Technology Inclusive Content of Application Project
For Non-Light Water Reactors

Versatile Test Reactor
TICAP Tabletop Exercise

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Disclaimer

Abstract

Non-light water reactor (non-LWR) technologies will play a key role in meeting the world's future energy needs and will build on the foundation established by the current light water reactor (LWR) nuclear energy fleet. Given the long timeframe and significant financial investment required to mature, deploy, and optimize these technologies, an efficient and cost-effective non-LWR-licensing framework that facilitates safe and cost-effective construction and operation is a critical element for incentivizing private sector investment. The Technology Inclusive Content of Application Project (TICAP) is an important step in establishing that licensing framework. This DOE cost-shared, owner/operator-led initiative will produce guidance for developing content for specific portions of the Nuclear Regulatory Commission (NRC) license application Safety Analysis Report (SAR) for non-LWR designs.

The portions of the SAR on which this work will focus are those addressed in the Nuclear Energy Institute (NEI) publication NEI 18-04, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development." [1] The TICAP guidance will help ensure completeness of information submitted to the NRC while avoiding unnecessary burden on the applicant and rightsizing the content of application commensurate with the complexity of the design being reviewed.

TICAP will generate a number of products culminating in an NRC-endorsable NEI document providing guidance for key elements of the content of an advanced reactor license application. In this report, the TICAP guidance is applied to the current Versatile Test Reactor (VTR) design. The VTR project applied the Licensing Modernization Project (LMP) process described in NEI 18-04 in support of authorization for building the VTR supported by a risk-informed, performance-based approach. The VTR LMP application described in this report included all of the major steps including documentation described in NEI 18-04, including Probabilistic Risk Assessment (PRA) development, Design Basis Event (DBE) selection, structures, systems, and components (SSC) Classification, Defense-in-Depth (DID) Evaluation, and Performance of the Independent Decision-making Panel (IDP).

The Scope of the PRA supporting LMP and the DID reviews are described in the report. As noted, although the entire process and associated steps were completed, not all of the steps were completed to the level needed for a final LMP application. For example, the PRA scope did not include everything needed to support the DBE selection, and the DID evaluation did not complete the programmatic review (due to plant programs not yet developed).

The application of LMP under the VTR project was performed in support of authorization under the U.S. DOE, and was included in the VTR Conceptual Safety Design Report (CSDR) [2] submitted to the DOE discussed below. Due to differences in rules and regulations between the NRC and DOE, the application of LMP required modification, including terminology, the F-C curve acceptance criteria, and SSC classification criteria. The first two subjects are in this report but are not included in the tabletop exercise, while SSC criteria is addressed. For this report, however, the terminology is modified to use the NRC LMP terminology. The selection of SSC classification during the VTR LMP application did however use the DOE risk criteria (goals), including use of additional requirements associated with onsite and worker dose (not included in the NRC criteria under NEI 18-04).

Acknowledgments

The VTR is a fast spectrum test reactor currently being developed in the United States under the direction of the U.S. Department of Energy (USDOE), Office of Nuclear Energy. The mission of the VTR is to enable accelerated testing of advanced reactor fuels and materials required for advanced reactor technologies. The conceptual design of the 300 MWth sodium-cooled metallic-fueled pool-type fast reactor has been led by U.S. National Laboratories in collaboration with General Electric-Hitachi and Bechtel National Inc. The VTR is utilizing a risk-informed performance-based approach for authorization by the USDOE, derived from recent efforts by the U.S. industry led Licensing Modernization Project. As part of this methodology, the PRA is a key input into decisions regarding the identification and selection of safety basis events, the safety classification of structures, systems, and components, and the evaluation of the adequacy of defense-in-depth. The paper provides an overview of key factors in the development of the VTR PRA, including applicable USDOE and industry PRA standards, the risk metrics and criteria to be utilized for risk-informed decision-making, and the selected structure of the PRA technical elements. The work reported in this report is the result of studies supporting a VTR conceptual design, cost, and schedule estimate for DOE to make a decision on procurement. As such, it is preliminary.

The team supporting the development of the VTR PRA, LMP analysis, and this Tabletop Report include participation from GE Hitachi Nuclear Energy, Argonne National Laboratory (ANL), and Idaho National Laboratory (INL); with INL responsible for the overall product. Key individuals supporting this effort include:

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LIST OF ABBREVIATIONS

AC	Alternating Current
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
AOO	Anticipated Operational Occurrence
ASD	Adjustable speed drive
BDBE	Beyond Design Basis Event
CDC	Complimentary Design Criteria
COA	Content of Application
CR	Control Rods
CSDR	Conceptual Safety Design Report
DA	Data Analysis
DBA	Design Basis Accident
DBE	Design Basis Event
DBEHL	Design Basis External Hazard Level
DID	defense-in-depth
DOE	Department of Energy
DOE	Department of Energy
EDRS	Early Design Response Spectra
EM	Electro-Magnetic
EMP	Electro-Magnetic Pump
EPRI	Electric Power Research Institute
ES	Event Sequence
ESF	Event Sequence Families
ESQ	Event Sequence Quantification
FC	Frequency-Consequence
FFTF	Fast Flux Test Facility
FSF	Fundamental Safety Function
HELB	High energy line breaks
HR	Human Reliability
HRS	Heat Rejection System
IDP	Independent Decision-making Panel
IE	Initiating Event
IEAP	Internal Events At Power
IHX	Intermediate Heat Exchanger
IRF	Inherent Reactivity Feedback
LBE	Licensing Basis Event
LMP	Licensing Modernization Project
LOHS	Loss of Heat Sink
LOOP	Loss of Offsite Power
LWR	light water reactor

NDC	NPH design categories
NEI	Nuclear Energy Institute
non-LWR	non-light water reactor
NPH	Natural phenomena hazard
NRC	Nuclear Regulatory Commission
NSR	Non-Safety-Related
NSRST	Non-Safety-Related with Special Treatments
NST	No Special Treatment
PB	Performance Based
PCS	Plant Control System
PDC	Principal Design Criteria
PHTS	Primary Heat Transport System
POS	Plant Operating State
PP	Primary EM Pumps
PSF	PRA Safety Functions
RAM	Reliability, availability and maintainability
RB	Reactor Building
RC	Radiological Consequence
RFDC	Required Functional Design Criteria
RI	Risk Integration
RIPB	risk-informed and performance-based
RPS	Reactor Protection System
RSF	Required Safety Functions
RVACS	Reactor Vessel Auxiliary Cooling System
SAHX	Sodium-to-Air Heat Exchanger
SAR	Safety Analysis Report
SBE	Safety Basis Event
SC	Safety-Class
SDIT	Safety design integration team
SFR	Sodium Fast Reactor
SRDC	Safety-Related Design Criteria
SSCs	Structure, System, and Components
SSPS	Secondary sodium purification system
ST	Special treatments
TICAP	Technology Inclusive Content of Application Project
TOP	Transient Overpower
VTR	Versatile Test Reactor

1.0 INTRODUCTION AND BACKGROUND

1.1 TICAP Description

Non-light water reactor technologies will play a key role in meeting the world's future energy needs and will build on the foundation established by the current light water reactor (LWR) nuclear energy fleet. Given the long timeframe and significant financial investment required to mature, deploy, and optimize these technologies, an efficient and cost-effective non-LWR-licensing framework that facilitates safe and cost-effective construction and operation is a critical element for incentivizing private sector investment. The TICAP is an important step in establishing that licensing framework. This DOE cost-shared, owner/operator-led initiative will produce guidance for developing content for specific portions of the NRC license application SAR for non-LWR designs.

The portions of the SAR on which this work will focus are those addressed in the NEI publication NEI 18-04, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development." [1] The TICAP guidance will help ensure completeness of information submitted to the NRC while avoiding unnecessary burden on the applicant and rightsizing the content of application commensurate with the complexity of the design being reviewed.

Existing LWRs are the country's largest source of emissions-free, dispatchable electricity, and they are expected to remain the backbone of nuclear energy generation for years to come. However, as the energy and environmental landscape has evolved, interest has grown in advanced nuclear energy systems that promise superior economics, improved efficiency, greater fissile-fuel utilization, reduced high-level waste generation, and increased margins of safety. In addition to electricity generation, these technologies can expand the traditional use of nuclear energy by providing a viable alternative to fossil fuels for industrial process heat production and other applications.

The current regulatory framework for nuclear reactors was developed over decades for LWRs using zirconium-clad uranium oxide fuel and coupled with the Rankine power cycle. Many advanced, non-LWRs are in development, with each reactor design differing greatly from the current generation of LWRs. For example, advanced reactors might employ liquid metal, gas, or molten salt as a coolant, enabling them to operate at lower pressures but higher temperatures than LWRs. Some employ a fast rather than a thermal neutron spectrum. A range of fuel types are under consideration, including fuel dissolved in molten salt and circulated throughout the primary coolant system. In general, advanced reactors emphasize passive safety features that do not require rapid action from powered systems to prevent radionuclide releases. Given these major technical differences, changes to the current regulatory framework are needed for the deployment of advanced reactor designs.

Therefore, the DOE authorized TICAP, a utility-led initiative to improve the effectiveness and efficiency of the NRC's current regulatory framework. The initiative recognizes that significant levels of industry input and advocacy are needed in collaboration with the NRC to enable the regulatory changes needed for advanced reactors.

The goal of TICAP is to develop license application content guidance with the following attributes:

- Technology inclusive to be generically applicable to all non-LWR designs
- Risk-informed and performance-based (RIPB) to:
    - Ensure the NRC review is focused on information that impacts the safety case of reactors.
    - Create coherency and consistency in the scope and level of detail requirements in the license application for various advanced technologies and designs.
    - Provide for flexibility during construction.
    - Encourage innovation by focusing on the final results as opposed to the pathway taken to achieve the results.

This modernized, technology inclusive RIPB license application content will advance:

- The NRC's longstanding focus on and commitment to continuous improvement
- The industry (developers and owners/operators) goal of having a safety-focused review that minimizes the burden of generating and supplying safety-insignificant information
- The NRC and industry objective of reaching agreement on how to implement reasonable assurance of adequate protection for non-LWRs
- NRC's stated objective and policy statement regarding the use of risk-informed decision-making to remove unnecessary regulatory burden

TICAP will build on the success of the LMP that produced NEI 18-04. That document presented a modern, technology inclusive, RIPB process for selection of Licensing Basis Events (LBEs); safety classification of SSCs and associated risk-informed special treatments; and determination of DID adequacy for non-LWRs. The TICAP application guidance will focus on the portion of the application related to LMP and the applicant's safety case. Ultimately, the information presented in the application must demonstrate reasonable assurance of adequate protection of public health and safety.

1.2 Purpose of TICAP Tabletop Exercises

TICAP will generate a number of products culminating in an NRC-endorsable NEI document providing guidance for key elements of the content of an advanced reactor license application. Figure 1-1 provides a list of the products with the subject of this report highlighted. Each of these products is described below.

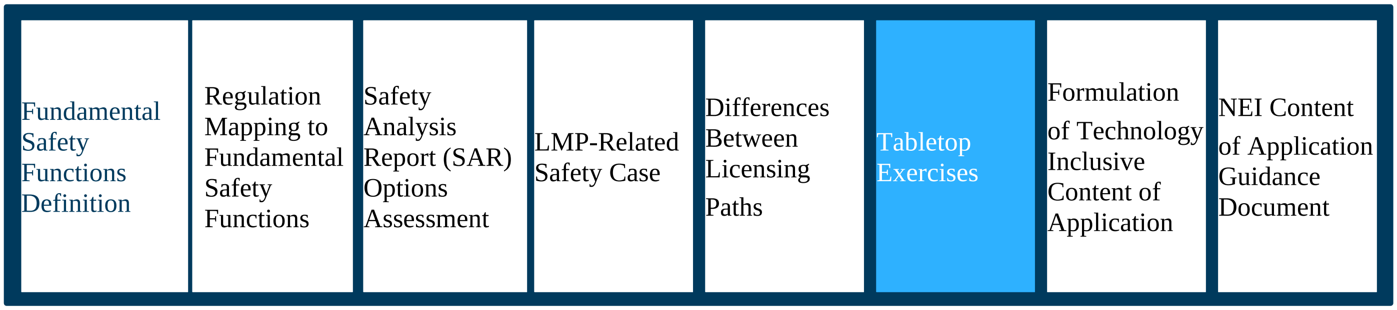

Figure 1-1: TICAP Products

Fundamental Safety Functions (FSFs) Definition—A set of high-level functions, labeled as Fundamental Safety Functions (also known as performance objectives), will be defined that, when accomplished, satisfy the public safety objective of the regulation. The FSFs are applicable, as relevant, throughout the lifetime of the facility for which the license is being submitted.

- Regulation Mapping to Fundamental Safety Functions—The underlying safety basis of the current regulatory requirements will be identified and will be mapped to the FSFs.
- SAR Options Assessment—The current SAR content will be reviewed to identify those sections that will be the subject of rightsizing in this project. It is important to note that only those sections/elements that are part of both the LMP's processes and their expected outputs will be targets of this project.
- LMP-Related Safety Case—The input (e.g., data, design information, analytical programs, and tools such as a probabilistic risk assessment) used to generate and select the LBEs, classify SSCs, and determine DID adequacy, as well as the outputs (e.g., the SSC classification results), will be delineated.
- Differences Between Licensing Paths—It is recognized that different applicants may select different licensing paths (e.g., combined construction and operating license, construction permit/operating license, or design certification) to deploy their reactor designs. To facilitate the execution of these options, the scope, level of details, and the maturity of the information that needs to be provided for several typical licensing paths will be defined.
- Tabletop Exercises—To improve the efficacy of the proposed process, some elements of the recommendations will be subjected to trial use tests. This effort will be supplemented by discussions with user communities (e.g., developers and/or prospective site applicants) in order to obtain the maximum independent insights on the proposed processes. Guidelines for conducting these tabletop exercises will be generated prior to the initiation of the exercises.
- Formulation of Technology Inclusive Content of Application—The formulation of and the basis for developing application content will be based on previous products, FSFs Definition, Regulation Mapping to FSFs, SAR Options Assessment, and the LMP-Related Safety Case.
- NEI Content of Application Guidance Document—The results of the above deliverables/activities will be finalized in an endorsable NEI document. This deliverable will

be an integrated product of various predecessor products that have been adjusted for the purposes of the Guidance Document.

As noted in the sections below, the VTR Tabletop is including four areas of the TICAP guidance document during the exercise including Sections 4.2 (DID evaluation), Chapter 5 (Safety Function, SSC Categorization, and Principal Design Criteria), Chapter 6 (Safety Related SSC Criteria and Capability), and Chapter 7 (NSRST/SS SSC Criteria and Capability). However, the focus of the exercise is limited to the heat removal function for both SR and NSRST functions. Although not part of the tabletop exercise; Chapter 3 presents the results of the VTR PRA and LMP analysis.

1.3 Linkage to LMP and TICAP Efforts

The VTR project applied the LMP process described in NEI 18-04 in support of authorization for building the VTR supported by a risk-informed, performance-based approach. The VTR LMP application described in Section 3.2 of this report involved all of the major steps including documentation described in NEI 18-04, including:

- PRA development
- DBE selection
- SSC Classification
- DID Evaluation
- Performance of the IDP

The VTR LMP application is applied to an example application using the draft TICAP guidance provided prior to the tabletop (January 2021). The TICAP guidance wording used for the scope included in this tabletop are included in the appendices for reference (with separate color coding). The TICAP guidance update process continued prior to and after the VTR tabletop, including as a result of the feedback from this tabletop exercise.

1.4 VTR Tabletop Exercise Scope, Objectives, and Deliverables

The Scope of the PRA supporting LMP is described in Section 3.1, and the DID reviews are described further in Chapter 4. As noted in these sections, although the entire process and associated steps were completed, not all of the steps were completed to the level needed for a final LMP application. For example, the PRA scope did not include everything needed to support the DBE selection, and the DID evaluation did not complete the programmatic review (due to plant programs not yet developed).

The application of LMP under the VTR project was performed in support of authorization under the U.S. DOE, and was included in the VTR CSDR [2] submitted to the DOE discussed below. Due to differences in rules and regulations between the NRC and DOE, the application of LMP required modification, including terminology, the F-C curve acceptance criteria, and SSC classification criteria. The first two subjects are described below, while SSC criteria is reviewed in Section 9.0APPENDIX B. For this report, however, the terminology is modified to use the NRC LMP terminology. The selection of SSC classification during the VTR LMP application did however use the DOE risk criteria (goals), including use of additional requirements associated with onsite and worker dose (not included in the NRC criteria under NEI 18-04).

The terminology/nomenclature used under the DOE application is described in Table 1-1, which compares the VTR-specific terminology and the LMP comparable term. Although the terms listed are comparable and similar, the definitions of each term are not identical [3]. For example, for Safety Significant (SS), the DOE requirements may be different and would consider onsite and worker dose criteria in the selection of SS SSCs. However, the frequency ranges for the event categories shown in the table are similar (e.g., Unlikely and DBE are between 1E-02/year and 1E-04/year).

