UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

RESEARCH & TEST REACTOR

Proposed Contents of PSAR Using NUREG-1537 Guidance for the Micro Modular Reactor (MMR®)

WHITE PAPER

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Proposed Contents of PSAR Using NUREG-1537 Guidance for the Micro Modular Reactor (MMR®)

White Paper

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EXECUTIVE SUMMARY

The University of Illinois Urbana-Champaign (UIUC) is preparing to apply for a permit to construct a Research & Test Reactor (RTR) designed by Ultra Safe Nuclear Corporation (USNC). The proposed reactor is a 15 MWt Micro Modular Reactor (MMR®) utilizing TRISO fuel, helium coolant, and graphite moderator. The construction permit application includes a preliminary safety analysis report (PSAR) which summarizes key aspects of the proposed reactor design.

NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors*, provides guidance from the U.S. Nuclear Regulatory Commission (NRC) on the contents, format, NRC review plan, and acceptance criteria for the safety analysis report. Although it explicitly acknowledges use of alternative coolants, the guidance is intended primarily for light-water cooled reactors (LWRs) of the pool or tank type, so it is not all applicable nor sufficient for the MMR design. Furthermore, not all of the content covered in NUREG-1537, which is intended to be included in a final safety analysis report (FSAR), will be available prior to submittal of the construction application, and this is implicitly acknowledged in 10 CFR 50.35(b) as well in NRC guidance.[1] This paper summarizes the contents that must be included in the PSAR and identifies differences from the content recommended in NUREG-1537 that is either due to features of the MMR design not covered under the guidance, or may not be included in the PSAR for authorization to proceed with construction, but will be incorporated into the FSAR.

[1] The USNRC DRAFT guidance on preapplication engagement for advanced reactors (Reference 1) states, *"…at the construction permit stage, the level of design completeness would not typically support reaching conclusive staff findings on some safety and security topics…"*

CONTENTS

ABBREVIATIONS & ACRONYMS

This list contains the abbreviations and acronyms used in this document.

Abbreviation or Acronym	Definition
AGR	Advanced Gas Reactor
ALARA	As Low as Reasonably Achievable
BDBA	Beyond-Design-Basis Event
CP	Construction Permit
DBA	Design-Basis Accident
DOE	U.S. Department of Energy
DRS	Design Response Spectra
ECCS	Emergency Core Cooling System
ESF	Engineered Safety Feature
FCM	Fully Ceramic Micro-Encapsulated
FPS	Fire Protection System
FSAR	Final Safety Analysis Report
GDC	General Design Criteria
HALEU	High-Assay Low-Enriched Uranium
HIS	Helium Inventory System
HMS	Helium Makeup System
HPS	Helium Purification System
HSS	Helium Switch Station
HTGR	High Temperature Gas-Cooled Reactor
HTR	High-Temperature Reactor
HTTR	High-Temperature Test Reactor
HTS	Heat Transport System
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Control
IHX	Intermediate Heat Exchanger
LCO	Limiting Condition of Operation
LWR	Light-Water Reactor
MHA	Maximum Hypothetical Accident
MMR®	Micro Modular Reactor
MWt	Megawatt Thermal
NRC	U.S. Nuclear Regulatory Commission

Abbreviation or Acronym	Definition
NRR	Office of Nuclear Reactor Regulation
NWPA	Nuclear Waste Policy Act of 1982
PDC	Principal Design Criteria
PMF	Probable Maximum Flood
PSAR	Preliminary Safety Analysis Report
PSHA	Probabilistic Seismic Hazard Analysis
QAPD	Quality Assurance Program Description
RAI	Request for Additional Information
RCCS	Reactor Cavity Cooling System
RCS	Reactivity Control System
RG	Regulatory Guide
RMS	Radiation Monitoring System
RPS	Reactor Protection System
RTR	Research and Test Reactor
SL	Safety Limit
SSCs	Systems, Structures, and Components
SNM	Special Nuclear Material
THTR	Thorium High-Temperature Reactor
TR	Topical Report
TRISO	Tri-Structural Isotropic Fuel Particles
UIUC	University of Illinois Urbana-Champaign
ULTB	Uranium Lease and Take-Back Program
USNC	Ultra Safe Nuclear Corporation
V&V	Verification and Validation

1.0 BACKGROUND AND PURPOSE

1.1. BACKGROUND

An Ultra Safe Nuclear Corporation (USNC) Micro Modular Reactor (MMR®) has been proposed for construction as a Research and Test Reactor (MMR-RTR) to be located on the University of Illinois Urbana-Champaign (UIUC) campus. UIUC has a long history of supporting nuclear technology innovation, operating a TRIGA® research reactor from 1960 until 1998. The proposed MMR-RTR is a 15 MWt helium-cooled, graphite-moderated prismatic block high-temperature gas-cooled reactor (HTGR). The reactor fuel consists of high-assay low-enriched uranium (HALEU) tri-structural isotropic (TRISO) microsphere particles encapsulated in fully ceramic micro-encapsulated (FCM®) compacts which will have excellent thermal stability and fission product retention. The fuel compacts are located in prismatic graphite fuel assemblies that make up the core assembly.

UIUC intends to apply for a Construction Permit (CP) under Title 10, Code of Federal Regulations Part 50 (10 CFR 50) to construct the MMR-RTR. To this end, the U.S. Nuclear Regulatory Commission (NRC) encourages early engagement throughout the pre-application period to decrease regulatory uncertainty and receive feedback on the proposed reactor design and licensing strategy (Reference 1). UIUC has submitted a Regulatory Engagement Plan (Reference 2) to the NRC which provides a project description, proposed licensing approach, and schedule expectations. As part of the CP application process, UIUC will submit a Preliminary Safety Analysis Report (PSAR) to the NRC. The PSAR describes the preliminary reactor design, presents design criteria and bases, and discusses potential accident scenarios along with the design features and operational procedures that mitigate their consequences. Guidance on the format and content of license applications for non-power reactors is provided in NUREG-1537 (Reference 3). In its review, “the Commission is directed to impose only such minimum amount of regulation of the licensee as the Commission finds will permit the Commission to fulfil its obligations under this [the Atomic Energy Act of 1954, as amended]” (Reference 4, Section 104).

