TOPICAL REPORT

SOLO^{TM} Micro Modular Nuclear Reactor Principal Design Criteria

(Non-Proprietary)

Total Pages:75

Document Number: SOLO-TR-2025-1

Revision 0

(Enclosure 4)

2025-06-07

Terra Innovatum s.r.l.

Via Matteo Trenta 117, 55100 Lucca (LU), Italy

Notes on revisions, source control and e-attachments:

Revision 0

First release.

Signatures

Role	Person	Signature
Author	Cesare Frepoli	
Reviewer	Marco Cherubini	
Approver	Alessandro Petruzzi	

Git commit

N/A

Archive Content (e-attachments)

None

Instructions

None.

STANDARD TERMS, ACRONYMS, AND DEFINITIONS

For convenience, Table 1 provides the definitions of common terms used in this section and Table 2 provides acronyms and abbreviations.

Table 1 - Definitions

Term	Definition
Anticipated Operational Occurrence (AOO)	Anticipated event sequences expected to occur one or more times during the life of a nuclear power plant, which may include one or more reactor modules. Event sequences with mean frequencies of 1×10^{-2}/plant-year and greater are classified as AOOs. AOOs take into account the expected response of all SSCs within the plant, regardless of safety classification.
Beyond Design Basis Event (BDBE)	Rare event sequences that are not expected to occur in the life of a nuclear power plant, which may include one or more reactor modules, but are less likely than a DBE. Event sequences with mean frequencies of 5×10^{-7}/plant-year to 1×10^{-4}/plant-year are classified as BDBEs. BDBEs take into account the expected response of all SSCs within the plant regardless of safety classification.
Computer Code	Any computerized description of mechanistic physical processes used in the design, licensing and maintenance of nuclear facilities.
Design Basis Accident (DBA)	Postulated accidents that are used to set design criteria and performance objectives for the design of safety-related (SR) SSCs. DBAs are derived from design basis events (DBEs) based on the capabilities and reliabilities of SR SSCs needed to mitigate and prevent accidents, respectively. DBAs are derived from the DBEs by prescriptively assuming that only SR SSCs classified are available to mitigate postulated accident consequences to within the frequency-consequence (F-C) limits.
Design Basis Event (DBE)	Infrequent event sequences that are not expected to occur in the life of a nuclear power plant, which may include one or more reactor modules, but are less likely than AOOs. Event sequences with mean frequencies of 1×10^{-4}/plant-year to 1×10^{-2}/plant-year are classified as DBEs. DBEs take into account the expected response of all SSCs within the plant regardless of safety classification.
Evaluation model	The calculational framework (and associated technical basis) addressing the management of safety analysis uncertainties, including compliance, engineering judgment, data applicability, code qualification, code usage and model development, model parameter uncertainty quantification, and human reliability and the consequence of failure, culminating in rules for the preparation, execution, and interpretation of calculations supporting decision-making.
Frozen code/model	The condition whereby the analytical tools and associated input models remain unchanged (and under configuration control) throughout a safety analysis, thereby ensuring traceability of and consistency in the final results.
Input	Information needed to perform a calculation and fed to the simulator of the specific physics.

Input model	A computer file prepared by an end-user containing information required by a computer code to perform the function desired by the end-user.
Licensing Basis Event (LBE)	The entire collection of event sequences considered in the design and licensing basis of the facility, which may include one or more reactor modules. LBEs include AOOs, DBEs, BDBEs, and DBAs.
Model	A set of reasoned formula or derived correlations describing a specific phenomenon.
Nodalization	Computer code inputs describing the mathematical discretization of a physical system or structure.
Non-Safety-Related with Special Treatment (NSRST) SSCs	Non-safety-related SSCs that perform risk-significant functions or perform functions that are necessary for defense-in-depth adequacy.
Output	Information that results from a calculation/experiment that shows the important results associated with specific physical processes.
Required Functional Design Criteria (RFDC)	Reactor design-specific functional criteria that are necessary and sufficient to meet the Required Safety Functions (RSFs). In risk-informed approach, the RFDC are synonymous with the Principal Design Criteria developed using NEI 21-07.
Required Safety Function	A function that is required to be fulfilled to maintain the consequence of one or more DBEs or the frequency of one or more high-consequence BDBEs inside the F-C Target.
Safety Significant SSCs	SSCs that perform a safety-related function or a function whose performance is necessary to achieve adequate defense-in-depth or is classified as risk-significant. Safety significant encompasses both SR and NSRST SSCs.
Safety-Related SSCs	SSCs that are credited in the fulfillment of RSFs and are capable to perform their RSFs in response to any design basis hazard level.
Systems code	The principal computer code of an evaluation model that describes the transport of mass, momentum, and energy throughout the reactor coolant systems.

Table 2 – Acronyms and Abbreviations

Term	Definition
AOO	Anticipated Operational Occurrence
ARDC	Advanced Reactor Design Criteria
BDBE	Beyond Design Basis Event
CDC	Complementary Design Criteria
CFR	Code of Federal Regulations
DBA	Design Basis Accident
DBE	Design Basis Event
DC	Design Criteria
DCA	Standard Design Certification Application
DHRS	Decay Heat Removal System
DG	Draft Regulatory Guide
DID	Defense-in-Depth
F-C	Frequency-Consequence
FSAR	Final Safety Analysis Report
GDC	General Design Criteria
HALEU	High-Assay, Low-Enriched Uranium
I&C	Instrumentation and Control
ICE	Instrumentation, Controls, and Electrical
IRC	Integrated Radiological Containment
ITAAC	Inspections, Tests, Analyses, And Acceptance Criteria
LBE	Licensing Basis Event
LEU	Low-Enriched Uranium
LWR	Light Water Reactor
MHTGR	Modular High-Temperature Gas-Cooled Reactor

NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
NSRST	Non-Safety-Related with Special Treatment
PCS	Power Conversion System
PDC	Principal Design Criteria
PHX	Primary Heat Exchanger
PRA	Probabilistic Risk Assessment
PTCS	Pressure Tubes Coolant System
QA	Quality Assurance
REP	Regulatory Engagement Plan
RFDC	Required Functional Design Criteria
RG	Regulatory Guide
RSF	Required Safety Function
RXS	Reactor System
SAR	Safety Analysis Report
SFR	Sodium-Cooled Fast Reactor
SR	Safety-Related
SSC	Structure, System, or Component
TICAP	Technology-Inclusive Content of Application Project
TI-RIPB	Technology-Inclusive, Risk-Informed, and Performance-Based
TRISO	Tristructural Isotropic

EXECUTIVE SUMMARY

Terra Innovatum is pursuing a Construction Permit (CP) and Operating License (OL) for the SOLO Micro Modular Reactor (SOLO MMR) as a non-power Research and Test Reactor (RTR) under Title 10 of the Code of Federal Regulations (10 CFR) Part 50, following the NUREG-1537 regulatory framework. To date, Terra Innovatum has engaged with the U.S. Nuclear Regulatory Commission (NRC) through pre-application activities, as described in the previously submitted Regulatory Engagement Plan (REP).

As outlined in the REP, Terra Innovatum is preparing several topical reports to support the licensing process. This Principal Design Criteria (PDC) Topical Report has been developed in preparation for NRC review and approval, as part of the CP/OL application for the SOLO MMR.

This report presents the development of the SOLO MMR PDC. The SOLO MMR shares fundamental similarities with conventional Light Water Reactors (LWRs) in terms of fuel design, design philosophy, and safety objectives. As a result, many of the General Design Criteria (GDC) in 10 CFR Part 50, Appendix A are directly applicable. The core safety functions and design basis principles of the SOLO MMR align closely with those of LWR technology—albeit in a less complex and inherently safe design configuration.

Key differences between the SOLO MMR and traditional LWRs include:

1. Use of a solid moderator instead of water;
2. Use of helium (He) gas as the coolant instead of water;
3. Enhanced separation between fuel pellets and coolant.

The use of helium coolant, a solid moderator matrix, and other design features introduce elements that are conceptually similar to those used in Modular High Temperature Gas-cooled Reactors (MHTGRs) and other advanced reactor designs. Consequently, where appropriate, Advanced Reactor Design Criteria (ARDC) from Regulatory Guide (RG) 1.232 have been considered in the development of the SOLO MMR PDC.

Given the non-power RTR licensing framework under NUREG-1537, the safety and licensing approach for the SOLO MMR follows a methodology tailored to RTRs rather than commercial power reactors. The PDC were derived from both the technology-neutral Design Criteria (DC) in RG 1.232 and the GDC in 10 CFR Part 50, Appendix A. Each GDC and ARDC from RG 1.232 was evaluated for applicability to the SOLO MMR design, resulting in three possible outcomes:

1. Retained without modification (for most GDC, due to SOLO MMR's alignment with LWRs);
2. Modified to account for technological differences (solid moderator, helium coolant, and RTR framework);
3. Determined to be inapplicable, based on RTR-specific regulatory considerations and the SOLO MMR design.

Some terminology used in the SOLO MMR PDC development is also informed by risk-informed performance-based (RIPB) approaches as outlined in Nuclear Energy Institute (NEI) 18-04 and NEI 21-07. However, Terra Innovatum has elected to apply a traditional deterministic licensing basis, using Probabilistic Risk Assessment (PRA) insights primarily to support and corroborate design decisions, rather than as a basis for defining the PDC.

This topical report provides a detailed justification for each modification to the PDC relative to RG 1.232, including the basis for each change where applicable. It also documents the rationale for determining certain GDC to be not applicable to the SOLO MMR under the RTR licensing framework.

Terra Innovatum intends to seek NRC review and approval of the proposed set of PDC for the SOLO MMR. The proposed list of inapplicable GDC, with supporting justifications, is included herein. This effort forms a key part of Terra Innovatum's broader licensing strategy to establish regulatory clarity and advance the safe and timely licensing of the SOLO MMR under 10 CFR Part 50.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 PURPOSE

This topical report documents the Principal Design Criteria (PDC) for the SOLO Micro Modular Reactor (MMR) design and the basis for their selection. The PDC includes the Design Criteria for expected Safety Significant Structures, Systems and Components (SSCs) that will be considered in the SOLO MMR design. Terra Innovatum is submitting this topical report for NRC review and approval in support of the future Construction Permit and Operating License for the SOLO MMR.

1.2 SCOPE

This topical report documents the PDC for the SOLO microreactor. U.S. Nuclear Regulatory Commission (USNRC) regulations in 10 CFR 50.34(a)(3)(i) require that applicants for a construction permit include the PDC for a facility. Similarly, NRC regulations in 10 CFR 52.47(a)(3)(i), 10 CFR 52.79(a)(4)(i), 10 CFR 52.137(a)(3)(i), and 10 CFR 52.157(a) require that applications for standard design certifications, combined licenses, standard design approvals, and manufacturing licenses include the PDC for a facility.

The set of PDC was developed for the SOLO microreactor based on its design, as summarily described in Section 2.0. The definition of the SOLO PDC was based on the guidance provided in Regulatory Guide (RG) 1.232 [1], the General Design Criteria (GDC) in 10 CFR Part 50 Appendix A, and incorporates the safety case for the SOLO microreactor. In addition SOLO is being licensed under 10 CFR Part 50 as a non-power research and test reactor (RTR), and the safety analysis and licensing approach follows the framework outlined in NUREG-1537, Parts 1 and 2 [2]. Moreover, risk insights derived from methodologies outlined in NEI 18-04 [3] and NEI 21-07 [4] are adopted when useful to corroborate SOLO safety case.

1.3 APPLICABLE REGULATIONS AND REGULATORY GUIDANCE

The requirement for including PDC and guidance for development of the PDC for the SOLO microreactor comes from a collection of regulatory requirements and guidance. SOLO MMR is being licensed under **10 CFR Part 50** as a **non-power reactor**, and the safety analysis and licensing approach follows the framework outlined in **NUREG-1537, Parts 1 and 2**, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors*.

10 CFR Part 50 provides regulations for licensing production and utilization facilities. 10 CFR Part 50 Appendix A contains the GDC that establish the minimum requirements for the PDC for water-cooled nuclear power plants. Appendix A GDC are generally but not always applicable to other types of nuclear power units and are intended to provide guidance in determining the PDC for such other units.

RG 1.232, “Developing Principal Design Criteria for Non-Light Water Reactors” [1] describes the NRC’s proposed guidance on how the GDC in 10 CFR Part 50 Appendix A may be adapted for non-light water reactor (non-LWR) designs. This guidance may be used by non-LWR reactor designers, applicants, and licensees to develop PDC for any non-LWR designs, as required by the applicable NRC regulations, for nuclear power plants. The RG also describes the NRC’s proposed guidance for modifying and supplementing the GDC to develop PDC that address two specific non-LWR design concepts: sodium-cooled fast reactors (SFRs), and modular high- temperature gas-cooled reactors (MHTGRs).

NEI 18-04, “Risk-Informed Performance-Based Guidance for Non-Light-Water Reactors” [3] presents a modern, technology-inclusive, risk-informed, and performance-based (TI-RIPB) process for selection of LBEs; safety classification of SSCs and associated risk-informed special treatments; and determination of defense-in-depth (DID) adequacy for non-LWRs.

RG 1.233, “Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certification, and Approvals for Non-Light-Water Reactors" [5] provides the NRC staff's guidance on using a technology-inclusive, risk-informed, and performance-based approach to inform the licensing basis and content of applications for non-LWRs. This guidance provides NRC's endorsement of use of NEI 18-04.

NEI 21-07, "Technology Inclusive Guidance for Non-Light Water Reactors: Safety Analysis Report Content for Applicants Using the NEI 18-04 Methodology" [4] describes one acceptable means of developing portions of the Safety Analysis Report (SAR) content for advanced reactor applicants that utilize NEI 18-04. The guidance focuses on the portions of the SAR that are generated by the application of NEI 18-04. The goal of the standardized content structure and formulation is to facilitate efficient preparation by the applicant, review by the regulator, and maintenance by the licensee.

RG 1.253 "Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water-Reactors" [6] describes an approach that is acceptable to the NRC staff for using a technology-inclusive content-of-application approach to inform specific portions of the SAR included as part of a non-LWR license application. Specifically, this guidance endorses NEI 21-07 with clarifications and additions, where applicable, as one acceptable process for use in developing certain portions of the SAR for an application for a non- LWR.

While the licensing basis for the SOLO MMR will be based on a deterministic approach and consistent with NUREG-1537, risk-informed aspects will be considered to confirm or corroborate decisions for SOLO MMR safety case.