Table 1-1: DOE and NRC Terminology Comparison [3]

VTR/DOE Term	LMP Term
Safety Basis Event (SBE) Category: • Anticipated • Unlikely • Extremely Unlikely	LBE Category: • Anticipated Operational Occurrence (AOO) • Design Basis Event (DBE) • Beyond Design Basis Event (BDBE)
SSC Classification: • Safety-Class (SC) • Safety Significant (SS) • Non-Safety (NS)	SSC Classification: • Safety-Related (SR) • Non-Safety-Related with Special Treatment (NSRST) • Non-Safety-Related with no Special Treatment (NST)

The LMP F-C curve is shown in NEI 18-04, Figure 3-1 [1]. The VTR LMP application also used an F-C curve for determining SSC classification, which are shown on Figures 1-2 and 1-3.

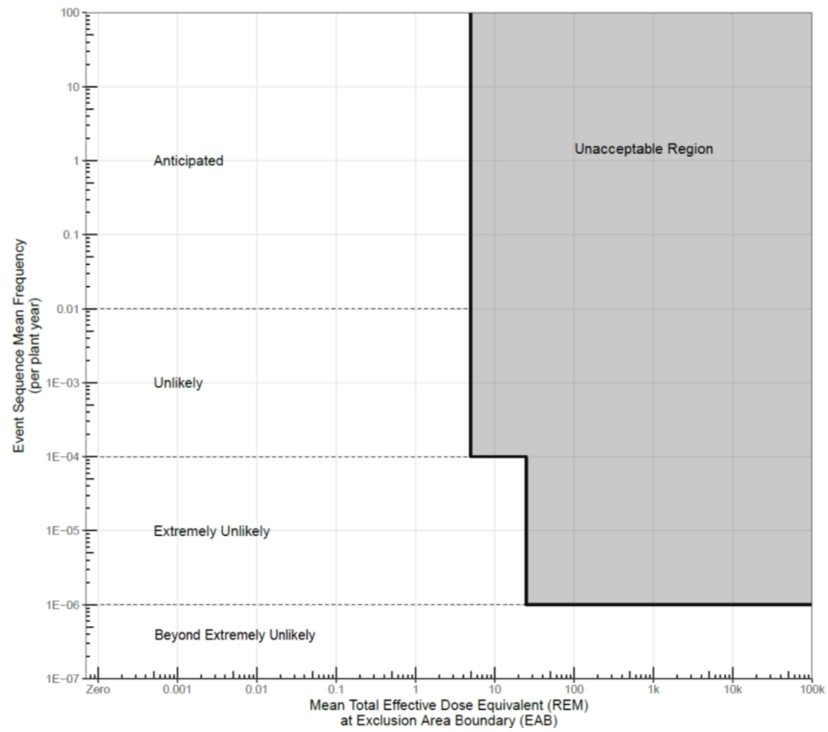

Figure 1-2: Offsite Population FC Threshold for VTR

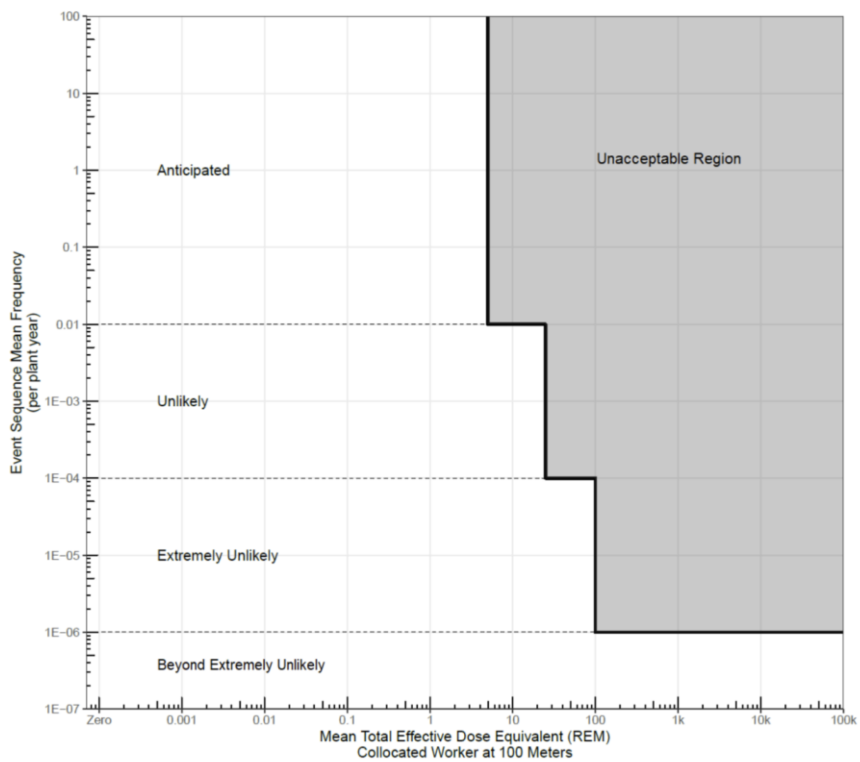

Figure 1-3: Collocated Worker FC Threshold for VTR

The LMP application for VTR supported the development of a CSDR submitted to the DOE for VTR authorization. The CSDR provided details on the PRA, completed LMP steps, and the resulting safety analysis supporting the LMP process. The CSDR included much of the information provided in this report, including most of the detailed descriptions provided in the Appendices of this report. However, the TICAP-specific tables are generally different that the format provided in the CSDR. The differences are not discussed further, since it is generally a matter of how the content is presented or the level of detail presented.

The objective of this tabletop exercise is to utilize the VTR LMP analysis, results and current documentation to develop either draft basis for developing application content or to provide recommendations for improvement for key areas in the draft TICAP guidance discussed in Section 1.2. This tabletop with include consideration for specific steps including:

- DID development
- SSC classification
- SR and NSRST criteria selection and capability evaluation

1.5 Report Organization

The report below includes a presentation of the VTR technical material provided in Chapters 2 through 9 and the proposed SAR content provided in Appendices A through D. Chapter 2 provides a VTR plant description to be used for the purposes of the tabletop; this information can be used in SAR Section 1.1, although Chapter 1 of the SAR is not within the scope of this tabletop. Chapter 3 provides a comprehensive review of the VTR PRA and LMP analysis including a description of key steps and outcomes. This information could be used to support the SAR Chapter 2 content, but again this is not within the scope of the tabletop.

Chapter 4 provides discussion of the VTR LMP DID evaluation, which is used to support the discussion in Appendix A. Chapter 5 provides a discussion on Safety Functions, Design Criteria and SSC classification with focus on the VTR Safety-Related and non-safety-related heat removal function. This chapter supports the development of Appendix B, which is the draft SAR content for this technical area. Chapter 6 provides discussion on Safety-Related SSC Criteria and Capabilities, with focus on Safety-Related heat removal. This chapter supports the development of Appendix C, which is the draft SAR content for this technical area. Chapter 7 provides the discussion on NSRST SSC Criteria and Capabilities, which supports the proposed SAR content provided in Appendix D.

Chapter 8 provides a summary of the tabletop report, and conclusions. References are provided in Section 9.

During the performance of the tabletop, a presentation on the plant design was provided. This presentation is provided in Appendix E.

2.0 VTR PLANT DESCRIPTION

This chapter provides an overview of the plant design and systems interfaces at a sufficiently detailed level that reviewers can understand the base plant design and how key systems described in subsequent chapters interact with each other and details about their respective design bases to support the discussions in subsequent chapters.

2.1 VTR Project Status

The VTR project is currently pursuing design activities ultimately leading to construction of a fast neutron irradiation capability. This project is being pursued utilizing the guidance and process in DOE O413.3B "Program and Project Management for the Acquisition of Capital Assets." This process generally applies a phased approach to design which applies decision and authorization gates called critical decisions. These critical decisions are stated as:

CD-0 Mission Need
CD-1 Conceptual Design Completion
CD-2 Preliminary Design Completion
CD-3 Final Design Completion
CD-4 Construction Completion and Turnover for Operations

VTR achieved CD-1 in September 2020 which reflects a detailed conceptual design, however significant detailed design work is still ongoing and necessary. This report reflects the status of the design and analysis at the conceptual design phase and has the potential to change as detailed design information becomes available during subsequent design phases.

2.2 VTR Summary Design Description

The VTR is proposed to be a 300 MWth pool-type SFR test facility. The VTR design benefits from favorable reactivity feedbacks that together with the low-pressure sodium coolant and reference metallic fuel provide passive shutdown and passive safety behavior under various reactor upset conditions. Since the primary mission of the reactor is reliable, fast flux testing, the VTR reactor plant will have no power conversion system and rejects its core heat to the atmosphere via sodium-to-air heat exchangers (SAHX) located outside the reactor building.

Depending on the fuel composition, the conceptual VTR reactor core can generate about 4.0×10^{15} n/cm^2-s of neutron flux above 0.1 MeV at a power level of 300 MWth. The core consists of 313 core assemblies. The design includes up to 66 positions for driver fuel assemblies, which generate the neutron flux; six boron carbide control rod absorber assemblies; and three boron carbide safety rod absorber assemblies. In its conceptual configuration the VTR reactor core provides up to 10 fast flux test locations in the active core. Since VTR is an irradiation test reactor, the composition and arrangement of the core are subject to change to meet varying testing requirements.

The primary heat transport system (PHTS) is installed inside of the reactor vessel in a pool-type configuration. The PHTS incorporates two intermediate heat exchangers (IHXs), one for each of the two heat removal systems (HRS) secondary sodium loops. Four submersible electromagnetic linear induction annular-cavity pumps (EM pumps) provide primary sodium circulation through the reactor. Each EM pump is provided with its own system to provide a flow coastdown (i.e., the sodium flow will not abruptly stop similar to a flywheel on a mechanical pump) in the event of loss of normal alternating current (AC) electrical power or pump trip.

The conceptual design provides that heat is removed by the PHTS, through the IHX, and finally rejects the heat through the HRS to the atmosphere via the SAHXs. The HRS incorporates two secondary sodium loops. Each secondary loop incorporates one IHX, five SAHXs, and two EM pumps in parallel. The pool-type reactor design, with an external guard vessel, reduces the likelihood of a loss of coolant accident (LOCA). This approach, with proper IHX shielding design, also reduces facility radiological dose rates, a desirable feature from an as low as reasonably achievable (ALARA) standpoint. The VTR also incorporates a Reactor Vessel Auxiliary Cooling System (RVACS) that is a completely passive natural circulation air cooling system for ultimate removal of decay heat if other HRS mechanisms fail. The RVACS is always in operation, providing an additional heat transport pathway to the air atmosphere heat sink.

3.0 VTR GENERIC AND SPECIFIC ANALYSIS

This chapter provides background and details of the VTR PRA and LMP analyses supporting TICAP tabletop report Chapters 4 through 7, which in turn support the TICAP-proposed SAR Chapters 3 through 7. The VTR TICAP Tabletop is not expected to develop the SAR content related to the PRA nor LMP results. However, the description of the VTR generic analyses provides the foundation of the follow-on TICAP activities. Table 3-2 includes the VTR generic analyses that have been performed.

3.1 VTR PRA Scope

The VTR PRA developed for the conceptual design phase includes the following scopes:

- Internal events
- Preliminary internal hazards
- Preliminary external hazards

As a result of the screening process in the preliminary hazards analysis, two hazard-specific scoping analyses have been conducted:

- Scoping sodium fire analysis
- Scoping seismic analysis

The above scopes were mainly developed for the full-power plant operating state (POS). A non-operational mode scoping analysis has also been performed to gain risk insights.

3.1.1 VTR Internal Events at Power (IEAP) PRA

The VTR IEAP PRA model provided a quantitative measure of risk by calculating the likelihood of potential radiological consequences and generated cutsets for all Event Sequence Families (ESFs), including event sequences both with and without fuel damage or radiological releases. The model also served as the foundation for the all-hazards and all-modes PRA models.

Figure 3-1 depicts the major PRA elements supporting IEAP risk. The VTR PRA analyses and results that were used in the LMP and follow-on processes can be summarized in two large categories: quantification of event frequencies and quantification of consequences.

The quantification of event frequencies encompassed:

- VTR Initiating Event Analysis (IE): this analysis identified transients, Loss of Offsite Power (LOOP), and special initiator groups based on review of industry PRAs, guidance documents, and design experience. The output of this analysis is a list of initiating events with their frequency estimates.
- VTR Event Sequence Analysis (ES): this analysis defined event tree structures and end states for each initiating event group based on review of industry PRAs and guidance documents. The outputs of this analysis include PRA modeled functions, event trees and event sequences.

- VTR Event Sequence Quantification Analysis (ESQ): this analysis combined the event tree logic developed by the ES and the functional failure probability fault tree models used by System Analysis (SY) to calculate the annual frequency of each of the event sequence end states. The outputs of this analysis are the cutsets with the supporting master fault tree and reliability database.
- Other VTR PRA analyses for event sequence development and quantification included the Success Criteria development, System Analysis (SY), Data Analysis (DA) and Human Reliability Analysis (HR). The outputs of these analyses include the definitions of success criteria, system fault tree models, component reliability and human reliability, all of which have been incorporated into the outputs for the above IE, ES and ESQ analyses.

The quantification of event consequences encompassed:

- VTR Success Criteria Analysis (SC): this analysis has been developed in support of the event trees. The non-OK end states for each event sequence have been grouped into a list of release categories, which are the inputs to the follow-on analyses.
- VTR Mechanistic Source Term Analysis (MS): this analysis defined the release of radioactive material from the plant as source terms. For risk-significant sequences, the transport of individual species from the core have been tracked to give a representative quantification of the release. The output of this analysis is the list of source terms.
- VTR Radiological Consequence Analysis (RC): this analysis calculated the health consequences to site workers and the public as the result of the release calculated in the MS. The outputs of this analysis are the consequences assigned to each release category.

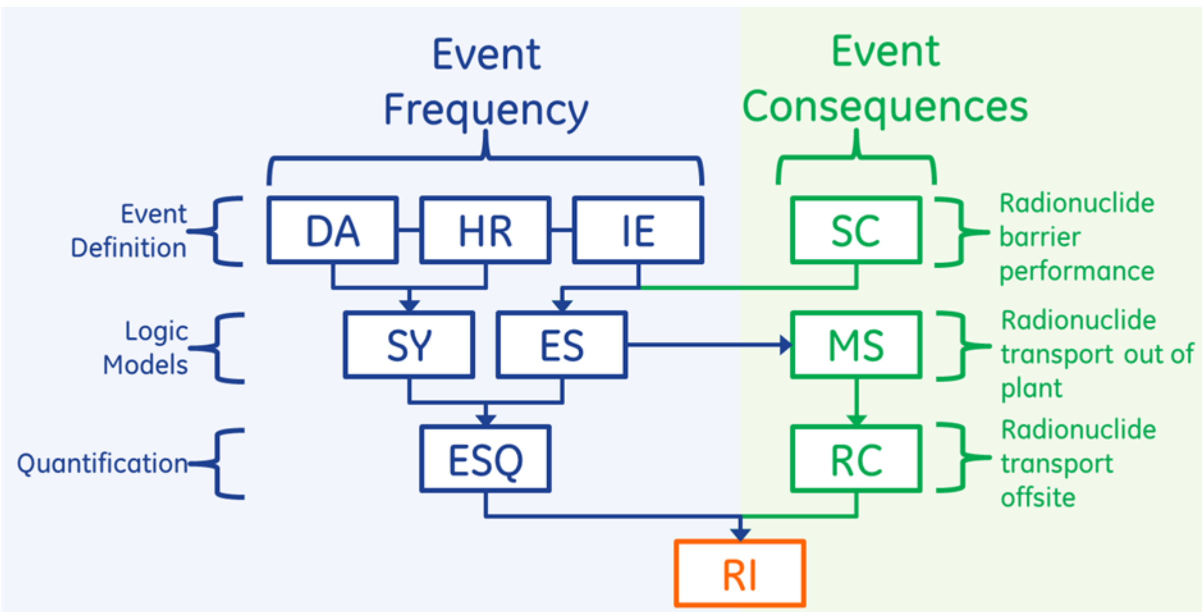

Figure 3-1: PRA Elements Supporting IEAP Risk

The Risk Integration analysis (RI) combines the results of the ESQ and RC. The VTR PRA generated risk results as event sequences in the form of cutsets and consequences for all release categories. These results were used as inputs to the LMP packages. The LMP packages have been used to generate the integrated risk metrics. In addition, key PRA assumptions and modeling uncertainties have been identified.

The methodologies and results of the VTR IEAP PRA are documented in Sections 2.1 and 3.0 of report 005N3526 Revision D, Versatile Test Reactor (VTR) Probabilistic Risk Assessment (PRA) Summary [4].

3.1.2 VTR Hazards Scoping Analyses

The scoping hazards analysis methodologies for Advanced Non-LWR PRAs [5] were applied to the VTR plant. Over 100 potential hazards were identified using well established hazard identification sources including Electric Power Research Institute (EPRI) report TR-1022997 [6]. For each identified hazard, a high-level SSC/function vulnerability assessment was performed and is documented in the VTR hazard-function matrix, which provided over 2400 hazard-function combinations.