1.2. PURPOSE

The purpose of this report is to identify (a) items that UIUC plans to include in the PSAR for the purposes of obtaining a CP only and (b) items that are specified in NUREG-1537 but are non-applicable due to unique design characteristics of the MMR. Additionally, some information required in the license application is not yet available because design and analysis work has not been finalized. This report will identify content appropriate for a HTGR non-power reactor and other content which may be deferred from the PSAR to the Final Safety Analysis Report (FSAR) without compromising the NRC’s ability to adequately review and approve the CP application.

UIUC requests that the NRC review this white paper submittal and provide feedback on the following:

1. Sufficiency of information (both topics covered and level of detail) for submittal of a PSAR.
2. For methodologies and content that conform with NUREG-1537, confirm that the interpretation of the guidance discussed herein is correct.
3. For design details that are not consistent with or addressed in NUREG-1537, confirm that the information planned to be provided is appropriate.
4. For content that is not expected to be available at the time of PSAR submittal, confirm that the information proposed to be provided in the PSAR is sufficient for the CP review.

2.0 GENERAL PSAR GUIDANCE

Section 50.34(a) of Title 10 of the Code of Federal Regulations (10 CFR 50.34(a)) (Reference 12.a) specifies that a PSAR must be submitted in an application for a CP and summarizes the information to be included. NUREG-1537 (Reference 3) provides detailed guidance on the content in a license application for a non-power reactor, as well as the standard review plan and acceptance criteria used by the NRC staff. Conforming with NUREG-1537 is not required but is strongly recommended to ensure completeness of the application, simplify the NRC review, reduce need for requests for additional information (RAIs), and shorten overall review time.

NUREG-1537 suggests framing the license application as 18 chapters addressing the following topics:

1. The Facility
2. Site Characteristics
3. Design of Structures, Systems, and Components
4. Reactor Description
5. Reactor Coolant Systems
6. Engineered Safety Features
7. Instrumentation and Control Systems
8. Electrical Power Systems
9. Auxiliary Systems
10. Experimental Facilities and Utilization
11. Radiation Protection Program and Waste Management
12. Conduct of Operations
13. Accident Analyses
14. Technical Specifications
15. Financial Qualifications
16. Other License Considerations
17. Decommissioning and Possession-Only License Amendments
18. Highly Enriched to Low-Enriched Uranium Conversions

The PSAR will follow this structure and provide the most up-to-date information and plans for each chapter. It is not expected that final design information or analysis results be presented in the PSAR, but sufficient detail shall be included to ensure the NRC staff has the requisite information "to promote the common defense and security and to protect the health and safety of the public and will permit the conduct of widespread and diverse research and development" (Reference 4, Section 104). The PSAR will identify any information that is not available at the time of submittal but will be included in the FSAR.

The PSAR does not need to address non-applicable content in detail, but adequate justification for why it does not apply to the MMR design will be included to facilitate the NRC staff review. In addition, gaps in the NUREG-1537 guidance pertinent to a HTGR will be addressed.

3.0 PSAR TOPICS

This section summarizes information to be included in each chapter of the PSAR. Content that is not applicable to the MMR or is not expected to be presented in the PSAR but will be provided in the FSAR is identified, as is supplemental information. As this document is intended to complement rather than replace NUREG-1537 (Reference 3) as a content guide and will be consulted throughout preparation of the PSAR, information that is consistent with NUREG-1537 will be provided in each section except where otherwise identified. NUREG-1537, Part 2 provides the NRC standard review plan and acceptance criteria which shall be used by UIUC and USNC to ensure completeness of the application. Given the LWR focus of NUREG-1537, Part 2, UIUC, USNC, and the NRC will work together to identify additional criteria that are not specifically addressed in the current document.

The numbering of the sub-sections below is consistent with that of the content guide in NUREG-1537. However, some sections do not deviate from the guidance of NUREG-1537 at all (e.g., introductions, summary descriptions), and therefore are not discussed in detail in this document. These sections are still included to preserve the numbering consistency.

3.1. THE FACILITY

3.1.1. Introduction

See Section 1.1 of NUREG-1537.

3.1.2. Summary and Conclusions on Principal Safety Considerations

See Section 1.2 of NUREG-1537.

3.1.3. General Description

See Section 1.3 of NUREG-1537.

3.1.4. Shared Facilities and Equipment

The MMR will be a standalone facility that is not expected to share structures, systems and components (SSCs) required for reactor safety with other facilities. However, it will share infrastructure with nearby facilities that is of low safety significance and non-safety-related not needed for reactor safety (e.g., AC electrical supply, water supply, gas for HVAC, access roads). Unless specifically identified by the design, the PSAR shall state that systems with high safety significance are not shared and perturbations at nearby facilities which may impact shared infrastructure will not adversely affect safe reactor operation.

3.1.5. Comparison with Similar Facilities

Comparisons will be drawn to other HTGRs, both operating and decommissioned, especially those with TRISO fuel encapsulated in prismatic fuel assemblies, helium coolant, or graphite moderator. More specifically:

- The 842 MWt Fort St. Vrain Generating Station (United States), which was the first HTGR in the United States to deploy a TRISO fuel cycle in prismatic shaped graphite fuel assemblies (Reference 5).
- The 10 MWt HTR-10 and 250 MWt HTR-PM (China) deploying TRISO fuel in a core geometry using graphite pebbles as the fuel assemblies (Reference 6).
- The 30 MWt HTTR (Japan) which also deploys TRISO fuel but in prismatic graphite fuel assemblies (Reference 7).

In addition, the use of graphite as a moderator has been demonstrated in the Advanced Gas Reactor (AGR) operated at five nuclear generating stations in the United Kingdom using CO_2 as coolant (Reference 8). The use of helium as the coolant has been demonstrated in several HTGRs, including Peach Bottom Unit 1 (United States, Reference 9), Fort St. Vrain, the HTTR, the HTR-10 and HTR-PM, the AVR (Germany, Reference 10), and the THTR-300 (Germany, Reference 11).

3.1.6. Summary of Operations

The PSAR will state the primary purpose of the reactor facility and summarize reactor operations. Parameters such as expected operating life, power level, and power cycling will be given. Fission product inventory, radioactive byproduct, and effluent release will be introduced in this section and will reference the discussion in Section 3.11.

3.1.7. Compliance with the Nuclear Waste Policy Act of 1982 (NWPA)

The MMR will be covered under the U.S. Department of Energy (DOE) Uranium Lease and Take-back Program (ULTB) which provides fresh fuel to domestic University Research Reactors and collects the spent fuel at the end of the operating life. The PSAR will state that disposal of high-level nuclear waste and spent fuel will be covered by the ULTB program.