1.4 REQUEST FOR NRC

Terra Innovatum is requesting NRC review and approval on the set of PDC for the SOLO microreactor provided in Section 4.0, including the list of the GDC identified as not applicable to the SOLO microreactor with the justification of those decisions. Section 2.0 provides background information for the SOLO microreactor design.

2 SOLO SYSTEM OVERVIEW

The SOLO MMR is a 5 MWth, helium-cooled, thermal neutron spectrum reactor designed to deliver steady-state thermal energy. Depending on the application, the thermal energy can be converted to approximately 1 Mwe using commercial off-the-shelf energy conversion systems. The reactor utilizes conventional zirconium-clad UO_2 fuel—consistent with standard light water reactor (LWR) fuel designs—embedded in a compact solid moderator composed of graphite and/or beryllia – as shown in the general assembly drawing (Figure 1). Beryllium inserts are incorporated into the graphite matrix to enhance neutronic performance and extend the operational cycle.

The reactor general assembly presents a multi-level configuration. More specifically, conventional zirconium-clad UO_2 fuel, depicted in black in Figure 1, **[[**

.]] The coolant is separated from the other components, **[[**]] which formed the Pressure Tubes Coolant System (PTCS) as specified in yellow in Figure 1. **[[**

]]

[[

]]

Standard PWR fuel pins are inserted into designated regions of the solid moderator, referred to as fuel assemblies. **[[**

]]

[[

]]

[[

]]

The reactor lower plenum (Figure 4) serves as connecting region between the coolant inlet channel and the multiple coolant channels **[[**
]]. More specifically, the flow coming from the inlet is re-directed towards the multiple coolant channels in the core. **[[**

]]

[[

]]

Similarly to the lower plenum, the upper plenum (Figure 5) serves as connecting region between the coolant channels and the coolant outlet, located at the top of the reactor. In an opposite manner with respect to the lower plenum, it has the function to re-direct the flow coming from the coolant channels to the single outlet pipe. [[

]]

[[

]]

[[

]]

The entire core and containment system is enclosed within the Monolith—a reinforced concrete structure serving as a biological shield and passive heat sink. It is also structurally qualified against external hazards such as seismic events and missiles. An air baffle between the IRC and the Monolith removes operational heat and protects the concrete structure from high temperature. In accident conditions, passive air circulation through this gap ensures indefinite decay heat removal via the SOLO Decay Heat Removal System (DHRS).

The SOLO MMR employs five independent, diverse reactivity control and shutdown systems:

1. Control absorbing plates
2. Safety absorbing plates
3. Moderator blocks with layered absorbing material
4. Absorbing cylinders
5. Gaseous absorber injection system

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

The SOLO MMR supports both local operation and remote monitoring through redundant instrumentation and control (I&C) systems. The reactor can be operated from a secure offsite facility. All remote systems include cybersecurity protections and fail-safe logic to ensure safe reactor shutdown in the event of power or communication loss.

A key feature and design object is for the reactor to be incapable of core melt or hydrogen production. Combined with its low power and limited radionuclide inventory, these characteristics justify limiting the Emergency Planning Zone (EPZ) to the reactor's physical boundary (i.e., the Monolith).

The system is factory-fabricated and delivered as a sealed module. Supporting systems are shipped separately. Site preparation, integration, and licensing testing are completed following delivery. Once spent, the reactor is shut down, cooled, and the core shipped offsite for decommissioning. No on-site spent fuel storage is required.

Staffing requirements are minimal, focusing on maintenance, inspection, and physical security. During operation, continuous monitoring is performed remotely. Figure 11 shows a rendering a possible future SOLO site with three modules. Note that the current licensing application is a for a single unit.

Figure 11: SOLO Microreactor Site with Three Units (Layout Rendering)

3 PRINCIPAL DESIGN CRITERIA DEVELOPMENT

3.1 REGULATORY FRAMEWORK

SOLO MMR is being licensed under **10 CFR Part 50** as a **non-power research and test reactor**, and the safety analysis and licensing approach follows the framework outlined in **NUREG-1537, Parts 1 and 2**, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors*.

Consistent with the guidance in **Regulatory Guide (RG) 1.232**, *Guidance for Developing Principal Design Criteria for Non-Light Water Reactors*, the PDC have been developed by adapting the intent of the General Design Criteria (GDC) from Appendix A to 10 CFR Part 50 to the unique features and functional safety needs of this reactor.

Sometimes, NEI 18-04 and NEI 21-07 Risk-Informed terminologies are adopted in the SOLO PDCs descriptions. However, the intent is to follow a deterministic approach for the definition of the safety case. PRA is only used for confirmation of corroboration about the safety of design choices.

3.2 SOLO MMR DESIGN PHILOSOPHY

The development of the SOLO PDC reflects its design principles that can be summarized in the following list of key characteristics:

- **Fuel**: The reactor employs a Low Enriched Uranium (<5%) LEU, LWR-type fuel with established performance characteristics, allowing for direct use of existing safety data and proven modeling tools.
- **Core Cooling**: Helium is used as the primary coolant. It is a single-phase, inert gas with favorable thermal properties and no chemical reactivity with core materials, reducing the likelihood of accident progression due to coolant interactions and/or generation of hydrogen.
- **Solid Moderator: [[**

  ].
- **Pressure Boundaries/Barriers**: The maximum pressure is in **[[**

  ]]. The core is contained within the Integrated Radiological Containment (IRC) which is for the most part filled with the solid moderator and maintained **[[**

  ]]
- **Operating Conditions**: The reactor operates at temperatures comparable to traditional LWRs but significantly lower pressure, simplifying material selection and ensuring known thermo-mechanical behavior of core components.
- **Power Level**: At a thermal power of **5 MWth**, the reactor falls well within the range considered for **reduced Emergency Planning Zone (EPZ)** and simplified design in NUREG-1537. The low power also enables a strong margin between credible accident scenarios and regulatory dose limits.
- **The Monolith**: The concrete structures serves the multiple functions:
  1. IRC containment physical protection against external hazards
  2. The removal of IRC heat losses in normal operation
  3. The passive removal of decay heat for an indefinite time

4. A biological shield to minimize radiation exposure to the public below required limits

Other features to enhance defense-in-depth:

1. **Fuel Region**
   - [[ ].
   - It houses the solid graphite/beryllium moderator and maintains a controlled internal helium environment at approximately **[[ ]]**, ensuring thermal stability and mechanical buffering.
2. **Passive Fission Product Retention and Overpressure Control**
   - **[[ ]]**
3. **Modular and Replaceable Core Structure**
   - [[ ]]
   - This supports transportable, sealed-core operation, simplifies decommissioning, and enhances operational flexibility.
4. **Structural Stability and Thermal Buffering**
   - The graphite matrix within the IRC provides thermal inertia, maintaining uniform core temperatures and acting as a buffer for power transients.
   - **[[ ]]**

[[ ]. The Monolith is a robust, integrated biological shield structure that provides multiple layers of defense-in-depth and plays a central role in both radiological protection and external hazard mitigation:

1. **EPZ Minimization:** [[ ]]This is consistent with the low source term and bounding dose evaluations expected for non-power reactors as described in NUREG-1537.
2. **External Hazards**: It is structurally qualified to withstand external events such as seismic loading, windborne missiles, and other credible hazards, thereby ensuring protection of safety-significant SSCs.

3. **[[**

]]

These safety functions enable a compact, small reactor footprint with simplified systems that maintain regulatory compliance while reducing operational complexity.

3.3 METHODOLOGY

SOLO MMR PDC are defined starting from the review of the GDC listed in 10 CFR Part 50 Appendix A. Each GDC is reviewed and compared with the ARDC documented in RG 1.232 [1]. In some cases the ARDC is adopted fully, in other cases, the SOLO either follows the GDC directly or create a modified description that better reflects SOLO design approach.

While the PDCs reference the language and structure of RG 1.232 and GDC from Appendix A, technical modifications are considered and justified by the non-power, low-risk nature of the reactor. The resulting set of criteria ensures a design that is robust, licensable, and aligned with modern regulatory expectations for research test reactors.

The licensing basis for the SOLO MMR will be based on a deterministic/bounding approach and consistent with NUREG-1537. Risk-informed aspects will be considered to confirm or corroborate decisions for SOLO MMR safety case. The guidance in NEI 18-04 and NEI 21-07 is reviewed from that perspective.

Each PDC has been developed to align with the functional requirements of the systems, structures, and components (SSCs) based on their safety classification as defined in NUREG-1537—i.e., **Safety-Related (SR)**, **Important-to-Safety (ITS)**, or **Non-Safety-Related**. The PDC support the following regulatory goals:

- Prevent or mitigate the consequences of postulated design basis accidents, here called Design Basis Events (DBEs) consistently with NEI 18-04.
- Maintain dose to occupational workers and the public within **10 CFR Part 20** limits during normal and abnormal conditions;
- Ensure structural integrity, confinement of radioactive materials, and core cooling functions under all operational states;
- Enable defense-in-depth through passive or inherent features, including reliance on robust physical structures and minimal active system dependence.

3.4 PDC DERIVED FROM RG 1.232

Table 3 through Table 9 provide a walkthrough on the derivation of the PDC starting from the GDC, the ARDC and the adoption or modifications for the SOLO PDC.

Table 3 - Summary of SOLO PDC Derived from RG 1.232: ***Overall Requirements***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
1	Quality standards and records	Same as GDC	Adopted. Applicable to all Safety-Related and Important-to-Safety SSCs.
2	Design bases for protection against natural phenomena	Same as GDC	Adopted. SOLO Monolith is credited for external hazards protection.
3	Fire protection	Modified for ARDC	Modified for SOLO. Fire protection provisions will be tailored to SOLO design and Monolith confinement.
4	Environmental and dynamic effects design bases	Modified for ARDC	Modified. Limited dynamic effects due to low power, small foot-print, and fewer systems.
5	Sharing of structures, systems, and components	Same as GDC	Adopted and expanded.

Table 4 - Summary of SOLO PDC Derived from RG 1.232: ***Multiple Barriers***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
10	Reactor design	Same as GDC	Adopted and expanded to reflect attention to SSCs supporting safety functions and extension to all core associated structures unique for SOLO design
11	Reactor inherent protection	Modified for ARDC	ARDC adopted for SOLO
12	Suppression of reactor power oscillations	Modified for ARDC	ARDC adopted for SOLO
13	Instrumentation and control	Modified for ARDC	ARDC adopted for SOLO but expanded to reflect specific goals for its design.
14	Reactor coolant pressure boundary	Modified for ARDC	ARDC adopted for SOLO
15	Reactor coolant system design	Modified for ARDC	ARDC adopted for SOLO
16	Containment design	Same as GDC	GDC adopted while putting more emphasis safety significant functions and limiting scope to Licensing Basis Events as defined in NEI 18-04.
17	Electric power systems	Modified for ARDC	ARDC adopted while limiting scope to AOOs and safety functions that rely on electric power for DBAs.
18	Inspection and testing of electric power systems	Modified for ARDC	Removed. Folded in PDC 6.
19	Control room	Modified for ARDC	Modified for SOLO considering unique aspects for micro reactor operation.

Table 5 - Summary of SOLO PDC Derived from RG 1.232: ***Reactivity Control***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
20	Protection system functions	Same as GDC	Modified for SOLO to reflect a direct relationship with radiological consequence.
21	Protection system reliability and testability	Same as GDC	Removed. Folded in PDC 6.
22	Protection system independence	Same as GDC	GDC adopted and modified for SOLO
23	Protection system failure modes	Same as GDC	GDC adopted as is.
24	Separation of protection and control systems	Same as GDC	GDC adopted as is.
25	Protection system requirements for reactivity control malfunctions	Modified for ARDC	ARDC adopted.
26	Reactivity control system redundancy and capability	Modified for ARDC	ARDC adopted.
27	Combined reactivity control systems capability	DELETED. Information incorporated into ARDC 26	N/A
28	Reactivity limits	Modified for ARDC	ARDC adopted.
29	Protection against anticipated operational occurrences	Same as GDC	GDC adopted as is.

Table 6 - Summary of SOLO PDC Derived from RG 1.232: ***Fluid Systems***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
30	Quality of reactor coolant pressure boundary	Modified for ARDC	ARDC adopted with minor modification to apply more generically apply to SOLO specifics.
31	Fracture prevention of reactor coolant pressure boundary	Modified for ARDC	Modified for SOLO to apply to its design
32	Inspection of reactor coolant boundary	Modified for ARDC	N/A. Removed. Folded in PDC 6.
33	Reactor coolant makeup	Modified for ARDC	Modified for SOLO
34	Residual heat removal	Modified for ARDC	Modified for SOLO
35	Emergency core cooling	Modified for ARDC	N/A – See Table 10
36	Inspection of emergency core cooling system	Modified for ARDC	N/A – See Table 10
37	Testing of emergency core cooling system	Modified for ARDC	N/A – See Table 10
38	Containment heat removal	Modified for ARDC	Modified for SOLO
39	Inspection of Containment Heat Removal System	Modified for ARDC	N/A – See Table 10
40	Testing of containment heat removal	Modified for ARDC	N/A – See Table 10

	system		
41	Containment atmosphere cleanup	Modified for ARDC	N/A – See Table 10
42	Inspection of containment atmosphere cleanup systems	Same as GDC	N/A – See Table 10
43	Testing of containment atmosphere cleanup systems	Modified for ARDC	N/A – See Table 10
44	Cooling water	Modified for ARDC	ARDC adopted.
45	Inspection of cooling water system	Modified for ARDC	N/A – See Table 10
46	Testing of cooling water system	Modified for ARDC	N/A – See Table 10

Table 7 - Summary of SOLO PDC Derived from RG 1.232: ***Reactor Containment***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
50	Containment design basis	Modified for ARDC	Modified for SOLO
51	Fracture prevention of containment pressure boundary	Modified for ARDC	Modified for SOLO
52	Capability for containment leakage rate testing	Modified for ARDC	Modified for SOLO
53	Provisions for containment testing and inspection	Modified for ARDC	N/A – See Table 10
54	Piping systems penetrating containment	Modified for ARDC	Modified for SOLO
55	Reactor coolant boundary penetrating containment	Modified for ARDC	N/A – See Table 10
56	Containment isolation	Modified for ARDC	N/A – See Table 10
57	Closed system isolation valves	Modified for ARDC	N/A – See Table 10

Table 8 - Summary of SOLO PDC Derived from RG 1.232: ***Fluid and Radioactivity Control***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
60	Control of releases of radioactive materials to the environment	Same as GDC	GDC adopted as is.
61	Fuel storage and handling and radioactivity control.	Modified for ARDC	ARDC adopted as is.
62	Prevention of criticality in fuel storage and handling	Same as GDC	GDC adopted as is.
63	Monitoring fuel and waste storage	Same as GDC	GDC adopted as is.
64	Monitoring radioactivity releases	Modified for ARDC	ARDC adopted as is.