Using the technology neutral criteria presented in the ASME/ANS Non-LWR PRA standard requirement EXT-B1 [7], a set of qualitative screening criteria was established. This criteria set was used to form ten hazard groups. One of these groups, water heat sink hazards, was qualitatively screened out since the VTR uses the atmosphere for the ultimate heat sink. The qualitative screening resulted in nine retained hazard groups, which are listed in Table 3-1 below.

Table 3-1: Retained Hazard Groups Qualitative Screening

Group Name
Seismic Events Hazard Group
Degraded Heat Sink Hazard Group
External Flooding Hazards
Internal Fires
Internal Flooding
Heavy load drops, other structural impacts
Catastrophic external impacts
Extreme weather events
Hazards affecting automatic actuation

A bounding frequency and response approach can then be used to estimate the quantitative impact of a given hazard group on the figures of merit for the VTR PRA. Using quantitative screening criteria from requirement EXT-C1, hazard groups may be screened out in these steps. However, since VTR is in the conceptual design phase, the detailed PRA analysis has not yet been performed. Instead, based on the all-hazards risk insights from previous sodium faster reactor PRAs, the following hazards were deemed acceptable to be included in the VTR PRA, supporting conceptual design phase:

- Seismic and related hazards - can affect multiple functions. Based on this, a focused scoping seismic study was performed.
- Internal fires - can potentially affect several VTR functions. Based on this, a focused scoping sodium internal fire study was performed.

The methodologies and results of the VTR hazards scoping analysis are documented in Section 4.0 of report 005N3526 Revision D, Versatile Test Reactor (VTR) Probabilistic Risk Assessment (PRA) Summary [4].

3.1.3 VTR All Modes Scoping Analyses

This scoping analysis systematically assessed the VTR design with respect to various POSs. The scoping level analysis was defined by the following:

- Inclusion of representative selections of POSs and event sequences,
- Simplification of assumptions made for the purpose of demonstrating the PRA methodology on the VTR technology,
- Identification of where further analysis will be beneficial to plant design.

The scoping analyses for non-operational modes identified the following representative IE groups and POSs:

- Loss of Heat Sink (LOHS) and LOOP IEs for POS Groups 2.A and 3.A, which correspond to the shutdown and refueling Plant Operating Modes, respectively.
- Bounding IEs defined in experimental module hazards and heavy load drops analyses for POS Groups 1.B, 3.1.b and 3.3.b, which correspond mainly to the refueling operating mode for fuel and/or test assemblies in transfer.

The results of VTR non-operational modes bounding plant response analysis in the form of representative event sequences have been summarized from the non-operational modes bounding event trees and quantification for the reactor core, the heavy load movement for the spent fuel and test assemblies, and the Experimental Module Hazard Analysis.

3.1.4 VTR Baseline Case PRA Model Quantification

While the VTR PRA summary report includes the generic analyses and results that support the LMP analysis and follow-on design activities, the VTR PRA results used by the LMP analysis to develop LBEs (Or SBEs for VTR) were represented as the baseline case cutsets. These cutsets were the quantification results from the VTR single-top master fault tree model, which combined the event sequences from IEAP, scoping sodium fire and scoping seismic PRA models.

The baseline case PRA model assumed that all PRA functions are available except for the dependencies that have already been included in the event tree and fault tree logic.

Both the OK and non-OK sequences (i.e., with and without potential radionuclide release) have been included in the quantification for LMP purposes. The baseline case cutsets included all sequence characteristics with the sequence markers and release category markers besides the initiating events and failed basic events.

3.1.5 VTR Sensitivity Case PRA Model Quantification

For VTR LMP analyses to determine the safety significance of the SSCs, two types of VTR sensitivity case PRA model quantifications have been performed:

- Function-specific risk achievement quantification: this analysis evaluated the risk achievement on the loss of single functions. The outputs of this analysis are the cutsets for function-specific sensitivity cases.
- Safety significance sensitivity case quantification: this analysis evaluated the risk significance of potential safety significant functions for a set of candidate safety-related (or safety-class) functions. The outputs of the safety significance studies include the cutsets for sensitivity cases with combinations of functions.

The VTR sensitivity cases were developed in an iterative manner because different design options can be tested with different combinations of the safety-related (safety-class) and safety significant (non-safety related with special treatment - NSRST) functions.

3.1.6 VTR PRA Peer Reviews

In support of the VTR PRA model development and LMP analyses, VTR PRA peer reviews will be performed. Currently for the VTR PRA and LMP at the conceptual design phase, partial self-assessments have been performed as part of the PRA model development. These self-assessments have identified some gaps to the Capability Category II (CC-II) requirements in the non-LWR PRA standard [7].

Future PRA peer reviews will ensure the technical adequacy of the VTR PRA against the CC-II requirements of the non-LWR PRA standard [7]. The outputs of the PRA peer reviews will be the peer review reports, which include Facts and Observations (F&Os) and proposed resolutions.

3.2 LMP Analysis and Results

Using the VTR PRA results described in Section 3.1, the generic LMP analyses have been performed in the following three major categories:

- LBE (or SBE) analyses
- LMP function/SSC importance analyses
- LMP risk significance analyses

3.2.1 LBE/SBE Analysis

The LBE (SBE) analyses build upon the VTR PRA results in terms of event tree and fault tree logic and event sequence information represented by cutsets. Two main analyses have been performed in this category:

- LBE (or SBE) quantification: this analysis was centered around processing the PRA Event Sequence (ES) and Systems Analysis (SY) models to form ESFs. The ESFs were defined and grouped with the key characteristics of the event sequences including IE, plant response and release category. After the definition of ESFs, the baseline PRA model quantification results (see Section 3.1.4) were then used to quantify the frequencies of the ESFs. The outputs of this analysis include the LBE/SBE definitions and baseline frequencies. With both the ESF frequencies and the dose consequences of the release categories obtained from VTR PRA, the outputs of this analysis can be plotted on the Frequency-Consequence (F-C) charts.
- LBE categorization: LBE/SBE categorization follows guidance from NEI 18-04, LBE Selection Task 4. Here it specifies that each ESF, "…is assigned to an LBE category based on mean event sequence frequency of occurrence per plant-year summed over all the event sequences in the LBE family." The outputs of this analysis include the LBE/SBE categories and sequence characteristics. Note the Design Basis Accidents (DBAs) can only be defined after the safety-related (or safety-class) functions are identified in later analyses.

After the above two LBE/SBE analyses, an LBE/SBE detailed review was performed. For each IE, the associated LBEs/SBEs were described and visualized on the F-C chart.

The LBE/SBE analyses and results are described in Sections 2 through 4 of the Appendix A in report 005N4450, Versatile Test Reactor (VTR) LMP Analysis [8].

3.2.2 LMP Function/SSC Importance Analyses

The LMP function/SSC importance analyses implement tasks 5a, 5b, 6 and 7c of NEI 18-04 [1]. In addition, VTR LMP analyses followed the guidance in SDS-422 [9] with the following three types of importance analyses:

- Function-specific risk achievement studies: these studies identified candidates of the Required Safety Functions (RSFs) by evaluating the sensitivity study results from the risk achievement studies for each single function. Major VTR functions (e.g. Reactor Protection System (RPS), control rod insertion and RVACS) were simulated as unavailable by setting their associated PRA model basic events and/or gates to a failed condition. The PRA sensitivity studies included in Section 3.1.5 were performed in an iterative manner to support these studies. The outputs of this analysis are the candidates for safety-related or safety-class functions.
- Success path studies: these studies took the list of candidates of safety-related or safety-class functions from the function-specific risk achievement studies and added selected new safety-related functions to ensure the combination of safety-related functions would be adequate to keep the LBEs (or SBEs) below the dose consequence thresholds. As a result, the outputs of this analysis could include multiple candidate sets of safety-related or safety-class functions.
- Safety significance studies: these studies continued from the candidate sets of safety-related functions to identify the NSRST functions/SSCs. Safety significance of single or combinations of non-safety-related functions/SSCs has been evaluated by simulating the risk changes between the sensitivity cases with and without these potential NSRST functions/SSCs. The outputs of this analysis include the candidate sets of NSRST functions/SSCs.

The VTR importance analyses and results are described in Section 5 of the Appendix A in report 005N4450, Versatile Test Reactor (VTR) LMP Analysis [8].

3.2.2.1 Example Function/SSC Importance Analysis for Heat Rejection System (HRS)

The function/SSC importance analysis for HRS is shown as an example in this sub-section.

The single function-specific risk achievement analysis for both the active and passive heat rejection functions showed that neither of the HRS functions (active and passive modes) is a candidate for safety-related or safety-class functions. The figure below shows the risk achievement results for both sensitivity cases (A.HRS for active HRS heat rejection mode and P.HRS for passive mode).

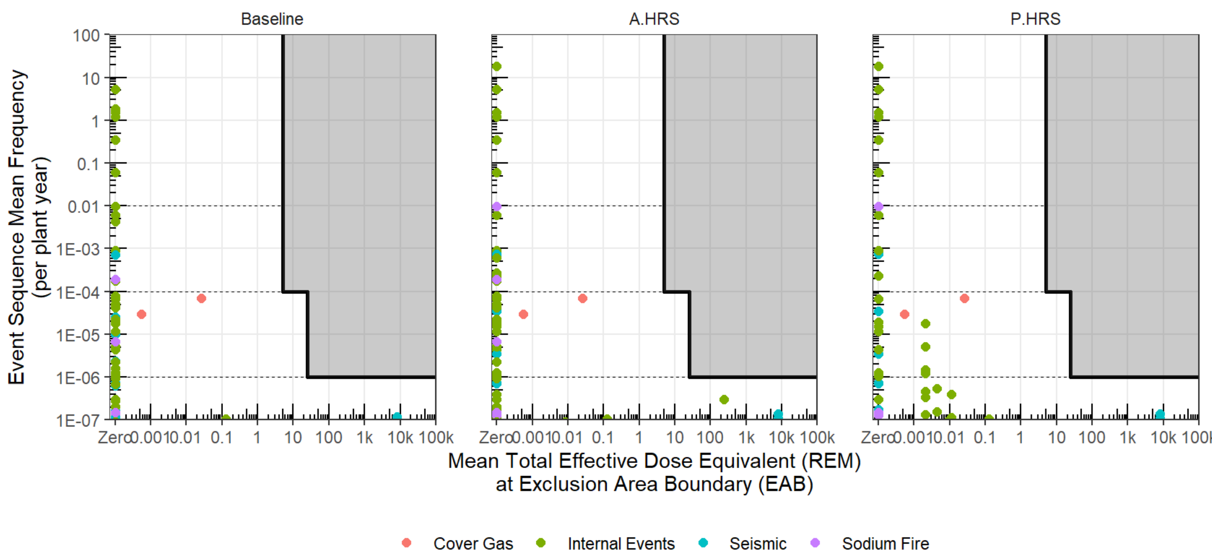

Figure 3-2: HRS Function-Specific Risk Achievement Study Results

In the success path studies, there was also no need to identify HRS functions as candidates for safety-related or safety-class functions. For a candidate set of safety-related functions (e.g., Set-2 in this example), the HRS functions have been evaluated further for their safety significance.

Although the success path studies demonstrated that the Set-2 safety-related functions/SSCs can ensure the AOOs and DBEs would not violate the F-C thresholds, a sensitivity case without crediting any non-safety-related functions/SSCs showed that the F-C thresholds would be violated for beyond DBE (BDBE) ESFs, which was expected (see results for "Set2" in figure below). Crediting any single additional function as safety significant (potential candidate for NSRST functions) did not return with a successful sensitivity case, which included the following two sensitivity cases related to HRS:

- Sensitivity case Set2.AHRS (Active HRS): crediting the safety-related functions in Set-2 and an additional HRS function for active mode heat rejection

- Sensitivity case Set2.PHRS (Passive HRS): crediting the safety-related functions in Set-2 and an additional HRS function for passive mode heat rejection

Additional sensitivity cases were developed to have two potential safety significant functions, which demonstrated successful results as shown in cases Set2.COMB1 and Set2.COMB2. The Set2.COMB2 case includes both manual Electro-Magnetic (EM) pump trip and HRS passive mode heat rejection functions as candidates for NSRST.

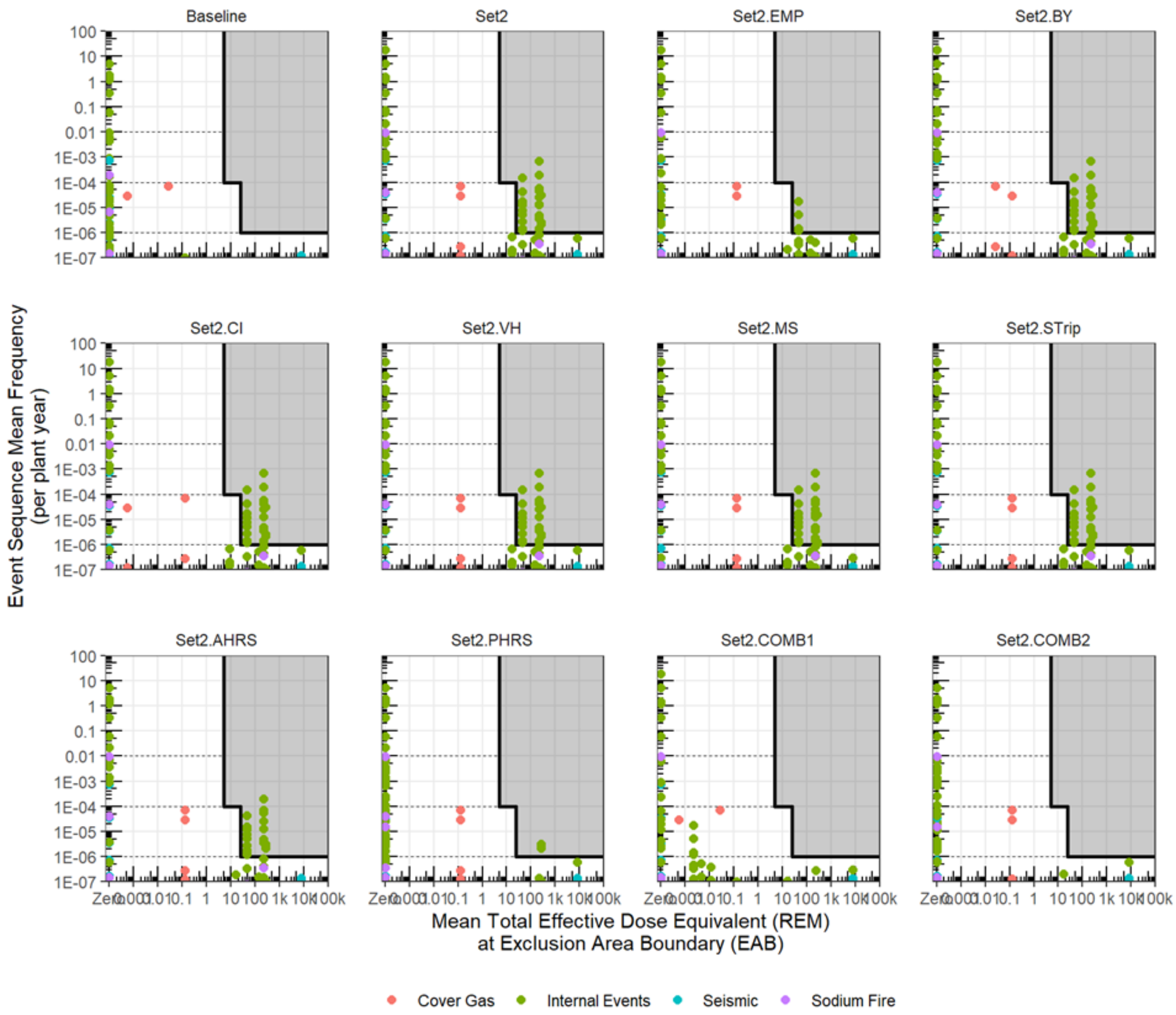

Figure 3-3: Potential Safety Significant Function Risk Achievement Results for Set-2 Safety-Related SSCs

3.2.3 Other LMP Risk-Significant Analyses

Other LMP risk significance analyses have been performed for VTR:

- Risk significance of SSCs and LBEs: this analysis used a qualitative examination to identify additional studies for potential risk-significant SSCs and risk-significant LBEs or SBEs beyond the scope of the above studies.
- Risk significance associated with cliff-edge LBEs: this analysis investigated the cliff-edge region defined in the VTR PRA plan. The outputs of this analysis are potential additional risk-significant SSCs associated with cliff-edge LBEs.

In addition, other specific LMP risk significance analyses have been requested from the design team or VTR IDP panel for risk insights which were used for decision-making. One example is the VTR importance analysis of the seismic early warning system, which is described in the following sub-section.

3.2.3.1 Example Specific Analysis - Seismic Sensitivity Analysis

One of the systems in the VTR design is the seismic scram initiation system, which if successful should fully insert the control rods before the arrival of any damaging seismic waves on site. This would prevent any rod insertion failure due to a seismic event.

The quantitative results demonstrated that the seismic scram initiation system as modeled is not required as a safety-related or safety-class function. It is important to note that the sensitivity analyses performed track details below a level of probability (e.g. less than 1E-8/yr) that likely has sufficiently high uncertainties about the accuracy of data at that level and would be anticipated to not be presented in the licensing submittal documentation.