Details of the ULTB Program agreement between UIUC and DOE, and required compliance by the licensee with the NWPA, will be provided in the FSAR.

3.1.8. Facility Modifications and History

This section is intended to document any facility modifications during a license amendment request. As a new facility undergoing initial construction, commissioning, and operations, it does not need to be included in the license application.

3.2. SITE CHARACTERISTICS

3.2.1. Geography and Demography

Site Location and Description

The CP application will need to comply with the reactor site criteria in 10 CFR 100, Subpart A (Reference 12.g) when selecting a site. The PSAR will describe the site location in Universal Transverse Mercator coordinates and discuss any prior use of the site. The site location will be identified with respect to nearby geographic features and major facilities (e.g., rivers, lakes, reservoirs, mountains, highways, industrial plants, airports). Boundary and zone area maps consistent with the 10 CFR 100.11 requirements will also be included in the PSAR.

Population Distribution

Population data from the most recent census data will be provided with sufficient information to inform the dose calculations at various distances from the facility. Maps will be included that clearly characterize the population distribution within 8 km of the site. The PSAR will discuss the resident and transient populations surrounding the reactor site. The MMR is located on the edge of the UIUC campus which has a student population of over 50,000 which is approximately a third of the size of the permanent resident population of Urbana-Champaign. Future population projections until the end of the reactor operating license will be included in the PSAR.

3.2.2. Nearby Industrial, Transportation, and Military Facilities

Major nearby facilities and transportation routes will be identified on maps showing the distance from the reactor site. Facilities and routes to consider include:

- Industrial plants (e.g., manufacturing, processing, chemical)
- Military bases or missile sites
- Highways, railroads, and waterways
- Airports and airways
- Pipelines

The impacts of potential accidents at the nearby sites on reactor operation must be evaluated. Accidents to consider include:

- Explosions
- Flammable vapor clouds
- Toxic chemical release
- Fire
- Aircraft collision

Preliminary evaluations of these external hazards will be included in the PSAR. Prior hazard analyses from nearby facilities may be cited to support the safety bases. More detailed site-specific evaluations will be provided in the FSAR.

Potential accidents associated with onsite chemical storage will be considered in the license application. However, it is not required that chemical storage amounts and locations be finalized prior to reactor construction. Therefore, evaluation of on-site chemical storage does not need to be discussed in the PSAR but will be included in the FSAR.

3.2.3. Meteorology

The regional climate of the site will be discussed in the PSAR. Meteorological phenomena to consider include:

- Thunderstorms and lightning
- Precipitation (rain, snow, hail, sleet, ice)
- Extreme winds, tornados, and hurricanes
- Average and extreme temperature and humidity

Historical meteorological data for the region and local site will be included to support the proposed design and operating basis values. The design basis will consider predicted meteorological conditions throughout the life of the facility, accounting for the impacts of climate change.

Atmospheric dispersion models for accidental radiological release are not expected to be included in the PSAR but will be included in the FSAR. The PSAR will include present meteorological data that will be input to the dispersion model and discuss the intended methodology and any preliminary results available at the time of submittal.

3.2.4. Hydrology

The PSAR will describe the local hydrology of the site including any major waterways, reservoirs, surface water, and groundwater. Flooding caused by severe rain or dam failure will be considered. Flooding analyses from nearby sites may be cited to support the safety basis. A site-specific probable maximum flood (PMF) evaluation will be included in the FSAR.

3.2.5. Geology, Seismology, and Geotechnical Engineering

The applicant is expected to comply with the seismic and geologic siting criteria in 10 CFR 100, Appendix A (Reference 12.h) when selecting a site. The PSAR will describe the geologic features in the region surrounding the reactor site. Any nearby known faults and associated seismic activity will be identified. A preliminary vibratory ground motion analysis, which includes a probabilistic seismic hazard analysis (PSHA) and establishes the design response spectra (DRS), shall be included in the PSAR. Site-specific seismic response analyses will be performed during site construction and the DRS updated accordingly in the FSAR. Surface faulting potential due to earthquakes and liquefaction potential of foundation (if not deployed to bedrock) will be evaluated in the FSAR, but do not need to be addressed in detail in the PSAR.

3.3. DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

3.3.1. Design Criteria

The PSAR will define principal design criteria (PDC) which, if satisfied, ensure safe reactor operation, shutdown, and response to potential accidents. Regulations and guidance documents that will be used in developing the PDCs, including RG 1.232 (Reference 20.a) and 10 CFR 50, Appendix A (Reference 12.f), will be identified. Appendix A of 10 CFR 50 provides guidance in establishing PDCs, but per RG 1.232, non-LWR applicants do not need to request exemptions from the general design criteria (GDC) in 10 CFR 50, Appendix A.

3.3.2. Meteorological Damage

The potential for damage to important-to-safety SSCs caused by severe precipitation and wind loads will be considered in the PSAR. The process for determining design basis loading conditions will be discussed.

3.3.3. Water Damage

The potential for damage to important-to-safety SSCs caused by internal or external flooding will be discussed in the PSAR. Design features that mitigate the consequences of flooding will be identified. A site-specific evaluation of the PMF will be provided in the FSAR.

3.3.4. Seismic Damage

The potential for damage to important-to-safety SSCs caused by seismic events will be discussed in the PSAR. Building codes used in the design of SSCs will be cited. The safety classification of SSCs regarding seismic design criteria will be provided. Structural analysis will be performed for SSCs that are credited in postulated accident scenarios.

3.3.5. Systems and Components

The design bases of SSCs required for safe reactor operation and shutdown and their responses to potential accident conditions and external events will be described in the PSAR. The safety classification and seismic classification of SSCs will be discussed. Comparisons to similar facility designs may be cited to support the design bases of the

SSCs. The design features that mitigate consequences of potential accidents such as flooding will be further evaluated in the FSAR.

3.4. REACTOR DESCRIPTION

3.4.1. Summary Description

See Section 4.1 in NUREG-1537.

3.4.2. Reactor Core

The PSAR will describe the reactor core, including the reactor fuel, reactor control and shutdown systems, neutron moderator and reflectors, neutron startup sources, and the core support structure. The key design principles of the FCM® TRISO fuel and the functional containment strategy will be discussed. The graphite moderator has unique degradation modes under irradiation that are not addressed in NUREG-1537 such as swelling, decrease in thermal conductivity, and decrease in thermal expansion coefficient, and the PSAR will discuss irradiation effects on graphite properties and performance. Graphite is also susceptible to oxidation and potentially combustion during an air ingress event; therefore, an evaluation of an air ingress event will be included in the PSAR. Operating limits (i.e., temperature, pressure) for the fuel and moderator will also be provided in the PSAR.

