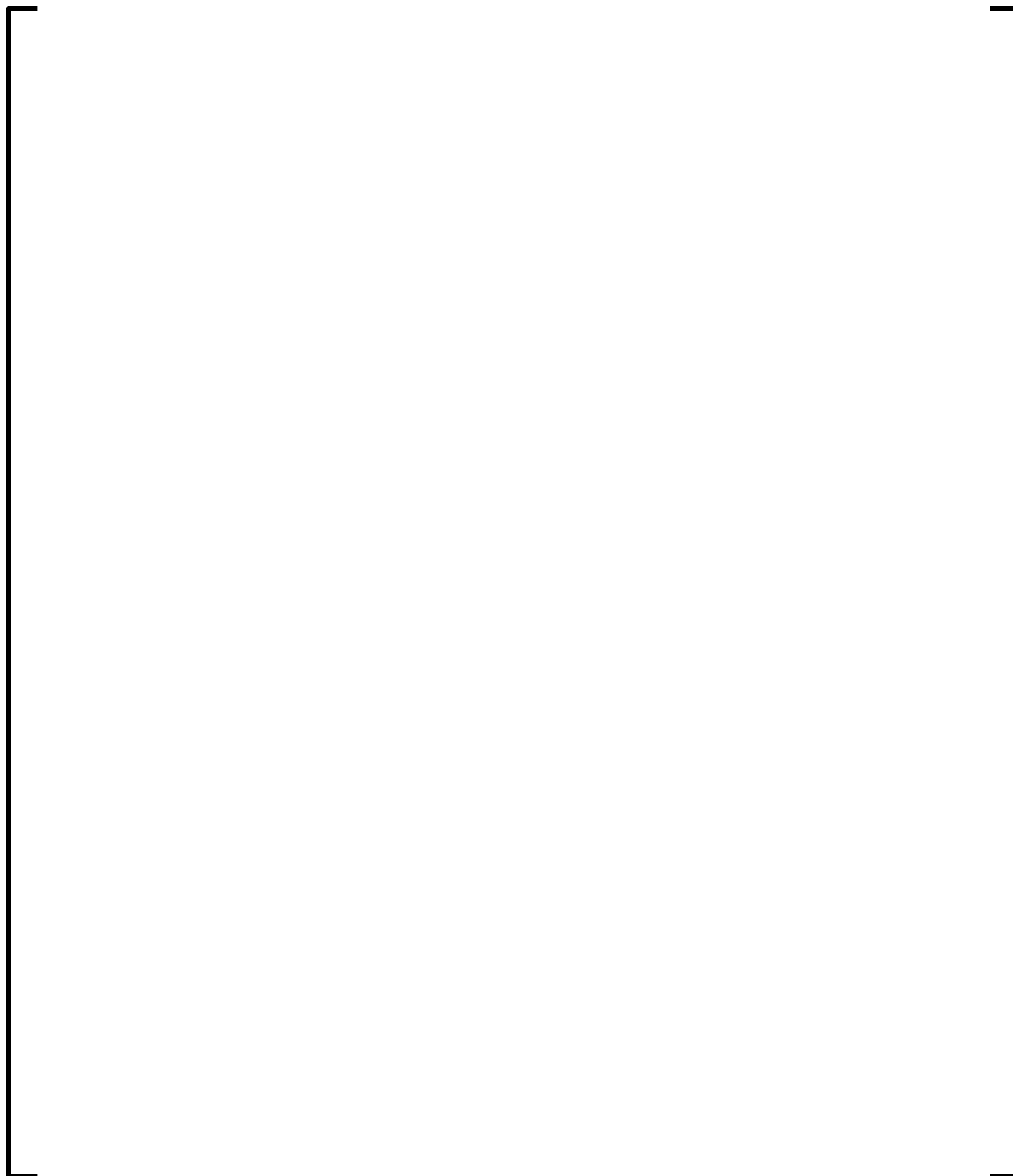
5.3.2 PBDA Reactor Trip

The requirements for the PBDA processing of the relative OPRM signal to determine the reactor trip timing is covered in Section B.2 of Reference 9 and sections 3.1 and 6.1 of NEDO-31960, Supplement 1, Reference 10. Comparing the two descriptions resulted in the following design elements that were applied to the development of the RAMONA5-FA PBDA implementation.

1. Oscillation period is defined as the time interval between two successive peaks or minima of an evaluated signal.
2. A peak is assumed to occur anytime the slope of the evaluated signal changes from positive (or zero) to negative.
3. A minimum is assumed to occur anytime the slope of the evaluated signal changes from negative (or zero) to positive.
4. The algorithm only accepts periods that are within the expected frequency range. The expected frequency range is mapped into a period band between the minimum oscillation period (typically in the range of 1.0 to 1.4 seconds) and the maximum oscillation period (typically in the range of 3.0 to 3.5 seconds).
5. The first period detected within the expected period band is defined as the base period.

6. The next period (based on the minima if the base period was for maxima or vice versa) is compared to the base period to determine if coherent oscillatory behavior is present.
 - a. If the current period is not within the specified tolerance of the current base period. The confirmation count and base period are reset to zero and the algorithm continues to process successive maxima and minima to establish a new base period (return to step 5).
 - b. If the current period is equal to the base period within a small tolerance (typically on the order of several times the signal sample interval) then oscillatory behavior is confirmed and the confirmation count is incremented by one. A new base period is calculated that is equal to the average of the consecutively confirmed periods
 - c. If the current confirmation count is less than the required confirmations for a reactor trip (N_p) or the peak magnitude is below the trip setpoint (S_p) the algorithm returns to step 6 to evaluate the next maxima or minima.
 - d. If the current confirmation count is greater than or equal to N_p and the peak magnitude is above the trip setpoint, S_p , the OPRM cell is tripped.
 - e. If any OPRM cell associated with an OPRM channel is tripped, the OPRM channel is tripped. If two out of four or one out of two taken twice OPRM channels are tripped then a reactor trip occurs and the oscillations are suppressed by control rod insertion.

5.4 *Multi-stage Analysis*



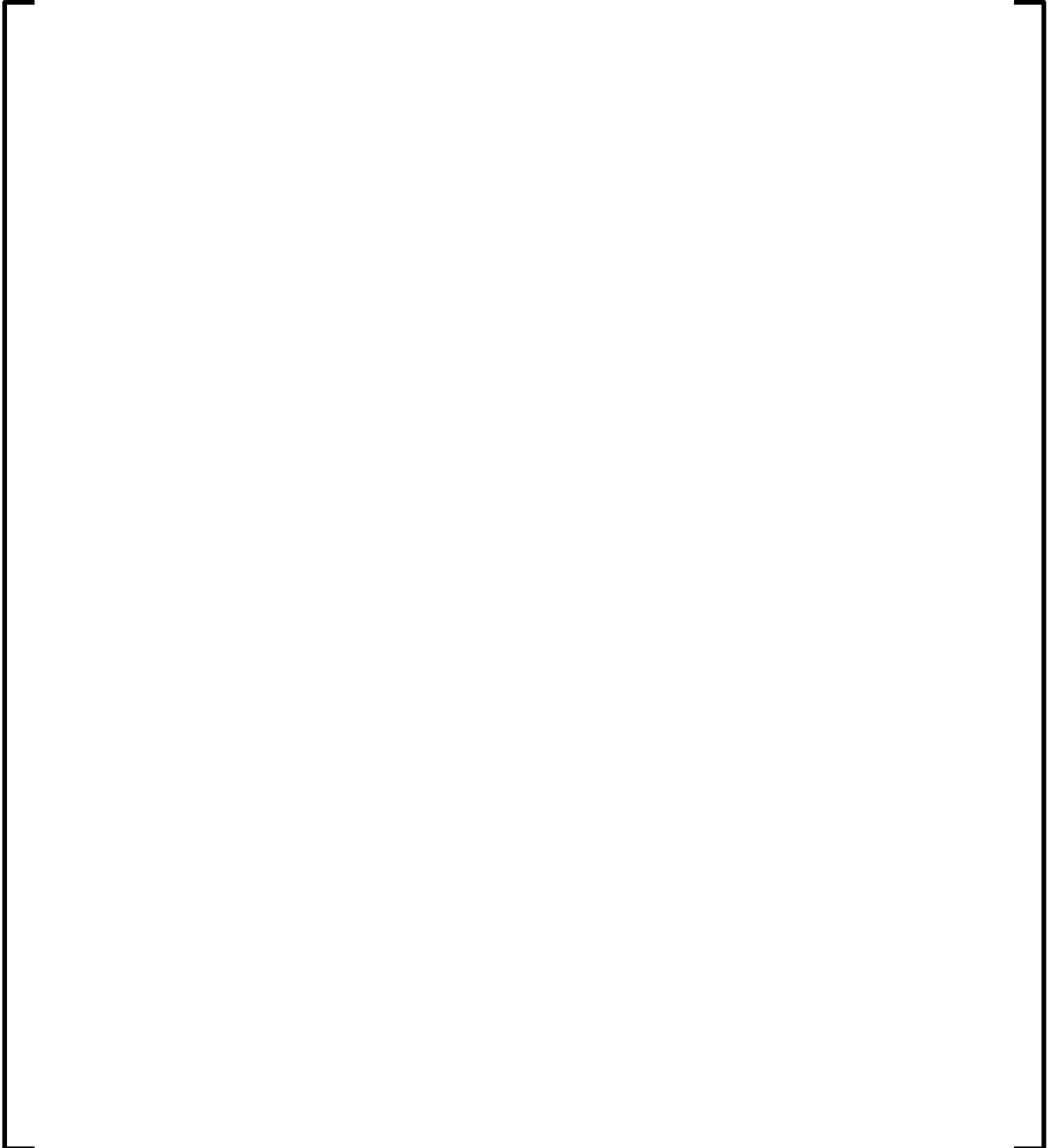




**Figure 5-1
Core Instrumentation**



Figure 5-2

[]



Figure 5-3
Sensitivities to Least Stable Channel Growth Ratio



6.0 CODE VALIDATION AND MODEL UNCERTAINTIES

The approved DIVOM and EO-III RAMONA5-FA code theory is described in Reference 1 and the modifications introduced for the BEO-III methodology were presented in Section 5.0. The code calculates the transient thermal-hydraulic response of a BWR with a detailed core representation of one channel per fuel assembly. It applies a [

]

The BEO-III analyses apply [

] The steady state simulator provides automated input coupling for the hydraulic and neutron cross section parameters. [

] The dynamic functionality of the algorithms which is important in stability and oscillation calculations is verified by benchmarking to stability specific data.

The benchmarking of the hydraulic models used in the BEO-III methodology and the determination of uncertainties is presented in the subsections that follow. Sections 6.1 and 6.2 present the benchmarking and uncertainties for the highly ranked phenomena based on steady-state data. The hydraulic models are then benchmarked against dynamic, single channel stability measurements from the KATHY test facility in Section 6.3. [

]

Section 6.4 presents the qualification of the Framatome ACE critical power correlations (References 12 and 13) against the KATHY oscillatory dryout and rewet experiments. These assessments demonstrate excellent predictions regarding the onset of dryout.

Sections 6.5 through 6.7 present the basis for the remaining uncertainties [

]

Finally, section 6.8 presents the nominal integral benchmarks against reactor instability events [

].

6.1 Void Fraction Assessments

The FRIGG experiments (References 15 and 16) have been included in the validating database because of the broad industry use of these experiments in benchmarking activities. The experiments include a wide range of pressure, subcooling, and quality from which to validate the general applicability of a void correlation. However, the experiments do not contain features found in modern rod bundles such as part length fuel rods and mixing vane grids. The lack of such features makes the data insufficient in validating correlations for modern fuel designs.