Two limitations have been noted for the seismic sensitivity study:

- The PRA scope for Phase 1 of VTR PRA development includes the Internal Events, Seismic and Sodium Fire hazards occurring during the At-Power POS. Other internal and external hazards and POSs will be quantitatively assessed in future VTR PRA development phases. By extension, only those SSCs directly modeled in the PRA event and fault trees will be analyzed, therefore SSCs that exclusively support other POSs and hazards (such as fuel handling equipment) are outside the scope.
- The Seismic model employed in this stage of VTR is a scoping model.

The above limitations have been considered in the IDP discussions, which have made a conservative decision to assign the safety-related (or safety-class) category to the seismic early warning system.

3.3 Defense-in-Depth (DID) Reviews

Following the framework for establishing DID adequacy in Section 5.2 of NEI 18-04 [1], the VTR DID evaluation has been integrated with the PRA analysis in Section 3.1 and LBE (SBE) selection and evaluation in Section 3.2.1 and is an integral part of the SSC classification and performance requirement determination in Section 3.2.2.

In addition, both the preliminary plant capability DID review and programmatic DID review have been performed. The outputs of these reviews include the evaluations of DID adequacy and recommendations. The details of the DID reviews are described in Section 4.

3.4 Performance of the IDP

Following the guidance described in Section 5.3 and 5.9 of NEI 18-04 [1], performance of the IDP has been used to guide the overall design effort (including development of plant capability and programmatic DID features), conduct the DID adequacy evaluation of the resulting design, and document the DID baseline. All the outputs from generic and specific analyses described in previous sections are used as inputs to the IDP reviews.

3.5 Use of the PRA and LMP Results for Licensing and Safety Analysis

The use of PRA and LMP results for licensing and Safety Analysis has been summarized at a high level in Table 3-2. More details of the application of the PRA and LMP results are described in Chapters 4 through 8.

Table 3-2: VTR TICAP Tabletop Report Chapter 3 Sub-Sections, Analyses and Supported SAR Chapters

Tabletop Report Chapter 3 Sub-section	VTR Analyses (Outputs)	Supported Tabletop Report Chapter	Supported SAR Chapter
3.1 VTR PRA and Scope	VTR IEAP PRA Model • VTR initiating event analysis (initiating events) • VTR event sequence analysis (PRA modeled functions, event trees, event sequences) • VTR event sequence quantification analysis (cutsets) • Other VTR PRA analyses for event sequence development and quantification (success criteria, system fault tree models, component reliability and human reliability) • VTR mechanistic source term analysis (source terms) • VTR radiological consequence analysis (consequences for each release category) • VTR Risk Integration analysis (integrated risk metrics, key PRA assumptions and modeling uncertainties)	Chapters 3 & 4	Chapters 3 & 4
	VTR Hazards Scoping Analyses • Qualitative hazard screening analysis (retained hazard groups) • Scoping sodium fire analysis (scoping sodium fire scenarios, event sequences and cutsets) • Scoping seismic analysis (scoping seismic scenarios, event sequences and cutsets)	Chapters 3 & 4	Chapters 3 & 4
	VTR All Modes Scoping Analyses: • VTR POS analysis • Representative Non-Operational Modes Event Sequences for Reactor Core • Representative Event Sequence from Experimental Module Hazard Analysis • Representative Heavy Load Movement Event Sequences	Chapters 3 & 4	Chapters 3 & 4
	VTR Baseline Case PRA Model Quantification (baseline case cutsets)	Chapters 3 & 4	Chapters 3 & 4

Tabletop Report Chapter 3 Sub-section	VTR Analyses (Outputs)	Supported Tabletop Report Chapter	Supported SAR Chapter
	VTR Sensitivity Case PRA Model Quantification		
	• Function-specific risk achievement quantification (cutsets for function-specific sensitivity cases)	Section 3.2, Chapters 5 & 6	Chapters 5 & 6
	• Safety significance sensitivity case quantification (cutsets for sensitivity cases with combinations of functions)	Section 3.2, Chapter 7	Chapter 7
	VTR PRA Self-Assessments and Peer Reviews • PRA self-assessments (self-assessment reports) • PRA peer reviews (peer review reports, including F&Os)	Chapters 3 & 4	Chapters 3 & 4
3.2 VTR LMP Analysis	LBE (or SBE) analyses: • LBE (or SBE) quantification (LBE/SBE definitions and frequencies) • LBE categorization (LBE/SBE categories and sequence characteristics)	Chapter 3	Chapter 3
	LMP Function/SSC Importance Analyses:		
	• Function-specific risk achievement studies (candidates of safety-related or safety-class functions)	Chapters 5 & 6	Chapters 5 & 6
	• Success path studies (candidate sets of safety-related or safety-class functions)	Chapters 5 & 6	Chapters 5 & 6
	• Safety significance studies	Chapter 7	Chapter 7
	Other LMP Risk Significance Analyses: • Risk significance of SSCs and LBEs (Risk-significant SSCs, Risk-significant LBEs or SBEs) • Risk significance associated with cliff-edge LBEs (risk-significant SSCs associated with cliff-edge LBEs)	Chapter 7	Chapter 7

Tabletop Report Chapter 3 Sub-section	VTR Analyses (Outputs)	Supported Tabletop Report Chapter	Supported SAR Chapter
3.3 DID Reviews	DID Reviews: • Plant capability DID review (evaluation of DID adequacy, and recommendations) • Programmatic DID review (evaluation of DID adequacy, and recommendations)	Chapter 4	Chapter 4
3.4 Performance of IDP	IDP Panel reviews (LBE/SBE selection, safety-related (or Safety-Class) classification, DID & NSRST (or SS) classification)	Chapter 4	Chapter 4
3.5 Use of PRA and LMP Results	N/A	Chapters 4 to 8	Chapters 4 to 8

4.0 TICAP DID DEVELOPMENT (SAR SECTION 4.2)

As discussed in Chapter 3, the VTR LMP analysis includes a number of key steps involving verification of adequate DID. NEI 18-04 Table 5-1 [1], Role of Major Elements of TI-RIPB Framework in Establishing DID Adequacy discusses the major steps for LMP. These include:

- Designer Development of Safety Design Approach
- Reactor-Specific PRA
- Selection and Evaluation of LBEs
- SSC Safety Classification and Performance Requirements
- Risk-Informed Evaluation of DID Adequacy.

Although all the steps in LMP support the DID adequacy, the last bullet is supported by the steps in Chapter 5 of NEI 18-05 [1] which are discussed below.

The DID process involves the use of an IDP. The analysis and review for DID is documented and presented to the IDP during the IDP meetings and in the final LMP documentation. The IDP evaluates the LMP quantitative results, SSC Safety Classification, DID-specific reviews, assignment of special treatment requirements, sensitivity analysis, etc. As a result, the IDP determines that the design and the outcome of the LMP analysis provide support for adequate DID.

The LMP steps are discussed in Chapter 3, while the above DID-specific steps are discussed below.

4.1 Plant Level DID Review Including Plant Capability DID

4.1.1 Methodology

The plant level DID review involves the review of the LMP LBE results against the DID layer guidance in Table 5-2 of NEI 18-04 [1]. For example, anticipated events (with frequency above 1E-02/year) are reviewed against the following criteria listed in NEI 18-04 Table 5-2:

A. Maintain frequency of all DBEs < 10-2/plant-year.
B. Minimize frequency of challenges to SR-SSCs.
C. Meet F-C Target for all DBEs and cumulative risk metric targets with sufficient margins.
D. No single design or operational feature, no matter how robust, is exclusively relied upon to satisfy five layers of DID.

Guidance for review against these criteria is discussed in Chapter 5 of NEI 18-04 [1]. The evaluation of plant capability DID adequacy focuses on the following:

- Completeness, resiliency, and robustness of the plant design with respect to addressing all hazards,
- Responding to identified IEs,

- Preventing and mitigating the progression of IEs through the availability of independent levels of protection, and
- Achieving sufficient protection of public health and safety through the use of redundant and diverse means.

This evaluation is performed for all DBEs and BDBEs.

4.1.2 Results

Each LBE identified by the LMP analysis was reviewed for plant capability DID including the review of the criteria in Table 5-2. Item C listed above was verified in the quantitative LMP evaluation through both the use of an F-C chart, and through quantification of each of the applied risk metrics. In all cases, significant margin was demonstrated, as discussed in Chapter 3.

An example of the Plant Capability review for a single LBE is provided in Table 4-1. A table containing all PRA generated LBEs was provided to the IDP for review and confirmation.

Table 4-1: Plant Capability DID Review – Example DBE Review

LBE	Freq.	Classification	Non-Zero Release	Successful Functions	Failed Functions	Discussion	DID Guidelines (NEI 18-04, Table 5-2)	Considerations
LBE-LOHS-1 Loss of Heat Sink including loss of a train of passive heat removal	9.7E-03	DBE	N	Control Rods (CR), Primary EM Pumps Tripped (PP), Passive Heat Removal (1 train passive B24 failed), RVACS (RV)	One train of Passive Heat Removal	RVACS Operation, reduced requirement due to one train B24 operating.	Maintain Frequency of all DBEs < 1E-02/plant-year	Reliability of passive heat removal from B24 is important, including prevention of leakage causing a LOHS.
							Minimize frequency of challenges to SR-SSCs	Passive Heat removal reliability is important to minimize the frequency of events where RVACS is needed.
							Meet Owner Requirements for Plant Reliability and Availability	Review is not complete for this phase of the VTR LMP.
							Meet F-C Targets and Risk Metrics	Ok for all LBEs. Not repeated for other events below.
							No Single Design or Operational Feature is exclusively relied upon to satisfy five layers of DID	This was reviewed for all LBEs, and no issues identified.

Note: Table 4-1 yellow columns would likely not be included in the final SAR content. The orange columns are based on the LMP review and would likely be adjusted for the SAR content.

4.2 DID for Defining Safety-Significant SSCs

4.2.1 Method

The guidelines in NEI 18-04 Table 5-2 [1] require that two or more independent plant design or operational features be provided to meet the plant capability requirements. As discussed in Section 4, SSCs are classified as safety-significant if they perform one or more risk-significant functions or provide a function or functions that are necessary for DID adequacy. Non-SR-SSCs that perform a function or functions that are necessary for DID adequacy are classified as NSRST. Special treatment requirements for NSRST SSCs include the setting of performance requirements for SSC reliability, availability, and capability and any other treatments deemed necessary by the IDP for completing the integrated design process in Figure 5-4 and evaluating DID adequacy.

4.2.2 Results

The quantitative identification of NSRST components is discussed in Section 3.2.3. This section also discusses the performance of the cliff-edge effects review, which can also result in the identification of NSRST SSCs or special treatment. A number of NSRST components were identified as a result of this process and documented in the LMP and IDP reports.

For Decay Heat Removal, the following were identified as SR and NSRST:

- SR
    - RVACS Structures, Inlet/Outlet Ducts
    - Reactor Vessel and Guard Vessel
    - Primary EM Pump Power Supply isolation breaker and diverse isolation (trip the primary EM pump to ensure additional pump heat is not added to the system)
    - Reactor internals, pump piping, inlet plenum, inlet modules and fuel assemblies (Ensures Core Flow is maintained)
- NSRST
    - Intermediate Heat Exchanger including tubing
    - HRS piping inside and outside containment up to the isolation valves to individual Sodium-Air Heat Exchangers
    - EM Pump Thermal Shutdown Device

For VTR however, since the plant design was in the conceptual design phase, the assignment of special treatment, reliability/availability requirements, or capability requirements was not complete for this phase. The assignment of special treatment for SR and NSRST SSCs will occur in a future phase during the VTR LMP process. Plant programs and special treatment will be discussed in Chapter 8 of the SAR.

4.3 Evaluation of LBEs Against Layers of Defense

The discussion below is not currently included in the draft TICAP guidance provided for this tabletop, but was included in Chapter 5 of NEI 18-04, and included in the VTR LMP evaluation.

4.3.1 Method

This review by the IDP is necessary to evaluate the plant capabilities for DID and to identify any programmatic DID measures that may be necessary for establishing DID adequacy. The process described in NEI 18-04; Section 5.7 [1] includes the IDP review of the following:

- Confirm that plant capabilities for DID are deployed to prevent and mitigate each LBE at each layer of defense challenged by the LBE. (discussed above including Table 4-1 – but reviewed by the IDP).
- Confirm that a balance between event prevention and mitigation is reflected in the layers of defense for risk-significant LBEs. (discussed above – but reviewed by the IDP).
- Identify the reliability/availability missions of SSCs that perform prevention and mitigation functions along each LBE and confirm that these missions can be accomplished. A reliability/availability mission is the set of requirements related to the performance, reliability, and availability of an SSC function that adequately ensures the accomplishment of its task, as defined by the PRA or deterministic analysis.
- Confirm that adequate technical bases for classifying SSCs as SR or NSRST exist and their capabilities to execute the RSFs are defined.
- Confirm that the effectiveness of physical and functional barriers to retain radionuclides in preventing or limiting release is established.
- Review the technical bases for important characteristics of the LBEs with focus on the most risk-significant LBEs and LBEs with relatively higher consequences. The technical bases for relatively high-frequency LBEs that are found to have little or no release or radiological consequences is also a focus of the review.
- Confirm that risk-significant sources of uncertainty in both the frequency and consequence estimates that need to be addressed via programmatic and plant capability DID measures have been adequately addressed.

An LBE margin review is performed and provided to the IDP for review. The LBE margins are initially provided in the F-C curve and establish the baseline margins between the frequencies and consequences of individual LBEs and the F-C Target. Tabular presentation of the margins is provided and include a review of AOOs, DBEs and BDBEs.

4.3.2 Results

The following provides a summary of the LBE capability for DID, discussed in the bullets above.

- The plant capability DID is discussed in Table 4-1 above. The results of the LBE-based DID was reviewed by the IDP for confirmation of adequate DID. Where changes to the SSC classification, LBE identification or special treatment was required, the IDP provided recommendations for these changes.

- The balance between prevention and mitigation is also reviewed by the IDP as a part of the plant capability DID discussed in Table 4-1.
- The reliability and availability requirements related to the performance of SSC functions was not completed for the VTR in this phase of design. The programmatic attributes for reliability/availability are discussed in Chapter 8 of the SAR, which is not within the scope of this tabletop exercise. Programs that ensure reliability and availability targets are met include:
    - The reliability, availability and maintainability (RAM) program, with the objective of maintaining the facility in a safe state.
    - SSC Testing, inspection and monitoring programs including application of the maintenance rule program.
    - Application of Technical Specifications including allowed outage times for SR-SSCs, where applicable.
    - Environmental Qualification Program, which ensures SSCs can perform their safety functions within the environmental and accident conditions that the SSCs might experience during an LBE.
- The technical bases for classifying SSCs is provided in Chapter 3, where the use of the LMP methodology is discussed. The SSC classification results are provided in Chapter 5 below as well as the SSC RSFs.
- The effectiveness of physical and functional barriers to retain radionuclides in preventing and limiting releases is demonstrated in the PRA and LMP F-C results discussed in Chapter 3. The results were reviewed by the IDP for confirmation of adequacy. As discussed in NEI 18-04, Table 5-4 [1]; the fraction of source term released from the fuel, coolant boundary and reactor building can be mitigated by inherent and passive capabilities including design margins to limit the release.
- The technical bases for important characteristics of the LBEs was reviewed by the IDP during several steps, including during the review of plant capability DID, review of the LMP results, and review of the high-consequence events (e.g., cliff-edge effects review). The plant capability review included the identification of whether the LBE involved a non-zero release, and the F-C curve discussed in Chapter 3 plotted the estimated dose release for each LBE. The PRA accident sequence characteristics were reviewed by the IDP for each LBE.
- Risk-significant sources of uncertainty in both the frequency and consequence estimates were documented in the PRA and LMP analysis and reviewed by the IDP. Sensitivity evaluations include the review of LBEs below the BDBE cutoff to confirm that LBEs would not cross into the BDBE region. This review focused on the high-consequence region, for any cliff-edge events, as described in NEI 18-04 [1]. The PRA uncertainties were also reviewed for potential impact on the PRA and LMP results.

The LBE margin review was completed by the IDP review of the F-C charts for groups of LBEs. These F-C charts provide both the baseline results and sensitivity analysis results for each group of LBEs. Table 4-2 provides a conservative summary of margins in which the 95th percentile upper bound values for both LBE frequency and dose are used to calculate the margins for all non-zero-dose BDBEs. Note that none of the AOOs and DBEs for the VTR are estimated to result in any dose release (all are zero-dose in the PRA).

Table 4-2: Risk Margins Based on the 95th Percentile Values of LBE Frequency and Dose

LBE Category	Limiting LBE			F-C Target			
	LBE Name	95th Percentile Freq./RYR	95th Percentile Dose (REM)	Freq. at LBE Dose/RYR	95th Percentile Frequency Margin	Dose at LBE Frequency (Rem)	95th Percentile Dose Margin
BDBE	BDBE-1	TBD					
BDBE	BDBE-1	TBD					

4.4 Programmatic DID Review

4.4.1 Method

For those areas applicable at this phase of the design, the VTR LMP results are reviewed against Tables 5-5 and 5-6 of NEI 18-04 [1]. The VTR programs used to monitor SR-SSCs and assure human performance and operational controls will be described with focus on RSFs. This will include programmatic controls that account for an manage risk-significant uncertainties identified in the DID evaluation.