The fuel fabrication, inspection, and quality control processes will be introduced in the PSAR but discussed in detail in the FSAR. The Quality Assurance program described in Section 12.9 will be shown to contain quality control provisions to ensure fabrication processes are consistent with design assumptions.

Prior fuel qualification efforts and future test plans will be explained. In particular, Topical Report (TR) EPRI-AR-1(NP)-A (Reference 13) and its applicability to the MMR fuel will be discussed. A complete evaluation of FCM TRISO fuel performance including analysis results and test data that demonstrate the conditions and limitations outlined in Reference 13 are not exceeded for the MMR will be included in the FSAR.

The reactivity control and shutdown system designs will be described in detail to understand how safe reactor shutdown from any operating state or accident condition is ensured. A detailed evaluation of the control and shutdown elements including quantification of reactivity change as a function of travel and time will be included in the FSAR to validate the reactivity insertion curves assumed for the safety analyses. The FSAR will also contain more detailed evaluations of the neutron moderator, reflector, and startup source behavior.

The major components, materials selection, and applicable standards for the core support structure will be identified in the PSAR. In particular, ASCE 43-19 (Reference 14) will be considered for seismic design and ACI 349-13 (Reference 15) for concrete structures. Detailed structural evaluation of the core support structure will be included in the FSAR.

3.4.3. Reactor Tank or Pool

The PSAR will provide an overview of the design and the latest drawings of the reactor vessel and vessel internals. The relevant PDCs and design features that ensure design limits are not exceeded shall be identified. Preliminary evaluations that ensure the reactor vessel can withstand design basis seismic and thermal loads will be presented. The more detailed structural evaluation will be included in the FSAR.

3.4.4. Biological Shield

The preliminary design for biological shielding to protect plant workers and the public from radiological exposure will be included in the PSAR. Methods for limiting neutron irradiation and activation of ground water or soil surrounding the reactor shield will be discussed. Applicable regulations and guidelines for shielding such as 10 CFR 20 will be identified. A detailed evaluation of shielding performance will be included in the FSAR.

3.4.5. Nuclear Design

The PSAR will include an overview of the core nuclear design including descriptions of the fuel design, control and shutdown elements, intrinsic reactivity feedback coefficients, and neutron moderators and reflectors. The startup plan, core configurations, and operating modes will be introduced in the PSAR, and detailed descriptions and procedures are to be provided in the FSAR.

Preliminary reactor physics calculations will performed to predict values of the following important parameters:

- Reactivity feedback coefficients (fuel temperature, coolant temperature and density, moderator/reflector temperature)
- Core power distribution (axial, radial, and azimuthal power peaking)
- Delayed neutron fraction (β)
- Prompt neutron generation time (Λ)
- Hold-down margin (i.e., amount of reactivity by which the reactor is subcritical with all control rods fully inserted)

These reactor physics parameters will be presented in the PSAR and updated as necessary in the FSAR. The PSAR will consider core operating limits and identify parameters that will require technical specifications to control.

3.4.6. Thermal-Hydraulic Design

The PSAR will include a description of the core geometry and cooling characteristics. Nominal thermal-hydraulic parameters such as core power, inlet and outlet temperature and pressure, and flow rate will be included. Heat transfer mechanisms and coolant flow paths will be identified. The design bases for maintaining core coolability under normal and accident conditions, including a loss of forced coolant circulation (i.e., passive cooling) or loss of coolant inventory, will be presented. Detailed analyses supporting the thermal-hydraulic stability and performance of the reactor will be presented in the FSAR.

3.5. REACTOR COOLANT SYSTEMS

3.5.1. Summary Description

See Section 5.1 of NUREG-1537.

3.5.2. Primary Coolant System

The PSAR will describe and provide design bases for the heat transport system (HTS) components including the reactor coolant, primary circuit piping, helium circulator, and intermediate heat exchanger (IHX). Nominal design parameters such as thermal power, flow rate, pressure, and core inlet and outlet temperature will be provided.

Detailed thermal-hydraulic and radionuclide transport (i.e., release to atmosphere, primary-to-secondary leak) analyses will be performed and presented in the FSAR. Descriptions of the HTS testing and inspection plans will also be provided in the FSAR.

3.5.3. Secondary Coolant System

The PSAR will describe and provide design bases for the secondary circuit including the molten salt coolant, secondary circuit piping, molten salt pump(s), and hot and cold storage tanks. The design bases for isolation between the primary and secondary circuits which prevents perturbations on the secondary side of the IHX from affecting the primary coolant loop will be discussed. The heat removal rates required to maintain primary coolant temperature within safety limits during normal operation and accident conditions will be specified.

Potential accidents such as a loss of secondary coolant flow/inventory or primary-to-secondary coolant leak and the corresponding system response will be discussed. However, the primary coolant loop will be demonstrated to be adequately isolated from the secondary coolant loop to preclude an abrupt event that could cause substantial primary-to-secondary leakage (e.g., tube rupture). Therefore, a transfer of primary coolant to secondary coolant system accident does not need to be explicitly evaluated in Section 13 as it is not a credible accident propagation pathway. The impacts of internal flooding caused by a molten salt leak on the primary coolant loop and other important-to-safety SSCs will be discussed.

Testing and inspection plans of the secondary circuit will be included in the FSAR.

3.5.4. Primary Coolant Cleanup System

The PSAR will describe the helium purification system (HPS) key components and functions. The electrical conductivity and pH range guidance in NUREG-1537 is not applicable since the MMR uses helium as a primary coolant.

Impurity concentration limits, testing and inspection plans, and administrative controls that ensure adequate primary coolant purity and radiological contaminant concentration will be provided in the FSAR.

3.5.5. Primary Coolant Makeup System

The PSAR will describe the helium makeup system (HMS) key components and function. It will also describe the helium inventory system (HIS) used to store primary coolant during maintenance and the helium switch station (HSS) which switches the helium flow paths between the HTS, HPS, and HMS.

The operational limits, testing and inspection plans, and administrative controls for the HMS, HIS, and HSS will be provided in the FSAR.

3.5.6. Nitrogen-16 Control System

The MMR does not use water as a coolant, so nitrogen-16 will not be produced in the core. The PSAR will clarify that this section is not applicable to this RTR.