Because of its prototypical geometry, the ATRIUM-10 and ATRIUM 10XM void data collected at KATHY have been useful in validating void correlation performance in modern rod bundles that include part length fuel rods, mixing vane grids, and prototypic axial/radial power distributions. The characteristics of the void fraction validation database are listed in Table 6-1.

The BEO-III general benchmarking to this database [] Table 6-2 and Figure 6-1 provide comparisons of predicted versus measured void fractions for the nominal BEO-III methodology using the [] correlation. This figure shows reasonable predictions as compared with the measured data. The prediction is characterized by a mean error (predicted – measured) of [] and a standard deviation of [].

[

]

6.1.1 []

The RAMONA5-FA computer program uses the [] correlation to predict the local drift flux parameters throughout the core. [

]

6.1.2

[

]



Table 6-1
Summary of Void Fraction Test Conditions

	FRIGG (Reference 15, 16)	ATRIUM-10 KATHY	ATRIUM 10XM KATHY
Axial Power Shape	uniform	[]	[]
Radial Power Peaking	mild peaking	[]	[]
Bundle Design	circular array with 36 rods + central thimble	[]	[]
Pressure (psi)	435, 725, 1000, and 1260	[]	[]
Inlet Subcooling (°F)	5.7 to 56.99	[]	[]
Mass Flow Rate (lbm/s) <i>(Based on mass flux assuming ATRIUM-10 inlet area)</i>	10.14 to 42.56	[]	[]
Max Void at Measurement Plane (fraction)	0.848	[]	[]
Number of Data	69 tests, 314 points	[]	[]

Table 6-2
Nominal Benchmarking Statistics [

]

[

]

Validation of [
Figure 6-1
] using FRIGG, ATRIUM-10 and
ATRIUM 10XM Void Data



Figure 6-2

Void Fraction []



Figure 6-3

Void Fraction []



Figure 6-4

[

]



Figure 6-5
Subcooled Void Fraction []



Figure 6-6
Subcooled Void Fraction []



Figure 6-7

[

]



6.2 *Pressure Drop Assessments*

Steady state pressure drop measurements have been performed for the ATRIUM-10, ATRIUM 10XM and ATRIUM 11 fuel designs at the KATHY test facility. These measurements included both single-phase and two-phase operating conditions. The characteristics of the pressure drop validation database and the statistical assessment of the RAMONA5-FA calculations to the measured data are listed in Table 6-3.

Figure 6-8 provides comparisons of predicted and measured pressure drops for the Framatome ATRIUM-10, ATRIUM 10XM and the ATRIUM 11 fuel designs. This figure shows that the majority of the predictions fall within the [] relative error bands for the measured data. The mean and standard deviation of the error were calculated using the method used in Reference 17. The combined two-phase statistics for the combined database reflect a mean relative error of [] and a standard deviation of []. The individual assembly design single- and two-phase statistics are presented in Table 6-4.



Table 6-3
Summary of KATHY Pressure Drop Test Conditions

	ATRIUM-10	ATRIUM 10XM	ATRIUM 11
Axial Power Shape	[]	[]	[]
Bundle Design	[]	[]	[]
Pressure (bar)	[]	[]	[]
Inlet Temperature (°C)	[]	[]	[]
Mass Flow Rate (kg/s)	[]	[]	[]
# of Two Phase Points	[]	[]	[]
# Single Phase Points	[]	[]	[]

Table 6-4 Summary of RAMONA5-FA Pressure Drop Relative Errors

Bundle Design	ATRIUM-10	ATRIUM 10XM	ATRIUM 11
Single Phase Data Mean	[]	[]	[]
Single Phase Std. Deviation	[]	[]	[]
Two Phase Data Mean	[]	[]	[]
Two Phase Std. Deviation	[]	[]	[]

Figure 6-8
Validation of Pressure Drop Prediction versus KATHY Measured
Data (ATRIUM-10, ATRIUM 10XM, ATRIUM 11)



Figure 6-9



Figure 6-10



6.3 *Benchmarking to KATHY Stability Tests*

Several measurement campaigns were performed in the KATHY loop under natural circulation configuration to quantify the stability characteristics of ATRIUM-9, ATRIUM-10, and ATRIUM 10XM BWR fuel designs. The results of these measurements were used for developing and validating Framatome's stability methodologies. Of particular interest here is the ATRIUM-10 stability test series (Bundle ID STS-49.1) and the ATRIUM 10XM test series (Bundle ID STS-115.1). [

]

The ATRIUM-10 tests were performed during the period of May 31-June 17, 1999. The test bundle STS-49.1 was characterized by a downskew power profile with [

] Decay

ratios and frequencies were calculated from the measured inlet flow data.

The ATRIUM 10XM tests were performed in the period of October 15-23, 2009. The test bundle STS-115.1 was characterized by a downskew power profile with [

] Decay

ratios and frequencies were calculated from the inlet flow data.

The data collected from the stability testing of the ATRIUM-10 and ATRIUM 10XM bundles in the KATHY loop are used for benchmarking RAMONA5-FA BEO-III. The

operating conditions of power and inlet subcooling were varied and data were collected for each operating point. [

]

There were [] ATRIUM-10 and [] ATRIUM 10XM tests used in this benchmark. The measured operating parameters for each test point are used as input to RAMONA5-FA BEO-III. The good comparison of the predicted and measured decay ratio and frequency for each test point are presented in Figure 6-11 and Figure 6-12.

6.3.1

[

]

Figure 6-11
Validation of Decay Ratio Prediction versus KATHY Data



Figure 6-12
Validation of Frequency Prediction versus KATHY Data



Figure 6-13

[

]



Figure 6-14

[

]



6.4 *Benchmarking to KATHY Dryout/Rewet Tests*

The hydraulic stability testing in the KATHY loop that was used in the qualification of the RAMONA5-FA decay ratio predictions in Section 6.3 also included extended testing for a few of the tests to the onset of cyclical dryout and rewetting. This was accomplished by increasing the electrical power input to the test assembly beyond the instability boundary until the magnitude of the flow oscillations result in cyclical dryout and rewetting for that fixed power level. The cyclical dryout and rewetting was evidenced by the temperature response of at least one (usually several) thermocouples affixed to the interior surface of the heated rods. The test conditions for all the pure hydraulic tests with the ATRIUM-10 and ATRIUM 10XM designs are summarized in Table 6-5.

These tests were used to benchmark the ability of RAMONA5-FA with the ACE correlations (References 12 and 13) to predict the onset of oscillatory dryout and rewet. The predicted time dependent CPRs are plotted along with the most limiting thermocouple in Figure 6-15 through Figure 6-21. The nominal ACE predictions are presented [

] The RAMONA5-FA predictions with the
approved ACE correlations demonstrate the ability of the methodology to predict the
critical power performance during density wave oscillations [

]

Table 6-5
Onset of dryout and rewetting KATHY test runs

Figure 6-15
Dryout Results for ATRIUM-10 Karlstein []



Figure 6-16
Dryout Results for ATRIUM-10 Karlstein []



Figure 6-17
Dryout Results for ATRIUM-10 Karlstein []



Figure 6-18
Dryout Results for ATRIUM XM Karlstein []





Figure 6-20
Dryout Results for ATRIUM XM Karlstein Case []



Figure 6-21
Dryout Results for ATRIUM XM Karlstein []



6.5 []

The MICROBURN-B2 steady state simulator provides automated input coupling for all of the neutron cross section parameters. [

]

6.6 []

[]

6.7 []

[]

6.8 *Benchmarking Reactor Instabilities*

In order to validate the RAMONA5-FA code for application as a best-estimate methodology, several sets of reactor benchmarks were performed. [

[

]

6.8.1

[

]

*

[

]

[

]

6.8.2

[

]

[

]

6.8.3

[

]

[

]

*

[

]

6.8.4 []

[

.]

6.8.5 Oskarshamn Nonlinear Instability

On February 25, 1999 as maintenance work was being performed on a switchyard outside of Oskarshamn Unit 2, the power supply to a bus bar was interrupted for 150 ms. A load rejection signal was sent to the main breaker that connects the unit to the grid. This signal caused the turbine to trip and consequently loss of steam supply to feedwater heaters, but a failure in the relay circuit resulted in this signal not being transmitted to the reactor protection system. The system continued at power until operators initiated a partial scram. Following the partial scram, power and flow were decreased. The feedwater temperature continued to decrease causing reactor power to further increase until the system crossed the stability boundary. The reactor continued to oscillate until a high power scram was reached at 140% of rated.

The Oskarshamn-2 nonlinear instability was analyzed with RAMONA5-FA BEO-III.

[

] The results of this

evaluation are given in Figure 6-22, Figure 6-23 and Figure 6-24. [

]

Figure 6-22
Oskarshamn-2 Simulation Core Power



Figure 6-23
Oskarshamn-2 Simulation Core Power - Zoom



Figure 6-24
Oskarshamn-2 Simulation Recirculation Flow



6.9 *STAIF Reactor Benchmarks Using New Fuel Rod Property Models*

A description of the STAIF reactor benchmarking suite is given in Section 4.0 of Reference 6. All reactor benchmarks in this suite were reanalyzed with the new fuel rod property models described in Section 5.1.

Table 6-6

[

]

[

]

Table 6-7

[

]

[

]

* Regional Oscillation Mode

Table 6-8

[

]

[

]

Table 6-9

[

]

[

]

Table 6-10

[

]

[

]

7.0 BEO-III CYCLE ANALYSES

7.1 *Statistical Methodology*

The BEO-III methodology evaluates the impact of code uncertainties on FoM values using a statistical process based on non-parametric order statistics, a Monte Carlo method that has wide acceptance in the nuclear industry. An application method for this type of statistics is described in References 18 and 19, and the method is further described in Section 9.4.1 of Reference 20 when multiple parameter uncertainties are being considered simultaneously.

The theory of non-parametric order statistics allows FoM results from the ensemble to be used to determine the value which bounds a specific fraction of the full ensemble results at a specific confidence level. This is done by sorting the ensemble FoM results in descending order, then counting down through the ordered list to an acceptance number value which is dependent on the sample size. It is noted that the relationship between the acceptance number and the required sample size is dependent on the number of parameter uncertainties being treated simultaneously. [

]

[

]

By use of this process, execution of the runs in a single ensemble may be used to simultaneously evaluate the impact of all code uncertainty parameters in an integrated manner, with concerns about the independence of various parameters being resolved by the process itself.

7.1.1 Sampled Parameters for Non-Parametric Analysis

The highly ranked phenomena from Table 4-1 are summarized in Table 7-2. For each highly ranked parameter, Table 7-2 presents modifications to RAMONA5-FA to sample on the code and modeling uncertainties or specifies the initial conditions that are considered in the analyses. There are a total of [] parameters that are sampled within the methodology. These are associated with the neutron kinetics [] fuel assembly hydraulics [] and fuel rod heat transfer []

] The final parameter that is sampled within an ensemble is []

] The highly ranked parameters and their associated sampling ranges for the ATRIUM 11 application at Brunswick are presented in Table 7-3.