4.4.2 Results

For this phase of the VTR design, the programmatic DID review was not yet complete. Programs and special treatment identified for SR and NSRST components are discussed in Chapter 6 and 7. Programs required to ensure reliability, availability and maintainability are discussed in 4.3 above.

4.5 DID Review Summary

The above DID steps were completed as a part of the VTR LMP evaluation, to the extent possible for a plant in the design phase. Integrated DID attributes are listed in NEI 18-04 Table 5-8: use of the risk-triplet outside of the PRA; state of knowledge adequacy; uncertainty management and, action refinements [1].

The LMP process described in NEI 18-04 [1] includes a significant number of steps and analysis that support the integrated DID evaluation for the VTR. Much of the PRA and LMP evaluations are systematically evaluated by the IDP to verify adequate DID as discussed above. Where changes to the LBEs, SSC classification or special treatments are needed as a result of the IDP review, the IDP required changes to address the DID or uncertainty.

As a result of the above DID review, the recommended SAR Content for Section 4.2 of the SAR is provided in Appendix A. As noted, the VTR LMP evaluation did not complete much of the programmatic DID review and has limited recommendations for SAR content in this area.

5.0 SAFETY FUNCTIONS, SSC CATEGORIZATION, AND PRINCIPAL DESIGN CRITERIA (PDC)

5.1 Safety Classification of SSCs

SSC safety classification is determined based upon the necessity to perform an identified safety function or limit the public/worker risk from an identified SBE to within the approved SBE evaluation guidelines in Chapter 3. This includes both risk-informed and prescriptive criteria. The risk-informed criteria gauge the importance of the SSC in limiting radionuclide releases to the public or worker, utilizing the offsite or worker dose F-C guidelines.

Three classifications of equipment are utilized for VTR SSCs based upon their importance in preventing or mitigating events that could lead to a release of uncontrolled radioactive or hazardous material. SR-SSCs are those utilized to protect the offsite public and have the most stringent associated requirements. The role of NSRST SSCs is primarily to protect co-located workers but can also be utilized for the assurance of DID or public protection from non-radiological hazardous material. All other SSCs are designated as Non-safety (NS) SSCs. Note that this SSC classification is similar but not completely analogous to the classification described in NEI 18-04 [1] for licensing by the U.S. NRC. The SSC classification and criteria are in Table 5-1.

Table 5-1: VTR SSC Classification and Criteria

SSC Classification	Criteria
Safety-Related (SR)	• Offsite F-C Curve[1]: ○ For SBEs greater in frequency than 10-6/yr., an SSC is SR if its removal causes the SBE to violate the F-C curve, when considering a one-by-one removal of SSCs, crediting all remaining SSCs, regardless of safety classification, at appropriate reliability levels (and with appropriate accounting of common cause failure). ○ For DBAs derived from SBEs in the "Unlikely" category (<10-2 to >10-4/yr.), an SSC is SR if it is necessary for the DBA to satisfy the 25 rem consequence limit when utilizing deterministic, prescriptive analysis of the event sequence and crediting *only* SR-SSCs. • If the SSC is required to ensure integrity of the primary coolant boundary. • If the SSC is required to ensure reactor shutdown. • If SR classification is determined necessary for the SSC based on IDP and SDIT review to address uncertainties or assumptions within the PRA analysis or specific, high-consequence DID adequacy.

SSC Classification	Criteria
Non-Safety-Related with Special Treatments (NSRST)	• Offsite F-C Curve[1]: ○ For SBEs in the "Extremely Unlikely" region (<10-4 to >10-6/yr.), an SSC is NSRST if its removal causes the SBE to violate the F-C curve when considering *only* SR and NSRST SSCs appropriate for the SBE. • Collocated Worker F-C Curve[1]: ○ For SBEs greater in frequency than 10-6/yr., an SSC is NSRST if its removal causes the SBE to violate the F-C curve when considering *only* SR and NSRST SSCs appropriate for the event sequence. • SSC performs a risk-significant function, where risk-significant is defined as: ○ If the SSC makes a significant contribution (>1% of the limit value) to the cumulative risk metrics. • If NSRST classification is determined necessary for the SSC based on IDP and SDIT review to address uncertainties or assumptions within the PRA analysis or DID adequacy. • SSC is necessary to protect public or workers from a chemical hazard above DOE limits.
Non-Safety (NS)	All other facility systems not classified as SR or NSRST are de facto classified as non-safety.

[1] For the treatment of uncertainties, all comparisons to frequency and consequence limits of the F-C curve will be performed utilizing the 95th-percentile of the uncertainty distributions associated with the LBE frequency and consequence. For preliminary analyses, additional margin to the limits may be applied in substitute for detailed uncertainty analyses.

The VTR approach to integrating design, safety analysis and safety basis topics has been to follow the risk-informed licensing process to the extent practicable while also complying with all applicable DOE requirements. In keeping with the intent of the process, VTR safety system classification has been performed with both risk-informed and deterministic criteria with additional input from a multi-disciplinary team, called the VTR IDP which serves a function consistent with the requirements of the Safety in Design Integration Team under the guidance of DOE-STD-1189-2016 [10].

5.2 Required Safety Functions (RSFs)

The RSFs were derived from the three types of importance studies performed in the LMP analysis:

- Function-specific risk achievement studies
- Success path studies
- Safety significance studies.

The first type of study generates the risk importance of a single function. The other two studies develop risk importance for a set of functions.

The risk achievement studies test each function's importance to risk by simulating its feature as unavailable in the PRA model and observing any changes in the F-C chart results. The cumulative studies examine the combination of functions necessary to fulfill certain dose criteria.

To perform these studies, major VTR functions are simulated as unavailable by setting their associated PRA model basic events and gates to a failed condition. The PRA model and LMP analysis are then re-quantified with this unavailability in place and the resultant F-C chart ESF placement is observed relative to the threshold line (Offsite or Worker). Any SBEs that violate the threshold for a given function study are identified, indicating that the function is important to meet guidance thresholds for VTR. If the function passed for all SBEs, then it is not important to meet guidance thresholds for this importance metric (it may still end up being important based on the success path analysis).

The success path studies utilize the PRA event trees to determine the combination of functions necessary to keep the Anticipated and Unlikely SBEs below the Offsite or Worker dose thresholds.

The in-scope SBEs are each tested against different sets of credited event tree functions to determine the release category that would result assuming only the credited functions were successful. If the release category is below the dose limit, then the set passes for the SBE, if above, it is identified. The set(s) that contain at least one identified SBE above the dose limit are not an acceptable combination of functions since the dose limit is violated for at least one in-scope SBE. If all SBEs pass for a set, then its combination of functions is acceptable and also considered important to meet guidance thresholds for this metric. When multiple sets pass all SBEs, the IDP can decide which set is preferred using other considerations such as complexity, cost, schedule, etc.

The resulting SSC classification criteria are based upon the IDP review of the exhaustive PRA sensitivity analysis, prescriptive criteria, and IDP judgement. The IDP review systematically stepped through all proposed RSFs and SSCs to determine the safety classification, RFDC, and all associated structures, systems, and components (as appropriate with the level of maturity of the design). It is important to note that while the IDP could elevate the classification of an SSC, they *could not reduce* the classification of an SSC if it met one of the designated SSC classification criteria.

5.3 Principal Design Criteria (PDC)

5.3.1 Required Functional Design Criteria (RFDC)

RFDC's were derived from the IDP review to provide:

- The success criterion for each of the design specific RSFs.
- A breakdown of each RSF into reactor design specific sub-functions that are necessary and sufficient to ensure successful completion of the RSF for all the DBAs. These form a bridge between the RSFs that are defined at a high level and the Safety-Related Design Criteria (SRDC).

- An identification of the design specific inherent or intrinsic reactor characteristics that must be preserved to support the LMP-Based Safety Case and are credited in the selection of the SR-SSCs.

5.3.2 Selection of Principal Design Criteria (PDC)

PDCs necessary to preserve system safety are derived from the RFDCs. For VTR, the RFDCs constitute the PDCs and there were no additional PDCs derived outside of the LMP analysis for the primary sodium heat removal safety function. Therefore, the RFDCs identified in the safety basis are the VTR PDCs

5.4 Safety-Related (SR) SSCs

5.4.1 Selection of SR-SSCs

The VTR IDP systematically reviewed the proposed safety SSC classifications. Four key documents were essential to support of this review. These key input documents are: VTR PRA [4], VTR LMP analysis [8], Ex-Vessel hazards analysis, and DID Summary Report. The IDP systematically stepped through each proposed safety SSC to determine the safety classification, safety function, and all associated structures, systems, and components (as appropriate with the level of maturity of the design). The approach includes utilizing the experience base of the broad team to ensure the following:

- Any specifically identified SSC is appropriate for the classification based upon actual or necessary functions to be performed
- The identified safety SSC solutions are implementable and designable
- Focusing on the ideal set of SSCs which perform the appropriate safety functions while also balancing facility cost and operational burdens.

The IDP reviewed the PRA, which aided the team members in their understanding of the plant response to potential transient scenarios. A detailed review of safety system sensitivity analyses utilizing the principles of the LMP was then performed, including the importance evaluations. The importance evaluation results provided sets of SR-SSCs necessary for the plant to remain within the evaluation guidelines for the identified transient scenarios. The IDP then discussed and determined which set of SR-SSCs would provide the optimal risk protection for VTR while also balancing other factors as well.

Following the SR set decision, the NSRST SSCs were then discussed, which included evaluations based on LMP guidance and DID considerations.

5.4.2 SR SSC Summary

A summary table is presented that lists all the SR-SSCs, the AOOs, DBEs, BDBEs, and the PRA Safety Functions (PSFs) responsible for preventing and mitigating each of these LBEs. See Table B-6 of Appendix B.

5.5 Selection and Classification of Non-Safety-Related with Special Treatments (NSRST) SSCs

The selection of NSRST SSCs is discussed in Section 3.2.3. This selection uses the LMP approach discussed in NEI 18-04, Chapter 4 [1]. Non-Safety-Related SSCs that are classified as NSRST because they perform risk-significant safety functions are identified in Section 5.5.1. Non-Safety-Related SSCs that are classified as NSRST because they performed safety functions deemed necessary for adequate DID are identified in Section 5.5.2. A summary of all the NSRST SSCs is provided in Section 5.5.3.

5.5.1 Non-Safety-Related SSCs Performing Risk-Significant Functions

There are two criterion within NEI 18-04 that identify NSRST SSCs based on risk significance:

1. The first criterion is based on identifying non-safety-related SSCs whose prevention or mitigation function is necessary to prevent one or more LBEs from exceeding the F-C Target. This is described in Step 4B of NEI 18-04, Figure 4-1 [1].
2. The second risk significance criterion is based on whether the cumulative contribution of the LBEs in which a SSC safety function is failed exceeds 1% of the cumulative risk metrics used for evaluating the risk significance of LBEs. In this case each risk-significant SSC is classified this way based on an accumulation of risk from multiple LBEs. This is described in Step 5B of NEI 18-04, Figure 4-1 [1].

The identification of NSRST using criterion 1 above resulted in the identification of NSRST SSCs as described in Table B-1 in Appendix B. The table includes the resulting PSFs.

As discussed in Chapter 4, the following PSFs are identified related to the Table B-7 - NSRST SSCs:

- NSRST PSFs associated with heat removal.
  - B24-1: Intermediate Heat Exchanger including tubing transfer heat from the primary coolant to the intermediate loop sodium following a reactor trip or transient.
  - B24-2: HRS passively removes heat from the intermediate loop to air following a reactor trip or transient.
  - B21-1: EM Pump Thermal Shutdown Device trips the primary EM pump when the primary coolant temperature exceeds the design temperature (TBD).

The above PSFs result in the generation of Complimentary Design Criteria (CDC) discussed in Section 5.6.

The second risk significance criterion is based on whether the cumulative contribution of the LBEs in which a SSC safety function is failed exceeds 1% of the cumulative risk metrics used for evaluating the risk significance of LBEs. In this case each risk-significant SSC is classified this way based on an accumulation of risk from multiple LBEs. For the VTR, there were no additional SSCs identified based on cumulative risk metrics.

5.5.2 Non-Safety-Related SSCs Performing Safety Functions Necessary for Adequate Defense-in-Depth

The NEI 18-04 process [1] includes classification of NSRST SSCs resulting from the DID steps discussed in Section 4.2. The DID steps are not repeated here.

No new NSRST SSCs were identified as a result of the plant capability DID review. The plant capability DID review confirmed the need for B24 passive heat removal function, including the need for preventing RVACS operation for an AOO.

The DID review for risk margins included the review of uncertainty including a cliff-edge effects review. No new NSRST components were identified from the cliff-edge effects review. However, additional NSRST SSCs were identified from the uncertainty DID review. The results are not presented in this report, since none relate to the heat removal function.

The programmatic DID review identified special treatment related to SR and NSRST SSCs but did not identify any new NSRST SSCs.

5.5.3 NSRST SSC Summary

The summary Table 5-3 in Appendix B lists all the NSRST SSCs, the AOOs, DBEs, BDBEs, and the PSFs responsible for preventing and mitigating each of these LBEs. This table summarizes the NSRST SSCs discussed in 5.5.1 and 5.5.2. There were no operator actions necessary to perform these NSRST functions.

5.6 Complementary Design Criteria for NSRST SSCs

The Complementary Design Criteria for NSRST SSCs are defined in terms of the success criteria for the PSFs that are represented in the PRA model to prevent and mitigate the LBEs responsible for the safety classification. CDCs associated with the B24 and B21 PSFs listed in Table 5-4 in Appendix B are listed below.

- **B24-1-1:** Each non-safety class HRS train shall have a passive mode with natural circulation sized such that either loop is capable of controlling primary temperature within normal operating limits following an end of cycle scram.
- **B24-1-2:** When a reactor scram occurs, the HRS EM pumps shall be tripped.
- **B24-1-3:** The Heat Rejection System coolant boundary shall be designed such that, when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of a rapidly propagating fracture is minimized.
- **B24-2-1:** The non-safety class HRS shall be designed such that each sodium-to-air heat exchanger unit can be isolated from the remainder of the HRS and drained through heated drain lines to the associated train drain tank while the remaining units continue to function.
- **B24-2-2:** System B24 shall prevent failure of its natural circulation heat removal function caused by sodium freezing.
- **B21-1-1:** When a reactor scram occurs, the PHTS EM pumps shall be tripped.

6.0 SAFETY-RELATED SSC CRITERIA AND CAPABILITY

This chapter provides the details and background for Safety-Related SSC Criteria and Capability. The proposed input to the SAR is included in Appendix C.

6.1 Design Requirements for Safety-Related SSCs (SRDCs)

This section describes the outputs of NEI 18-04 Section 4.1, Task 7 [1]. It includes design basis external hazard levels, SRDCs derived from LBEs, and external hazard requirements for non-safety-related (NSR) SSCs that are necessary to protect SR-SSCs.

6.1.1 Design Basis External Hazard Levels

This section outlines the design bases necessary to protect SR-SSCs from external hazards (the design basis external hazard levels – DBEHLs). Following TICAP/LMP guidance, the DBEHLs would be derived from hazards with frequencies down to 10-4 /yr. For the example VTR SAR content in Appendix C, surrogate DBEHLs are presented from preliminary assessments of DOE natural phenomena design criteria, which may or may not be aligned with the frequency guidance of TICAP/LMP.

In addition, as detailed in Section 5.1, the SR SSC classification criteria for VTR includes LBEs with frequencies below 10^{-4} /yr., including those from external hazards. Therefore, the VTR SR-SSCs may contain SRDCs that are derived from external hazards with LBE frequencies as low as 10-6 /yr.

6.1.2 Summary of SRDC

This section provides a linkage between the RFDCs and SRDCs for each of the SR-SSCs. For the example VTR SAR content in Appendix C, the LBEs applicable to each RFDCs were reviewed. The limiting SSC requirements for the RFDC (such as maximum heat removal capability or seismic capability) were found from the applicable LBEs. These were used to derive the SRDCs for each SR SSC.

6.1.3 Summary of DBEHL-related Requirements for NSR SSCs

This section provides information on the external hazard-related requirements for NSR SSCs that are necessary to protect SR-SSCs. For the example VTR SAR content in Appendix C, preservation of the integrity of the reactor building, which is NSR, is required to ensure the operational capacity of RVACS (the SR heat removal pathway). Although the TICAP/LMP guidance is to tie these requirements to the DBEHLs, as the VTR SR SSC classification criteria included frequencies below 10-4 /yr. (see Section 6.1.1), other external hazard level information is also included.

The evaluation for NSR SSCs necessary to protect SR-SSCs has not been completed for the VTR beyond the identification of reactor building integrity, which is provided in Table 6-3 in Appendix C.

6.2 Special Treatment Requirements for SR-SSCs

This section provides information on special treatments for SR-SSCs, which are any controls or programs beyond normal industrial practices. Although this level of analysis has not yet been completed for VTR, a preliminary assessment of applicable programs and controls for the SR-SSCs is provided in Appendix C.