Table 9 - Summary of SOLO PDC Derived from RG 1.232: ***SOLO Technology-Specific Criteria***

10 CFR 50 Appendix A GDC	Current GDC Title	ARDC Title/Status	SOLO Design Status
70	N/A	N/A	
71	N/A	N/A	

4 SOLO PRINCIPAL DESIGN CRITERIA

4.1 SCREENING OF GENERAL DESIGN CRITERIA AND RATIONALE FOR EXCLUSIONS

This Section provides a screening of the GDC. Table 10 provides the rationale by which the GDC are either addressed or excluded from SOLO PDC.

Table 10 - GDC Exclusions

Criterion	Screening Rationale from the GDC
18	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
21	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
27	The objective of this requirement is satisfied by PDC 26 for reactivity control.
32	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
35	SOLO microreactor does not require an ECCS
36	This requirement is N/A considering the elimination of Criterion 35
39-43	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
45-46	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
53	All monitoring, inspection, and testing requirements for SR and NSRST SSCs for the SOLO microreactor are covered in PDC 6.
55	In SOLO MMR, the primary coolant **[[** **]]**. Therefore this criterion does not apply.
56-57	This requirements are N/A. Containment Isolation function is not needed in SOLO MMR (see PDC 50)
61-63	N/A. SOLO Microreactor does not require an onsite fuel storage and handling and radioactivity control.

4.2 ADDED PRINCIPAL DESIGN CRITERIA (GDC)

The two additional criterion listed in Table 11 are added and specific to SOLO MMR because they are not reflected in either the GDC or ARDC. These are presented as PDC 70 and PDC 71 in Section 4.9.

Table 11 – Added PDC

Criterion	SOLO-Specific PDC
70	Radioisotope Production
71	[[ ]]

4.3 SOLO PRINCIPAL DESIGN CRITERIA (PDC)

4.3.1 SOLO-PDC-01: Quality Standards and Records

Description:

Structures, systems, and components (SSCs) important to safety shall be designed, fabricated, installed, and tested to quality standards that are commensurate with their safety significance. Recognized codes and standards shall be identified and evaluated for applicability and sufficiency. Where necessary, these standards shall be supplemented or adapted to ensure SSCs perform their intended safety functions under all design conditions. A graded quality assurance (QA) program shall be established and implemented in accordance with the safety classification of SSCs, consistent with NUREG-1537 guidance for non-power research and test reactors. This QA program shall apply more rigorous controls to Safety-Related (SR) and Important-to-Safety (ITS) SSCs, while allowing simplified provisions for non-safety systems. Records of design, fabrication, inspection, and testing of SR and ITS SSCs shall be maintained for the life of the facility to support continued assurance of function and traceability.

Source Reference: GDC 1 (10 CFR Part 50, Appendix A)

Criterion 1—Quality standards and records.

Structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

Source Reference: PDC 1 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adapts the intent of GDC 1 and ARDC 1 to a research and test reactor (RTR) context in accordance with the guidance in NUREG-1537, which allows for a graded approach to quality assurance based on safety significance.

Key aspects of the basis:

1. Graded QA Program Justified by Reactor Type and Risk Profile

- NUREG-1537, Chapter 1, explicitly allows non-power RTRs to implement graded quality assurance programs.
- The SOLO MMR is a low-power (5 MWth) facility with passive design features, resulting in a lower overall risk profile than power reactors.
- The PDC therefore reflects this by calling for stricter QA for SR and ITS SSCs, while allowing simplified QA for non-safety systems.

2. Recognition of Non-Light Water Technologies
   - While GDC 1 assumes an LWR design, the SOLO MMR uses helium coolant and indirect heat transfer via a solid moderator, which may require non-traditional or modified codes and standards.
   - The PDC explicitly calls for evaluation and, if necessary, adaptation of industry standards to reflect these novel materials and geometries.
   - This aligns with both Regulatory Guide 1.232 and NUREG-1537, which permit applicants to propose suitable standards.

3. Emphasis on Records and Traceability
   - The requirement to maintain lifecycle records for Safety-Related and Important-to-Safety SSCs remains consistent with GDC 1.
   - For a research reactor intended to support long-term experimentation, operational learning, and possible safeguards relevance, traceability of design and fabrication is critical.

4. Consistency with NRC Expectations
   - The PDC maintains the original intent of GDC 1 — ensuring that all safety-significant SSCs are held to high quality standards appropriate to their function.

4.3.2 SOLO-PDC-02: Design bases for protection against natural phenomena

Description:

Structures, systems, and components (SSCs) important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, high winds, and flooding, without loss of capability to perform their safety functions. The design bases for SSCs shall reflect appropriate consideration of the most severe natural phenomena historically reported for the site, with sufficient margin to account for uncertainty in the historical data and hazard characterization.

Source Reference: GDC 2 (10 CFR Part 50, Appendix A)

Criterion 2—Design bases for protection against natural phenomena.

Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

Source Reference: PDC 2 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts the intent of GDC 2 and PDC 2 from RG 1.232, with adaptations consistent with NUREG-1537 guidance for research and test reactors (RTRs). While the original criterion is written for commercial power reactors, the underlying objective — ensuring that safety-significant structures, systems, and components (SSCs) maintain their function under credible external hazards — remains fully applicable.

For the SOLO MMR, the applicable natural phenomena include seismic events, high winds, and flooding, based on site-specific hazard screening. Due to the reactor's small scale (5 MWth), the radiological consequences of external events are limited, allowing for a graded approach to hazard evaluation and structural qualification.

The Monolith, a robust, reinforced structural biological shield, plays a central role in this PDC. It provides mechanical protection to the core and key SSCs and is structurally qualified to withstand seismic loads, wind-borne debris, and external mechanical impacts. Because safety-significant SSCs are self-contained within the Monolith, they are isolated from external environmental conditions and hazards.

Additionally, the reactor's passive decay heat removal system design,[[
]], enhances its resilience to external initiating events. The use of helium coolant and solid moderator materials which provides high heat capacity contributes to inherent safety margins and further reduces the need for external support systems that could be compromised during natural phenomena.

This approach is consistent licensing principles reflected in NUREG-1537enabling design-specific defenses-in-depth that are appropriate for RTR-scale consequences and operational characteristics.

4.3.3 SOLO-PDC-03: Fire protection

Description:

Structures, systems, and components (SSCs) important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effects of fires and explosions. Noncombustible and heat-resistant materials shall be used wherever practical throughout the facility, particularly in areas that house safety-related SSCs, including the interior of the Monolith. Fire detection and suppression systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on safety-related SSCs. These systems shall be designed to ensure that their failure or inadvertent activation does not significantly impair the safety functions of other SSCs.

Source Reference: GDC 3 (10 CFR Part 50, Appendix A)

Criterion 3—Fire protection.

Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

Source Reference: PDC 3 (RG 1.232, Appendix A)

Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions.

Noncombustible and fire- resistant materials shall be used wherever practical throughout the unit, particularly in locations with structures, systems, or components important to safety. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to ensure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

Basis:

The SOLO MMR adopts the structure and intent of ARDC 3 as defined in Regulatory Guide 1.232, with adaptations aligned to the research reactor context described in NUREG-1537.

Although the reactor operates at a relatively low thermal power level (5 MWth), fire protection remains a relevant safety consideration due to the presence of safety-related electrical systems, localized control functions, and limited quantities of combustible materials. The design incorporates several features that inherently reduce the probability and consequences of fire events.

The IRC, which encloses the reactor core and many important-to-safety SSCs, is constructed using noncombustible structural material. This architectural configuration minimizes fire propagation pathways and limits the potential for fire-induced damage to safety-significant equipment.

Graphite, while chemically stable under normal operating conditions, presents a latent fire risk in the presence of sufficient oxygen and elevated temperatures. To address this, the graphite moderator matrix is sealed within an inert helium environment, and the surrounding IRC prevents air ingress, even during off-normal events. Moreover, the reactor's thermal design ensures that internal temperatures—under both normal operation and credible accident conditions—are not expected to exceed approximately 650°C, which approaches the threshold at which graphite oxidation becomes self-sustaining in air. These features, in combination with the reactor's low power level and its safety systems, reduce the likelihood of a graphite ignition event to a level consistent with RTR safety goals.

Additionally, the reactor's safety strategy and compact footprint and assembly further reduce the risk of fire initiation and spread. Fire detection and suppression systems will be incorporated where appropriate. These systems will be designed to ensure they do not impair the function of nearby safety-related equipment, even in the case of inadvertent actuation or local system failure.

This basis supports a graded approach to fire protection, consistent with NUREG-1537 guidance for research and test reactors, ensuring protection of SSCs important to safety without introducing unnecessary complexity for low-consequence areas.

4.3.4 SOLO-PDC-04: Environmental and dynamic effects design bases.

Description:

Structures, systems, and components (SSCs) important to safety shall be designed to accommodate the environmental conditions and dynamic effects associated with normal operation, anticipated operational occurrences (AOOs), and design basis accident (DBAs). This includes consideration of internally and externally generated dynamic loads such as thermal stresses, pressure transients, and mechanical impacts, as well as the effects of potential pipe breaks or component failures, where applicable. The reactor shall be designed to ensure that no dynamic interaction or environmental effect results in a loss of safety function for any safety-related SSC.

Source Reference: GDC 4 (10 CFR Part 50, Appendix A)

Criterion 4—Environmental and dynamic effects design bases.

Structures, systems, and components important to safety shall be designed to accommodate the effects of and be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. These structures, systems, and components shall be *appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping. The design of the nuclear power unit shall include provisions to accommodate the effects of environmental conditions, such as radiation and humidity, determined to be necessary from time to time for the duration of time that the structures, systems, and components are required to remain functional.*

Source Reference: ARDC 4 (RG 1.232, Appendix A)

Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. These structures, systems, and components, shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

Basis:

The SOLO MMR adopts the intent of GDC 4 / ARDC 4, applied to a helium-cooled, research reactor context and an approach consistent with NUREG-1537. Postulated accidents are referred to as Design Basis Accidents according to the definitions adopted in NEI 18-04.

The use of helium gas pressurized to approximately **[[ ]]** in the PTCS, introduces stored energy that must be considered in the design basis for dynamic effects. However, unlike high-energy liquid systems in conventional LWRs, the helium coolant loop operates with inert, single-phase gas and exhibits predictable thermophysical behavior under both steady-state and transient conditions.

While localized pressure transients may occur, the reactor's internal helium system is structurally compact, integrated into the IRC, and designed using qualified high-integrity materials (e.g., Graphite, Steel, Zircaloy, etc.). This configuration inherently limits the potential for dynamic effects such as pipe whip, jet forces, or high-energy missile generation, which are otherwise critical considerations in liquid-phase systems. **[**

]]

Dynamic interactions between SSCs are minimal due to the absence of complex mechanical actuation. Internally generated loads—such as from helium system transients—are anticipated to be low in magnitude and will be bounded by conservative design analyses.

The Graphite structure offers an environmental buffer, shielding other critical SSCs which reside within the Integrated Radiological Containment (IRC). SSCs are qualified to perform their safety function under all applicable environmental conditions associated with normal operation, AOOs, and DBA scenarios.

This approach is consistent with the graded evaluation of environmental and dynamic effects for non-power reactors, and aligns with the GDC intent (10 CFR 50 Appendix A) and when needed the risk-informed, consequence-based framework endorsed by NUREG-1537 and NEI 18-04.

4.3.5 SOLO-PDC-05: Sharing of structures, systems, and components.

Description:

Structures, systems, and components (SSCs) important to safety shall not be shared among facilities unless it can be demonstrated that such sharing will not impair their ability to perform required safety functions. Where SSCs important to safety are shared, provisions shall be made to ensure that the shared use does not introduce dependencies or failure modes that could compromise safety in any operating or accident condition. The design shall provide for independence, redundancy, or isolation sufficient to ensure that shared SSCs do not result in a reduction in safety margins.

Source Reference: GDC 5 (10 CFR Part 50, Appendix A)

Criterion 5—Sharing of structures, systems, and components.

Structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

Source Reference: ARDC 5 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 5, recognizing that GDC 5 was developed for multi-unit nuclear power plants. In the case of SOLO MMR, no SSCs important to safety are shared with other facilities or operational units. The reactor is self-contained, and all safety-related systems, including the reactor protection system, helium boundary, IRC, Monolith, Balance of Plant (BoP), and Instrumentation and Control (I&C) systems, are dedicated exclusively to this reactor module. This ensures physical and functional independence, avoids the introduction of inter-facility failure dependencies, and simplifies the safety analysis.

This independent and modular architecture avoids the introduction of inter-facility failure dependencies and supports a simplified safety case. Should any ancillary systems (e.g., electrical power, ventilation, or operator interface systems) be considered for future shared use, they will be assessed to ensure compliance with GDC 5. Any such systems will be isolated or designed with redundancy to prevent potential compromise of safety functions.

Criterion numbers 6-9 are not used in 10 CFR 50 Appendix A.

4.4 SOLO PDC II. MULTIPLE BARRIERS

4.4.1 SOLO-PDC-10: Reactor design

Description:

The reactor core and associated structures, systems, and components (SSCs) important to safety shall be designed to maintain the reactor in a safe condition under normal operating conditions, anticipated operational occurrences (AOOs), and DBAs. The design shall ensure adequate core cooling capability, reactivity control, structural integrity, and support of safety functions.

Source Reference: GDC 10 (10 CFR Part 50, Appendix A)

Criterion 10—Reactor design.

The reactor core and associated coolant, control, and protection systems shall 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 anticipated operational occurrences.

Source Reference: ARDC 10 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 10 / ARDC 10 beyond fuel performance margins to the broader goal of maintaining the reactor in a safe condition under normal, anticipated, and postulated conditions. This reflects a shift toward evaluating design outcomes (e.g., safe shutdown, containment, heat removal) rather than specific fuel limits, particularly relevant to non-LWR and RTR designs.