7.1.2 Sampling Range Applicability

The sampling ranges shown for most of the variables in Table 7-3 are considered to be generically applicable to all BWR plant types and for all plant applications. These sampling ranges address uncertainties which are universally inherent in the BEO-III models being used, or are based on conservative arguments which would make them appropriate for universal generic use. [

]

The remaining parameters, [

]

7.1.3 Statistical Independence of Sampled Variables

[

7.1.4 Sampling Methods for Non-Parametric Process



7.1.5 Truncation of Sampled Parameter Distributions



[

]

7.1.6 Application of Statistical Analysis

The following practices will be employed in performing the cycle-specific statistical evaluation:

- The sample size and the order statistic selection for the upper tolerance limit will be selected from Table 7-1,
- The sample size will be chosen prior to initiating statistical licensing calculations,
- An auditable record will be maintained to demonstrate that the process for performing statistical licensing calculations has been executed in an unbiased manner.

7.2 *BEO-III Calculation Procedure*

The BEO-III methodology is performed on a cycle-specific basis to confirm that pump trip scenarios that lead to instabilities are non-limiting relative to events that set the initial OLMCPR. [

] This section is devoted to the general description of the methodology and the procedure for performing the calculations.

In summary, the application procedure includes the following elements:

1. Definition of the state points to be analyzed.



2. The RAMONA5-FA base deck for the statistical analyses is prepared as a best estimate model. [

]

3. For each of the initial power/flow state points, [

]

4. For each of the exposure steps, [

Table 7-1

[

]

[

]

Figure 7-1

[

]

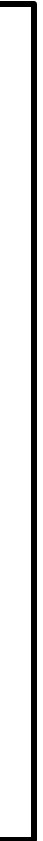


Table 7-2
Disposition of Highly Ranked Phenomena

Table 7-2
Disposition of Highly Ranked Phenomena (continued)

Table 7-3
Sampled Parameters for BEO-III ATRIUM 11 Statistical Analyses

7.3 Backup Stability Protection Calculation Procedure

In cases where the OPRM system is declared inoperable, Backup Stability Protection (BSP) will be provided in accordance with Reference 21. BSP curves will be evaluated using STAIF (Reference 6 and the modifications described in Section 5.1) to determine endpoints that meet decay ratio criteria for the BSP Base Minimal Region I (scram region) and Base Minimal Region II (controlled entry region). The definitions of these regions and their associated actions are contained in Reference 21 (BWROG Letter), and have been continually utilized at Brunswick since the implementation of Option III. These regions are defined by power and flow points along the Natural Circulation Line (NCL) and the High Flow Control Line (HFCL) and are connected with the Generic Shape Function (GSF) which represents a constant decay ratio line. The basic calculation procedure for the cycle specific confirmation of the BSP regions is summarized below:

1. Obtain accurate cycle- and exposure-dependent inputs from the core simulator. Calculations to support reduced feedwater temperature BSP regions use the appropriate minimum licensed feedwater temperature relationship.
2. The calculation is performed for several points during the cycle to determine the most limiting point. The limiting values are typically at EOC, EOC minus 1000 MWD/MTU, EOC minus 2000 MWD/MTU, or EOC minus 3000 MWD/MTU. Haling depletions are used for exposures near or at EOC and rodged depletions are used for BOC.
3. NCL points are based on depletion restarts originating from 100% power and 100% flow. HFCL points are based on depletion restarts originating from 100% power and minimum flow.
4. Perform best-estimate stability calculations using Framatome's STAIF computer code (Reference 6) to determine the core, regional and channel decay ratios using the guidance provided in Table 7-4. The BSP regions are confirmed if the decay ratios meet the acceptance criteria of the frequency domain code.

5. If the acceptance criteria are not met, the region needs to be expanded by lowering power on the NCL or increasing core flow along the HFCL.

Table 7-4
BSP Region Calculation Procedure

Application	Calculation Procedure
Reactivity Coefficients	• Exposure-dependent 1-D kinetics model void coefficient • Included Doppler coefficient
Xenon and Feedwater Temperature Concentration	Scram Region • On the NCL, constant Xenon at rated operating conditions • On the HFCL, constant Xenon at rated operating conditions • Rated feedwater temperature prior to runback Controlled Entry Region • On the NCL, no Xenon • On the HFCL, equilibrium Xenon • Statepoint-specific equilibrium feedwater temperature
Radial Power Distribution	• Multiple channel groups used to model core consistent with approved MB2/STAIF methodology requirements.

8.0 BRUNSWICK ATRIUM 11 EQUILIBRIUM CYCLE ANALYSES

In order to demonstrate that the LTSS hardware installed at the Brunswick reactors can detect and suppress oscillations with a high confidence level for the ATRIUM 11 fuel design the BEO-III methodology described in this document was applied using the calculation procedure described in Section 7.2. An equilibrium ATRIUM 11 core in Brunswick Unit 1 was analyzed. The primary difference between Unit 1 and 2 that directly affects this event is the inlet pressure drop. Since Brunswick Unit 1 has a much lower inlet pressure drop due to larger inlet orifices, the fuel assemblies will be hydraulically less stable and therefore bound the results for Unit 2 [

] consistent with Section 7.2.

For the Brunswick application, the PBDA trip is a defense in depth component and the CDA is the licensing basis algorithm. The parameters used for the PBDA application for the ATRIUM 11 equilibrium cycle analyses are presented in Table 8-1. One clarification on Table 8-1 is that since the BEO-III calculations conservatively assume that the most responsive OPRM channel is failed, the trip logic is effectively 3 out of 4 channels must trip to initiate a reactor scram.

For the limiting MELLLA+ statepoint at rated core power and 85% of rated core flow, a sample size of [] trials was utilized. The statistical results are presented graphically in Figure 8-1 and Figure 8-2. Based on a [] OLMCPR the 95/95 MCPR is shown to be above the SLMPCR of [

] A sensitivity study on the

[

]

[

]

The other pump trip scenarios identified in Section 3.0 are the lowest core flow at rated core power within the MELLLA domain with the minimum allowed feedwater temperature allowed by the licensee for the feedwater heater out-of-service (FWHOOS) scenario and the highest core power under single loop operation (SLO). These analyses used [] trials in the statistical analysis.

The limiting FWHOOS statepoint at rated power for the MELLLA domain is at 99% of rated flow. The statistical results are presented in Figure 8-3 and Figure 8-4 for this statepoint. Based on a [] OLMCPR the 95/95 MCPR is well above the SLMCPR [

]

The limiting single pump trip was analyzed at 71.1% of rated power and 58.4% of rated flow. The statistical results are presented in Figure 8-5 and Figure 8-6 for this statepoint. Based on a [] power dependent OLMCPR the 95/95 MCPR is well above the SLMCPR [

]

Table 8-1
Brunswick OPRM and PBDA Parameters

Number of OPRM Channels	4
Number of OPRM Cells	24
Number of LPRMs per OPRM Cell	≤ 4
OPRM Trip Logic	2 out of 4
PBDA Trip Confirmation Count (N_P) versus PBDA Magnitude Setpoint (S_P)	$N_P = 15$ $S_P = 1.15$
PBDA Minimum Oscillation Period	1.0 sec
PBDA Maximum Oscillation Period	4.0 sec
PBDA Period Tolerance	0.10 sec
OPRM High Frequency Cutoff for Signal Oscillation Component	1.00 Hz
OPRM High Frequency Cutoff for Signal Average Component	1/6 Hz

Figure 8-1
Limiting MELLLA+ MCPR



Figure 8-2
Limiting MELLLA+ []



Figure 8-3
Limiting MELLLA with FWHOOS MCPR



Figure 8-4
Limiting MELLLA with FWHOOS []



Figure 8-5
Limiting SLO MCPR



Figure 8-6
Limiting SLO []



9.0 REFERENCES

1. EMF-3028P-A Volume 2 Revision 4, "RAMONA5-FA: A Computer Program for BWR Transient Analysis in the Time Domain Volume 2 -- Theory Manual," AREVA NP Inc., March 2013.
2. BAW-10255(P)(A) Revision 2, "Cycle-Specific DIVOM Methodology Using the RAMONA5-FA Code," AREVA NP, May 2008.
3. ANP-10262PA Revision 0, "Enhanced Option III Long Term Stability Solution", AREVA NP, May 2008.
4. FQM, Revision 3, AREVA NP Fuel Sector Quality Management Manual, AREVA NP, June 2008.
5. NUREG/CR-6743, LA-UR-00-3122, "Phenomenon Identification and Ranking Tables (PIRTS) for Power Oscillations Without Scram in Boiling Water Reactors Containing High Burnup Fuel," September 2001.
6. EMF-CC-074(P)(A) Volume 4 Revision 0, "BWR Stability Analysis – Assessment of STAIF with Input from MICROBURN-B2," Siemens Power Corporation, August 2000.
7. ANP-3694(P) Revision 0, "ATWS-I Analysis Methodology for Brunswick Using RAMONA5-FA," June 2018.
8. BAW-10247PA Revision 0, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, AREVA NP, February 2008.
9. NEDO-31960-A, BWR Owners' Group Long-Term Stability Solutions Licensing Methodology, November 1995.
10. NEDO-31960-A, Supplement 1, BWR Owners' Group Long-Term Stability Solutions Licensing Methodology, November 1995.
11. EMF-2158(P)(A) Revision 0, "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2," Siemens Power Corporation, October 1999.
12. ANP-10249P-A Revision 2 "ACE/ATRIUM-10 Critical Power Correlation," AREVA, March 2014.
13. ANP-10298P-A Revision 1, "ACE/ATRIUM 10XM Critical Power Correlation," AREVA, March 2014.
14. ANP-10300P-A, Revision 1, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios," Framatome, January 2018.
15. O. Nylund et al., "Hydrodynamic and Heat Transfer Measurements on A Full-Scale Simulated 36-Rod Marviken Fuel Element with Uniform Heat Flux Distribution," FRIGG-2, R-447/RL-1007, May 1968.

-
16. O. Nylund et al., "Hydrodynamic and Heat Transfer Measurements on A Full-Scale Simulated 36-Rod Marviken Fuel Element with Non-Uniform Radial Heat Flux Distribution," FRIGG-3, R-494/RL-1154, November 1969.
 17. XN-NF-79-59(P)(A), Methodology for Calculations of Pressure Drop in BWR Fuel Assemblies, October 1983.
 18. Paul N. Somerville, Tables for Obtaining Non-Parametric Tolerance Limits", Annals of Mathematical Statistics, Vol. 29, Number 2, 1958.
 19. J. L. Jaech, On the Use of Tolerance Intervals in Acceptance Sampling by Attributes, Journal of Quality Technology, Vol. 4, No. 2, April 1972.
 20. EMF-2103P-A, Revision 3, Realistic Large Break LOCA Methodology for Pressurized Water Reactors, Topical Report, AREVA NP Inc., June 2016.
 21. OG02-0119-260, Backup Stability Protection (BSP) for Inoperable Option III Solution, GE Nuclear Energy, July 17, 2002.

Affidavit for ANP-3703P, BEO-III Analysis Methodology for
Brunswick Using RAMONA5-FA

A F F I D A V I T

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3703P, Revision 0, "BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA," dated August 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(a), 6(b), 6(c), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

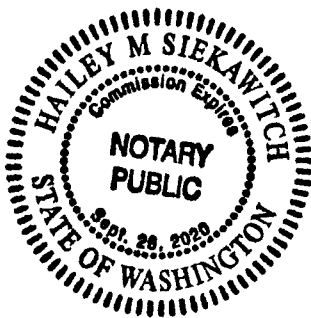
Alan B. Metz

SUBSCRIBED before me this 16th

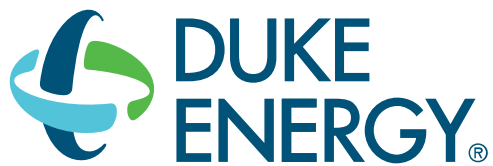
day of August, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



DPC-NE-1009, Brunswick Nuclear Plant Implementation
of Best-estimate Enhanced Option-III



Brunswick Nuclear Plant
Implementation of Best-estimate
Enhanced Option-III

DPC-NE-1009
Revision 0
September 2018

Statement of Disclaimer

There are no warranties expressed, and no claims of content accuracy implied. Duke Energy and its subsidiaries disclaim any loss or liability, either directly or indirectly as a consequence of applying the information presented herein, or in regard to the use and application of the before mentioned material. The user assumes the entire risk as to the accuracy and the use of this document.