6.3 System Description of SR-SSCs

This section provides a brief description of each SR SSC, including key details related to the RSFs and applicable codes and standards. Although this level of detail has not yet been completed for RVACS as part of VTR, a preliminary assessment of applicable codes and standards is provided in Appendix C.

7.0 NSRST/SS SSC CRITERIA AND CAPABILITY

This chapter provides the details and background for NSRST SSC Criteria and Capability. The proposed input to the SAR is included in Appendix D.

The discussion in Section 7.1 is not currently in the draft TICAP guidance document. The section is included to develop a parallel between Chapters 6 and 7 in the development of special treatments for NSRST SSCs.

7.1 Design Requirements for NSRST SSCs

Table 7-1 in Appendix D provides a summary of the NSRST SSC CDCs and associated design criteria. Details of the analysis for the development of the Table 7-1 summary are available in the VTR design record. The design requirements are derived from the LBE evaluations summarized Section 5.5 and supported by the DID evaluations discussed in Section 4.2.

7.2 Special Treatment Requirements for NSRST SSCs

This section provides information on special treatments for NSRST SSCs, which are any controls or programs beyond normal industrial practices. Although this level of analysis has not yet been completed for VTR, a preliminary assessment of applicable programs and controls for the NSRST SSCs is provided in Appendix D.

7.3 System Descriptions for NSRST SSCs

This section provides a brief description of each SR SSC, including key details related to the RSFs and applicable codes and standards. Although this level of detail has not yet been completed for HRS as part of VTR, a preliminary assessment of applicable codes and standards is provided in Appendix D.

8.0 SUMMARY AND CONCLUSIONS

8.1 Summary of the VTR Work to Date

As described in Chapter 3, the VTR conceptual design includes the development of a partial scope PRA which was applied for an LMP evaluation using the processes in NEI 18-04 [1]. The process included performance of all steps including LBE evaluation, SSC categorization, DID evaluation, performance of the IDP and application of the LMP results in support of the VTR CSDR. Steps that were not fully completed, such as performance of the programmatic DID review, are described in Chapters 3 and 4.

The LMP results as well as the CSDR were used to develop an example content of application for Section 4.2 and Chapters 5, 6 and 7 of the SAR using the draft TICAP Content of Application (COA) guidance. The example content is included in the Appendices of this report. Recommendations for potential changes to the COA guidance are also provided in the Appendices, where applicable, and summarized in the following section.

As noted in Chapter 1; since the VTR content was developed for a DOE submittal, the content provided in Chapters 3 to 7 and the appendices should be considered initial draft of a potential content of application. It is expected that the information provided would be significantly refined, especially related to level of detail. For example, the system description for the SR and NSRST components is noted to be not indicative of the level of detail in a final SAR – since the SR system would be supported by (in general) more level of detail, while the NSRST would be supported (again, in general) by less level of detail.

As noted, the information provided in this report and the appendices focused on the heat removal function only, which limited the amount of information to SR and NSRST SSCs that support heat removal. When expanded to include all functions, the level of detail and information contained in each section would be more comprehensive.

The TICAP tabletop was performed on March 5th, 2021. The exercise involved the review of draft information contained within this report, including focus on the Appendices A to D. The Tabletop included a short presentation on the VTR design, included in Appendix E, followed by review of each Appendix in Detail. The review of the information including discussion on recommended changes to the draft TICAP guidance document discussed in 8.2 below.

8.2 Recommendations

The VTR LMP application was compared with draft TICAP guidance document used as an input to this tabletop. Overall, the VTR tabletop exercise confirmed the guidance provided supporting information needed to develop a potential VTR content of application. As a result, the developed tabletop content matched well the draft guidance.

The Appendices include some recommended improvements to the draft TICAP guidance, as indicated through the green font text. Additionally, two sections not included in the draft TICAP guidance document are included in the VTR application of the guidance. This includes the following sections:

- Evaluation of LBEs Against Layers of Defense (discussed in 4.3 and A.4.2.2)
- Design Requirements for NSRST SSCs (discussed in Chapter 7.1 and D.7.1)

9.0 REFERENCES

[1] Nuclear Energy Institute, "NEI 18-04: Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development, Revision N," Washington D.C., 2018.

[2] Idaho National Laboratory, "Versatile Test Reactor Conceptual Design Report (CSDR), Draft 0," Idaho Falls, Idaho, 2020.

[3] D. Grabaskas, J. Andrus, D. Henneke, M. Bucknor, J. Li, D. Gerstner, M. Warner and T. Fanning, "Application of the Licensing Modernization Project Approach to the Authorization of the Versatile Test Reactor," in *American Nuclear Society Winter Meeting*, Chicago, IL, USA, 2019.

[4] GE Hitachi Nuclear Energy, "005N3526 Versatile Test Reactor (VTR) Probabilistic Risk Assessment (PRA) Summary (005N3526, Rev. D)," 2020.

[5] GE Hitachi Nuclear Energy, "Deliverable #3 Technical Report: Scoping Analysis Methodologies for All Hazards/External Events for Advanced Non-LWR PRAs (003N7742) – REPORT# DOEGEHC08325," 2016.

[6] EPRI, "Identification of External Hazards for Analysis in Probabilistic Risk Assessment Update of Report 1022997," 2015.

[7] ASME/ANS Joint Committee on Nuclear Risk, "Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants, ASME/ANS RA-S-1.4-2013," 2013.

[8] GE Hitachi Nuclear Energy, "Versatile Test Reactor (VTR) Licensing Modernization Project (LMP) Analysis (005N4450 Rev. B)," 2019.

[9] Idaho National Laboratory, "SDS-422: Safety Design Strategy for the Versatile Test Reactor, Revision 0," Idaho Falls, ID, 2018.

[10] U.S Department of Energy , "DOE-STD-1189-2016, Integration of Safety into the Design Process," 2016.

[11] U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.232 - Guidance For Developing Principal Design Criteria for Non-Light-Water Reactors," 2018.

[12] "Document Number SC-29980-100 Rev 1, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: Selection and Evaluation of Licensing Basis Events," 2020.

APPENDIX A DID Input to SAR (Example Input)

The text in black included in the Appendices is the proposed VTR TICAP wording, based on the draft guidance document provided as input to the tabletop. Where there is no content provided for specific section (e.g., A.4.1 below), this is noted.

For this Report, the guidance is provided in Blue including markup, and the proposed tabletop wording is provided in Black.

> Any clarifications from the VTR team on the guidance are provided in Green and indented.

A.4. Integrated Evaluations

A.4.1 Overall Plant Risk Performance Summary

Note: Nothing is provided for this tabletop in this section. This section of the report includes Site Boundary Dose, EAB Boundary Early Fatality Risk, and Latent Cancer Risk.

A.4.2 Defense-in-Depth

The VTR has utilized the LMP process, as described in NEI 18-04 and in Chapter 3 [1]. The risk-informed evaluation of DID process involves evaluation of the following:

- Input to identification of safety-significant SSCs
- Input to the selection of SR-SSCs
- Evaluation of roles of SSCs in the prevention and mitigation of LBEs
- Evaluation of the LBEs to assure adequate functional independence of each layer of defense
- Evaluation of single features that have a high level of risk importance to assure no overdependence on that feature and appropriate special treatment to provide greater assurance of performance
- Input to SSC performance requirements for reliability and capability of risk-significant prevention and mitigation functions
- Input to SSC performance and special treatment requirements
- Integrated evaluation of the plant capability DID
- Integrated evaluation of programmatic measures for DID

The DID process involves the use of an IDP. The analysis and review for DID is documented and presented to the IDP during the IDP meetings and in the final LMP documentation. The IDP evaluates the LMP quantitative results, SSC Safety Classification, DID-specific reviews, assignment of special treatment requirements, sensitivity analysis, etc. As a result, the IDP determines that the design and the outcome of the LMP analysis provide support for adequate DID.

Although the entire LMP process involves ensuring adequate DID, as shown in Figure 5-4 of NEI 18-04 [1], specific DID adequacy steps are included in the LMP process. These steps include the Plant Capability DID, Programmatic DID, and the Integrated Assessment of DID. Each of these are discussed in the sections below.

Guidance Document Wording and Markup by the VTR team

The following sections provide a summary of results of Plant Capability DID; Programmatic DID and the Integrated Assessment of DID, respectively. They reflect the outcomes for the topics in NEI 18-04 Table 5-1 Risk-Informed Evaluation of DID Adequacy [1] *including:*

- ~~*Evaluation of DID attributes for DID*~~
- *Input to identification of safety-significant SSCs*
- *Input to the selection of SR-SSCs*
- *Evaluation of roles of SSCs in the prevention and mitigation of LBEs*
- *Evaluation of the LBEs to assure adequate functional independence of each layer of defense*
- *Evaluation of single features that have a high level of risk importance to assure no overdependence on that feature and appropriate special treatment to provide greater assurance of performance*
- *Input to SSC performance requirements for reliability and capability of risk-significant prevention and mitigation functions*
- *Input to SSC performance and special treatment requirements*
- *Integrated evaluation of the plant capability DID*
- *Integrated evaluation of programmatic measures for DID*

The summary focus is on safety significant topics, LBEs, SSCs and human actions that receive special treatments as described in NEI 18-04. The summary need not address DID evaluations that did not identify further provisions for DID. The content of the DID Summary provides the foundation for the DID adequacy evaluation baseline as described in NEI 18-04 Section 5.9.5. Evidence of the complete DID evaluation should be retained in design records [1].

It is not clear that all of the bullets above are needed, since the sections below do not summarize all of the DID steps performed during the LMP process. We have deleted the first bullet, since this is not summarized, but other bullets can be either deleted or revised – in other words the list does not need to exactly match what is in LMP.

Note also that the sections below include overall discussion areas; plant capability, Programs, and Margins. The plant capability section involves a number of bullets above, as does the programmatic review section (e.g., performance, special treatment, etc.). However, margins Review is not in the bulleted list.

A.4.2.1 Plant Capability Summary

The plant level DID review involves the review of the LMP LBE results against the DID layer guidance in Table 5-2 of NEI 18-04. For example, Anticipated events (with frequency above 1E-02/year) are reviewed against the following criteria listed in NEI 18-04 Table 5-2 [1]:

A. Maintain frequency of all DBEs < 10-2/plant-year.

B. Minimize frequency of challenges to SR-SSCs.

C. Meet F-C Target for all DBEs and cumulative risk metric targets with sufficient margins.

D. No Single Design or Operational Feature, no matter how robust, is exclusively relied upon to satisfy five layers of DID.

Guidance for review against these criteria is discussed in Chapter 5 of NEI 18-04 [1]. The evaluation of plant capability DID adequacy focuses on the following:

- Completeness, resiliency, and robustness of the plant design with respect to addressing all hazards,
- Responding to identified IEs,
- Preventing and mitigating the progression of IEs through the availability of independent levels of protection, and
- Achieving sufficient protection of public health and safety through the use of redundant and diverse means.

This evaluation is performed for all DBEs and BDBEs.

Each LBE identified by the LMP analysis was reviewed for plant capability DID including the review of the criteria in Table 5-2. Item C listed above was verified in the quantitative LMP evaluation through both use of an F-C chart, and through quantification of each of the applied risk metrics. In all cases, significant margin was demonstrated, as discussed in Chapter 3.

An example of the plant capability review for a single LBE is provided in Table A-1. A table containing all PRA generated LBEs was provided to the IDP for review and confirmation.

Table A-1: Plant Capability DID Review – Example DBE Review

LBE	Freq.	Classification	Non-Zero Release	Successful Functions	Failed Functions	Discussion	DID Guidelines (NEI 18-04, Table 5-2)	Considerations
LBE-LOHS-1 Loss of Heat Sink including loss of a train of passive heat removal	9.7E-03	DBE	N	Control Rods (CR), Primary EM Pumps Tripped (PP), Passive Heat Removal (1 train passive B24 failed), RVACS (RV)	One train of Passive Heat Removal	RVACS Operation, reduced requirement due to one train B24 operating.	Maintain Frequency of all DBEs < 1E-02/plant-year	Reliability of passive heat removal from B24 is important, including prevention of leakage causing a LOHS.
							Minimize frequency of challenges to SR-SSCs	Passive Heat removal reliability is important to minimize the frequency of events where RVACS is needed.
							Meet Owner Requirements for Plant Reliability and Availability	Review is not complete for this phase of the VTR LMP.
							Meet F-C Targets and Risk Metrics	Ok for all LBEs. Not repeated for other events below.
							No Single Design or Operational Feature is exclusively relied upon to satisfy five layers of DID	This was reviewed for all LBEs, and no issues identified.

Note: Table A-1 yellow columns would likely not be included in the final SAR content. The orange columns are based on the LMP review, and would likely be adjusted for the SAR content .

Plant capability DID attributes are listed in NEI 18-04 Table 5-3: initiating event and event sequence completeness, layers of defense, functional reliability, and prevention and mitigation balance. As outlined in NEI 18-04 Table 5-9, the qualitative evaluation should address the evaluation of margin adequacy, multiple protective measures, and prevention and mitigation balance and the physical categories of functional reliability and over-reliance on any single feature [1].

The application should state affirmatively that the guidelines for Plant Capability Attributes provided in NEI 18-04 Table 5-2 [1] have been evaluated and confirmed. Separate discussions of additional plant capability provided as a result of the attribute evaluations should be provided in this section.

During the DID adequacy evaluation process, safety-significant SSC functions and the associated SSC reliabilities and capabilities may have been deemed necessary for DID adequacy. This information should be documented in tabular form in a manner that is traceable to the LBEs in Section 3. This section will document why any specific LBE is selected for NSRST treatment. The discussion provided should indicate the dominant contributors to the selection of any LBE SSCs for NSRST treatments and guide the selection of special treatments in Chapter 7.

For each LBE, each qualitative guideline in NEI 18-04 Table 5-2 [1] should be addressed and any departures from the stated criteria addressed. The Layers of Defense should be identified.

A.4.2.1.1 LBE Margin Summary

An LBE margin review is performed and provided to the IDP for review. The LBE margins are initially provided in the F-C curve and establish the baseline margins between the frequencies and consequences of individual LBEs and the F-C Target. Tabular presentation of the margins are provided and include a review of AOOs, DBEs and BDBEs.

The LBE margin review was completed by the IDP review of the F-C charts for groups of LBEs. These F-C charts provide both the baseline results and sensitivity analysis results for each group of LBEs. Table A-2 provides a conservative summary of margins in which the 95th percentile upper bound values for both LBE frequency and dose are used to calculate the margins for all non-zero-dose BDBEs. Note that none of the AOOs and DBEs for the VTR are estimated to result in any dose release (all are zero-dose in the PRA). As a result, Table A-2 is currently not completed for this document.

Table A-1: Risk Margins Based on the 95th Percentile Values of LBE Frequency and Dose

	Limiting LBE	F-C Target

LBE Category	LBE Name	95th Percentile Freq./RYR	95th Percentile Dose (REM)	Freq. at LBE Dose/RYR	95th Percentile Frequency Margin	Dose at LBE Frequency (Rem)	95th Percentile Dose Margin
BDBE	BDBE-1	TBD					
BDBE	BDBE-1	TBD					

This section provides the baseline margins established between the frequencies and consequences of individual LBEs and the F-C Target. The tables should differentiate between risk-significant LBEs and other safety –significant LBEs used for establishing NSRST SSCs for DID adequacy purposes.

These margins are established for the LBEs having safety-significance within each of the three LBE categories: AOOs, DBEs, and BDBEs. The margins for specific LBEs in the baseline should be displayed in tabular or graphical formats or cross-referenced to LBE margin results in Section 3. A tabular format example is shown in Section 2.9.1 of the LMP DID Report.[1]

> Note from the VTR Team on above Guidance: The Current VTR analysis uses the DOE F-C charts, which have different target lines (See Chapter 3). This will change the margins assessment, as the current BDBE scenarios in our analysis are below the AOO acceptance dose -which results in no upper limit for frequency. As a result, the only margin review would be the dose limit at the base and 95th percentile frequencies (under DOE these are 5 Rem and 25 rem respectively). It may be that for the VTR results, showing uncertainty bands on the F-C chart are sufficient for this review.
>
> Additionally, as noted in the write-up; most of the VTR LBEs are zero-dose release, with only two non-zero-dose LBEs noted (both BDBE region). It would be clearer in the guidance to limit the margins review to LBEs with a dose release, and not require this for zero-dose LBEs (e.g., success scenarios in the PRA).
>
> Finally, the VTR performed a review of Cliff-Edge Effects events (e.g., high-consequence, low frequency events). This is mentioned several times in NEI 18-04, such as Task 4, Section 5.7.2 and under the F-C Evaluation Criteria review in 3.2.1 (e.g., part of the margins Review). It may be that we mention here the cliff-edge effects review was completed, although I would think the detailed review would not need to be included in the SAR content.

A.4.2.2 Evaluation of LBEs Against Layers of Defense

Note: The discussion below is not currently included in the draft TICAP guidance provided for this tabletop, but was included in Chapter 5 of NEI 18-04, and included in the VTR LMP

1 "Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: Risk-Informed and Performance-Based Evaluation of Defense-in-Depth Adequacy," Document Number SC-29980-103 Rev 1, March 2020.

evaluation. This section is copied from the LMP DID analysis, but would likely be reduced for a SAR submittal.