The reactor employs pressurized helium gas cooling, with active heat removal under normal operation, and fully passive heat removal in accident conditions. This dual-mode design ensures reliable heat transfer during power generation and eliminates the need for operator intervention or active equipment to prevent core damage during off-normal scenarios.

[[ ]] the Graphite matrix which serves as buffering medium for the potential release of fission products as well as providing a energy storage capacity to safely ride off loss of primary core cooling function or power excursions. The Integrated Radiological Containment (IRC), and the entire system is protected by the Monolith, a robust structural and shielding element. The solid moderator geometry, the use of LWR-type fuel, along with the inert helium coolant, contributes to thermal stability and provides negative reactivity feedback in response to temperature increases. Safety functions such as reactivity control, heat removal, and radiological confinement are provided by systems with no shared dependencies and minimal mechanical complexity.

This design philosophy is consistent with NUREG-1537, which encourages minimizing reliance on operator action in RTRs to ensure robust safety outcomes even in the absence of rapid human response. The compact, self-contained architecture further simplifies accident progression and enables safety-critical functions to be performed inherently or passively, without need for external support systems.

4.4.2 SOLO-PDC-11: Reactor inherent protection.

Description:

The reactor core and associated systems that contribute to reactivity feedback shall be designed so that, in the power operating range, the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.

Source Reference: GDC 11 (10 CFR Part 50, Appendix A)

Criterion 11—Reactor inherent protection.

The reactor core and associated coolant systems shall be designed so that in the power operating range the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.

Source Reference: ARDC 11 (RG 1.232, Appendix A)

The reactor core and associated systems that contribute to reactivity feedback shall be designed so that, in the power operating range, the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.

Basis:

The SOLO MMR adopts ARDC 11, which emphasize the need for reactor designs to incorporate prompt inherent nuclear feedback characteristics that mitigate rapid reactivity insertions in the power operating range. ARDC 11 expands the scope of GDC 11 by explicitly including all systems that contribute to reactivity feedback, beyond just the core and coolant systems.

The SOLO MMR uses LWR fuel and a solid graphite moderator, **[[**

]] Therefore the coolant does not contribute to reactivity effects.

The reactor's negative reactivity feedback is provided by Doppler broadening of fuel resonance absorption and thermal expansion of the graphite moderator, which shifts the neutron spectrum during temperature rise. The use of helium gas as coolant — being inert, single-phase, and with stable thermophysical properties — avoids phase changes or pressure-driven positive reactivity events common in water-moderated systems.

This design philosophy minimizes the likelihood of uncontrolled power excursions and provides a first line of defense through physics, rather than active intervention.

4.4.3 SOLO-PDC-12: Suppression of reactor power oscillations

Description:

The reactor core; associated structures; and associated coolant, control, and protection systems shall be designed to ensure that power oscillations that can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.

Source Reference: GDC 12 (10 CFR Part 50, Appendix A)

Criterion 12—Suppression of reactor power oscillations.

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 detected and suppressed.

Source Reference: ARDC 12 (RG 1.232, Appendix A)

The reactor core; associated structures; and associated coolant, control, and protection systems shall be designed to ensure that power oscillations that can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.

Basis:

The SOLO MMR adopts the intent of ARDC 12, ensuring that reactor power oscillations, which may result in conditions exceeding specified acceptable fuel design limits, are either inherently suppressed or can be reliably and readily detected and suppressed. The ARDC expands GDC, but considering structures beyond the fuel and the coolant, which is more compatible with SOLO MMR systems. The reactor core features LWR fuel **[[**

]]Doppler broadening in the fuel and the graphite moderator coefficient contribute to self-limiting feedback in the power and temperature operating ranges experience in the SOLO reactor.

The Reactor Protection System (RPS) is designed to detect and mitigate any deviations in reactivity that could lead to sustained power oscillations. As stated for the PDC-12, the use of helium gas coolant, minimizes thermal and reactivity instabilities typically associated with two-phase coolants.

4.4.4 SOLO-PDC-13: Instrumentation and control

Description:

Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions, as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the fuel, the moderator assembly, the helium coolant boundary, the IRC and associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.

Source Reference: GDC 13 (10 CFR Part 50, Appendix A)

Criterion 13—Instrumentation and control.

Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions as appropriate to assure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core, the reactor coolant pressure boundary, and the containment and its associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.

Source Reference: ARDC 13 (RG 1.232, Appendix A)

Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions, as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core**,** the reactor coolant boundary, and the containment and its associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.

Basis:

The SOLO MMR adopts the intent of ARDC 13, ensuring that appropriate instrumentation is provided to monitor and control variables and systems affecting the fission process, core integrity, and other systems important to safety. The ARDC replaced the term "Reactor coolant pressure boundary" in the GDC with "reactor coolant boundary" which is a more broadly applicable to non-LWR term that defines the boundary without giving any implication of system operating pressure. This definition also applies better to SOLO MMR considering the unique feature of **[[**

.**]]**

Few adaptions were included to reflect the following points:

1. Expanded Scope for Safety-Critical Systems

The design of the SOLO MMR extends beyond the core and reactor coolant boundary to explicitly include:

- **Fuel Integrity**: Monitoring variables affecting fuel condition ensures that reactivity excursions and operational transients remain within safety limits.
- **Helium Coolant Boundary**: Pressure, temperature and flow characteristics of the helium coolant boundary (PTCS) are continuously monitored to ensure cooling efficiency and system integrity.
- **Integrated Radiological Containment (IRC)**: Instrumentation assesses radiological conditions and ensures that the IRC maintains its safety function under normal and off-normal conditions.

2. Operational Range and Safety Margins

Instrumentation and associated controls are designed to:

- Cover the full range of anticipated conditions, including normal operation, anticipated operational occurrences (AOOs), and accident conditions (DBAs).
- Ensure that safety-significant variables remain within prescribed operating ranges during all modes of operation.

3. Reactor Protection and Real-Time Monitoring

The Reactor Protection System (RPS) provides real-time monitoring and automated response to deviations from normal operating conditions. Key safety functions are supported by passive and active I&C systems that continuously assess variables impacting fuel performance, reactivity control, and containment integrity.

4.4.5 SOLO-PDC-14: Reactor coolant boundary

Description:

The reactor coolant boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

Source Reference: GDC 14 (10 CFR Part 50, Appendix A)

Criterion 14—Reactor coolant pressure boundary.

The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

Source Reference: ARDC 14 (RG 1.232, Appendix A)

The reactor coolant boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

Basis:

The SOLO MMR adopts the intent of ARDC 14, ensuring that the reactor coolant boundary is designed, fabricated, erected, and tested to have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture. The ARDC 14 is the same as GDC 14 with the exception of the title which has been relabeled to "reactor coolant boundary" to create a more broadly applicable non-LWR term that defines the boundary without giving any implication of system operating pressure.

For the SOLO MMR, the reactor coolant boundary is defined as:

- **[[**

]]

2. Fabrication and Material Selection

- The material used for the Pressure Tubes Coolant System (PTCS) are selected to provide high resistance to thermal fatigue, corrosion, and mechanical stress.
- Fabrication and erection processes follow ASME Section III Class 1 standards where applicable, ensuring the highest quality of materials and welds to minimize failure probability.
- Welds and joints are inspected using non-destructive examination (NDE) techniques to identify and mitigate any defects.

3. Testing and Verification

- Pre-service testing ensures that the helium boundary will provide the required integrity during both normal operation and off-normal conditions.
- Periodic inspections will not be required considering that rapidly propagating failure, and of gross rupture are not credible events. **[[**

]]

4. Mitigation of High-Pressure Failures

- The differential pressure across the **[[** **]]**during normal operation.
- Pressure relief mechanisms and redundancy in the helium boundary system prevent over-pressurization and reduce the likelihood of gross rupture.

4.4.6 SOLO-PDC-15: Reactor coolant system design

Description:

The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the reactor coolant boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

Source Reference: GDC 15 (10 CFR Part 50, Appendix A)

Criterion 15—Reactor coolant system design.

The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the reactor coolant pressure boundary are not exceeded during normal operation, including anticipated operational occurrences.

Source Reference: ARDC 15 (RG 1.232, Appendix A)

The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the reactor coolant boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

Basis:

The ARDC is the same as GDC with the exception of the title which has been relabeled to "reactor coolant boundary" to create a more broadly applicable non-LWR term that defines the boundary without giving any implication of system operating pressure. For those reasons, the SOLO MMR adopts the ARDC 15 definition, ensuring that the reactor coolant system (RCS) and its associated systems are designed with sufficient margin to prevent the design limits of the reactor coolant boundary from being exceeded during normal operation and anticipated operational occurrences (AOOs).

1. Unique Attributes of the SOLO MMR Coolant System

- **Helium Coolant System:** The primary coolant is pressurized helium gas, the PTCS. The PTCS is maintained at approximately **[[** **]]** during normal operation. The Helium flows **[[** **]]** Helium, as an inert gas, eliminates the potential for phase change and associated dynamic effects, ensuring predictable thermodynamic behavior across all operating conditions.
- **Solid Moderator Buffer: [[**

]]

- **Integrated Radiological Containment (IRC):** The IRC surrounds the Reactor which includes the fuel, the solid moderator, and serves as an additional safety barrier, preventing the release of radioactive materials in the event of a boundary breach. It is structurally designed to withstand pressure transients under both normal and off-normal conditions.
- **Monolith Protection:** The Monolith provides structural and radiological containment, further isolating the coolant boundary from external hazards, maintaining boundary integrity during off-normal conditions.

The IRC, along with the Monolith that provides radiological shielding and external hazards protection, forms the final defense-in-depth containment layer, enhancing the safety margin for postulated accident scenarios.

2. Design Margins and Operational Safety

- **High Design Margins:** The RCS and pressure boundary materials are designed to withstand thermal stresses and high pressures with conservative safety factors.
- **Thermal and Pressure Margins:** Safety margins account for AOOs, ensuring that transient conditions, including reactivity changes or heat removal variations, do not exceed design limits.
- **Redundancy and Defense-in-Depth:** Auxiliary, control, and protection systems are configured to provide multiple layers of defense, mitigating the effects of postulated transients.

3. Reactor Protection System (RPS) and Active Controls

- **Reactor Protection System (RPS):** Continuously monitors core parameters and initiates automatic protective actions if pre-set thresholds are exceeded.
- **I&C System Integration:** Instrumentation and Control (I&C) systems provide active management of RCS conditions, ensuring that pressure, temperature, and flow parameters remain within safe operational ranges.

4. Mitigation of Overpressure and Abnormal Conditions

- **Pressure Relief and Safety Valves:** Overpressure scenarios are mitigated by high-reliability pressure relief valves that maintain boundary integrity.
- **Passive Heat Dissipation:** In case of loss-of-flow or heat removal failure, passive heat can be dissipated by heat conduction from the fuel through the moderator compound within the IRC until it reaches the IRC external surface from which it is removed by natural convection within the Monolith air baffle.

4.4.7 SOLO-PDC-16: Containment design

Description:

A functional containment shall be provided to control the release of radioactivity to the environment and to ensure that the safety significant functional containment design conditions are not exceeded for as long as licensing basis event (LBE) conditions require.

Source Reference: GDC 16 (10 CFR Part 50, Appendix A)

Criterion 16—Containment design.

Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

Source Reference: ARDC 16 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts the intent of GDC 16, ensuring that a functional containment is provided to control the release of radioactive materials to the environment and to ensure that the safety-significant functional containment design conditions are not exceeded for as long as licensing basis event (LBE) conditions require.

1. Functional Containment Approach in the SOLO MMR

- **Integrated Radiological Containment (IRC):**
  - The IRC serves as the functional containment boundary in the SOLO MMR, providing a radiological barrier that prevents the release of radioactive materials under normal and accident conditions.
  - The IRC is structurally designed to withstand pressure transients and thermal loads during postulated accidents.
- **Monolith as Structural Protection:**
  - The Monolith, a robust concrete biological shield, surrounds the IRC and protects it from external hazards such as seismic events, external missiles, and other off-normal conditions.
  - The Monolith also serves as a heat loss and decay heat removal system, passively dissipating heat in normal and accident scenarios, maintaining containment integrity.
- **IRC+Monolith** are functionally equivalent to a "**double-containment**" barrier:
  - The SOLO MMR employs a dual-barrier containment strategy composed of the IRC, which provides a sealed boundary for fission products, and the Monolith, which serves as a structural and radiological shield as well as a passive heat removal system.

2. Post-Accident Containment Integrity

There are different physical barriers between the fuel and the environment: **[[**

]]

The first four are pressure boundaries. The pressure in each barrier is calibrated to ensure that **[[** **]]**. The Monolith is open to the atmosphere but serves multiple functions:

- **Biological Shielding:** Protects against radiation.
- **Physical Protection:** Shields the containment from external hazards.
- **Decay Heat Removal System (DHRS):**
  - The DHRS is represented by the air baffle between the outer surface of the IRC and the inner surface of the Monolith.

- This passive heat removal system ensures that decay heat is dissipated effectively, maintaining containment integrity after postulated accidents.

3. Containment Monitoring and Control Systems

- **Instrumentation and Control (I&C) for Containment Monitoring:**
  - I&C systems provide continuous monitoring of pressure, temperature, and radiation levels inside the containment boundary.
  - Real-time data allows for prompt detection of deviations from normal operating conditions, ensuring that containment integrity is maintained.
- **Reactor Protection System (RPS) Interface:**
  - The RPS interfaces with containment systems to initiate automatic protective actions that prevent containment breaches and mitigate the consequences of off-normal events.

4. Containment Boundary Qualification and Structural Resilience

- **Seismic and External Hazard Qualification:**
  - The Monolith and IRC are structurally qualified to withstand seismic and external dynamic loads, preventing breach of the containment boundary.
  - Containment systems are tested and qualified under extreme accident scenarios to ensure long-term structural resilience.

4.4.8 SOLO-PDC-17: Electric power systems

Description:

Electric power systems shall be provided when required to permit the functioning of structures, systems, and components (SSCs) important to safety. Each power system required by an SSC to perform a safety function shall provide sufficient capacity and capability to ensure that: (1) the design limits for the fission product barriers are not exceeded as a result of anticipated operational occurrences (AOOs), and (2) safety functions that rely on electric power are maintained in the event of design basis accidents (DBAs).