3.5.7. Auxiliary Systems using Primary Coolant

The MMR does not use the primary coolant to cool auxiliary systems, so this section does not need to be included in the license application.

3.6. ENGINEERED SAFETY FEATURES

3.6.1. Summary Description

See Section 6.1 in NUREG-1537.

3.6.2. Detailed Descriptions

Confinement and Containment

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR. The PSAR shall describe the proposed functional containment strategy for protecting against radiological release. TRISO particles can contain radioactive material and fission products from release under both normal and accident conditions, including a loss of primary coolant flow or inventory, as well as from coated particles with manufacturing defects. The FCM matrix is expected to provide an additional barrier that will contain radiological material released from fuel particles. Therefore, the fuel provides confinement and containment of radionuclides for the MMR. Pressure zones in the reactor building provide additional containment of radionuclides. Radionuclide release design limits will be specified in the FSAR.

The NRC commission paper SECY-18-0096 (Reference 16), which supports a functional containment approach for non-light-water reactors (non-LWRs), will be cited and discussed. Other operating reactors that rely on a similar containment strategy will also be identified.

Emergency Core Cooling System

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The MMR does not rely on active safety systems and can maintain core cooling through natural circulation of ambient air in the event of a loss of primary coolant. Therefore, there is no safety-related emergency core cooling system (ECCS).

The PSAR will describe and provide design bases for the reactor cavity cooling system (RCCS) which facilitates air-cooled natural convection. The final design, testing and inspection plans, and analysis results supporting the performance of the RCCS will be included in the FSAR.

3.7. INSTRUMENTATION AND CONTROL SYSTEMS

3.7.1. Summary Description

See Section 7.1 of NUREG-1537.

3.7.2. Design of Instrumentation and Control Systems

This section of NUREG-1537 describes the topics that will be discussed for each instrumentation and control (I&C) system in the following subsections. For each system, the following will be addressed:

- System description
- Design criteria

- Design bases
- System performance evaluation

This section of NUREG-1537 is for informational purposes and a corresponding section does not need to be included in the license application.

3.7.3. Reactor Control System

The PSAR will describe and provide design criteria and bases for the Reactivity Control System (RCS).

Analysis results supporting the performance of the RCS will be included in the FSAR.

3.7.4. Reactor Protection System

The PSAR will describe and provide design criteria and bases for the Reactor Protection System (RPS).

Analysis results supporting the performance of the RPS, proposed trip setpoints including trip delays and measurement accuracy requirements, and surveillance requirements will be included in the FSAR.

3.7.5. Engineered Safety Features Actuation Systems

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The MMR relies solely on passive safety features to mitigate accident consequences and minimize radiological release. Therefore, there are no Engineered Safety Feature (ESF) actuation systems that need to be discussed. This section of the PSAR will demonstrate the MMR does not rely on active ESFs.

3.7.6. Control Console and Display Instruments

The PSAR will describe the major components and functions of the main and secondary control rooms. Design features that allow for the control rooms to remain operable and habitable during normal and accident conditions will be explained.

Procedures and administrative controls for ensuring safe reactor operation and shutdown will be provided in the FSAR.

3.7.7. Radiation Monitoring Systems

The preliminary design and function of the Radiation Monitoring System (RMS) will be provided in the PSAR.

The final design description, operational limits, and administrative controls that ensure radiological release limits are measured and not exceeded will be provided in the FSAR.

3.8. ELECTRICAL POWER SYSTEMS

3.8.1. Normal Electrical Power Systems

The PSAR will describe the normal electrical system including the offsite power source, major system equipment, and design parameters. A simplified electrical diagram will be included. The safety classification of the electrical system and any impacts of a loss of electrical power on safe shutdown will be discussed.

A detailed schematic and list of electrical loads and the buses that they are powered from will be included in the FSAR.

3.8.2. Emergency Electrical Power Systems

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The MMR nuclear plant does not contain an AC emergency electrical power system, and instead relies on a passive cooling approach during a loss of offsite power. Limited battery power is supplied to instrumentation for post-accident monitoring. The nuclear plant passive cooling approach which does not rely on a backup power system or any active systems following a loss of offsite power will be discussed in the PSAR.

There will be a non-safety-related backup power system to supply the radiation monitoring instrumentation, nuclear plant auxiliary loads (e.g., lighting), and the adjacent plant in the event of a loss of offsite power.

A more detailed description and list of loads within the nuclear plant that will be supplied by backup power will be included in the FSAR.

3.9. AUXILIARY SYSTEMS

3.9.1. Heating, Ventilation, and Air Conditioning Systems

The PSAR will describe the reactor building heating, ventilation, and air conditioning (HVAC) system major components and functions. The reactor building HVAC is not a safety-related system and is not relied upon during design basis accidents or credited in the defense-in-depth strategy.

Operating parameter limits (i.e., air temperature, quality, humidity, pressure) and inspection and test plans will be included in the FSAR.

3.9.2. Handling and Storage of Reactor Fuel

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The MMR is designed for a once-through fuel cycle, with no required refueling for the life of the plant. The PSAR will explain and provide design bases for this fueling approach. Although, no fuel handling or storage systems are expected to be required during reactor operation, there will need to be a fuel handling and storage program to allow for initial loading, removal of fuel following reactor operation, and eventual fuel transportation and disposal. Preliminary plans for fuel loading, fuel storage following the end of the operating life, and eventual unloading, transportation, and disposal will be discussed.

The FSAR will provide procedures and administrative controls for fuel handling including initial fuel loading and eventual removal, transportation, and disposal at the end of plant life. Because no refueling is required, there will be no need to handle used fuel outside the reactor prior to end of core life. The depleted core will remain in the reactor vessel until decay heat has dropped to the point that the fuel may be transferred to and sealed in its transport cask. In accordance with the DOE ULTB, DOE will take custody and transfer used fuel from the UIUC site, and this action is not dependent on construction and permitting of a geological repository.

3.9.3. Fire Protection Systems and Programs

The PSAR will describe the fire protection system (FPS) design and functions. Major system components including the fire water source, storage, tank, piping, pumps, valves, and sprinkler/spray systems will be identified. Passive design features such as the use of non-flammable materials in construction will be discussed.

The FPS design criteria, applicable regulations and standards, and building and fire codes will be identified. In particular, ANSI/ANS 15.17 (Reference 17) and NFPA 801 (Reference 18) will be considered.