A.4.2.2.1 Method

This review by the IDP is necessary to evaluate the plant capabilities for DID and to identify any programmatic DID measures that may be necessary for establishing DID adequacy. The process described in NEI 18-04; Section 5.7 [1] includes the IDP review of the following:

- Confirm that plant capabilities for DID are deployed to prevent and mitigate each LBE at each layer of defense challenged by the LBE. (discussed above including Table 4-1 – but reviewed by the IDP).
- Confirm that a balance between event prevention and mitigation is reflected in the layers of defense for risk-significant LBEs. (discussed above – but reviewed by the IDP).
- Identify the reliability/availability missions of SSCs that perform prevention and mitigation functions along each LBE and confirm that these missions can be accomplished. A reliability/availability mission is the set of requirements related to the performance, reliability, and availability of an SSC function that adequately ensures the accomplishment of its task, as defined by the PRA or deterministic analysis.
- Confirm that adequate technical bases for classifying SSCs as SR or NSRST exist and their capabilities to execute the RSFs are defined.
- Confirm that the effectiveness of physical and functional barriers to retain radionuclides in preventing or limiting release is established.
- Review the technical bases for important characteristics of the LBEs with focus on the most risk-significant LBEs and LBEs with relatively higher consequences. The technical bases for relatively high-frequency LBEs that are found to have little or no release or radiological consequences is also a focus of the review.
- Confirm that risk-significant sources of uncertainty in both the frequency and consequence estimates that need to be addressed via programmatic and plant capability DID measures have been adequately addressed.

A.4.2.2.2 Results

The following provides a summary of the LBE capability for DID, discussed in the bullets above.

- The plant capability DID is discussed in Table A-1 above. The results of the LBE-based DID was reviewed by the IDP for confirmation of adequate DID. Where changes to the SSC classification, LBE identification or special treatment was required, the IDP provided recommendations for these changes.
- The balance between prevention and mitigation is also reviewed by the IDP as a part of the plant capability DID discussed in Table A-1.

- The reliability and availability requirements related to the performance of SSC functions was not completed for the VTR in this phase of design. The programmatic attributes for reliability/availability are discussed in Chapter 8 of the SAR, which is not within the scope of this tabletop exercise. Programs that ensure reliability and availability targets are met include:
  - The RAM program, with the objective of maintaining the facility in a safe state.
  - SSC Testing, inspection and monitoring programs including application of the maintenance rule program.
  - Application of Technical Specifications including allowed outage times for SR-SSCs, where applicable.
  - Environmental Qualification Program, which ensures SSCs can perform their safety functions within the environmental and accident conditions that the SSCs might experience during an LBE.
- The technical bases for classifying SSCs is provided in Chapter 3, where the use of the LMP methodology is discussed. The SSC classification results are provided in Chapter 5 as well as the SSC RSFs.
- The effectiveness of physical and functional barriers to retain radionuclides in preventing and limiting releases is demonstrated in the PRA and LMP F-C results discussed in Chapter 3. The results were reviewed by the IDP for confirmation of adequacy. As discussed in NEI 18-04, Table 5-4 [1]; the fraction of source term released from the fuel, coolant boundary and reactor building can be mitigated by inherent and passive capabilities including design margins to limit the release.
- The technical bases for important characteristics of the LBEs was reviewed by the IDP during several steps, including during the review of plant capability DID, review of the LMP results, and review of the high-consequence events (e.g., cliff-edge effects review). The plant capability review included the identification of whether the LBE involved a non-zero release, and the F-C curve discussed in Chapter 3 plotted the estimated dose release for each LBE. The PRA accident sequence characteristics were reviewed by the IDP for each LBE.
- Risk-significant sources of uncertainty in both the frequency and consequence estimates were documented in the PRA and LMP analysis and reviewed by the IDP. Sensitivity evaluations include the review of LBEs below the BDBE cutoff to confirm that LBEs would not cross into the BDBE region. This review focused on the high-consequence region, for any cliff-edge events, as described in NEI 18-04 [1]. The PRA uncertainties were also reviewed for potential impact on the PRA and LMP results.

A.4.2.3 Programmatic DID Summary

For those areas applicable at this phase of the design, the VTR LMP results are reviewed against Tables 5-5 and 5-6 of NEI 18-04. The VTR programs used to monitor SR-SSCs and assure human performance and operational controls will be described with focus on RSFs. This will include programmatic controls that account for an manage risk-significant uncertainties identified in the DID evaluation.

For this phase on the VTR design, the programmatic DID review was not yet complete. Programs and special treatment identified for SR and NSRST components are discussed in Chapter 6 and 7.

Programmatic DID attributes are listed in NEI 18-04 Table 5-5: quality/reliability, compensation for uncertainties, and offsite response [1].

The application should state affirmatively that the guidelines for Programmatic Capability Attributes provided in NEI 18-04 Table B-6 [1] have been evaluated and included in the design development. Separate discussions of additional programmatic additions or changes as a result of the DID Programmatic attribute evaluations, including identification of the safety-significant LBEs leading to additional DID programmatic actions resulting safety-significant compensatory actions should be provided in this section. Summary information should be provided for the individual DID evaluation results that led to changes to the protective measures required for adequate programmatic DID.

A.4.2.3.1 Programs Required for SR SSC Performance Monitoring

For this phase on the VTR design, the programmatic DID review was not yet complete. Programs and special treatment identified for SR components are discussed in Chapter 6.

This section should identify the SR plant-specific programs used to perform monitoring of SR-SSCs and to assure human performance and operational controls for risk-significant functions. Risk-significant functional performance requirements described in Section 6 should be cross-referenced to the associated programs. Additions to or modification of the programmatic controls provided in Section 6 to account for and manage risk-significant uncertainties as a result of the DID evaluation should be summarized in this section.

> In reviewing the above wording; it is not clear what are additions to account for uncertainty and DID, and those resulting from the PSFs. The IDP reviews the recommended special treatment (generally at a higher level, and not specifics such as the reliability goal for an SSC), and recommends changes based on the LMP results including sensitivity and uncertainty. In the end, the IDP required special treatments are not separated into baseline and uncertainty requirements. In some cases, the IDP members, who are the best experts in certain areas such as Safety Analysis, PRA, Maintenance, Operations, etc. recommend certain changes based on their experience and knowledge. These are not necessarily due to uncertainty/DID, but rather Engineering Judgement from the IDP. Overall, I would just recommend leaving in the first sentence, and adjusting the second sentence to say the requirements include consideration for DID and uncertainty. Otherwise, we need to adjust the IDP process and NEI 18-04 guidance to identify where the special treatment comes from (e.g., baseline or as a result of uncertainty/DID).

A.4.2.3.2 Programs Required for NSRST SSC Performance Monitoring

For this phase on the VTR design, the programmatic DID review was not yet complete. Programs and special treatment identified for NSRST components are discussed in Chapter 7.

This section should identify the other plant-specific programs used to perform monitoring of NSRST SSCs and to assure human performance and operational controls for safety-significant functions. Safety-significant functional performance requirements described in Section 7 should be cross-referenced to the associated programs. Additions to or modification of the programmatic controls provided in Section 7 to account for and manage safety-significant uncertainties as a result of the DID evaluation to provide additional DID assurance should be summarized in this section.

See discussion in the previous sub-section.

A.4.2.4 Integrated DID Summary

The LMP process described in NEI 18-04 includes steps and analysis that support the integrated DID evaluation for the VTR. Much of the PRA and LMP evaluations are systematically evaluated by the IDP to verify adequate DID as discussed above. Where changes to the LBEs, SSC classification or special treatments are needed as a result of the IDP review, the IDP required changes to address the DID or uncertainty.

As noted above, for this phase on the VTR design, the programmatic DID review was not yet complete. Programs and special treatment identified for SR and NSRST components are discussed in Chapter 6 and 7.

Integrated DID attributes are listed in NEI 18-04 Table 5-8: use of the risk-triplet outside of the PRA; state of knowledge adequacy; uncertainty management and, action refinements [1].

The section summary of should identify additional actions taken as a result of the integrated DID evaluation, the attributes addressed by the actions, identification of the LBEs leading to additional DID actions, and a brief summary of the rationale for compensatory actions to support the DID baseline.

Please think about whether the summary is needed. We have the introductory discussion in the beginning of 4.2, which introduces and summarizes the DID steps both under LMP and in the SAR. In some cases, the summary here just repeats things for the 3rd time. Best to minimize repeating text in the SAR content.

APPENDIX B Draft Content for SAR Chapter 5 – Safety Functions, Design Criteria, and SSC Safety Classification

For this Report, the guidance is provided in Blue including markup, and the proposed tabletop wording is provided in Black.

Any clarifications from the VTR team on the guidance are provided in Green and indented.

B.5. Safety Functions, Design Criteria, and SSC Safety Classification

This section includes the Required Safety Functions and Required Functional Design Criteria, Principal Design Criteria, Safety Classification of SR and NSRST SSCs, and the Complementary Design Criteria.

B.1.1 Safety Classification of SSCs

SSC safety classification is determined based upon the necessity to perform an identified safety function or limit the public/worker risk from an identified LBE to within the approved LBE evaluation guidelines in Chapter 3. This includes both risk-informed and prescriptive criteria. The risk-informed criteria gauge the importance of the SSC in limiting radionuclide releases to the public or worker, utilizing the offsite or worker dose F-C guidelines.

Three classifications of equipment are utilized for VTR SSCs based upon their importance in preventing or mitigating events that could lead to release of uncontrolled radioactive or hazardous material. SR-SSCs are those utilized to protect the offsite public and have the most stringent associated requirements. The role of NSRST SSCs is primarily to protect co-located workers but can also be utilized for the assurance of DID or public protection from non-radiological hazardous material. All other SSCs are designated as Non-safety (NS) SSCs. Note that this SSC classification is similar but not completely analogous to the classification described in NEI 18-04 [1] for licensing by the U.S. NRC. The SSC classification and criteria are in Table B-1.

Table B-1: VTR SSC Classification and Criteria

SSC Classification	Criteria
Safety-Related (SR)	• Offsite F-C Curve[1]: ○ For LBEs greater in frequency than 10-6/yr., an SSC is SR if its removal causes the SBE to violate the F-C curve, when considering a one-by-one removal of SSCs, crediting all remaining SSCs, regardless of safety classification, at appropriate reliability levels (and with appropriate accounting of common cause failure). ○ For DBAs derived from LBEs in the "Unlikely" category (<10-2 to >10-4/yr.), an SSC is SR if it is necessary for the DBA to satisfy the 25 rem consequence limit when utilizing deterministic, prescriptive analysis of the event sequence and crediting *only* SR-SSCs.

SSC Classification	Criteria
	• If the SSC is required to ensure integrity of the primary coolant boundary. • If the SSC is required to ensure reactor shutdown. • If SR classification is determined necessary for the SSC based on IDP and SDIT review to address uncertainties or assumptions within the PRA analysis or specific, high-consequence DID adequacy.
Non-Safety-Related with Special Treatments (NSRST)	• Offsite F-C Curve[1]: ○ For LBEs in the "Extremely Unlikely" region (<10-4 to >10-6/yr.), an SSC is NSRST if its removal causes the SBE to violate the F-C curve when considering *only* SR and NSRST SSCs appropriate for the SBE. • Collocated Worker F-C Curve[1]: ○ For LBEs greater in frequency than 10-6/yr., an SSC is NSRST if its removal causes the SBE to violate the F-C curve when considering *only* SR and NSRST SSCs appropriate for the event sequence. • SSC performs risk-significant function, where risk-significant is defined as: ○ If the SSC makes a significant contribution (>1% of the limit value) to the cumulative risk metrics. • If NSRST classification is determined necessary for the SSC based on IDP and SDIT review to address uncertainties or assumptions within the PRA analysis or DID adequacy. • SSC is necessary to protect public or workers from a chemical hazard above DOE limits.
Non-Safety (NS)	All other facility systems not classified as SR or NSRST are de facto classified as non-safety.

[1] For the treatment of uncertainties, all comparisons to frequency and consequence limits of the F-C curve will be performed utilizing the 95th-percentile of the uncertainty distributions associated with the LBE frequency and consequence. For preliminary analyses, additional margin to the limits may be applied in substitute for detailed uncertainty analyses.

The VTR approach to integrating design, safety analysis, and safety basis topics has been to follow the risk-informed licensing process to the extent practicable while also complying with all applicable DOE requirements. In keeping with the intent of the process, VTR safety system classification has been performed in a risk-informed manner with input from a multi-disciplinary team, called the VTR IDP which serves a function consistent with the requirements of the Safety in Design Integration Team under the guidance of DOE-STD-1189-2016 [10].

The NEI 18-04 methodology affords some flexibility, so the specific manner in which the classification approach has been applied should be described as necessary to provide an adequate description of the LMP-Based Affirmative Safety Case. It is not necessary to repeat aspects of the methodology already covered in NEI 18-04, but rather to point out the specifics of how the methodology was applied within the range of options specified in NEI 18-04 [1]. Details of the analyses should be present in the design records and available for NRC audit.

The safety classification approach in NEI 18-04 [1] is based on the PRA Safety Functions (PSFs) that are identified in the definition and selection of the AOOs, DBEs, and BDBEs in Chapter 3. Tables in the following sub-sections list the SR-SSCs and NSRST SSCs, the specific prevention and mitigation functions reflected in the LBEs and resulting safety classification.

B.1.2 Required Safety Functions (RSFs)

The RSFs are the PSFs that are responsible for successfully mitigating the consequences of all the DBEs inside the F-C Target and for successfully preventing any high-consequence BDBEs from increasing in frequency beyond the F-C Target. The RSFs derived from the IDP review are listed in Table B-2.

Table B-2: VTR Required Safety Functions

Required Safety Function	Applicability to the Fundamental Safety Function to control heat removal
Primary sodium heat removal	The primary sodium heat removal function ensures that systems are in place to remove decay heat through reactor vessel geometry and natural circulation within the reactor systems, in addition to ensuring that the primary EM pumps do not provide additional heat to the system.

This section should present the Required Safety Functions (RSFs) which are the products of applying Step 5a in Figure 3-2 of NEI 18-04 [1]. The RSFs are the PSFs that are responsible for successfully mitigating the consequences of all the DBEs inside the F-C Target and for successfully preventing any high-consequence BDBEs (i.e. those with doses exceeding 25rem) from increasing in frequency beyond the F-C Target. A summary level justification for why the reactor-specific RSFs adequately support the FSFs should be included. Examples of RSFs from MHTGR and PRISM are found in the LMP LBE Report [12], and other examples for Xe-100, Kairos FHR, Westinghouse eVinci, MSRE, and PRISM are in the LMP table top reports found on the NRC website under *Advanced Reactors, Licensing Modernization Project*.[1]

B.1.3 Required Functional Design Criteria (RFDC) and Principal Design Criteria (PDC)

Regulations (10 CFR 50.34 or 10 CFR 52.47) require the identification of Principal Design Criteria (PDC). For reactors that use the NEI 18-04 methodology [1], the PDCs that flow from the LMP methodology and are needed to support the LMP-based safety case are derived from the RSFs and the Required Functional Design Criteria (RFDC). The identification of RFDC is described in Task 7 under Figure 4-1 in NEI 18-04 [1]. Each RFDC constitutes a PDC. There may be additional PDCs that cover items outside the scope of the LMP methodology.

This section should present the PDCs in terms of the RFDC for each of the RSFs as described in Task 7 of Figure 4-1 in NEI 18-04. These RFDCs may be regarded as a decomposition of the

* https://www.nrc.gov/reactors/new-reactors/advanced.html#modern

RSFs into sub-functions that are necessary and sufficient to support the RSFs. The key elements of the RFDC that should be identified include:

- The success criterion for each of the design specific RSFs.
- A breakdown of each RSF into reactor design specific sub-functions that are necessary and sufficient to ensure successful completion of the RSF for all the DBAs. These form a bridge between the RSFs that are defined at a high level and the SRDCs.
- An identification of the design specific inherent or intrinsic reactor characteristics that must be preserved to support the LMP-Based Safety Case and are credited in the selection of the SR-SSCs.

Examples of RFDCs that were developed for the MHTGR are found in Appendix A, Table A-3 of the LMP SSC Report[1].

In the guidance document, there is a table in 5.6 on CDCs, which ask for the PRA Safety Function, etc. The same information is mentioned this information in 5.3 on RFDCs; but you do not seem to have the equivalent table. Please include this here or delete the table in 5.6

PDCs necessary to preserve system safety are derived from the RFDCs. For VTR, the RFDCs constitute the PDCs and there were no additional PDCs derived outside of the LMP analysis for the primary sodium heat removal safety function. Therefore, the RFDCs identified in Table B-3 are the VTR PDCs. RFDC's were derived for the primary sodium heat removal RSF from the IDP review and are broken down into sub-functions with the RFDCs in Table B-3:

Table B-3: VTR RFDC by Sub-function

Required Safety Function	Sub-functions	Required Functional Design Criteria
Primary sodium heat removal	Provide primary sodium heat removal pathway	Provide sufficient heat removal capability to prevent the release of radionuclides from the fuel (i.e., cladding failure) for applicable LBEs
	Prevent non-nuclear primary sodium heat generation	Preserve heat removal capability of RVACS for applicable LBEs by ensuring that primary EM pump heat does not contribute to total system heat load

1 Southern Company "Modernization of Technical Requirements for Licensing of Advanced Non Light Water Reactors: Safety Classification and Performance Criteria for Structures, Systems, and Components", Document Number SC 29980 102 Rev 1, March 1, 2020.