Electric power systems that are required to perform a required safety function shall include an onsite power source and an additional independent power source. The onsite electric power system shall have sufficient independence, redundancy, and testability to perform its function, assuming a single failure. The additional power system shall have sufficient independence and testability to perform its function.

If electric power is not needed for anticipated operational occurrences or postulated accidents, the design shall demonstrate that power for important to safety functions is provided. Alternatively, in SOLO MMR, SSCs performing required safety functions are designed and installed with fail-safe provisions such that, in the absence of an electrical power source, the function is guaranteed.

Source Reference: GDC 17 (10 CFR Part 50, Appendix A)

Criterion 17—Electric power systems.

An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational *occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.*

The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies.

Source Reference: ARDC 17 (RG 1.232, Appendix A)

Electric power systems shall be provided when required to permit functioning of structures, systems, and components. The safety function for each power system shall be to provide sufficient capacity and capability to ensure that (1) that the design limits for the fission product barriers are not exceeded as a result of anticipated operational occurrences and (2) safety functions that rely on electric power are maintained in the event of postulated accidents.

The electric power systems shall include an onsite power system and an additional power system. The onsite electric power system shall have sufficient independence, redundancy, and testability to perform its safety functions, assuming a single failure. An additional power system shall have sufficient independence and testability to perform its safety function.

If electric power is not needed for anticipated operational occurrences or postulated accidents, the design shall demonstrate that power for important to safety functions is provided.

Basis:

The SOLO MMR adopts the intent of **GDC 17 / ARDC 17**, ensuring that electric power systems are provided when required to permit the functioning of structures, systems, and components (SSCs) important to safety. The power systems are designed to provide sufficient capacity and capability to ensure that:

- The design limits for the fission product barriers are not exceeded as a result of anticipated operational occurrences (AOOs).
- Safety functions that rely on electric power are maintained in the event of design basis accidents.

1. Electric Power System Configuration in SOLO MMR

- **Onsite Electric Power System:**
    - The onsite power system includes backup power sources that provide sufficient independence, redundancy, and testability to perform safety functions, assuming a single failure.

    - The system is designed to power key systems, including the Reactor Protection System (RPS), Instrumentation and Control (I&C) systems, and heat removal mechanisms under all operating and accident conditions.
- **Additional Electric Power System:**
    - The additional power system serves as an alternate power source to ensure continued operation of safety-significant SSCs in case of the failure of the primary onsite system.
    - This system is also designed with sufficient independence and testability to maintain its safety function.

2. Independence, Redundancy, and Testability

- **Independence:**
    - The power systems are physically and electrically independent to ensure that a single failure does not compromise safety-related power supplies.
- **Redundancy:**
    - Redundant power sources and automatic transfer systems ensure that power is available to safety-related SSCs, even in the event of a single failure.
- **Testability:**
    - The power systems are designed to allow for regular testing and verification of their operational readiness, ensuring that safety functions are maintained.

3. Fail-Safe Design and Power Availability

- **Fail-Safe Principles:**
    - The SOLO MMR systems are inherently designed to operate based on **fail-safe principles** with respect to electric power availability.
    - In the event of a loss of electric power, critical safety functions such as core cooling and containment heat removal are maintained through **passive safety mechanisms**, ensuring that the system transitions to a safe, stable state without operator intervention.
- **Automatic Response to Power Loss:**
    - Safety systems automatically revert to a safe configuration under loss-of-power conditions, ensuring that no active response is required to maintain containment and heat removal.

4. Loss of Power Scenarios and Passive Safety

- **Passive Safety During Loss of Power:**
    - The SOLO MMR is designed to rely on **passive heat removal** during postulated loss-of-power scenarios, minimizing the need for active cooling.
    - Decay heat is dissipated passively through the Monolith and air gap, ensuring core stability and preventing damage to the fission product barriers.

4.4.9 SOLO-PDC-18: Inspection and testing of electric power systems

N/A – See Table 10.

4.4.10 SOLO-PDC-19: Control Capability

Description:

Microreactor control capability shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions. Adequate radiation protection shall be provided to permit access and occupancy of microreactor control areas under accident conditions without personnel receiving radiation exposures in excess of 5 rem total effective dose equivalent as defined in § 50.2 for the duration of the accident.

Adequate habitability measures shall be provided to permit access and occupancy of the microreactor control areas during normal operations and under accident conditions. Equipment at locations outside of the microreactor control area shall be provided with a design capability for prompt hot shutdown of the reactor.

In addition to local control capability, provisions shall be made to allow for remote monitoring and control of the reactor, enabling safe shutdown and monitoring of safety-critical parameters from a secure, remote facility. Remote control systems shall be designed with adequate redundancy, cybersecurity protections, and fail-safe mechanisms to ensure continued safety and operational integrity.

Source Reference: GDC 19 (10 CFR Part 50, Appendix A)

Criterion 19—Control room.

A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions, including loss-of-coolant accidents. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem whole body, or its equivalent to any part of the body, for the duration of the accident. Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.

Applicants for and holders of construction permits and operating licenses under this part who apply on or after January 10, 1997, applicants for design approvals or certifications under part 52 of this chapter who apply on or after January 10, 1997, applicants for and holders of combined licenses or manufacturing licenses under part 52 of this chapter who do not reference a standard design approval or certification, or holders of operating licenses using an alternative source term under § 50.67, shall meet the requirements of this criterion, except that with regard to control room access and occupancy, adequate radiation protection shall be provided to ensure that radiation exposures shall not exceed 0.05 Sv (5 rem) total effective dose equivalent (TEDE) as defined in § 50.2 for the duration of the accident.

Source Reference: ARDC 19 (RG 1.232, Appendix A)

A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem total effective dose equivalent as defined in § 50.2 for the duration of the accident.

Adequate habitability measures shall be provided to permit access and occupancy of the control room during normal operations and under accident conditions. Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.

Basis:

The SOLO MMR adopts the intent of GDC 19 / ARDC 19, ensuring that a control room or equivalent control capability is provided to permit the safe operation of the microreactor under normal conditions and to maintain it in a safe condition under accident conditions.

1. Microreactor Control Capability and Remote Monitoring

- **Local and Remote Control Capabilities:**
  - The SOLO MMR provides both **local control capability** within the microreactor control area and provisions for **remote monitoring and control** from a secure, offsite location.
  - The remote control system[1] is designed with adequate **redundancy, cybersecurity protections, and fail-safe mechanisms** to ensure safe operation, monitoring, and shutdown of the reactor under all operating and design basis accident conditions.
- **Remote Shutdown and Safety Parameter Monitoring:**
  - Remote capabilities enable **prompt hot shutdown** of the reactor, ensuring that safety-significant variables remain within prescribed limits.
  - Real-time monitoring of critical safety parameters ensures that deviations from normal operating conditions are identified and addressed promptly.

2. Radiation Protection within the Operational Boundary

- The control area within the Operational Boundary is designed to provide **adequate radiation protection** that limits personnel radiation exposure to less than 5 rem total effective dose equivalent (TEDE) during design basis accident conditions, in compliance with **§ 50.2**.
- Shielding, and other protective measures ensure that radiation exposure is minimized, allowing for safe access during accident conditions.

3. Provisions for Equipment Outside the Monolith:

- **Hot Shutdown and Cold Shutdown Capability:**
  - Equipment at appropriate locations outside the control area is provided with a **design capability** for prompt hot shutdown of the reactor.
  - The system also includes potential capability for **subsequent cold shutdown** through the use of established procedures and suitable manual actions, if necessary.

4. Fail-Safe Design and Cybersecurity Protections

- **Fail-Safe Control Systems:**
  - Both local and remote control systems are designed to **fail-safe**, ensuring that the reactor transitions to a safe condition automatically in the event of system failure or power loss.
- **Cybersecurity and System Integrity:**

1 The remote control capabilities are not credited for the FOAK

- The remote control systems incorporate **robust cybersecurity measures** to protect against cyber threats and ensure continuous operational integrity.

4.5 SOLO PDC III. REACTIVITY CONTROL

4.5.1 SOLO-PDC-20: Protection system functions.

Description:

The protection system shall be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to ensure that the specified acceptable system radionuclide release design limits is not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of safety significant systems and components.

Source Reference: GDC 20 (10 CFR Part 50, Appendix A)

Criterion 20—Protection system functions.

The protection system shall be designed (1) to initiate automatically the operation of appropriate systems including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of systems and components important to safety.

Source Reference: ARDC 20 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 20 / ARDC 20, incorporating protection system functions that are consistent with NUREG-1537 expectations for research test reactors. The description is adapted to reflect the regulatory vocabulary of NEI 18-04 and NEI 21-07, replacing the term *"important to safety"* with *"safety significant"*.

The protection system is designed to:

1. Initiate automatically the operation of appropriate systems, including the reactivity control systems, to ensure that the specified acceptable system radionuclide release design limits are not exceeded as a result of anticipated operational occurrences (AOOs); and
2. Sense accident conditions and initiate the operation of safety significant systems and components required to mitigate or terminate the event.

SOLO MMR design integrates sixdiverse and redundant reactivity control, shutdown and safety systems. These systems are independently actuated and are applicable to different design basis scenarios based on their structural and environmental resilience.

All systems are designed to be fail-safe and capable of functioning autonomously or remotely, supported by instrumentation embedded in the Reactor Protection System (RPS). The RPS continuously monitors reactor parameters, automatically initiates protective actions, and generates operator alerts. Passive responses and conservative actuation thresholds minimize reliance on human intervention, consistent with NUREG-1537 expectations for research test reactors.

The protection system meets the performance objectives of PDC 20 by combining automatic actuation, diverse safety mechanisms, and remote and passive operational capability in a design consistent with modern RTR licensing expectations.

4.5.2 SOLO-PDC-21: Protection system reliability and testability.

N/A – See Table 10.

4.5.3 SOLO-PDC-22: Protection system independence.

Description:

The protection system shall be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and licensing basis event conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.

Source Reference: GDC 22 (10 CFR Part 50, Appendix A)

Criterion 22—Protection system independence.

The protection system shall be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.

Source Reference: ARDC 22 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 22 / ARDC 22 with adaptations to reflect consistency with NUREG-1537 and risk-informed, performance-based (RIPB) definitions as described in NEI 18-04, NEI 21-07. The phrasing has been updated to use the term "*licensing basis event*" in place of "*postulated accident*".

The reactor's protection system architecture is explicitly designed to ensure that natural phenomena (e.g., seismic events) and licensing basis event conditions do not compromise the protection function. This is achieved through:

1. Redundancy and Physical Separation
   - All five reactivity control systems (absorbing plates, graphite/B4C blocks, B4C cylinders, and He-3 injection) are independently actuated.
   - Critical safety functions are not reliant on a single path of actuation, control, or energy source, reducing the potential for common cause failure.
2. Diversity of Function and Principle of Operation
   - The four shutdown systems are based on fundamentally different principles: **[[**

     ]
   - This functional diversity ensures that no single failure mode—electrical, mechanical, or structural—can prevent safe shutdown across all systems.
3. Fail-Safe Design Philosophy
   - Each system is either inherently passive **[[** **]]** or designed to default to a safe state upon power loss or signal interruption.
   - Systems are designed to avoid mutual interference during actuation or testing.

4. Licensing Basis Event Coverage
   - Scenario-based mitigation logic ensures that only those systems robust under the initiating condition are credited (e.g., excluding He-3 injection during seismic scenarios due to external line vulnerability).
   - This selective crediting supports a more realistic and robust safety analysis, consistent with the RIPB approach.
5. Testability and Maintenance
   - Channels are designed to be testable without requiring simultaneous removal from service or impacting the safety function of redundant systems.
   - System health monitoring, remote diagnostics, and fail-safe logic support ongoing verification of functionality without undermining protection system integrity.

Overall, the SOLO MMR satisfies the independence requirement of PDC 22 through a carefully balanced combination of redundancy, functional diversity, physical independence, and fail-safe actuation, aligned with a modern RIPB licensing framework for non-power microreactors.

4.5.4 SOLO-PDC-23: Protection system failure modes

Description:

The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, and radiation) are experienced.

Source Reference: GDC 23 (10 CFR Part 50, Appendix A)

Criterion 23—Protection system failure modes.

The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, and radiation) are experienced.

Source Reference: ARDC 23 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 23 / ARDC 23 with no changes. The reactor is designed with multiple passive and active shutdown mechanisms, underscored by a low linear heat rate and maximum decay heat that does not allow fuel damage in the event of a complete loss of coolant.

1. Failsafe Design Philosophy

- Reactor protection system (RPS) is engineered to place the reactor in a safe shutdown state (SCRAM) upon failure, loss of signal, or power interruption.
- Passive safety features are actuated without external power or command logic.

2. Low Linear Heat Rate

- The low linear heat rate and low decay heat prevent the reactor from reaching melting point temperatures in a shutdown state without cooling.

3. Fault Detection & Isolation

- System health is monitored continuously with self-test capability.
- Detected failures are alarmed and isolated, and redundant channels continue operation without compromising safety function.

4. Inert Helium Environment

- Use of helium coolant avoids failure modes related to phase change, chemical reactions, pressure spikes, or boiling behavior that complicate failure response in light-water systems.

4.5.5 SOLO-PDC-24: Separation of protection and control systems

Description:

The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to assure that safety is not significantly impaired.

Source Reference: GDC 24 (10 CFR Part 50, Appendix A)

Criterion 24—Separation of protection and control systems.

The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to assure that safety is not significantly impaired.

Source Reference: ARDC 24 (RG 1.232, Appendix A)

Same as GDC.

Basis:

The SOLO MMR adopts the intent of GDC 24 / ARDC 24 with no changes. The SOLO MMR conforms to the intent of GDC 24 / ARDC 24 through the use of dedicated protection logic and hardware that is physically and functionally separated from the control systems. This separation is implemented through a tiered architecture where:

- The protection system (RPS) is composed of redundant digital trip channels, sensor arrays, and actuation devices dedicated solely to safety-related functions.
- The control system handles routine power regulation, startup/shutdown operations, and user interfaces, and has no authority over safety actuation logic.

The RPS function is performed by the following four diverse and independent safety-related systems:

- [[

]]

The protection system operates independently of the reactor control system and uses a combination of redundant sensors, digital logic, and passive shutdown mechanisms. The design incorporates diverse actuation pathways to meet safety function requirements even in the event of single failures or spurious signals. Periodic self-testing and fault diagnostics are embedded in the digital logic to ensure ongoing integrity of the protective functions.