A detailed design description, fire hazards analysis including potential radiological consequences, and testing and inspection plans for the FPS will be included in the FSAR.

3.9.4. Communication Systems

The PSAR will describe the purpose and function of a communication system during normal and emergency conditions. The communication system is not part of the reactor safety-related systems and will not relied upon in accident scenarios for a safe shutdown. The communication system will comprise diverse subsystems with different technologies such that failure of one system does not cause a total loss of system function.

Testing and inspection plans for the communication systems will be included in the FSAR.

3.9.5. Possession and Use of Byproduct, Source, and Special Nuclear Material

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The PSAR will discuss the types and uses of special nuclear material (SNM), source material, and byproduct material that will be possessed, utilized, and stored at the MMR. In the context of the MMR, the high-assay low-enriched uranium (HALEU) fuel particles are considered SNM, depleted uranium fuel is considered source material, and radioactive fission and decay products are considered byproduct materials. The plans for fresh fuel handling, radioactive waste management, and depleted fuel storage and disposal will be discussed in the PSAR.

The amounts of SNM, source material, and byproduct material expected to be handled throughout the life of the plant will be discussed in the FSAR. Administrative controls and procedures related to the storage and handling of SNM, source material, and byproduct material will also be included in the FSAR.

3.9.6. Cover Gas Control in Closed Primary Coolant Systems

The MMR uses helium as a primary coolant which provides for an inert environment and prevents buildup of impurities such as oxygen, hydrogen, and particulates. Therefore, no separate cover gas system is required. The PSAR will explain how the HPS provides cleanup of chemical and radioactive impurities to maintain an inert atmosphere within the reactor primary loop.

3.9.7. Other Auxiliary Systems

Other auxiliary systems that are important to reactor plant operations but are not specifically identified in NUREG-1537 will be discussed in the following subsections, as applicable. Systems to consider include:

- Cooling water system
- Equipment handling system
- Reactor building and auxiliary building lighting systems
- Civil infrastructure systems (roads, drains, dams, fencing)
- Grounding, lightning, heat tracing, and cathodic protection system

Preliminary descriptions and design bases will be presented for each of these systems in the PSAR. Detailed design descriptions, administrative controls, and inspection and test plans (if applicable) for each system will be included in the FSAR.

3.10. EXPERIMENTAL FACILITIES AND UTILIZATION

This section of the PSAR will contain departures from the guidance in NUREG-1537 due to the design of the MMR.

The MMR will not contain experimental facilities for irradiation testing or isotope production. This section in the PSAR will briefly explain the purpose of the MMR and note that experimental facilities directly involving fuel handling will not be included in the design. However, the facility will support teaching, research, and development of applications of nuclear power from microreactors such as standard reactor measurements including rod worth measurement, xenon transients, and changes in power demand.

3.11. RADIATION PROTECTION PROGRAM AND WASTE MANAGEMENT

3.11.1. Radiation Protection

Radiation Sources

The PSAR will include a table that lists expected sources of radiation and the radioactive contents that they may release. Potential sources include:

- Reactor vessel
- Heat transport system
- Helium purification, inventory, and makeup systems
- Radioactive waste systems (solid, liquid, and gaseous)
- Reactor building HVAC system
- Reactor cavity cooling system

More details on the radiation sources, including activity levels, estimated maximum annual worker dose, and estimates of external radiation fields, will be provided in the FSAR.

Radiation Protection Program

The PSAR will state the purpose and function of the radiation protection program. Relevant regulations and guidance documents to which the radiation protection program will be designed will be identified, including:

- ANSI/ANS-15.11, *Radiation Protection at Research Reactor Facilities* (Reference 19)
- 10 CFR 20 Subpart B, *Radiation Protection Programs* (Reference 12.b)
- 10 CFR 20 Subpart D, *Radiation Dose Limits for Individual Members of the Public* (Reference 12.d)
- Regulatory Guide (RG) 4.20, *Constraints on Releases of Airborne Radioactive Materials to the Environment for Licensees other than Power Reactors*, (Reference 20.e)

- RG 8.2, *Administrative Practices in Radiation Surveys and Monitoring* (Reference 20.h)
- RG 8.13, *Instruction Concerning Prenatal Radiation Exposure* (Reference 20.m)
- RG 8.29, *Instruction Concerning Risks from Occupational Radiation Exposure* (Reference 20.o)

Details of the radiation protection program including administrative controls and procedures, organizational structure, interfaces with other safety-related systems, and training programs will be included in the FSAR.

ALARA Program

A program to ensure doses to workers and the public are as low as reasonably achievable (ALARA) will be developed. The facility will strive to limit doses well below the limits of 10 CFR 20. The PSAR will explain the purpose and function of the ALARA program. Relevant regulations and guidance documents that the program will be designed to such as RG 8.10 (Reference 20.l) will be identified.

A detailed description of the ALARA program, program criteria and goals, and the program implementation plan will be provided in the FSAR.

Radiation Monitoring and Surveying

The PSAR will state the purpose and functions of radiation monitoring and surveying programs. Relevant regulations and guidance documents that the programs will be designed to will be identified, examples of which are:

- 10 CFR 20, Subpart C, *Occupational Dose Limits* (Reference 12.c)
- 10 CFR 20 Subpart F, *Surveys and Monitoring* (Reference 12.e)
- RG 8.2, *Administrative Practices in Radiation Surveys and Monitoring* (Reference 20.h)
- RG 8.4, *Personnel Monitoring Device-Direct-Reading Pocket Dosimeters* (Reference 20.i)
- RG 8.7, *Instructions for Recording and Reporting Occupational Radiation Dose Data* (Reference 20.j)
- RG 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program* (Reference 20.k)
- RG 8.25, *Air Sampling in the Workplace* (Reference 20.n)
- RG 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses* (Reference 20.p)

Details of the radiation monitoring and surveying program including administrative controls and procedures, a list of radiation monitoring and sampling equipment, methods and intervals for monitoring and sampling, and test and calibration plans will be included in the FSAR.

Radiation Exposure Control and Dosimetry

The PSAR will identify requirements for radiation exposure controls and dosimetry equipment. Expected radioactive material release points and radiological control areas will be identified.

A detailed description of the dosimetry equipment and controls that limit exposure to workers and the public, including entry control devices (e.g., alarms, signals, locks), personal protective equipment, administrative radiation exposure limits, and analysis of radioactive effluent release, will be included in the FSAR.