Abstract

Boiling Water Reactors (BWR) are required to demonstrate compliance with General Design Criteria (GDC) 10 and 12 of 10 CFR 50 Appendix A which preclude operation under oscillatory conditions. Systems based on the Detect & Suppress philosophy include plant hardware and software to issue Reactor Protection System (RPS) trip signals upon detection of oscillatory behavior of the neutron flux that is indicative of thermal-hydraulic instability. These systems group Local Power Range Monitors (LPRM) into several Oscillation Power Range Monitor (OPRM) cells for inspection with instability detection algorithms.

Brunswick Nuclear Plant (BNP) is currently licensed for operation at Extended Power Uprate (EPU) at Maximum Extended Load Line Limit Analysis Plus (MELLLA+) conditions using GE Hitachi's (GEH) Detect and Suppress Solution – Confirmation Density to meet the requirements of GDC 10 and 12. However, this stability solution has not been expanded to include Framatome fuel types at BNP besides the ATRIUM 10XM.

With the introduction of advanced fuel designs, a new stability solution is required. The proposed stability solution is based on a plant specific application of Framatome's Best-estimate Enhanced Option-III (BEO-III) analysis methodology which maintains the Confirmation Density Algorithm (CDA) as the licensing basis algorithm. BNP's application of BEO-III is described in detail in Framatome report ANP-3703P and the use of the CDA is described in the body of this report. Additionally, this report will describe the Backup Stability Protection (BSP) method that will be utilized when the OPRM Upscale trip function is deemed inoperable using exclusion regions of the power-to-flow map where core stability margin is reduced.

Table of Contents

1.0	Introduction	1-1
2.0	Overview	2-1
2.1.	Use of the CDA with the BEO-III Methodology	2-1
3.0	Methodology.....	3-1
3.1.	Confirmation Density Algorithm.....	3-1
3.2.	BEO-III/CDA Reload Process	3-2
3.3.	Impact of Later CDA Trip Times.....	3-4
4.0	ATRIUM 11 Equilibrium Cycle Analyses	4-1
5.0	Backup Stability Protection	5-1
5.1.	Automated BSP Scram Region.....	5-1
6.0	Conclusion	6-1
7.0	References.....	7-1

List of Tables

Table 4-1 CDA Suspect Cases	4-3
Table 4-2 [.....]	4-3

List of Figures

Figure 3-1 Flow Reduction Event MCPR.....	3-5
Figure 3-2 F/I MCPR []	3-5
Figure 3-3 MCPR Reduction over Flow Reduction	3-6
Figure 4-1 MELLLA+ Final MCPR Results	4-4
Figure 4-2 SLO Final MCPR Results.....	4-4
Figure 4-3 MELLLA+ Final / Initial MCPR Results	4-5
Figure 4-4 SLO Final / Initial MCPR Results	4-5
Figure 5-1 Example Brunswick MELLLA+ Power/Flow Map	5-2

List of Acronyms

1RPT	One Recirculation Pump Trip
2RPT	Two Recirculation Pump Trip
ABA	Amplitude Based Algorithm
ABSP	Automated Backup Stability Protection
APRM	Average Power Range Monitor
AOO	Anticipated Operational Occurrence
BEO-III	Best-estimate Enhanced Option-III
BNP	Brunswick Nuclear Plant
BSP	Backup Stability Protection
BWR	Boiling Water Reactor
BWROG	BWR Owners Group
CDA	Confirmation Density Algorithm
COLR	Core Operating Limits Report
EPU	Extended Power Uprate
F/I MCPR	Final-over-Initial Minimum Critical Power Ratio
FoM	Figure of Merit
GDC	Generic Design Criteria
GEH	General Electric – Hitachi
GRA	Growth Rate Algorithm
ICO	Independent Channel Oscillations
LPRM	Local Power Range Monitor
LSSS	Limited Safety System Setting
LTSS	Long-Term Stability Solution
MCPR	Minimum Critical Power Ratio
MELLLA	Maximum Extended Load Line Limit Analysis
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
NUMAC	Nuclear Measurement and Control
OLMCPR	Operating Limit MCPR
OPRM	Oscillation Power Range Monitor
PBA	Period Based Algorithm
PBDA	Period Based Detection Algorithm
PRNMS	Power Range Neutron Monitoring System
RPS	Reactor Protection System
SCC	Successive Confirmation Count
SLMCPR	Safety Limit MCPR
SLO	Single Loop Operation
TLO	Two Loop Operation

1.0 INTRODUCTION

This report describes a method for determining Minimum Critical Power Ratio (MCPR) operating limits that protect the Safety Limit MCPR (SLMCPR) against thermal-hydraulic instability using the plant specific Best-estimate Enhanced Option-III (BEO-III) methodology with the Confirmation Density Algorithm (CDA) installed in the BNP plant hardware. The BEO-III methodology, as described in Reference 1, utilizes a best-estimate plus uncertainty approach to ensure margin to the SLMCPR is maintained at the time of oscillation suppression for limiting stability events (e.g. two recirculation pump trip, 2RPT). BEO-III also ensures that the least stable fuel assemblies have not become decoupled from the core MCPR response and thus do not invalidate the conclusion of margin to the SLMCPR due to Independent Channel Oscillations (ICO).

The CDA is a stability algorithm that is able to detect oscillations at the onset of instability before significant reduction in margin to the SLMCPR. The CDA was installed as the licensing basis algorithm at BNP with the approval of MELLLA+ (Reference 2) and was incorporated into Technical Specifications, plant procedures, and training programs. It is integral to the Oscillation Power Range Monitor (OPRM) function of the Nuclear Measurement Analysis and Control (NUMAC) Average Power Range Monitor (APRM) hardware which is part of the Power Range Neutron Monitoring System (PRNMS). For these reasons, the CDA is maintained as the primary stability protection mechanism of the OPRM Upscale reactor trip function for BNP instead of the Period Based Detection Algorithm (PBDA) that serves as the licensing basis for BEO-III. The PBDA, along with the other Option-III algorithms (GRA and ABA) from References 3 and 4, is maintained for defense-in-depth functions and is not credited in the SLMCPR margin determination.

Backup Stability Protection (BSP) is required when the OPRM Upscale trip function is inoperable. To achieve this, two methods are employed consistent with the current BNP Technical Specifications: an Automated BSP (ABSP) scram region and manual BSP exclusion regions when ABSP is not available. The Automated BSP (ABSP) creates an automatic scram region defined by adjustments to the APRM Simulated Thermal Power (STP) flow-biased scram setpoint. The manual BSP regions (scram and controlled entry) require specific operator actions in the event these regions of the power/flow map more likely to challenge the stability of the reactor are entered. Use of the manual BSP regions limits operation to below the MELLLA boundary (i.e., BSP boundary).

Sections 2.0 and 3.0 describe the use of the CDA with the BEO-III methodology and Section 4.0 contains a demonstration of the methodology for a BNP ATRIUM 11 equilibrium cycle. Section 7.3 of Reference 1 defines the calculation process for the manual BSP regions and the utilization of the ABSP feature of the BNP hardware is described in Section 5.0 of this report.

2.0 OVERVIEW

2.1. *Use of the CDA with the BEO-III Methodology*

BEO-III is a cycle-specific stability methodology where limiting flow reduction events are simulated with RAMONA5-FA to determine the final-over-initial MCPR (F/I MCPR) response at the time of oscillation suppression or when a limit cycle is reached at amplitudes below the trip setpoint. BEO-III also ensures that the least stable fuel assemblies have not become decoupled from the core MCPR response and thus do not invalidate the conclusion of margin to the SLMCPR. BEO-III uses a multi-stage analysis approach to confirm these Figures of Merit (FoM) in the same event simulation which is described in detail in Section 5.4 of Reference 1. [

]

BEO-III samples uncertainties in the key parameters at multiple exposures throughout the cycle to ensure margin to the SLMCPR with at least a 95% probability at a 95% confidence level (95/95). BEO-III relies on the BWR Owners Group (BWROG) Option-III PBDA described in References 3 and 4 to determine the time of oscillation suppression.

To support MELLLA+ operation, BNP installed the CDA as the licensing basis algorithm and intends to maintain it with the implementation of BEO-III. To achieve this, Duke Energy post-processes the RAMONA5-FA transient LPRM data to determine the time of oscillation suppression with software that replicates the CDA installed in the plant hardware. This post-processing software, CDACALC, is described in Reference 7. In the event a limit cycle is determined by BEO-III and the RAMONA5-FA simulation ends, this conclusion is independent of algorithm and remains applicable to the CDA.

The CDA time of suppression or limit cycle is then used to determine the F/I MCPR ratio for the given event simulation. These results are sorted for each exposure statepoint and the 95/95 F/I MCPR is determined based on the sample size as shown in Table 7-1 of Reference 1. The minimum 95/95 F/I MCPRs from the cycle analysis are used to establish the minimum OLMCPRs that are required to protect the SLMCPR.

The CDA is expected to trip at or before the Option-III PBDA which will preserve the ICO assessment performed with RAMONA5-FA based on PBDA time of suppression [

](Section 8.0 of Reference 1). In the event the

CDA does not trip at or prior to the simulation time BEO-III performs the ICO assessment and final MCPR determination, the validity of these evaluations will be addressed as described in Section 3.3.

3.0 METHODOLOGY

3.1. *Confirmation Density Algorithm*

The CDA is a GEH proprietary stability detection algorithm that is described in detail in Section 3.0 of Reference 5. It is based on the References 3 and 4 Period Based Algorithm (PBA) which inspects the normalized OPRM cell signal and tracks peaks and valleys to monitor for periods that are indicative of thermal-hydraulic instability. If the oscillation period is within a defined range, the PBA calculates a base period for comparison against the period calculated at the next peak or valley. The PBA records a successive confirmation count (SCC) if this period is within the period range and within the period tolerance of the base period. A new base period is calculated with each SCC. If the period is outside the period range or is different than the base period by more than the period tolerance, the confirmation counts and base period are reset to zero.

An OPRM channel CDA trip occurs when a preset number of OPRM cells in a channel achieve a defined number of SCCs (i.e. confirmation density) and when one of these OPRM cells reaches or exceeds the amplitude discriminator setpoint. The Brunswick RPS requires two-out-of-four OPRM channels to trip concurrently to initiate an automatic scram. A single channel is allowed to be out-of-service, so the most responsive channel is assumed to fail in the BEO-III methodology. With this, three-out-of-four OPRM channels need to concurrently trip before an RPS trip is credited in the analysis. The OPRM Upscale trip function is only active when the plant is operating in the OPRM Enabled Region of the power/flow map which is defined for Brunswick as reactor power greater than 23% of rated and recirculation drive flow less than 75% of rated.

The Option-III PBDA utilized by BEO-III is also based on the PBA for detecting oscillations. The PBA contained in the BNP hardware has been slightly modified from Option-III to support the CDA and is applied to the defense-in-depth PBDA as well. These differences are described in Section 3.4.1.1 of Reference 5 and have been implemented in the CDACALC post-processing software.