This approach aligns with the ARDC's broader safety function focus and NUREG-1537's emphasis on simplicity, inherent safety, and robustness for non-power reactor designs.

4.5.6 SOLO-PDC-25: Protection system requirements for reactivity control malfunctions.

Description:

The protection system shall be designed to ensure that specified acceptable fuel design limits are not exceeded during any anticipated operational occurrence accounting for a single malfunction of the reactivity control systems.

Source Reference: GDC 25 (10 CFR Part 50, Appendix A)

Criterion 25—Protection system requirements for reactivity control malfunctions.

The protection system shall be designed to assure that specified acceptable fuel design limits are not exceeded for any single malfunction of the reactivity control systems, such as accidental withdrawal (not ejection or dropout) of control rods.

Source Reference: ARDC 25 (RG 1.232, Appendix A)

The protection system shall be designed to ensure that specified acceptable fuel design limits are not exceeded during any anticipated operational occurrence accounting for a single malfunction of the reactivity control systems.

Basis:

The SOLO MMR design adheres to ARDC 25 by incorporating a protection system capable of detecting single failures in the reactivity control mechanisms and initiating protective action before fuel design limits are exceeded. Reactivity control is managed through **[[**
]]. Safety systems intervenes to showdown the core on loss of signal or power, ensuring a fail-safe response. Accidental withdrawal of a control systems (e.g., due to mechanical fault or command error) is prevented with specific design of the control mechanisms. The reactor protection system (RPS) monitors core neutron flux and temperature to detect reactivity increases.

The core design includes limited excess reactivity and negative feedback coefficients, such that power rise rates are slow and bounded. Trip setpoints are conservatively chosen to account for maximum worth of a single rod withdrawal under AOO conditions, ensuring no violation of fuel thermal or mechanical limits.

The helium coolant's inert, single-phase behavior further reduces transient severity by eliminating void or moderator feedback effects common in water-moderated systems. Additionally, the modular core geometry limits the spatial effect of local reactivity disturbances.

4.5.7 SOLO-PDC-26: Reactivity control systems

Description:

A minimum of two reactivity control systems or means shall provide:

(1) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the design limits for the fission product barriers are not exceeded and safe shutdown is achieved and maintained during normal operation, including anticipated operational occurrences.

(2) A means which is independent and diverse from the other(s), shall be capable of controlling the rate of reactivity changes resulting from planned, normal power changes to assure that the design limits for the fission product barriers are not exceeded.

(3) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the capability to cool the core is maintained and a means of shutting down the reactor and maintaining, at a minimum, a safe shutdown condition following a postulated accident.

(4) A means for holding the reactor shutdown under conditions which allow for interventions such as fuel loading, inspection and repair shall be provided.

Source Reference: GDC 26 (10 CFR Part 50, Appendix A)

Criterion 26—Reactivity control system redundancy and capability.

Two independent reactivity control systems of different design principles shall be provided. One of the systems shall use control rods, preferably including a positive means for inserting the rods, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck rods, specified acceptable fuel design limits are not exceeded. The second reactivity control system shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes (including xenon burnout) to assure acceptable fuel design limits are not exceeded. One of the systems shall be capable of holding the reactor core subcritical under cold conditions.

Source Reference: ARDC 26 (RG 1.232, Appendix A)

A minimum of two reactivity control systems or means shall provide:

(1) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the design limits for the fission product barriers are not exceeded and safe shutdown is achieved and maintained during normal operation, including anticipated operational occurrences.

(2) A means which is independent and diverse from the other(s), shall be capable of controlling the rate of reactivity changes resulting from planned, normal power changes to assure that the design limits for the fission product barriers are not exceeded.

(3) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the capability to cool the core is maintained and a means of shutting down the reactor and maintaining, at a minimum, a safe shutdown condition following a postulated accident.

(4) A means for holding the reactor shutdown under conditions which allow for interventions such as fuel loading, inspection and repair shall be provided.

Basis:

The SOLO MMR adopts ARDC 26 as PDC 26 with no changes.

This PDC is interpreted as addressing the function of **power control**, consistent with the intent of ARDC 26 item (2), which requires a means to reliably control the rate of reactivity changes resulting from planned, normal power changes. To fulfill this function, the SOLO MMR design integrates **two diverse reactivity control means**:

- [[

]]

4.5.8 SOLO-PDC-27: Combined reactivity control systems capability

N/A – DELETED—Information incorporated into ARDC 26.

4.5.9 SOLO-PDC-28: Reactivity limits

Description:

The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures, or other reactor vessel internals to impair significantly the capability to cool the core.

Source Reference: GDC 28 (10 CFR Part 50, Appendix A)

Criterion 28— Reactivity limits.

The reactivity control systems shall 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 shall include consideration of rod ejection (unless prevented by positive means), rod dropout, steam line rupture, changes in reactor coolant temperature and pressure, and cold water addition.

Source Reference: ARDC 28 (RG 1.232, Appendix A)

The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures, or other reactor vessel internals to impair significantly the capability to cool the core.

Basis:

SOLO MMR adopts ARDC 28 as the PDC 28 with no changes. SOLO MMR meets the intent of PDC 28 through a combination of inherent design features, passive safety characteristics, and conservative analytical limits on reactivity insertion events.

The core is designed with limited excess reactivity, negative temperature coefficients, and uses helium coolant, which lacks the phase-change instabilities (e.g., void coefficient effects) associated with water-moderated systems. These features naturally constrain the magnitude and rate of reactivity increase.

To fulfill control and showdown functions, the SOLO MMR design integrates diverse and redundant reactivity control systems as discussed in PDCs 24 and 26. The protection system (PDC 24) ensures rapid trip response to limit energy addition and thermal shock during AOOs or postulated accidents.

Transient analyses verify that:

- Coolant boundary strain remains within elastic limits (limited local yielding).
- The core remains geometrically stable and coolable under all design basis reactivity events.

The Integrated Radiological Containment (IRC) is structurally robust and provide sufficient inertia and shielding to contain reactivity transients without compromising core cooling.

4.5.10 SOLO-PDC-29: Protection against anticipated operational occurrences.

Description:

The protection and reactivity control systems shall be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.

Source Reference: GDC 29 (10 CFR Part 50, Appendix A)

Criterion 29— Protection against anticipated operational occurrences.

The protection and reactivity control systems shall be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.

Source Reference: ARDC 29 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts GDC 29 with no alterations. SOLO MMR's protection and reactivity control systems are designed with the intent of GDC 29 / ARDC 29, ensuring an extremely high probability of functional reliability and timely protective response under AOOs. The system integrates:

- Redundant and independent trip logic channels
- Diverse instrumentation to monitor power, temperature, and pressure
- Fail-safe control rod actuation (e.g. gravity-driven insertion)
- Conservative trip setpoints based on bounding fuel and thermal limits

The design basis includes a range of AOOs such as:

- Operator errors (e.g., unintended absorbing plates movement)
- Equipment failure
- Control logic faults
- Minor transients in coolant flow, pressure, or temperature

SOLO MMR's helium coolant system and low-power core enhance resilience to AOOs by slowing transient responses and removing phase-change sensitivity. This allows for ample response time margins for trip actuation before any safety limit is approached. Any single failure in sensors, logic, or actuation mechanisms does not compromise the reactor's ability to trip in response to AOOs.

4.6 SOLO PDC IV. FLUID SYSTEMS

4.6.1 SOLO-PDC-30: Quality of reactor coolant boundary

Description:

The reactor coolant boundary shall be designed, fabricated, erected, and tested to ensure a high probability of an acceptable level of integrity during the service lifetime of the reactor. All components forming the boundary, integral helium channels, pressure-retaining structures, structural welds, instrumentation penetrations, and mechanical interfaces shall be constructed using qualified materials and fabrication techniques that are compatible with the helium coolant environment and anticipated service conditions. The design shall consider long-term degradation mechanisms, helium-specific leak risks, and shall incorporate design features to ensure boundary integrity is maintained throughout all conditions of normal operation, anticipated operational occurrences (AOOs), and DBEs events.

Source Reference: GDC 30 (10 CFR Part 50, Appendix A)

Criterion 30—Quality of reactor coolant pressure boundary.

Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

Source Reference: ARDC 30 (RG 1.232, Appendix A)
Components that are part of the reactor coolant boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

Basis:

The SOLO MMR adopts the intent of GDC 30 and ARDC 30, as described in Regulatory Guide 1.232, tailored for a helium-cooled, low-power research reactor. The only difference between the ARDC and GDC is that "Reactor coolant pressure boundary" was relabeled as "reactor coolant boundary" to create a more broadly applicable non-LWR term that defines the boundary without giving any implication of system operating pressure.

The coolant boundary comprises the Integrated Radiological Containment (IRC), the Pressure Tubes Coolant System (PTCS) which are **[[**

]

Unlike LWR systems, the helium coolant in SOLO MMR is inert, single-phase, and chemically non-corrosive, significantly reducing the likelihood of chemical degradation or phase-driven transients. However, helium introduces specific leakage risks due to its molecular size and high diffusivity. For this reason, materials are carefully selected for compatibility with helium at elevated temperatures **[[(** **]]** and qualified under relevant service conditions.

The IRC serves as a dedicated pressure-retaining component, separating the solid moderator matrix and embedded fuel pins from the actively circulating helium coolant in embedded cooling channels, the PTCS. The IRC helium pressure is maintained above fuel rod internal pressure at all times to ensure containment of fission products within the fuel pin in the event of cladding breach.

All reactor coolant boundary components are subject to high-quality assurance standards and fabrication controls equivalent to ASME Section III (adapted for research reactors). Welds and seals are optimized for long-term integrity under cyclic thermal loading. Nondestructive examination (NDE), helium leak testing, and validation through integrated test campaigns are used during manufacturing and commissioning. During operations, the boundary is monitored using passive indicators (e.g., pressure decay rate, acoustic detection) that allow verification of system integrity without operator action.

This approach provides a graded but robust framework for ensuring the integrity of the helium pressure boundary throughout the reactor's operational life.

4.6.2 SOLO-PDC-31: Fracture prevention of reactor coolant boundary

Description:

The SOLO MMR coolant boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions the probability of rupture is minimized. The design shall reflect consideration of service temperatures, service degradation of material properties, creep, fatigue, stress rupture, and other conditions of the boundary material(s) under operating, maintenance, testing, and postulated accident conditions including uncertainties.

Source Reference: GDC 31 (10 CFR Part 50, Appendix A)

Criterion 31—Fracture prevention of reactor coolant pressure boundary.

The reactor coolant pressure boundary shall be designed with sufficient margin to ensure that when stressed under operating, maintenance, testing, and postulated accident conditions, (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures, service degradation of material properties, creep, fatigue, stress rupture, and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation and coolant composition, including contaminants and reaction products, on material properties, (3) residual, steady-state, and transient stresses, and (4) size of flaws.

Source Reference: ARDC 31 (RG 1.232, Appendix A):

The reactor coolant boundary shall be designed with sufficient margin to ensure that when stressed under operating, maintenance, testing, and postulated accident conditions, (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures, service degradation of material properties, creep, fatigue, stress rupture, and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation and coolant composition, including contaminants and reaction products, on material properties, (3) residual, steady-state, and transient stresses, and (4) size of flaws.

Basis:

The SOLO MMR adopts the intent of GDC 31 and ARDC 31, applied to a helium-cooled research reactor. The reactor coolant boundary is constructed from high-temperature metallic alloys qualified for long-term service at design temperatures and a nominal operating pressure of approximately 8 MPa. Non-metallic materials used internally are not relied upon for pressure retention and are evaluated for fracture behavior using appropriate brittle material qualification methods.

All coolant boundary components are designed to remain above their ductile-to-brittle transition temperature, with allowances for irradiation-induced property changes over the operational life of the reactor. Stress and fracture analyses confirm large safety margins below applicable stress intensity limits. The dry, inert helium environment eliminates corrosion-related degradation mechanisms and hydrogen embrittlement common in water-cooled systems.

The terminology “reactor coolant pressure boundary” has been revised to “reactor coolant boundary” to reflect the broader applicability of this criterion to non-light water reactor designs. This adjustment avoids assumptions tied to water-based systems and is appropriate for the SOLO MMR, which operates with a sealed helium system at 8 MPa. The revised terminology supports a material-focused, deterministic evaluation of structural integrity under high-temperature gas-cooled reactor conditions.

4.6.3 SOLO-PDC-32: Inspection of reactor coolant boundary

N/A – See Table 10.

4.6.4 SOLO-PDC-33: Reactor coolant inventory maintenance

Description:

A means shall be provided to maintain reactor coolant inventory during and following postulated events to ensure continued core cooling and the integrity of safety-related structures, systems, and components (SSCs). The system shall be capable of preventing significant coolant loss or restoring sufficient inventory to maintain the heat transfer capability of the reactor coolant boundary under conditions resulting from anticipated operational occurrences (AOOs) and postulated accidents. The reactor coolant inventory function may be fulfilled by passive means, including boundary design features, system sealing, and inert gas containment, as justified by the reactor’s design, power level, and thermal margins. The system shall function without reliance on offsite power or operator action for a duration consistent with safety analysis assumptions.

Source Reference: GDC 33 (10 CFR Part 50, Appendix A)

Criterion 33—Reactor coolant makeup

A system to supply reactor coolant makeup for protection against small breaks in the reactor coolant pressure boundary shall be provided. The system safety function shall be to assure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant loss due to leakage from the reactor coolant pressure boundary and rupture of small piping or other small components which are part of the boundary. The system shall be designed to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished using the piping, pumps, and valves used to maintain coolant inventory during normal reactor operation.

Source Reference: ARDC 33 (RG 1.232, Appendix A)

A system to maintain reactor coolant inventory for protection against small breaks in the reactor coolant boundary shall be provided as necessary to ensure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant inventory loss due to leakage from the reactor coolant boundary and rupture of small piping or other small components that are part of the boundary. The system shall be designed to ensure that the system safety function can be accomplished using the piping, pumps, and valves used to maintain reactor coolant inventory during normal reactor operation.

Basis:

GDC 33 was developed for light-water reactor designs, where large loss-of-coolant events represent a principal design concern and necessitate the inclusion of emergency systems capable of rapidly restoring reactor coolant inventory to ensure continued core cooling.