Contamination Control

The PSAR will discuss plans for limiting the spread of radioactive contamination. Relevant regulations and guidance documents such as RG 4.21 (Reference 20.f) will be identified.

A detailed description of the design features that will control contamination will be provided in the FSAR.

Environmental Monitoring

The PSAR will state the purpose of environmental monitoring and identify regulations and guidance documents that will be used to develop the environmental monitoring program, including:

- RG 4.1, *Radiological Environmental Monitoring for Nuclear Power Plants* (Reference 20.d)
- NUREG-1301, *Offsite Dose Calculation Manual Guidance: Standard Radiological Effluent Controls for Pressurized Water Reactors* (Reference 21)

A detailed description of the environmental monitoring program including procedures and surveillance plans will be included in the FSAR.

3.11.2. Radioactive Waste Management

Radioactive Waste Management Program

The PSAR will briefly describe the radioactive waste management program and provide a preliminary organizational structure for the program.

A detailed description of the program will be provided in the FSAR.

Radioactive Waste Control

The PSAR will discuss preliminary radioactive waste control plans and identify SSCs that will maintain control of radioactive waste.

Detailed plans and procedures for radioactive waste control will be provided in the FSAR.

Release of Radioactive Waste

The PSAR will summarize methods for controlled release, transfer, and disposal of gaseous, liquid, and solid radiological waste.

A detailed description of radioactive waste release plans, including expected locations and quantities of release and effluent monitoring equipment, will be included in the FSAR.

3.12. CONDUCT OF OPERATIONS

3.12.1. Organization

The PSAR will provide a high-level chart depicting the organizational structure of the facility within the UIUC hierarchy, as well as the operating organization charged with operation and utilization of the RTR. The responsibilities of each entity in the organizational chart will be discussed.

The PSAR will briefly discuss staffing and personnel training considerations, including minimum staffing levels, staff qualifications, and timing and procedures for hiring personnel for reactor operations, maintenance and radiation safety. Relevant standards or guidelines such as ANSI/ANS 15.4-2007 (Reference 22) and ANSI/ANS 15.1-2007 (Reference 23) will be utilized.

Detailed discussion of staffing and training considerations and final procedures will be provided in the FSAR, including details regarding the authority of the radiation safety staff in respect to other facility staff.

3.12.2. Review and Audit Activities

The PSAR will identify the entity who will establish the review and audit committee. The process for reporting review and audit activities will be briefly discussed. Section 6.2 of ANSI/ANS 15.1-2007 (Reference 23) discusses required review and audit activities for research reactors.

A detailed description of the review and audit committee, including its composition, charter and rules, functions, and interface with facility management, will be included in the FSAR.

3.12.3. Procedures

The PSAR will describe the purpose of procedures and identify topics that will require them. Section 6.4 of ANSI/ANS 15.1-2007 (Reference 23) provides a list of topics that require procedures. The processes for drafting, reviewing, approving, and changing procedures will be detailed in the FSAR.

3.12.4. Required Actions

The PSAR will acknowledge that operator actions are required and must be reported when safety limits (SLs) or limiting conditions of operation (LCOs) are violated. Section 6.6 of ANSI/ANS 15.1-2007 (Reference 23) provides a list of required actions for research reactors. The Technical Specifications which define reportable events and required actions will be included in the FSAR.

3.12.5. Reports

The PSAR will acknowledge that Technical Specifications will specify reporting requirements for normal operations, reportable events, and notable changes at the facility to the NRC. Section 6.7 of ANSI/ANS 15.1-2007 (Reference 23) provides the minimum reporting requirements for research reactors. The Technical Specifications which define reporting requirements will be included in the FSAR.

3.12.6. Records

The PSAR will discuss the program responsible for facility record-keeping. Section 6.8 of ANSI/ANS 15.1-2007 (Reference 23) provides a requirements for recordkeeping for research reactors. The Technical Specifications will provide record-keeping requirements which will be included in the FSAR.

3.12.7. Emergency Planning

10 CFR 50.34(a)(10) provides specific requirements on information that needs to be included in the preliminary emergency plan included in the PSAR. Other guidance documents to consider include:

- ANSI/ANS 15.16-2015, *Emergency Planning for Research Reactors* (Reference 24)
- RG 2.6, *Emergency Planning for Research and Test Reactors* (Reference 20.c)
- NUREG-0849, *Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors* (Reference 25)

The preliminary emergency plan will be attached as an appendix to Chapter 12 of the PSAR. The preliminary plan will contain sufficient information to ensure compatibility with facility design features, site layout, and site location with respect to considerations such as access routes, surrounding population distributions, land use, and local jurisdiction boundaries. The release source term for the MMR will be very low due to the low power and excellent radionuclide retention of the FCM TRISO fuel, so minimal off-site emergency response is expected to be required to mitigate accident consequences. If the emergency plans will not rely on emergency response by outside organizations, that will be justified in the PSAR.

The emergency plan will be updated in the FSAR with additional details including roles and responsibilities of all emergency response personnel, emergency classification levels and corresponding actions, arrangements with local emergency response and governmental organizations, emergency preparedness training plans, locations and inventories of emergency equipment and supplies, and radionuclide identification equipment.

3.12.8. Security Planning

The PSAR will identify relevant regulations and guidelines regarding security planning, including RG 5.59 (Reference 20.g). A description of the security plan will be provided in the FSAR.

3.12.9. Quality Assurance

The PSAR will identify relevant regulations and guidelines regarding quality assurance applied to the design, fabrication, construction, and testing of the SSCs of the facility, including:

- ANSI/ANS 15.8-1995 (R2005), Q*uality Assurance Program Requirements for Research Reactors* (Reference 26)
- ASME NQA-1-2015, *Quality Assurance Requirements for Nuclear Facility Applications* (Reference 27)
- RG 2.5, *Quality Assurance Program Requirements for Research and Test Reactors* (Reference 20.b)

The Quality Assurance Program Description (QAPD) will be prepared in accordance with these guidelines and attached as an appendix to Chapter 12 of the PSAR.

3.12.10. Operator Training and Requalification

The PSAR will identify the relevant regulations and guidelines that will be used to develop the operator training and requalification plan including ANSI/ANS 15.4-2007 (Reference 22). Preliminary operator training and qualification plans will be included in the PSAR.

Final training, qualification and requalification plans will be included in the FSAR.

3.12.11. Startup Plan

The PSAR will acknowledge the requirement that a startup plan is to be prepared for inclusion in the FSAR.