Licensing basis CDA settings restricted from change without NRC approval will not be modified from the values approved by the NRC in Reference 2 for MELLLA+ implementation. Required MELLLA+ testing confirms the adequacy of the amplitude discriminator and period range to protect against spurious scrams due to plant noise. The cycle-specific BEO-III analysis with CDA will demonstrate that the amplitude discriminator combined with the minimum required stability OLMCPR will protect the SLMCPR.

A separation of 0.05 in amplitude between the defense-in-depth PBDA amplitude setpoint and the CDA amplitude discriminator is recommended in Section 3.4.1 of Reference 6 and the PBDA SCC threshold is selected above the similar SCC threshold for the CDA. The separation between these settings reduces the likelihood that the PBDA trips before the CDA. The use of the defense-in-depth PBDA settings within the BEO-III simulations is merely a convenient way to run the RAMONA5-FA simulations out to a sufficient time where the CDA trip or a limit cycle are expected to have been achieved.

3.2. BEO-III/CDA Reload Process

The case matrix is defined by the statistical requirements of the BEO-III methodology and is not impacted by the replacement of the PBDA with the CDA as the licensing basis. Section 7.2 of Reference 1 defines the selection of the case matrix for the specific analysis type. The process below defines how Duke Energy will post-process the RAMONA5-FA simulations to evaluate the CDA for the BEO-III case matrix:

1. Determine the BEO-III cases to analyze with the CDA.
 - a. All MELLLA+ 2RPT cases from 100% power and 85% flow (limiting stability event) with a MCPR decrease (F/I MCPR less than 1.0) at time of BEO-III suppression with PBDA or limit cycle will be analyzed with the CDA. Cases with no decrease in MCPR will not be evaluated, because they are not limiting and a CDA trip before the time of the BEO-III PBDA trip makes these cases even less limiting. In the infrequent cases where PBDA trips before CDA, MCPR is not expected to decrease enough for these F/I MCPR > 1.0 cases to challenge the limiting 95/95 F/I MCPR ratio by the time the CDA trip occurs. Figure 3-1 shows the slow changing nature of the core MCPR for a representative non-limiting case. The ICO assessment is not affected by this screening since Figure 3-2 shows that [
 - b. Screening Single Loop Operation One Recirculation Pump Trip (SLO-1RPT) cases based on F/I MCPR less than 1.0 would include excessive non-limiting cases because the SLO-1RPT experiences a larger initial drop in MCPR during the flow reduction compared to the MELLLA+ 2RPT, as shown in Figure 3-3. Therefore, in the event SLO-1RPT cases are required by the BEO-III methodology (e.g., new fuel introduction), the percentage of most limiting SLO cases analyzed with the CDA will be no less than ten times the ratio of the applicable order statistic to the sample size from Table 7-1 of Reference 1 to provide assurance the most MCPR limiting order statistic number of cases as determined by CDA are identified. This requirement does not apply if all cases with F/I MCPR less than 1.0 are analyzed consistent with the discussion in Item 1.a above. The ICO assessment is not affected by this screening since Figures 8-2 and 8-6 of Reference 1 demonstrate [

]

- c. Section 8.0 of the Reference 1 BEO-III methodology concluded that the Reduced Feedwater Temperature (RFT) cases in MELLTA [

]

2. Post-process RAMONA5-FA output for the selected cases to determine the CDA time of trip or until the end of simulation when a limit cycle is reached.
 - a. BEO-III (and CDACALC) explicitly models the RPS voter logic to determine time of trip.
 - i. With the most responsive OPRM channel failed, three of four OPRM channels need to meet the CDA trip criteria to produce an RPS trip.
 - b. A scram delay time is added to the RPS trip time to account for the response times of the plant hardware and the time for the scram to sufficiently suppress the oscillations.
3. For each statepoint, sort cases based on F/I MCPR at time of oscillation suppression or limit cycle to determine the 95/95 F/I MCPR result based on sample size in accordance with Reference 1.
4. From the 95/95 F/I MCPR* results, determine the minimum required OLMCPR required to protect the SLMCPR, defined as:

$$OLMCPR_{stab} = \frac{SLMCPR}{F/I MCPR_{95/95}}$$

5. Confirm that this value, when conservatively rounded, is bound by the minimum OLMCPR from the limiting transients. If not, increase the OLMCPR on an exposure dependent basis to this value.

The BEO-III ICO assessment is based on the time of suppression as determined by the Option-III PBDA within RAMONA5-FA or when a limit cycle is achieved below the trip setpoint. In the event that the CDA suppression time is at or before the end of the BEO-III simulation, this assessment remains valid since Section 8.0 of Reference 1 demonstrates the core will be in a more stable state. [

]

Because BEO-III is a statistical methodology that utilizes a large sample population, infrequent cases where the Option-III PBDA trips before the CDA are possible. In these cases, the Final MCPR and ICO assessment will be dispositioned or reanalyzed as described in Section 3.3.

* In no case will 95/95 F/I MCPR greater than 1.0 be used.

3.3. *Impact of Later CDA Trip Times*

The use of the defense-in-depth PBDA settings within the BEO-III simulations is merely a convenient way to run the RAMONA5-FA simulations out to a sufficient time where the CDA trip or a limit cycle are expected to have been achieved. For cases where a limit cycle is determined by RAMONA5-FA, the Final MCPR is determined either at the time of CDA suppression or the end of simulation. In the event CDA trips later than the Option-III PBDA in the RAMONA5-FA simulation, the following two options are available:

1. The cases will be considered limiting in the 95/95 F/I MCPR and ICO determination for their corresponding exposure statepoint. This is a conservative treatment since these cases, when non-limiting, will require a more limiting result to be selected.
2. The RAMONA5-FA simulation time will be extended to evaluate the F/I MCPR and ICO through the time of CDA suppression.



Figure 3-1 Flow Reduction Event MCPR



Figure 3-2 F/I MCPR [

]



Figure 3-3 MCPR Reduction over Flow Reduction

4.0 ATRIUM 11 EQUILIBRIUM CYCLE ANALYSES

In Section 8.0 of Reference 1 a sample BEO-III analysis was performed for a Brunswick Unit 1 ATRIUM 11 equilibrium cycle. The only difference between the Brunswick units from a stability perspective is the sizing of the inlet orifices for which Unit 1 is more limiting. The specific analyses that were performed are shown below:

- 2RPT from 100%P/85%F (MELLLA+)
 - [] trials per statepoint
 - [] cases with decrease in MCPR
- 1RPT from 71.1%P/58.4%F (SLO)
 - [] trials per statepoint
 - [] of the most limiting F/I MCPR BEO-III cases []

As specified in Section 3.2, the MELLLA w/ RFWT case will not be evaluated with the CDA since it was demonstrated to be bound by the MELLLA+ results in Reference 1. The above cases were analyzed with the CDA to determine the F/I MCPR at time of oscillation suppression or when a limit cycle is achieved. There are only four MELLLA+ cases and six SLO cases of the thousands analyzed (see bullets above) where the time of CDA suppression is after the end of the RAMONA5-FA simulation. These cases are summarized in Table 4-1.

As can be seen in Table 4-1, most of these cases have a CDA trip before the end of simulation where a limit cycle is achieved without an Option-III PBDA trip. These cases are not a concern since a limit cycle has been achieved which indicates there has been sufficient time with no change in the MCPR response and the oscillations are not growing. Case *M+_09001_F02*, shown in italics, is one in which the CDA trip occurs between the PBDA trip and suppression times. The F/I MCPR [] for this case is not expected to degrade significantly in the 0.83 seconds between the end of simulation and CDA suppression. However, it will be conservatively treated as if the CDA did not trip.

The cases shown in bold in Table 4-1 requires further disposition since there is no indication of CDA trip prior to the end of simulation. The conservative Option 1 from Section 3.3 will be employed for this sample problem and will be extended to all Table 4-1 cases for demonstration purposes. This option requires for each exposure statepoint a new 95/95 ICO [] in addition to determining the 95/95 F/I MCPR with these cases considered to be the most limiting for the determination process.

* Minimum limiting population for analysis defined as ten times the ratio of the order statistic [] to the sample size [].

Figure 4-1 shows the final MCPR assuming a [] OLMCPR for MELLLA+ and Figure 4-2 shows the Final MCPR for SLO with a representative power dependent OLMCPR value for SLO at 71.1% power. Consistent with the conclusion of Section 8.0 of Reference 1, SLO remains non-limiting in terms of margin to the SLMCPR compared to the MELLLA+ cases. Figures 4-3 and 4-4 show the F/I MCPR ratios. For simplicity, the cycle minimum F/I MCPR results will be utilized in determining the minimum stability OLMCPR. Exposure dependent OLMCPRs could also be developed to bound specific exposure ranges of the cycle*. The cycle minimum TLO 95/95 F/I MCPR is [] and the minimum SLO 95/95 F/I MCPR is [] which produce the following minimum stability OLMCPRs based on their respective SLMCPRs:

* In cases where exposure dependent limits are developed, the minimum population requirements for SLO from Section 3.2 Item 1.b would apply for each exposure range.

Table 4-1 CDA Suspect Cases

Table 4-2 [

]



Figure 4-1 MELLLA+ Final MCPR Results



Figure 4-2 SLO Final MCPR Results



Figure 4-3 MELLLA+ Final / Initial MCPR Results



Figure 4-4 SLO Final / Initial MCPR Results

5.0 BACKUP STABILITY PROTECTION

The section describes the Backup Stability Protection (BSP) methods that are currently incorporated in the Brunswick Technical Specifications. These methods will be maintained with the implementation of the plant specific BEO-III Long-Term Stability Solution (LTSS) methodology. The preferred method is the Automated BSP (ABSP) scram region since it requires no operator action to protect against fast developing oscillations following a 2RPT from the MELLLA+ operating domain. If this feature is unavailable, manual BSP exclusion regions on the power/flow map will be employed and operation will be restricted to the MELLLA operating domain. This is enforced in the Brunswick Technical Specifications which requires operation to be lowered below the BSP Boundary (MELLLA Boundary) as specified in the cycle-specific Core Operating Limits Report (COLR) in the event the ABSP is not available.

The calculation process for the Manual BSP regions is described in Section 7.3 of Reference 1 and is consistent with previous Brunswick BSP analyses to support MELLLA+ (References 8 and 9).

5.1. *Automated BSP Scram Region*

The ABSP is contained in the NUMAC APRM hardware that was installed to support MELLLA+ implementation and will be maintained as described in this section. This feature produces an automatic scram if potentially unstable regions of the power flow map are entered (i.e. ABSP). This is done with adjustments to the APRM flow-biased scram setpoints to encompass the nominal feedwater temperature manual BSP scram region. The manual BSP scram region is determined on a cycle-specific basis as described in Section 7.3 of Reference 1. Due to the automatic scram upon entry into this region, operation in MELLLA+ is allowed since there is no reliance on operator actions in the event of an inadvertent flow reduction event that challenges the stability of the reactor core. No adjustments are needed to the ABSP setpoints for reduced feedwater temperature (RFT) since the main purpose of the ABSP is to protect against high growth rate oscillations resulting from a 2RPT from the MELLLA+ region which does not allow RFT.

The APRM flow-biased scram setpoints utilize drive flow for boundary definition while the manual scram region is specified in core flow. To ensure that the ABSP region bounds the manual scram region, the Brunswick core flow to drive flow relationship is utilized. This is shown on an example Brunswick power/flow map in Figure 5-1.