The SOLO MMR adopts the intent of ARDC 33, tailored to a helium-cooled, non-power research reactor. In this design, the reactor coolant inventory consists of a fixed volume of inert helium gas maintained at a nominal operating pressure of approximately **[[ ]]** within the PTCS and associated helium loops.

Loss of coolant can be accommodated without compromising the ability to remove the decays heat which relies on passive means with the DHRS (the air baffle between the IRC and the Monolith).

Helium inventory is monitored using system pressure and flow instrumentation, capable of detecting deviations from nominal values and informing appropriate operator response. This approach is consistent with the guidance in **NUREG-1537, Part 1, Section 4.5**, which allows for simplified coolant system designs in research reactors where coolant loss does not challenge fuel integrity or heat removal capabilities.

4.6.5 SOLO-PDC-34: Residual heat removal

Description:

A means shall be provided to remove residual heat from the reactor core following shutdown and under postulated accident conditions. The system shall be capable of maintaining fuel temperatures and system pressures within design limits, assuming a loss of normal power, forced circulation, or other initiating events. The residual heat removal function may be accomplished through passive means, such as natural convection, conduction, or radiation, as justified by the reactor's design, power level, and thermal margins. For normal operations and anticipated operational occurrences, residual heat shall be transferred to an ultimate heat sink at a rate sufficient to ensure that specified acceptable system radionuclide release design limits and design conditions of the reactor pressure boundary are not exceeded. The system shall function without reliance on offsite power or operator action for a duration consistent with safety analysis assumptions.

Source Reference: GDC 34 (10 CFR Part 50, Appendix A)

Criterion 34—Residual heat removal.

A system to remove residual heat shall be provided. The system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary are not exceeded.

Source Reference: ARDC 34 (RG 1.232, Appendix A)

A system to remove residual heat shall be provided. For normal operations and anticipated operational occurrences, the system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant boundary are not exceeded.

Suitable redundancy in components and features and suitable interconnections, leak detection, and isolation capabilities shall be provided to ensure that the system safety function can be accomplished, assuming a single failure.

Basis:

The SOLO MMR adopts the intent of GDC 34 and ARDC 34, as described in Regulatory Guide 1.232, tailored for a helium-cooled, low-power research reactor. Residual heat removal is provided by passive means, consistent with the reactor's design characteristics and safety objectives.

Following shutdown or a postulated event, the reactor core continues to generate decay heat. The reactor design ensures that this residual heat is reliably transferred from the core to an ultimate heat sink under all applicable conditions, including loss of offsite power and failure of active systems. Heat is removed passively through conduction and natural convection pathways between the outside surface of the Integrated Radiological Containment (IRC) structure and the inner surface of the Monolith (the DHRS).

The reactor core, internals, and vessel are constructed from materials with high thermal conductivity, high heat capacity and temperature tolerance, ensuring effective heat transfer away from the fuel. These features maintain core temperatures within design limits in accordance with safety analysis assumptions. No active pumps, valves, or operator actions are required to initiate or sustain the residual heat removal function.

The sealed and structurally simple configuration avoids failure modes typical of liquid-cooled systems, such as boiling instability or pump failure. Deterministic safety analysis confirms that, under all design basis conditions—including anticipated operational occurrences and postulated accidents—the passive heat removal capability is sufficient to prevent exceedance of fuel temperature or system pressure limits. This approach is consistent with **NUREG-1537, Part 1, Section 4.5**, which supports the use of passive residual heat removal mechanisms in non-power research reactors when justified by thermal margins, material performance, and system simplicity.

4.6.6 SOLO-PDC-35: Emergency core cooling system

N/A – See Table 10.

4.6.7 SOLO-PDC-36: Inspection of emergency core cooling system

N/A – See Table 10.

4.6.8 SOLO-PDC-37: Testing of emergency core cooling system

N/A – See Table 10.

4.6.9 SOLO-PDC-38: Containment heat removal

Description:

A means shall be provided to remove heat from the containment following postulated accident conditions in which energy is released into the containment volume. The heat removal function shall be capable of maintaining containment structural integrity and pressure control within design limits for the duration required by safety analysis. This function may be fulfilled by passive means such as radiation, conduction, or natural convection, provided such mechanisms are shown to be effective under the applicable environmental and boundary conditions. The design shall not rely on offsite power or operator action for containment heat removal over timeframes critical to containment integrity.

Source Reference: GDC 38 (10 CFR Part 50, Appendix A)

Criterion 38—Containment heat removal.

A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels.

Source Reference: ARDC 38 (RG 1.232, Appendix A)

A system to remove heat from the reactor containment shall be provided as necessary to maintain the containment pressure and temperature within acceptable limits following postulated accidents.

Suitable redundancy in components and features and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to ensure that the system safety function can be accomplished, assuming a single failure.

Basis:

The SOLO MMR adopts the intent of GDC 38 and ARDC 38, interpreted for a helium-cooled, low-power research reactor employing an integrated passive containment approach. In this design, the Integrated Radiological Containment (IRC) serves as the primary volume for retaining helium, fission products, and thermal energy that may be released under postulated accident conditions.

Due to the reactor's low power, compact core geometry, and the absence of high-energy or multiphase coolant inventories, thermal loads within the IRC are expected to be minimal and increase gradually during postulated events. The use of inert, single-phase helium eliminates the potential for pressure spikes or steam-driven transients.

Heat is removed from the IRC boundary through passive means—primarily conduction through the solid moderator and structural materials—without the need for sprays, fans, or mechanical heat exchangers. The IRC is designed with sufficient thermal mass and thermal conductivity to absorb and reject decay heat from the core and internals and surrounding structures. The external environment or passive heat sink structures may contribute to long-term heat dissipation.

Surveillance data and deterministic safety analysis confirm that containment pressures and temperatures remain within allowable limits for all credible design basis events. The containment heat removal function is passive and does not require actuation, operator action, or external power to perform its safety function.

4.6.10 SOLO-PDC-39: Inspection of Containment Heat Removal System

N/A – See Table 10.

4.6.11 SOLO-PDC-40: Testing of containment heat removal system

N/A – See Table 10.

4.6.12 SOLO-PDC-41: Containment atmosphere cleanup

N/A – See Table 10.

4.6.13 SOLO-PDC-42: Inspection of containment atmosphere cleanup systems

N/A – See Table 10.

4.6.14 SOLO-PDC-43: Testing of containment atmosphere cleanup systems

N/A – See Table 10.

4.6.15 SOLO-PDC-44: Structural and equipment cooling

Description:

A system to transfer heat from structures, systems, and components important to safety to an ultimate heat sink shall be provided, as necessary, to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.

Suitable redundancy in components and features and suitable interconnections, leak detection, and isolation capabilities shall be provided to ensure that the system safety function can be accomplished, assuming a single failure.

Source Reference: GDC 44 (10 CFR Part 50, Appendix A)

Criterion 44—Cooling water.

A system to transfer heat from structures, systems, and components important to safety, to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.

Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Source Reference: ARDC 44 (RG 1.232, Appendix A)

A system to transfer heat from structures, systems, and components important to safety to an ultimate heat sink shall be provided, as necessary, to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.

Suitable redundancy in components and features and suitable interconnections, leak detection, and isolation capabilities shall be provided to ensure that the system safety function can be accomplished, assuming a single failure.

Basis:

RG 1.232 renamed ARDC accounts for advanced reactor design system differences to include cooling requirements for SSCs, when applicable and other changes to remove specifics of LWRs and apply the criterion more broadly.

The SOLO MMR adopts the intent of ARDC 44, interpreted for a helium-cooled, low-power research reactor employing an integrated passive containment approach. In this design, the Integrated Radiological Containment (IRC) serves as the primary volume for retaining helium, fission products, and thermal energy that may be released under postulated accident conditions and transfer to equipment included within the IRC.

4.6.16 SOLO-PDC-45: Inspection of structural and equipment cooling systems

N/A – See Table 10.

4.6.17 SOLO-PDC-46: Testing of structural and equipment cooling systems

N/A – See Table 10.

4.7 SOLO PDC V. REACTOR CONTAINEMENT

4.7.1 SOLO-PDC-50: Containment design basis

Description:

The containment function for the SOLO MMR is provided by the Integrated Radiological Containment (IRC), a sealed pressure boundary that encloses the helium coolant system and all safety-significant components. The IRC is designed to maintain its integrity under postulated accident conditions and is supported structurally and thermally by the Monolith, a non-pressurized, high-integrity concrete block that provides passive decay heat removal, biological shielding, and protection against external hazards.

The IRC is constructed to be inherently leak-tight, with no traditional containment penetrations or active isolation systems. All interfacing piping is fully integrated into the IRC boundary and monitored for leakage using internal helium pressure control and external radiation sensors. This architecture ensures that the containment function is maintained without reliance on valve actuation or external power.

The combined IRC and Monolith are designed with sufficient margin to accommodate pressure and temperature transients resulting from postulated accidents, while accounting for material property uncertainties, conservatism in modeling, and the limited empirical data available for high-temperature gas-cooled systems. This approach supports the safety objective of maintaining radiological containment and limiting the Emergency Planning Zone (EPZ) to the site boundary.

Source Reference: GDC 50 (10 CFR Part 50, Appendix A)

Criterion 50—Containment design basis.

The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can *accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.*

Source Reference: ARDC 50 (RG 1.232, Appendix A)

The containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from postulated accidents. This margin shall reflect consideration of (1) the effects of potential energy sources that have not been included in the determination of the peak conditions, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.

Basis:

The SOLO MMR adopts the intent of **ARDC 50** to establish a technology-neutral, performance-based containment design criterion, appropriately tailored to reflect the specific characteristics of the reactor's design. The ARDC formulation is preferred over GDC 50 because it removes LWR-specific references (e.g., steam generators, ECCS assumptions) and expands the applicability to a broader set of postulated accidents relevant to non-LWR technologies.

The following ARDCs 51–57 support ARDC 50 and apply specifically to non-LWR designs that use a **fixed containment structure**. The word "structure" was added in these ARDCs to clarify that the criterion applies to designs incorporating a physical barrier between fission products and the environment. The word "reactor" was removed to reflect the fact that containment applies to all radiological sources, not just the reactor core.

For the SOLO MMR, the **Integrated Radiological Containment (IRC)** serves as the containment structure. The IRC encloses the helium coolant boundary and all safety-significant components necessary to maintain radiological integrity under postulated accident conditions. The **Monolith**, which surrounds the IRC, is a non-pressurized, high-integrity structural block that provides passive **biological shielding**, **external hazard resistance** (e.g., impact, fire, seismic), and **natural convection-driven decay heat removal**. Together, the IRC and Monolith implement a **layered containment strategy** aligned with the risk-informed, performance-based (RIPB) framework.

The SOLO MMR does not use emergency core cooling systems (ECCS). Instead, fuel integrity is preserved through **inherent reactivity feedback** and **passive heat removal** capabilities of the core and Monolith. Accordingly, the containment design basis reflects accident conditions distinct from conventional LWRs. Pressure and temperature response evaluations for the IRC consider:

- **Decay heat** following reactivity insertion, depressurization, or localized thermal excursions;
- **Thermodynamic behavior of helium** as a compressible, inert coolant gas under accident conditions involving a breach of the **Pressure Tubes Coolant System (PTCS)**;

A key design feature is that **there are no traditional containment penetrations** such as piping with active isolation valves. Piping systems that traverse the IRC are constructed as **leak-tight extensions of the IRC boundary**, eliminating the need for isolation systems. Leak detection is performed by monitoring helium pressure and external radiation sensors, with mitigating actions defined based on leak significance. This architecture ensures that containment integrity is preserved without reliance on isolation valve actuation.

Sufficient **design margin** is maintained to account for modeling uncertainties, limited experimental data applicable to high-temperature gas-cooled systems, and conservative assumptions in thermal and structural analysis. This approach is consistent with **NUREG-1537** for research and test reactors and supports the goal of limiting the **Emergency Planning Zone (EPZ)** to the site boundary by bounding the radiological consequences of postulated accidents within the IRC containment envelope.

4.7.2 SOLO-PDC-51: Fracture prevention of containment pressure boundary

Description:

The Integrated Radiological Containment (IRC) of the SOLO MMR serves as the primary pressure boundary and is designed to prevent brittle fracture and rapidly propagating failure under all operating and Licensing Basis Events (LBEs) conditions. The IRC materials are selected to maintain ductile behavior over the full range of service temperatures and mechanical loads, with sufficient margin to account for uncertainties in material properties, stress conditions, and flaw characteristics. The pressure in the IRC is monitored for leaks detection. This fracture prevention approach supports the structural integrity of the IRC as a single, leak-tight barrier critical to structural and radiological containment/confinement.

Source Reference: GDC 51 (10 CFR Part 50, Appendix A)

Criterion 51—Fracture prevention of containment pressure boundary.

The reactor containment boundary shall be designed with sufficient margin to assure that under operating, maintenance, testing, and postulated accident conditions (1) its ferritic materials behave in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary material during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties, (2) residual, steady state, and transient stresses, and (3) size of flaws.

Source Reference: ARDC 51 (RG 1.232, Appendix A)

The boundary of the containment structure shall be designed with sufficient margin to ensure that, under operating, maintenance, testing, and postulated accident conditions, (1) its materials behave in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary materials during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties, (2) residual, steady-state, and transient stresses, and (3) size of flaws.

Basis:

The SOLO MMR adopts the intent of **ARDC 51** to establish a technology-neutral, performance-based criterion for ensuring the structural integrity of the containment pressure boundary. The ARDC formulation is preferred over GDC 51 because it avoids LWR-specific language (e.g., "ferritic materials") and is more appropriate for high-temperature, non-LWR systems such as the SOLO MMR.

In the SOLO MMR, the **Integrated Radiological Containment (IRC)** provides the primary pressure-retaining boundary. The **Monolith** supports the IRC structurally but does not function as a pressure boundary and is therefore excluded from this PDC. The IRC is fabricated from materials and joints selected for high toughness and resistance to brittle failure under normal operating conditions and LBEs. LBE scenarios may include helium depressurization, localized internal pressurization associated with temperature excursions, or mechanically induced loading from seismic or impact events.

The IRC is a fully welded and sealed pressure envelope with no traditional penetrations or external isolation systems. All piping and instrumentation that traverse the IRC are treated as part of the pressure boundary and designed to meet the same fracture resistance criteria.