3.12.12. Environmental Reports

An environmental assessment to ensure compliance with NEPA requirements for the construction and operation of the MMR will be performed. An environmental report does not need to be included in the PSAR, and will be separately submitted to ensure NEPA compliance.

3.13. ACCIDENT ANALYSES

The PSAR will identify and describe potential accident initiating events and scenarios. Event categories to consider include:

- Maximum Hypothetical Accident (MHA)
- Insertion of excess reactivity
- Loss of coolant inventory
- Loss of coolant flow
- Loss of external power
- Air ingress
- Mishandling or malfunction of fuel
- Mishandling or malfunction of equipment
- External events (e.g., seismic events, floods, tornados, aircraft collision)

For each accident category, plausible events that could affect the MMR facility will be identified and categorized by significance. The methodology for determining initiating events and their significance will be described. Rejection of events will be justified in this section. The most limiting accident(s) for each category and likelihood of occurrence will be selected for more detailed analysis.

The MHA is used to demonstrate that the maximum consequences of operating the reactor at a specific site are within acceptable limits. As stated in NUREG-1537, "The initiating event for the MHA need not be credible nor evaluated, but the progression of the scenario should be based on sound physical principles and assumptions amenable to logical analyses." Therefore, the MHA is an event with conservative assumptions that result in fission product release that would have worse consequences than any credible postulated event. The details and assumptions are specific to the MMR. The potential consequences will be analyzed and evaluated. The MHA will be evaluated by calculating the source term to determine the maximum effective internal and external dose to facility staff and the public. The MHA should result in a dose less than the limits established in 10 CFR 20. Safety analysis of the limiting accident scenarios will be performed for each event category to demonstrate that all credible events are bounded by the MHA.

The PSAR will describe the accident selection process and summarize the detailed analyses of limiting events. For each accident analysis, the PSAR will discuss:

- Accident scenario sequence of events
- Assumptions

- Methodology
- Computer codes and their verification and validation (V&V) plan
- Results
- Conclusions

If any updates in the reactor design following submittal of the PSAR impact a safety analysis, the analysis will be revised and updated in the FSAR.

3.14. TECHNICAL SPECIFICATIONS

The PSAR will identify variables and conditions that are expected to be controlled by Technical Specifications according to the guidance of ANSI/ANS 15.1 (Reference 23). Parameters that may require Safety Limits (SLs) include:

- Core thermal power
- Reactor coolant flow
- Reactor inlet pressure
- Reactor vessel differential pressure
- Primary coolant loop pressure
- Primary coolant temperature
- Core outlet coolant temperature
- Vessel and citadel wall surface temperatures

Parameters and systems requiring limiting conditions for operation (LCOs) include:

- Key reactor core parameters
- Reactor control and shutdown systems
- Coolant systems
- SSCs and ESFs credited with accident mitigation
- Radiation monitoring and release systems

The MMR is not expected to contain experimental facilities directly integrated into the core, so experiments do not need to be discussed.

The proposed parameters will be listed as a table consistent with the format and numbering of Appendix 14.1 of NUREG-1537).

The detailed technical specification values and bases will be provided in the FSAR.

3.15. FINANCIAL QUALIFICATIONS

The PSAR will provide reasonable assurance that UIUC will have the financial ability to construct, operate, and decommission the reactor facility. Estimates of the total construction cost and funding sources will be included in an enclosure to the PSAR. The strategy for maintaining funds to operate the facility throughout the life of the facility will be discussed.

More details about the financial qualifications, including an estimate of operating costs for each of the first five years and a decommissioning plan with estimated costs and financial assurances, will be included in the FSAR.

3.16. OTHER LICENSE CONSIDERATIONS

3.16.1. Prior Use of Reactor Components

The MMR is to be constructed as a new facility without utilizing used SSCs. Therefore, this section of the PSAR is not applicable.

3.16.2. Medical Use of Non-Power Reactors

The MMR facility is not intended to be used to generate medical isotopes or perform radiation therapy. Therefore, this section of the PSAR is not applicable.

3.17. DECOMMISSIONING AND POSSESSION-ONLY LICENSE AMENDMENTS

3.17.1. Decommissioning

Decommissioning does not need to be discussed in detail in the PSAR. A decommissioning report addressing facility dismantling, radioactive waste removal and disposal, methods for limiting personnel exposure, schedule, cost estimate, and financial assurances will be provided in the FSAR.

3.17.2. Possession-Only License Amendment

Possession-only license amendments do not need to be provided in the license application, so this section will not be included.

3.18. HIGHLY ENRICHED TO LOW-ENRICHED URANIUM CONVERSIONS

The MMR will use high-assay low enriched uranium (HALEU) as its fuel, so there is no need for conversion. This section is not applicable.

4.0 REFERENCES

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4. Senate and House of Representatives of the United States of America in Congress, "Atomic Energy Act of 1954," as amended through P.L. 117-81, enacted December 27, 2021.
5. United States Atomic Energy Commission, "Safety Evaluation by the Division of Reactor Licensing U.S. Atomic Energy Commission in the Matter of Public Service Company of Colorado Fort St. Vrain Nuclear Generating Station," Docket No. 50-267, January 1972.
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9. United States Nuclear Regulatory Commission, "Updated Final Safety Analysis Report: Peach Bottom Atomic Power Station Unit 1, Docket No. 50-171, Revision 7, April 2012.
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11. K. Hofmann and W. Trapp, "THTR 300 MWe Prototype Reactor – Safety Assessment," July 2001.
12. Code of Federal Regulations:
    a. "Contents of Applications; Technical Information," 10 CFR 50.34.
    b. "Radiation Protection Programs," 10 CFR 20, Subpart B.
    c. "Occupational Dose Limits," 10 CFR 20, Subpart C.

d. "Compliance with Dose Limits for Individual Members of the Public," 10 CFR 20, Subpart D.

e. "Surveys and Monitoring," 10 CFR 20, Subpart F.

f. "General Design Criteria for Nuclear Power Plants," 10 CFR 50, Appendix A.

g. "Evaluation Factors for Stationary Power Reactor Site Applications Before January 10, 1997 and Testing Reactors," 10 CFR 100, Subpart A.

h. "Seismic and Geologic Siting Criteria for Nuclear Power Plants, 10 CFR 100, Appendix A.

13. Electric Power Research Institute, "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance, TR EPRI-AR-1(NP)-A, Docket No. 3002019978, November 2020.

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