The OPRM setpoints (including the ABSP region) are considered as nominal values and are not considered to be Limited Safety System Settings (LSSS) because power oscillations are treated as a special event and not as an Anticipated Operational Occurrence (AOO), which defines LSSSs.

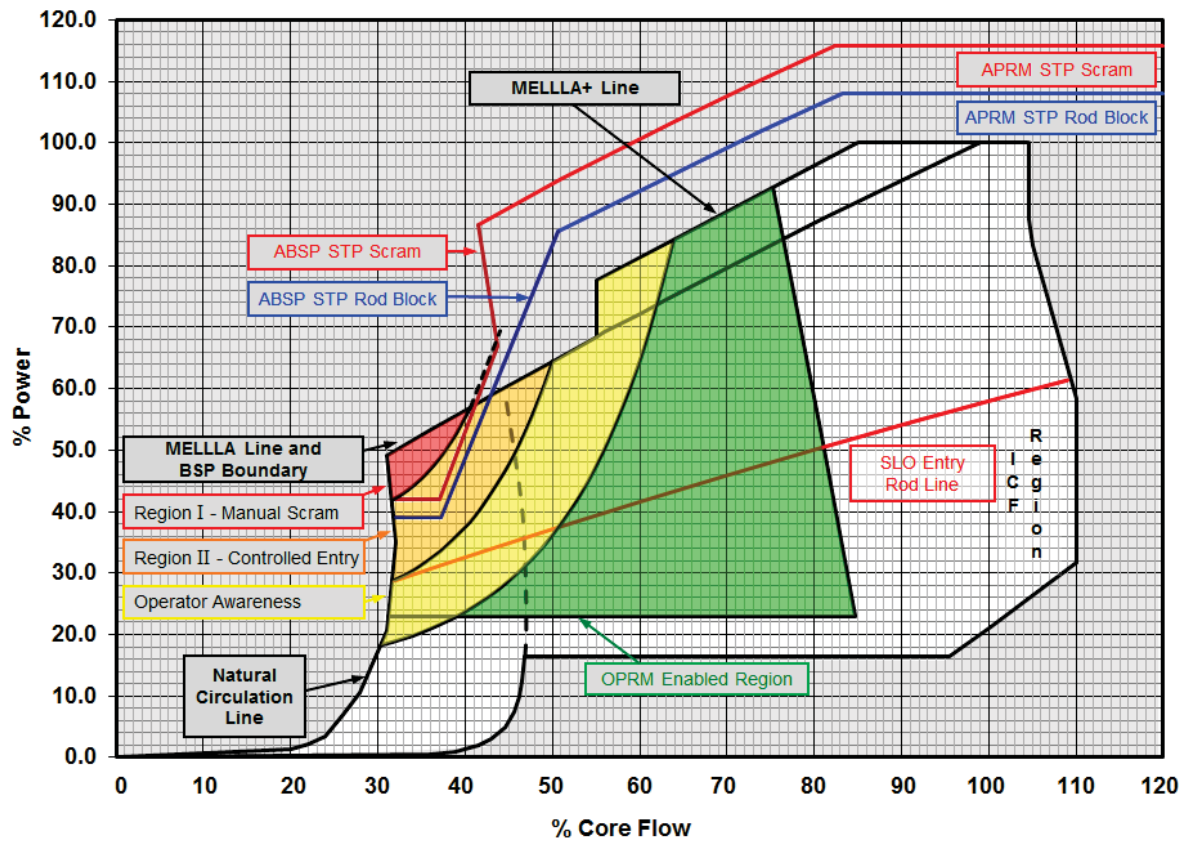


Figure 5-1 Example Brunswick MELLLA+ Power/Flow Map

6.0 CONCLUSION

The method described in this report establishes minimum required OLMCPRs to protect the Brunswick SLMCPR with at least a 95% probability at a 95% confidence level for the most limiting instability event from the MELLLA+ operating domain. The multi-stage analysis verifies that ICO do not invalidate the assumption that the RPS can detect and suppress oscillations prior to violation of fuel design limits at the same probability and confidence level. The process described in Section 3.2 ensures the use of the proprietary CDA installed at the Brunswick plant as the licensing basis provides an equivalent level of protection as described in Reference 1. As described in Section 3.3, in the event that the RAMONA5-FA simulation for a particular case does not bound the time of CDA suppression or algorithm independent limit cycle the case will be treated as most-limiting for both FoM or the RAMONA5-FA simulation time will be extended.

The calculation process for the manual BSP regions (scram and controlled entry) is described in Reference 1 and both of the two BSP methods defined in the Brunswick Technical Specifications are based on these cycle-specific calculations. The preferred method is the ABSP which utilizes adjustments to the automatic APRM STP flow-biased scram setpoint to bound the manual BSP scram region. Due to the automatic scram feature of the ABSP, operation in the MELLLA+ operating domain is allowed. The alternate method uses the manual BSP regions and limits operation to below the BSP Boundary. The Brunswick BSP Boundary is defined in this report as the MELLLA boundary which ensures potential instabilities following flow reduction events develop more slowly and can be effectively addressed by the specific BSP manual operator actions.

7.0 REFERENCES

1. ANP-3703P Revision 0, BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA, August 2018.
2. NRC letter to Duke Energy dated September 18, 2018, Brunswick Steam Electric Plant, Units 1 and 2 – Issuance of Amendment Regarding Core Flow Operating Range Expansion (MELLLA+) (EPID L-2016-LLA-0009).
3. NEDO-31960-A, BWR Owner's Group Long-Term Stability Solutions Licensing Methodology, June 1991.
4. NEDO-31960-A Supplement 1, BWR Owner's Group Long-Term Stability Solutions Licensing Methodology, November 1995.
5. NEDC-33075P-A Revision 8, GE Hitachi Boiling Water Reactor Detect and Suppress Solution – Confirmation Density, November 2013.
6. NEDO-33075-A Revision 8, GE Hitachi Boiling Water Reactor Detect and Suppress Solution – Confirmation Density, November 2013.
7. Duke Energy SQA AR 2207955, CDACALC User's, Programmer's and Theory Manual, Revision 0.
8. ANP-3636P Revision 0, Brunswick Unit 1 Cycle 22 Reload Safety Analysis, December 2017 (NRC ADAMS Accession No. ML18211A662).
9. ANP-3560P Revision 0, Brunswick Unit 2 Cycle 23 Reload Safety Analysis, January 2017 (NRC ADAMS Accession No. ML18211A662).

Affidavit for DPC-NE-1009-P, Brunswick Nuclear Plant
Implementation of Best-estimate Enhanced Option-III

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report DPC-NE-1009-P, Revision 0, "Brunswick Nuclear Plant Implementation of Best-estimate Enhanced Option-III," dated September 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(c), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

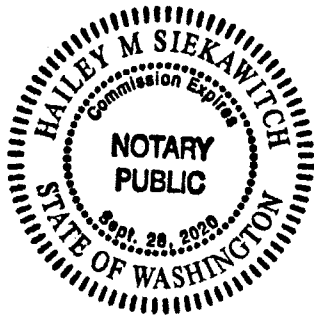
9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

Alan E. Mag

SUBSCRIBED before me this 10th
day of September, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



ANP-3714NP, Brunswick ATRIUM 11 Control Rod Drop
Accident Analyses with the AURORA-B CRDA
Methodology



Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology

ANP-3714NP
Revision 0

September 2018

Framatome Inc.

(c) 2018 Framatome Inc.

Copyright © 2018

**Framatome Inc.
All Rights Reserved**

**ATRIUM is a trademark or registered trademark of Framatome or its
affiliates, in the USA or other countries.**

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 REGULATORY BASIS	2-1
3.0 INITIAL METHODOLOGY DEMONSTRATION.....	3-1
3.1 Initial Conditions	3-1
3.2 Group Pull Sequence.....	3-1
3.3 Inoperable Rod Positions.....	3-1
3.4 Time in Cycle	3-5
3.5 Group Critical Position	3-5
3.6 Determination of Static Rod Worth	3-7
3.7 Transient Evaluation	3-8
4.0 EVALUATION AGAINST CLADDING FAILURE CRITERIA.....	4-1
4.1 High Temperature Cladding Failure	4-1
4.2 PCMI Cladding Failure.....	4-2
4.3 Molten Fuel Cladding Failure Threshold	4-3
5.0 RADIOLOGICAL CONSEQUENCES	5-1
6.0 SYSTEM PRESSURE AND CPR	6-1
7.0 CORE COOLABILITY.....	7-1
8.0 LIMITS AND CONDITIONS	8-1
9.0 REFERENCES	9-1
APPENDIX A EVALUATION THRESHOLD DETERMINATION	A-1
APPENDIX B CRITICAL HEAT FLUX APPLICATION IN STARTUP RANGE	B-1

List of Tables

Table 3.1	Group Pull Sequences	3-1
Table 3.2	Near Critical Range	3-5
Table 3.3	Group Out Eigenvalues	3-6
Table 3.4	Selected Rods with no Inoperable Control Rods	3-7
Table 3.5	Selected Rods with Inoperable Control Rods	3-7
Table 3.6	Initial Conditions	3-8
Table 3.7	Maximum Prompt Enthalpy Rise	3-9
Table 3.8	Total Enthalpy for Rod Drops	3-10
Table 5.1	Example Revised Release Fractions	5-3
Table 7.1	Peak Radial Average Fuel Enthalpy	7-1

List of Figures

Figure 3.1 Location of High Worth A-Sequence Rods.....	3-2
Figure 3.2 Location of High Worth B-Sequence Rods.....	3-3
Figure 3.3 Initial Set of Inoperable Rods for A-Sequence	3-3
Figure 3.4 Initial Set of Inoperable Rods for B-Sequence	3-4
Figure 3.5 Second Set of Inoperable Rods for A-Sequence.....	3-4
Figure 3.6 Second Set of Inoperable Rods for B-Sequence.....	3-5
Figure 4.1 Total Enthalpy versus High Temperature Cladding Failure Threshold	4-1
Figure 4.2 Minimum Failure Threshold Based on EOFP Hydrogen Content.....	4-2
Figure 4.3 PCMI Cladding Failure Results	4-3

Nomenclature

Acronym	Definition
ASME	American Society of Mechanical Engineers
AST	alternate source term
BOC	beginning of cycle
BPWS	banked position withdrawal sequence
BWR	boiling water reactor
CFR	code of federal regulations
CHF	critical heat flux
CPR	critical power ratio
CRDA	control rod drop accident
CWSR	cold work stress relief aka SRA
CZP	cold zero power
EPU	extended power uprate
FoM	figure of merit
GDC	general design criteria
LBRF	licensing basis release fraction
LTR	licensing topical report
LWR	light water reactor
NRC	Nuclear Regulatory Commission, U.S.
PCMI	pellet clad mechanical interaction
PHE	peak hot excess reactivity
RIA	reactivity insertion accident
RPS	reactor protection system
SE	safety evaluation
SRA	stress relief annealed
SRP	standard review plan
SSRF	steady state release fraction
TFGR	transient fission gas release
U. S. NRC	Nuclear Regulatory Commission, U. S.
ΔH	transient change in enthalpy
ΔH_p	prompt enthalpy rise
ΔH_{tot}	total enthalpy rise

1.0 INTRODUCTION

The Framatome AURORA-B CRDA methodology has been used to evaluate the Brunswick ATRIUM 11 equilibrium fuel cycle (Reference 1). The methodology includes the use of a nodal three-dimensional kinetics solution with both thermal-hydraulic (T-H) and fuel temperature feedback. These models provide more precise localized neutronic and thermal conditions than previous methods to show compliance with regulatory criteria for the BWR CRDA event as presented in the U. S. NRC Standard Review Plan Section 15.4.9 (Reference 2) or that presented in Draft Regulatory Guide DG-1327 (Reference 3). The report summarizes the application of the AURORA-B CRDA methodology (Reference 4) on the Brunswick ATRIUM 11 equilibrium cycle.