The fracture prevention strategy reflects conservative assumptions and industry-recognized practices in flaw tolerance and fracture mechanics, including:

1. Characterization of **material properties** under thermal, irradiation, and time-dependent aging effects;
2. Assessment of **stress states**, including fabrication-induced residual stresses and operational thermal/mechanical transients;
3. Conservative **flaw evaluations** that bound critical flaw sizes using methods from ASME Section III and Section XI, adapted as needed for the unique materials and geometry of the SOLO MMR.

This approach ensures that the IRC maintains its integrity under all credible conditions, thereby preserving the safety function of the containment boundary without reliance on active systems. It supports the goals of NUREG-1537 and reinforces the SOLO MMR's objective of limiting offsite radiological consequences and restricting the **Emergency Planning Zone (EPZ)** to the site boundary.

4.7.3 SOLO-PDC-52: Capability for containment leakage rate testing

Description:

The Integrated Radiological Containment (IRC) of the SOLO MMR, including any components forming part of the pressure boundary, is designed to support verification of containment integrity consistent with regulatory expectations for leakage control. Rather than relying on conventional periodic pressurization testing, the IRC employs continuous monitoring of internal helium pressure and external radiation sensors to detect and characterize any leakage. This approach provides a non-intrusive, real-time capability to confirm that the IRC remains leak-tight and within acceptable limits throughout the reactor's life without disrupting passive safety functions.

Source Reference: GDC 52 (10 CFR Part 50, Appendix A)

Criterion 52—Capability for containment leakage rate testing.

The reactor containment and other equipment which may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.

Source Reference: ARDC 52 (RG 1.232, Appendix A)

The containment structure and other equipment that may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.

Basis:

The SOLO MMR adopts the intent of **ARDC 52** to provide assurance that containment integrity can be verified under design pressure conditions. While the language and purpose of ARDC 52 remain consistent with GDC 52, the SOLO MMR implements this capability through a technology-adapted methodology suited to a sealed, non-penetrated containment system.

The **Integrated Radiological Containment (IRC)** is a fully welded, high-integrity structure with no traditional penetrations or isolation valves. All components that traverse the IRC boundary are integrated into the pressure envelope and qualified to maintain leakage performance under all operational and postulated accident conditions. As a result, the SOLO MMR does not rely on periodic integrated pressurization testing typical of large LWR containments.

Instead, the IRC employs a **real-time leak detection strategy** based on:

- **Helium inventory control** and pressure monitoring within the containment;
- **External radiation sensors** to detect radionuclide migration outside the IRC boundary;
- **Criteria** for evaluating leak significance and initiating appropriate mitigating actions, if required.

This approach ensures containment integrity is continuously verified throughout the reactor lifecycle without requiring disassembly or artificial over-pressurization. It also preserves the **passive safety features** and operational simplicity of the microreactor design.

The SOLO MMR's approach remains consistent with the intent of **NUREG-1537**, which allows flexibility in demonstrating containment performance for non-power, sealed-core microreactors.

4.7.4 SOLO-PDC-53: Provisions for containment testing and inspection

N/A – See Table 10.

4.7.5 SOLO-PDC-54: Piping systems penetrating containment

Description:

Piping systems that extend through the Integrated Radiological Containment (IRC) of the SOLO RTR are designed as integral components of the IRC pressure boundary rather than traditional containment penetrations. These systems are engineered to be leak-tight and do not rely on isolation valves to fulfill containment functions. Potential leaks from the IRC are monitored indirectly through controlled helium pressure atmosphere within the IRC and through radiation sensors positioned externally. If a leak is detected, the system assesses the safety significance of the release and initiates appropriate mitigating actions. The design ensures that the IRC maintains its containment function under all operating and postulated accident conditions without dependence on active isolation systems.

Source Reference: GDC 54 (10 CFR Part 50, Appendix A)

Criterion 54—Piping systems penetrating containment.

Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems. Such piping systems shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits.

Source Reference: ARDC 54 (RG 1.232, Appendix A)

Piping systems penetrating the containment structure shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities that reflect the importance to safety of isolating these piping systems. Such piping systems shall be designed with the capability to verify, by testing, the operational readiness of any isolation valves and associated apparatus periodically and to confirm that valve leakage is within acceptable limits.

Basis:

The SOLO MMR adopts the intent of ARDC 54, but with significant adaptation to reflect its unique design approach, in which no traditional containment penetrations exist. Instead, piping systems that pass through the containment boundary are integrated directly into the IRC structure and constructed to be inherently leak-tight. This design eliminates the need for isolation valves as part of the containment function, deviating from the assumptions inherent in ARDC 54.

Rather than using conventional containment isolation provisions, the SOLO MMR employs a pressurized helium environment within the IRC and external radiation monitoring systems to detect potential leakage. This approach enables early detection of any loss of containment integrity and supports the identification and execution of appropriate risk-informed mitigating actions based on the safety significance of the leak.

All materials, welds, and structural interfaces associated with these piping extensions are qualified to maintain containment integrity during normal operation, maintenance, testing, and postulated accident conditions. This strategy aligns with the containment monitoring and assurance principles outlined in NUREG-1537.

This deviation from the traditional isolation valve model reflects both the compact, sealed, and modular nature of the SOLO MMR design, and its reliance on passive safety features and structural robustness to maintain containment performance.

4.7.6 SOLO-PDC-55: Reactor coolant boundary penetrating containment

N/A – See Table 10.

4.7.7 SOLO-PDC-56: Containment isolation

N/A – See Table 10.

4.7.8 SOLO-PDC-57: Closed system isolation valves

N/A – See Table 10.

4.8 SOLO PDC VI. FUEL AND RADIOACTIVITY CONTROL

4.8.1 SOLO-PDC-60: Control of releases of radioactive materials to the environment.

Description:

The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.

Source Reference: GDC 60 (10 CFR Part 50, Appendix A)

Criterion 60—Control of releases of radioactive materials to the environment.

The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.

Source Reference: ARDC 60 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts the GDC 60 / ARDC 60 with no changes. SOLO MMR adopts the intent of GDC 60 / ARDC 60 by incorporating design features and operational strategies to minimize and control radioactive effluent releases to the environment. Key aspects of the design include:

- Use of an inert helium coolant, which does not become significantly radioactive and limits activation product formation.
- A sealed primary loop within the PTCS and Integrated Radiological Containment (IRC) to prevent radioactive material leakage.
- Continuous radiological monitoring of gaseous streams exiting confinement boundaries, with alarms and automatic isolation capability for excursions.
- Operational controls consistent with ALARA principles and 10 CFR Part 20 and Part 50, Appendix I limits.

4.8.2 SOLO-PDC-61: Fuel storage and handling and radioactivity control

Description:

The fuel storage and handling, radioactive waste, and other systems that may contain radioactivity shall be designed to ensure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage cooling under accident conditions.

Source Reference: GDC 61 (10 CFR Part 50, Appendix A)

Criterion 61—Fuel storage and handling and radioactivity control.

The fuel storage and handling, radioactive waste, and other systems which may contain radioactivity shall be designed to assure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage coolant inventory under accident conditions.

Source Reference: ARDC 61 (RG 1.232, Appendix A)

The fuel storage and handling, radioactive waste, and other systems that may contain radioactivity shall be designed to ensure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage cooling under accident conditions.

Basis:

The SOLO MMR adopts the ARDC 61 with no changes.

4.8.3 SOLO-PDC-62: Prevention of criticality in fuel storage and handling.

Description:

Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.

Source Reference: GDC 62 (10 CFR Part 50, Appendix A)

Criterion 62—Prevention of criticality in fuel storage and handling.

Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.

Source Reference: ARDC 62 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts the GDC 62 / ARDC 62 with no changes.

4.8.4 SOLO-PDC-63: Monitoring fuel and waste storage

Description:

Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.

Source Reference: GDC 63 (10 CFR Part 50, Appendix A)

Criterion 63—Monitoring fuel and waste storage.

Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions..

Source Reference: ARDC 63 (RG 1.232, Appendix A)

Same as GDC

Basis:

The SOLO MMR adopts the GDC 63 / ARDC 63 with no changes.

4.8.5 SOLO-PDC-64: Monitoring radioactivity releases

Description:

Means shall be provided for monitoring the reactor containment atmosphere, effluent discharge paths, and plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents.

Source Reference: GDC 64 (10 CFR Part 50, Appendix A)

Criterion 64—Monitoring radioactivity releases.

Means shall be provided for monitoring the reactor containment atmosphere, spaces containing components for recirculation of loss-of-coolant accident fluids, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents.

Source Reference: ARDC 64 (RG 1.232, Appendix A)

Means shall be provided for monitoring the reactor containment atmosphere, effluent discharge paths, and plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents.

Basis:

The SOLO MMR adopts the ARDC 64 with no changes. The SOLO MMR designs provides for sensors for radioactivity monitoring within and outside the IRC.

4.9 SOLO-SPECIFIC PDC

4.9.1 SOLO-PDC-70: Radioisotope Production

Description:

The SOLO MMR includes design provisions and operational flexibility to support the production of medical and industrial radioisotopes. The reactor core, control systems, and irradiation channels are configured to enable the controlled insertion, irradiation, and retrieval of target materials with high positional accuracy and predictable neutron flux profiles. This capability does not interfere with the reactor's primary safety functions and is compatible with normal operation, shutdown, and postulated accident conditions.

Source Reference: GDC 64 (10 CFR Part 50, Appendix A)

N/A

Source Reference: ARDC 64 (RG 1.232, Appendix A)

N/A

Basis:

The SOLO MMR is designed to support **radioisotope production** as an integral mission function. This includes the production of medical isotopes (e.g., Mo-99, I-131, Lu-177), industrial tracers, and research materials. The reactor's compact core and high thermal neutron flux, combined with precisely engineered irradiation locations, provide an ideal environment for neutron activation and transmutation processes.

The isotope production capability is supported by the following design features: **[[**

]]

The incorporation of isotope production into the SOLO MMR design reflects a **risk-informed, mission-flexible architecture** and aligns with the guidance of **NUREG-1537**, which allows for multipurpose reactor applications in research and isotope generation.

By formalizing this capability through PDC 70, the design and licensing basis explicitly acknowledges and supports the safe, controlled use of the reactor for beneficial medical and industrial applications, without compromising its fundamental safety envelope or containment integrity.

4.9.2 SOLO-PDC-71: Integrated On-line Safeguards

Description:

The SOLO MMR includes an integrated system for **[[** **]]** safeguards that enables **[[**

]]

Source Reference: GDC 64 (10 CFR Part 50, Appendix A)

N/A

Source Reference: ARDC 64 (RG 1.232, Appendix A)

N/A

Basis:

[[

]

This PDC reflects a **safeguards-by-design** approach, consistent with **IAEA INFCIRC/225/Rev.5**, the **U.S. DOE/NNSA Next-Generation Safeguards Initiative (NGSI)** principles. It also reinforces the reactor's physical and cyber-security posture, by ensuring that any attempt to tamper with safeguards data would itself be detectable and reportable.

By formalizing this capability in PDC 71, the SOLO MMR licensing basis acknowledges and institutionalizes the role of integrated digital safeguards as essential to safe, secure, and internationally deployable microreactor designs.

5 CONCLUSIONS

The development of the Principal Design Criteria (PDC) for the SOLO Micro Modular Reactor (SOLO MMR) represents a key element of Terra Innovatum's overall licensing strategy under the non-power Research and Test Reactor (RTR) framework of 10 CFR Part 50 and NUREG-1537.

The SOLO MMR design incorporates a combination of established Light Water Reactor (LWR)-based safety principles and innovative features derived from advanced reactor technologies, including the use of a helium-cooled core and solid moderator. The PDC development process has carefully evaluated the applicability of the General Design Criteria (GDC) in 10 CFR Part 50, Appendix A, and the Advanced Reactor Design Criteria (ARDC) of RG 1.232 to the unique design features and licensing basis of the SOLO MMR.

Each GDC and ARDC was systematically assessed to determine whether it should be:

- Retained without modification,
- Adapted to reflect the technological and operational characteristics of the SOLO MMR under the RTR framework, or
- Determined to be inapplicable based on the regulatory context and specific design features.

The resulting set of SOLO MMR PDC provides a clear, traceable, and well-justified licensing basis for the reactor's core safety functions. This approach supports a strong alignment with the NRC's safety expectations while appropriately accounting for the differences between the SOLO MMR and conventional power reactors.

Additionally, Terra Innovatum has adopted a traditional deterministic licensing approach for the SOLO MMR, supported by insights from risk-informed methodologies such as NEI 18-04 and NEI 21-07. This integrated approach ensures that the PDC framework is both robust and adaptable to future licensing and design development activities.

Terra Innovatum considers this topical report and the proposed set of PDC to represent a sound and complete foundation for the NRC's review and approval. The adoption of the proposed PDC will provide regulatory clarity and facilitate the progression of the Construction Permit and Operating License applications.

Moving forward, the approved PDC will guide the continued development of the SOLO MMR's safety analyses, system designs, and licensing documentation, ensuring consistency and transparency throughout the NRC review process.

6 REFERENCES

[1] "US Nuclear Regulatory Commission, Guidance for Developing Principal Design Criteria for Non-Light Water Reactors, RG 1.232, Revision 0".

[2] "US Nuclear Regulatory Commission, Guidelines for Preparing and Reviewing Applications for Licensing of Non-Power Reactors, NUREG-1537, Part 1 and Part 2".

[3] "NEI, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development", NEI 18-04, Revision 1," August 2019.

[4] "NEI, "Technology Inclusive Guidance for Non-Light Water Reactors, Safety Analysis Report Content for Applicants Using the NEI 18-04 Methodology", NEI 21-07, Revision 1," February 2022.

[5] "US Nuclear Regulatory Commission, GUIDANCE FOR A TECHNOLOGY-INCLUSIVE, RISK-INFORMED, AND PERFORMANCE-BASED METHODOLOGY TO INFORM THE

LICENSING BASIS AND CONTENT OF APPLICATIONS FOR LICENSES, CERTIFICATIONS, AND APPROVALS FOR NON-LI , RG 1.233, Revision 0," 2020.

[6] "US Nuclear Regulatory Commission - GUIDANCE FOR A TECHNOLOGY-INCLUSIVE CONTENT-OF-APPLICATION METHODOLOGY TO INFORM THE LICENSING BASIS AND CONTENT OF APPLICATIONS FOR LICENSES, CERTIFICATIONS, AND APPROVALS FOR NON-LIGHT-WATER REACTORS, RG 1.253, R0," 2024.