2.0 REGULATORY BASIS

The current regulatory basis for the acceptance criteria for the Brunswick licensing is fuel failure at 170 cal/g and violent expulsion of fuel at 280 cal/g consistent with Reference 5 (SRP 15.4.9, Revision 2). It is anticipated that the final criteria will be similar to that presented in DG-1327 and will be applied in the near future. Therefore this demonstration evaluation using the methodology of Reference 4 is applied assuming the criteria of DG-1327.

3.0 INITIAL METHODOLOGY DEMONSTRATION

The initial application of the AURORA-B CRDA methodology involves sensitivity studies and determination of an evaluation boundary. The determination of the evaluation boundary provided in Appendix A is a demonstration of the process discussed in Reference 4 for Brunswick.

3.1 *Initial Conditions*

Sensitivity studies are performed [

]

3.2 *Group Pull Sequence*

All allowed pull orders are evaluated such that each rod group, with the exception of rod groups 5 and 6, are pulled as the second group as indicated in Table 3.1.

Table 3.1 Group Pull Sequences

	Analyzed Groups for both A and B sequences
1 st and 2 nd groups	(1,2), (2,1), (3,4), (4,3)
3 rd and 4 th groups	(3,4), (4,3), (1,2), (2,1)

3.3 *Inoperable Rod Positions*

A maximum of 8 inoperable rods are allowed for this plant with-up to three inoperable rods per group. To maximize the worth of the second group rod drops, three inoperable rods are assigned to the first group in each sequence. [

] The assignment of inoperable rods adhered to the separation criteria on a group bases.

The locations of high worth control rod drops without inoperable control rods were identified as indicated in Figure 3.1 and Figure 3.2. Inoperable control rods were assigned to increase these dropped worth values. The inoperable rods are first set nearer the core periphery as indicated in Figures 3.3 and 3.4. For the second set of inoperable rods, the inoperable rods are moved further in from the edge to further reduce the effective core size and increase the rod worth as indicated in Figure 3.5 and 3.6. For each set of inoperable rods, all rods in the next group were dropped to evaluate the impact of the inoperable rods.

A sequence

	1	2	3	4	5	6	7	8	9	10	11	12	13
51					5	2	6	1	5				
47			3	6	4	7	3	7	4	6	3		
43		1	9	2	10	1	9	2	10	1	9	2	
39		6	4	7	3	8	4	8	3	7	4	6	
35	5	2	10	1	9	2	10	1	9	2	10	1	5
31	4	7	3	8	4	7	3	7	4	8	3	7	4
27	6	1	9	2	10	1	9	2	10	1	9	2	6
23	3	7	4	8	3	7	4	7	3	8	4	7	3
19	5	2	10	1	9	2	10	1	9	2	10	1	5
15		6	3	7	4	8	3	8	4	7	3	6	
11		1	9	2	10	1	9	2	10	1	9	2	
7			4	6	3	7	4	7	3	6	4		
3					5	2	6	1	5				
	2	6	10	14	18	22	26	30	34	38	42	46	50

Figure 3.1 Location of High Worth A-Sequence Rods

B sequence

	1	2	3	4	5	6	7	8	9	10	11	12	13
51					1	5	2	5	1				
47			6	3	10	4	9	3	10	4	6		
43		5	1	8	2	7	1	7	2	8	1	5	
39		3	10	4	9	3	10	4	9	3	10	4	
35	1	8	2	7	1	8	2	8	1	7	2	8	1
31	6	4	9	3	10	4	9	3	10	4	9	3	6
27	2	7	1	8	2	7	1	7	2	8	1	7	2
23	6	3	9	4	10	3	9	4	10	3	9	4	6
19	1	8	2	7	1	8	2	8	1	7	2	8	1
15		4	10	3	9	4	10	3	9	4	10	3	
11		5	1	8	2	7	1	7	2	8	1	5	
7			6	4	10	3	9	4	10	3	6		
3					1	5	2	5	1				
	2	6	10	14	18	22	26	30	34	38	42	46	50

Figure 3.2 Location of High Worth B-Sequence Rods

Figure 3.3 Initial Set of Inoperable Rods for A-Sequence



Figure 3.4 Initial Set of Inoperable Rods for B-Sequence



Figure 3.5 Second Set of Inoperable Rods for A-Sequence



Figure 3.6 Second Set of Inoperable Rods for B-Sequence

3.4 *Time in Cycle*

[

]

3.5 *Group Critical Position*

The first step is to evaluate the end of group or bank position k-effective values to determine where criticality is anticipated to occur for the given rod withdrawal sequence. The near critical range, determined per Section 7.4.1 of Reference 4, is given in Table 3.2. The calculated k-effective values at the end of groups 1 through 4 for the A and B sequence withdrawals are given in Table 3.3. [

]

Table 3.2 Near Critical Range

[		]

[illegible]

3.6 ***Determination of Static Rod Worth***

Based on the results of the group worth, static rod worths were then determined. From the static rod drops, [

] The

selected rods for transient evaluation are:

Table 3.4 Selected Rods with no Inoperable Control Rods

Table 3.5 Selected Rods with Inoperable Control Rods

3.7 *Transient Evaluation*

The evaluation of each rod drop is performed with the AURORA-B system. The initial pre-rod drop state point is established with the MICROBURN-B2 core simulator. The initial conditions used for the transient calculation are identified in Table 3.6.

Table 3.6 Initial Conditions

The channel grouping with a [] is used for this analysis.

Once the channel grouping is defined, the power history information is processed to obtain the fuel rod characteristics for use in the RODEX-4 rod mechanical models.

The maximum prompt enthalpy increase for the peak rod and the maximum total enthalpy reported include the application of the uncertainty multiplier of [] on the enthalpy increase. The prompt enthalpy increase is given in Table 3.7 and the total enthalpy is given in Table 3.8.

Table 3.7 Maximum Prompt Enthalpy Rise

Table 3.8 Total Enthalpy for Rod Drops

4.0 EVALUATION AGAINST CLADDING FAILURE CRITERIA

4.1 *High Temperature Cladding Failure*

[

]



Figure 4.1 Total Enthalpy versus High Temperature Cladding Failure Threshold

4.2 *PCMI Cladding Failure*

The ATRIUM 11 fuel is clad with stress relief annealed (SRA) Zircaloy-2 cladding. (Framatome uses the term Cold Work Stress Relieved CWSR to refer to SRA material.) Since it is not recrystallized annealed (RXA) cladding, the SRA low temperature failure threshold is applied.

To establish the minimum failure threshold, the maximum pin nodal hydrogen at end of cycle was tabulated for each assembly. [

]



Figure 4.2 Minimum Failure Threshold Based on EOFP Hydrogen Content

Since 150 $\Delta\text{cal/g}$ is the maximum of the failure threshold curve, [

] The rod drops were evaluated with and

without inoperable control rods. [

]



Figure 4.3 PCMI Cladding Failure Results

4.3 Molten Fuel Cladding Failure Threshold

[

]

5.0 RADIOLOGICAL CONSEQUENCES

The dose consequences for the CRDA determined for Brunswick are summarized in the BSEP UFSAR. The current licensing basis dose evaluation bounds 1129 ATRIUM 11 rod failures. Since no rod failures were determined, for high temperature cladding failure, PCMI failure, or molten fuel cladding failure, this event remains within the current evaluated dose consequences for Brunswick.

Evaluation of dose consequences for rod failures

If rod failures had been identified, then revised release fractions or total release fraction (TOTR) would be determined using the Licensing Basis Release Fractions (LBRF) from RG 1.183 as the steady state release fractions (SSRF) with the transient fission gas release (TFGR) as described in DG-1327. A ratio of the new TOTR to the LBRF used in the original licensing basis is then generated following the method provided in ANP-10333PA. The following example of this application is provided to show the impact if rod failures occur.

The transient release terms, from Reference DG-1327, expressed as a fraction are:

Peak Pellet BU < 50 GWd/MTU:

$$TFGR = \frac{[(0.26 * \Delta H - 13)]}{100} \geq 0$$

Peak Pellet BU ≥ 50 GWd/MTU:

$$TFGR = \frac{[(0.26 * \Delta H - 5)]}{100} \geq 0$$

The total rod release fraction TOTR is dependent on the nuclide group and the enthalpy dependent TFGR average over the 25 nodes of fuel for a full length fuel rod. (If the failure were in a shorter rod, the number of axial nodes would be decreased accordingly.)

Burnup < 50:

$$TOTR = SSRF + \frac{\sum_k \frac{[(0.26 * \Delta H) - 13]}{25}}{100} * GMUL$$

Burnup ≥ 50 :

$$TOTR = SSRF + \frac{\sum_k \frac{[(0.26 * \Delta H) - 5]}{25}}{100} * GMUL$$

Where,

- ΔH fuel enthalpy increase (cal/g)
- SSRF is the steady state release fraction
- Three multipliers (GMUL) are established in DG-1327 to be applied to the above TFGR term:

Group	GMUL	Applied to
Stable long lived isotopes (e.g., Kr-85)	1.0	Kr-85
Cs-134 and Cs-137	1.414	Alkali Metals
Short-lived radioactive isotopes (i.e., I, Xe and Kr noble gases except Kr-85)	0.333	Iodines, nobles, halogens

As noted above, the LBRF are utilized for Brunswick as the SSRF for the respective groups.

For this example, 43 rods were forced to fail by applying a hypothetical threshold of 100 cal/g and it is assumed for simplicity that the enthalpy increase in all rods is the same as that of the peak rod. If actual rod failures had been identified, enthalpy increase specific to each failed rod would be used. The total rod release fractions are provided in Table 5.1. [

]

6.0 SYSTEM PRESSURE AND CPR

The impact of the CRDA on system pressure was addressed in Reference 4 and does not cause stresses to exceed Emergency Condition (Service Level C), as defined in Section III of the ASME Boiler and Pressure Vessel code. This generic evaluation on the impact of CRDA on system pressure remains applicable for Brunswick.

The CPR response was evaluated in Section 7.7 of Reference 4 and resulted in a conclusion that the CRDA in the power range is [

]

7.0 CORE COOLABILITY

Two criteria are identified in Reference 3 for allowable limits with respect to core coolability.

- Peak radial average enthalpy <230cal/g
- The peak fuel temperature in the outer 90 percent of the pellet's volume must remain below incipient fuel melting conditions

[

]

Table 7.1 Peak Radial Average Fuel Enthalpy

8.0 LIMITS AND CONDITIONS

The SER for the Reference methodology included a number of limitations and conditions. Some of the conditions are from the base AURORA-B AOO methodology (Reference 6) and additions specific to the CRDA are included. The numbering of the limitations and conditions below is consistent with that found in the AURORA-B CRDA SER.

1. AURORA-B may not be used to perform analyses that result in one or more of its CCDs (S-RELAP5, MB2-K, MICROBURN-B2, RODEX4) operating outside the limits of approval specified in their respective TRs, SEs, and plant-specific license amendment requests (LARs). In the case of MB2-K, MB2-K is subject to the same limitations and conditions as MICROBURN-B2. *(This is Condition 1 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

This condition is met for application of the AURORA-B CRDA methodology to Brunswick.

14. The scope of the NRC staff's approval of AURORA-B does not include the ABWR design. *(This is Condition 14 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

This condition is met for Brunswick since it is a BWR/4.

20. The implementation of any new methodology within the AURORA-B EM (i.e., replacement of an existing CCD) is not acceptable unless the AURORA-B EM with the new methodology incorporated into it has received NRC review and approval. An existing NRC-approved methodology cannot be implemented within the AURORA-B EM without NRC review of the updated EM. *(This is a revised version of Condition 20 of the SE for the base AURORA-B TR, rewritten to be specific to the CRDA application. It remains applicable to CRDA analyses for BWRs/2-6.)*

The evaluation model will be implemented for Brunswick as described in the base AURORA-B and AURORA-B CRDA Topical Reports. No CCD as described in the TR are replaced and therefore the intent of this condition is met.

21. NRC-approved changes that revise or extend the capabilities of the individual CCDs comprising the AURORA-B EM may not be incorporated into the EM without prior NRC

approval. *(This is Condition 21 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

[

]

22. As discussed in Section 3.3.1.5 and Section 4.0 of Reference 6 (the SE for the base AURORA-B TR), the SPCB and ACE CPR correlations for the ATRIUM-10 and ATRIUM-10XM fuels, respectively, are approved for use with the AURORA-B EM. Other CPR correlations (existing and new) that would be used with the AURORA-B EM must be reviewed and approved by the NRC or must be developed with an NRC-approved approach such as that described in EMF-2245(P)(A), Revision 0, "Application of Siemens Power Corporation's Critical Power Correlations to Co-Resident Fuel". Furthermore, if transient thermal-hydraulic simulations are performed in the process of applying AREVA CPR correlations to co-resident fuel, these calculations should use the AURORA-B methodology. *(This is Condition 22 of the SE for the base AURORA-B TR. It remains applicable to at-power CRDA analyses for BWRs/2-6.)*

This condition is met within ANP-10333PA for at power evaluations.

23. Except when prohibited elsewhere, the AURORA-B EM may be used with new or revised fuel designs without prior NRC approval provided that the new or revised fuel designs are substantially similar to those fuel designs already approved for use in the AURORA-B EM (i.e., thermal energy is conducted through a cylindrical ceramic fuel pellet surrounded by metal cladding, flow in the fuel channels develops into a predominantly vertical annular flow regime, etc.). New fuel designs exhibiting a large deviation from these behaviors will require

NRC review and approval prior to their implementation in AURORA-B. *(This is Condition 23 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

This condition is met as ATRIUM 11 does exhibit the structural similarities described in the restriction.

24. Changes may be made to the AURORA-B EM in the [

] areas discussed in Section 4.0 of Reference 6 (the SE for the base AURORA-B TR) without prior NRC approval. *(This is Condition 24 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

This condition is met through the use of the Framatome software development procedures which include the 10CFR50.59 licensing evaluation.

25. The parallelization of individual CCDs may be performed without prior NRC approval as discussed in Section 4.0 of Reference 6 (the SE for the base AURORA-B TR). *(This is Condition 25 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

No confirmation is required for this condition.

26. AREVA must continue to use existing regulatory processes for any code modifications made in the [

] areas discussed in Section 4.0 of Reference 6 (the SE for the base AURORA-B TR). *(This is Condition 26 of the SE for the base AURORA-B TR. It remains applicable to CRDA analyses for BWRs/2-6.)*

This condition is met through the use of the Framatome software development procedures which include the 10CFR50.59 licensing evaluation.

27. The control rod model at each location in the core used for CRDA analyses with the AURORA-B EM shall use a control rod geometry and composition that is verified to bound the control rod worth for the physical control rod used in that location, for all axial elevations.

[

] Therefore, this condition is met.

28. Licensees utilizing AURORA-B to perform CRDA analyses using the methodology described in this TR shall confirm that the recommended maximum rod velocity of 3.11 ft/s is conservative for their control rods.

The licensee has confirmed that this condition is met for the control rods at Brunswick.

29. If the check to verify that the total enthalpy is limiting at 10 percent core flow CZP conditions by [

] fails, AREVA shall perform a more comprehensive evaluation to verify that they have identified the limiting initial conditions for that plant. This evaluation should consider a range of flow values and corresponding plant-specific minimum temperatures that is sufficiently broad to clearly identify the combination of initial conditions which maximizes the total enthalpy for the limiting rod.

[

1

Therefore, the initial condition of 10% flow at 68F is a conservative initial condition for Brunswick with ATRIUM 11 fuel for determining the total enthalpy.

30. When individual control rods are evaluated using the CRDA analysis methodology, if necessary, alternate distributions of inoperable rods should be utilized to ensure inclusion of at least one evaluation within each group of 4 quadrant symmetric control rods that maximizes the change in face- and/or diagonally-adjacent uncontrolled cells as a result of the candidate control rod withdrawal.

Alternate inoperable control blade patterns were evaluated for all rods [

】 For the Brunswick core, pushing power to the center is an effective means of increasing rod worth by making the effective core size smaller.

31. The evaluation boundary curve used to determine candidate control rods for further evaluation based on their static rod worths must be verified to bound the following local

characteristics of the fuel being evaluated: design pin peaking factors, fuel assembly design, location in or adjacent to the outermost ring of control rods, and average burnup for the 16 fuel assemblies surrounding the rod of interest.

This condition is addressed in Appendix A for this demonstration analysis.

32. If the highest worth rod at a given core statepoint results in a total enthalpy that is higher than the minimum high temperature failure threshold (i.e., lowest threshold for all rod internal pressures), additional rods must be considered for evaluation. This may be done by evaluating the next highest worth rods at the core statepoint of interest until the minimum high temperature failure threshold is met, or by using an approach analogous to the evaluation boundary curve used for the PCMI failure threshold (as subject to condition 29).

The highest rod worth did result in a total enthalpy which exceeded the minimum high temperature failure threshold. Therefore, additional rods were evaluated to address this condition. (See Section 4.1)

33. If the methodology described in ANP-10333 is used to analyze the CRDA event with a fuel assembly design that has a different fuel rod geometry and/or manufacturing tolerances than the one used as a basis for the sensitivity study on gap width, the sensitivity study shall be repeated for the new fuel assembly design, using bounding values consistent with the uncertainty range for [] limiting increase in the peak total enthalpy, the total uncertainty shall be increased accordingly for total enthalpies calculated based on the new fuel assembly design.

The ATRIUM 11 product line requires an evaluation of the gap sensitivity study. The sensitivity studies were performed with a bounding value for the uncertainty range of []

[]. The resulting increase in peak total enthalpy []

34. The uncertainty designated in the CRDA TR of [] for the enthalpy rises calculated using the CRDA analysis methodology may not be reduced without prior NRC approval.

The uncertainty of [] percent is used in this evaluation.

9.0 REFERENCES

1. ANP-3661P, Revision 0, Brunswick ATRIUM 11 Equilibrium Cycle Fuel Cycle Design, Framatome, July 2018.
2. NUREG-0800, Section 15.4.9, Revision 3, "SPECTRUM OF ROD DROP ACCIDENTS (BWR)." *Standard Review Plan: LWR Edition*, US NRC: Washington, DC. March 2007.
3. DG-1327, Pressurized Water Reactor Control Rod Ejection and Boiling Water reactor Control Rod Drop Accidents, November 2016 (NRC ADAMS ML16124A200).
4. ANP-10333P-A, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Control Rod Drop Accident (CRDA), Framatome, March 2018.
5. NUREG-0800, Section 15.4.9, Revision 2, "SPECTRUM OF ROD DROP ACCIDENTS (BWR)." *Standard Review Plan: LWR Edition*, US NRC: Washington, DC. July 1981.
6. ANP-10300P-A, Revision 1, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Framatome, January 2018.

Appendix A Evaluation Threshold determination

Limitation and Condition 31 states:

31. The evaluation boundary curve used to determine candidate control rods for further evaluation based on their static rod worths must be verified to bound the following local characteristics of the fuel being evaluated: design pin peaking factors, fuel assembly design, location in or adjacent to the outermost ring of control rods, and average burnup for the 16 fuel assemblies surrounding the rod of interest.

The process to generate an evaluation threshold is demonstrated based upon the process described in the response to RAI-5 in ANP-10333Q1P (included in Reference 4). The peak pin enthalpy rise was elevated using a multiplication factor of [] to double the uncertainty. The elevated enthalpy rise values were then tabulated against the static rod worth.



Figure A.1 Establishing Evaluation Boundary



Figure A.2 Evaluation boundary for ATRIUM 11 Core

Using the evaluation boundary on this cycle, for interior assemblies, [

]

For peripheral control rods [

]

The local characteristics of fuel used to establish the evaluation boundary with respect to design pin peaking factors, fuel assembly design, core location, and the average burnup of the 16 assemblies around the dropped rod have been are provided in Table A.1. This table is for use with future core licensing to confirm the applicability of the evaluation boundary curve.

Table A.1 Example Evaluation Boundary Characteristics

Appendix B Critical Heat Flux Application in startup range

[

]

Framatome Inc.

ANP-3714NP

Revision 0

Brunswick ATRIUM 11 Control Rod Drop Accident
Analyses with the AURORA-B CRDA Methodology

Page B-2

[

]



Figure B.1 Total Enthalpy Rise with CHF Multipliers

Appendix B References

- B-1. D. C. Groeneveld, S. C. Cheng and T. Doan, "1986 AECL-UO Critical Heat Flux Table," Heat Transfer Engineering, 7, pp. 46-62, 1986.
- B-2. D. C. Groeneveld, L. K. H. Leung, P. L. Kirillov, V. P. Bobkov, I. P. Smogalev, V. N. Vinogradov, X. C. Huang, E. Royer, "The 1995 look-up tables for critical heat flux in tubes," Nuclear Engineering and Design, 163, pp.1-23, 1996.
- B-3. D. C. Groeneveld, L. K. H. Leung, Y. Guo, A. Vasic, M. El Nakla, S. W. Peng, J. Yang and S. C. Cheng, "Lookup Tables for Predicting CHF and Film Boiling Heat Transfer: Past, Present, and Future," Nucleat Technology, 152, pp.87-104, 2005.
- B-4. D. C. Groeneveld, J. Q. Shan, A. Z. Vasic, L. K. H. Leung, A. Durmayz, J. Yang, S. C. Cheng and A. Tanase, "The 2006 CHF look-up table," Nuclear Engineering and Design, 237, pp. 1909-1922, 2007.
- B-5. M. Lee, "A critical heat flux approach for square rod bundles using the 1995 Groeneveld CHF table and bundle data of heat transfer research facility," Nuclear Engineering and Design, 197, pp. 357-374, 2000.
- B-6. N. I. Kolev, Check of the 2005 look up table for prediction of CHF in bundles, Nuclear Engineering and Design (In Press 2006).
- B-7. ANP-10332P, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios, February 2014.

Affidavit for ANP-3714P, Brunswick ATRIUM 11 Control
Rod Drop Accident Analyses with the AURORA-B CRDA
Methodology

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report ANP-3714P, Revision 0, "Brunswick ATRIUM 11 Control Rod Drop Accident Analyses with the AURORA-B CRDA Methodology," dated September 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

- (a) The information reveals details of Framatome's research and development plans and programs or their results.
- (b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.
- (c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.
- (d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.
- (e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(a), 6(b), 6(c), 6(d) and 6(e) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge,
information, and belief.

Alan E. McGinnis

SUBSCRIBED before me this 18th

day of September, 2018.

Hailey M. Siekawitch

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020