B.1.4 Safety-Related SSCs

B.1.4.1 Selection of Safety-Related (SR) SSCs

The results from the importance evaluation for the primary sodium heat removal functions in the LMP are shown in Figure B-1.

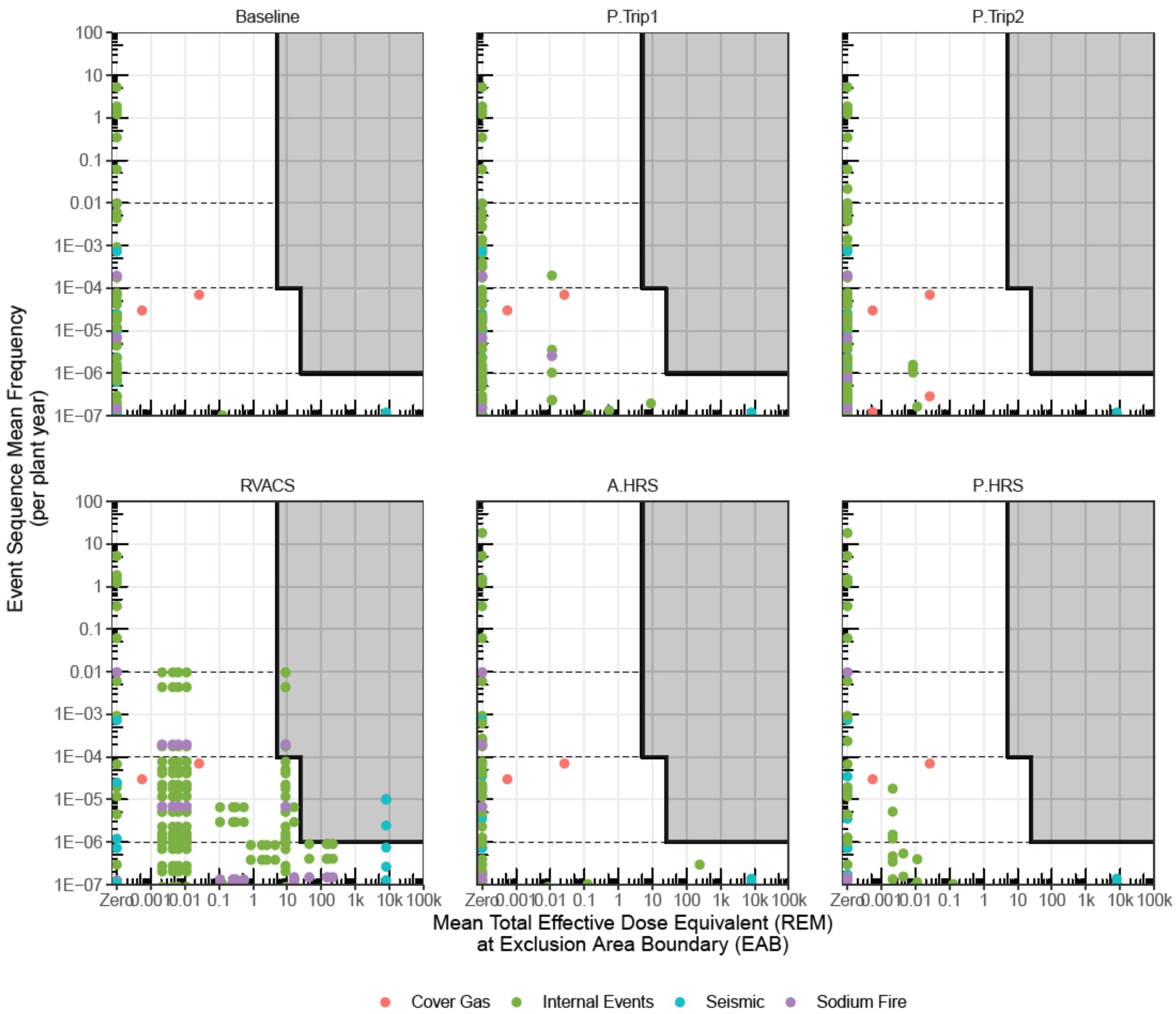

Figure B-1: Primary Sodium Heat Removal Functions Importance Evaluation

The outcomes presented in Figure B-1 show that for the RVACS study many LBEs exceed the threshold if RVACS functionality is not included. The LMP risk achievement studies also determined that the primary EM pump trip was necessary for the heat removal function to mitigate below the public dose limits. The primary EM pump trip ensures the primary EM pumps are tripped and do not add any additional heat to the primary sodium such that the RVACS function is compromised. The IDP determined that the SSC associated with the heat removal functions would be classified as SR-SSCs to provide optimal risk protection. Table B-4 provides the SR-SSCs as derived from the heat removal sub-function.

Table B-4: SR-SSCs Derived from the Primary Sodium Heat Removal Sub-function

Primary Sodium Heat Removal Sub-function	SR-SSCs
Provide primary sodium heat removal pathway	• RVACS structures including the inlet and outlet ducts • Reactor guard vessel • Reactor vessel • Reactor internals, pump piping, inlet plenum, inlet modules and fuel assemblies (Ensures Core Flow is maintained)
Prevent non-nuclear primary sodium heat generation	• Primary EM pump power supply isolation breaker • Diverse EM pump power isolation (adjustable speed drive (ASD) front end controller preferred)

An analysis was performed to show that the SR-SSC would be available for the associated VTR DBAs and is shown in Table B-5.

Table B-5: SR-SSCs and associated DBAs

RSF	RSF Sub-Function	SR-SSCs	Availability		
			DBA-1	DBA-2	DBA-3
Primary sodium heat removal	Provide primary sodium heat removal pathway	• RVACS structures • Reactor guard vessel • Reactor vessel • Reactor internals, pump piping, inlet plenum, inlet modules and fuel assemblies	Yes	Yes	Yes
	Prevent non-nuclear primary sodium heat generation	• Primary EM pump power supply isolation breaker • Diverse EM pump power isolation (adjustable speed drive (ASD) front end controller preferred)	Yes	Yes	Yes

This section presents the technical basis for the selection of SR-SSCs, presents the SR-SSCs, and identifies the RSFs and PSFs reflected in the LBEs in Section 3.

The first set of tables describes the combinations of SSCs that are provided in the design to fulfill each RSF and identifies whether each set of SSCs is available or not on each of the DBEs. There is one table per RSF. The provisions in the design for alternative ways to perform each RSF is one element of Plant Capability DID. The tables identify which combination of SSCs is selected as Safety-Related (SR) for each RSF.

An example adapted from the MHTGR examples[2] for a core heat removal RSF is shown in the following table. Note that the selection of safety-related SSCs in this example include SSCs needed to preserve the intrinsic characteristics of the reactor such as power level, power density, shape and selection of materials that enable the RSF to be fulfilled with the other identified SSCs.

SSC Combinations Capable of Providing Core Heat Removal*	Available for DBE-1?	Available for DBE-2?	…	Available for DBE-N?	Selected as Safety-Related?
• Reactor • Heat Transport System • Energy Conversion Area (ECA)	Yes	No	…	No	No
• Reactor • Shutdown Cooling System • Shutdown Cooling Water System (SCWS)	No	Yes	…	No	No
• Reactor • Reactor Vessel (RV) • Reactor Cavity Cooling System (RCCS)	Yes	Yes	…	Yes	Yes
• Reactor • Reactor Vessel • Reactor Building (RB) passive heat sinks	Yes	Yes	…	Yes	No

* Note the entries in this column and the example selection as Safety-Related are examples from the MHTGR found in Appendix A, Table A-3 of the LMP SSC Report[1].

B.1.4.2 SR SSC Summary

The SR-SSCs identified in Table B-4 are listed in Table B-6 with the LBEs, LBE type, and the resulting PSFs.

1 Southern Company, "Modernization of Technical Requirements for Licensing of Advanced Non Light Water Reactors: Safety Classification and Performance Criteria for Structures, Systems, and Components", Document Number SC 29980 102 Rev 1, March 1, 2020.

2 U.S Department of Energy, "Preliminary Safety Information Document for the Standard MHTGR, DOE-HTGR-86-024", 1988.

Table B-6: Summary of SR-SSCs for Primary Sodium Heat Removal

SR SSC	LBEs	LBE Type	PSF
RVACS structures	**LBE-1**: LOHS with SCRAM and one SAHX of the HRS available in passive mode	DBE	RVACS structures provide passive heat removal from PHTS
	LBE-2: LOHS with SCRAM and the HRS unavailable	DBE	RVACS structures provide passive heat removal from PHTS
	LBE-3: Seismic Cat 1 (S01) with SCRAM and the HRS unavailable	DBE	RVACS structures provide passive heat removal from PHTS
	LBE-4: General Transient with SCRAM and one SAHX of the HRS available in passive mode	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-5: General Transient with SCRAM and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-6: LOF (1 or 2 EM pumps) with SCRAM one SAHX of the HRS available in passive mode	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-7: TOP with SCRAM and one SAHX of the HRS available in passive mode	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-8: TOP with SCRAM and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-9: Seismic Cat 2 (S02) with SCRAM and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-10: Seismic Cat 3 (S03) with SCRAM and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-11: LOOP with SCRAM and one SAHX of the HRS available in passive mode	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-12: LOHS with IRF power reduction and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-13: General Transient with IRF power reduction and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
	LBE-14: LOF (1 or 2 EM pumps) with IRF power reduction and the HRS unavailable	BDBE	RVACS structures provide passive heat removal from PHTS
Reactor guard vessel	(same as above)		Reactor guard vessel transfers heat from PHTS to RVACS
Reactor vessel	(same as above)		Reactor vessel transfers heat from PHTS to RVACS
Reactor internals, pump piping, inlet plenum, inlet modules and fuel assemblies	(same as above)		Natural circulation necessary to transfer core decay heat to the primary sodium and reactor vessel as part of RVACS passive heat removal
Primary EM pump power supply isolation breaker	(same as above)		Primary EM Pumps trip within the required timeframe
Diverse EM pump power isolation	(same as above)		Primary EM Pumps trip within the required timeframe

A summary table as shown below should be presented that lists all the SR-SSCs, the AOOs, DBEs, BDBEs, and the PSFs responsible for preventing and mitigating each of these LBEs. Given there are multiple RSFs and that each RSF may require the use of multiple SSCs, there will in general be multiple SR-SSCs. Operator actions that may be necessary to perform any of these functions should be identified as well as the instrumentation and equipment needed to implement those operator actions.

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
SR SSC_1	LBE_{11}	?	PSF_{11}
	LBE_{12}	?	PSF_{12}
	…	…	…
	LBE_{1n}	?	PSF_{1n}
Additional SR-SSCs…	…	…	…

The LBE index numbers in the second column should be keyed to LBE indexes identified in Chapter 3, or alternatively spelled-out. For each PSF identified in the last column, the spelled-out function should be listed.

B.1.5 Non-Safety-Related with Special Treatments (NSRST) SSCs

The selection of NSRST SSCs is discussed in Section 3.2.3. This selection uses the LMP approach discussed in NEI 18-04, Chapter 4 [1]. Non-Safety-Related SSCs that are classified as NSRST because they perform risk-significant safety functions are identified in Section 5.5.1. Non-Safety-Related SSCs that are classified as NSRST because they performed safety functions deemed necessary for adequate DID are identified in Section 5.5.2. A summary of all the NSRST SSCs is provided in Section 5.5.3.

This section presents the technical basis for the selection of NSRST SSCs, presents the NSRST SSCs, and identifies the PSFs for the NSRST SSCs reflected in the LBEs in Section 3. Non-Safety-Related SSCs that are classified as NSRST because they perform risk-significant safety functions are identified in Section 5.5.1. Non-Safety-Related SSCs that are classified as NSRST because they performed safety functions deemed necessary for adequate defense-in-depth (DID) are identified in Section 5.5.2. A summary of all the NSRST SSCs is provided in Section 5.5.3.

B.1.5.1 Non-Safety-Related SSCs Performing Risk-Significant Functions

There are two criterion within NEI 18-04 that identify NSRST SSCs based on risk significance:

1. The first criterion is based on identifying non-safety-related SSCs whose prevention or mitigation function is necessary to prevent one or more LBEs from exceeding the F-C Target. This is described in Step 4B of NEI 18-04, Figure 4-1 [1].
2. The second risk significance criterion is based on whether the cumulative contribution of the LBEs in which a SSC safety function is failed exceeds 1% of the cumulative risk

metrics used for evaluating the risk significance of LBEs. In this case each risk-significant SSC is classified this way based on an accumulation of risk from multiple LBEs. This is described in Step 5B of NEI 18-04, Figure 4-1 [1].

The identification of NSRST using criterion 1 above resulted in the identification of NSRST SSCs as described in Table 5-2. The table includes the resulting PSFs.

Table B-7: NSRST SSC Selection Resulting in LBE F-C Target Mitigation

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
B24 Passive Heat Removal	LBE-LOHS-1: Loss of one of two HRS trains.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-NAFire-1: Sodium fire from one of two HRS trains.	DBE	PSF_{B24-1} PSF_{B24-2} PSF_{B24-3}
	LBE-EMPTrip-1: All four primary EM pumps trip.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-IHX-1: Leak in one of two Intermediate Heat Exchangers.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-SEIS-1: Seismic Event not failing HRS passive cooling.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-CG-1: Cover Gas leak outside of containment.	BDBE	PSF_{B24-1} PSF_{B24-2}
	Additional example BDBEs not developed further.		
B21 – Primary EM Pump Trip	LBE-LOHS-1: Loss of one of two HRS trains.	DBE	$PSFB_{21-1}$
	LBE-MAN-1: Manual Shutdown, 1 EM pump fails to trip.	BDBE	$PSFB_{21-1}$
	… repeat LBEs listed for B24 above, as well as the SR table – where EM pump trip is credited.	…	…
RS-NSRST SSC_N	LBE_N	?	PSF_{RS-N}

As discussed in Chapter 4, the following PSFs are identified related to the Table B-7 NSRST SSCs:

- NSRST PSFs associated with heat removal.
  - B24-1: Intermediate Heat Exchanger including tubing transfer heat from the primary coolant to the intermediate loop sodium following a reactor trip or transient.

- B24-2: HRS passively removes heat from the intermediate loop to air following a reactor trip or transient.
- B24-3: A fire in a single HRS train will not impact the opposite train.
- B21-1: EM Pump Thermal Shutdown Device trips the primary EM pump when the primary coolant temperature exceeds the design temperature (TBD).

The above PSFs result in the generation of CDCs discussed in Section 5.6.

The identification of NSRST using criterion 2 above resulted in no additional SSCs identified based on cumulative risk metrics

This section identifies the non-Safety-Related SSCs that perform risk-significant functions and meet the risk significance criteria for classification as NSRST. The risk significance classification is based on applying Steps 4B and 5B in Figure 4-1 in NEI 18-04 and the SSC risk significance criteria noted in Section 4.2.2 of NEI 18-04 [1]. Supporting documentation for details, calculations, etc., that were used to establish risk-significant SSC functions should be part of the design records and available for NRC audit.

There are two types of risk significance criteria that come into play in NEI 18-04. The first criterion is based on identifying non-safety-related SSCs whose prevention or mitigation function is necessary to prevent one or more LBEs from exceeding the F-C Target. Any SSC functions that are risk-significant based on this criterion should be identified in a table such as the following example. The purpose of the table is to identify the risk-significant SSCs, the PSFs that are responsible for the classification, and the LBEs that would exceed the F-C Target if the PSFs were not available [1].

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
RS-NSRST-SSC_1	LBE_{RS-1}	?	PSF_{RS-1}
RS-NSRST SSC_2	LBE_{RS-2}	?	PSF_{RS-2}
	…	…	…
RS-NSRST SSC_N	LBE_N	?	PSF_{RS-N}

The second risk significance criterion is based on whether the cumulative contribution of the LBEs in which a SSC safety function is failed exceeds 1% of the cumulative risk metrics used for evaluating the risk significance of LBEs. In this case each risk-significant SSC is classified this way based on an accumulation of risk from multiple LBEs. These risk-significant SSCs should be identified in a table such as the following example. The purpose is to identify the SSC classified as risk-significant, the LBEs in which the SSC is failed, and the PSF associated with that LBE.

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
RS-NSRST-SSC$_1$	LBE$_{RS-11}$	?	PSF$_{RS-11}$
	LBE$_{RS-12}$	?	PSF$_{RS-12}$
	…	…	…
	LBE$_{RS-1n}$	?	PSF$_{RS-1n}$
Additional RS-NSRST SSCs…	…	…	…

Comment: Some additional terminology may be helpful. Currently, with SR components; the PSFs lead to RSFs/RFDCs which lead to PDCs. For NSRST components, PSFs lead to two possible categories of functions, which lead to NSRST SSC design criteria and CDCs. I would recommend we develop another term. See the figure below from the presentation to the NRC.

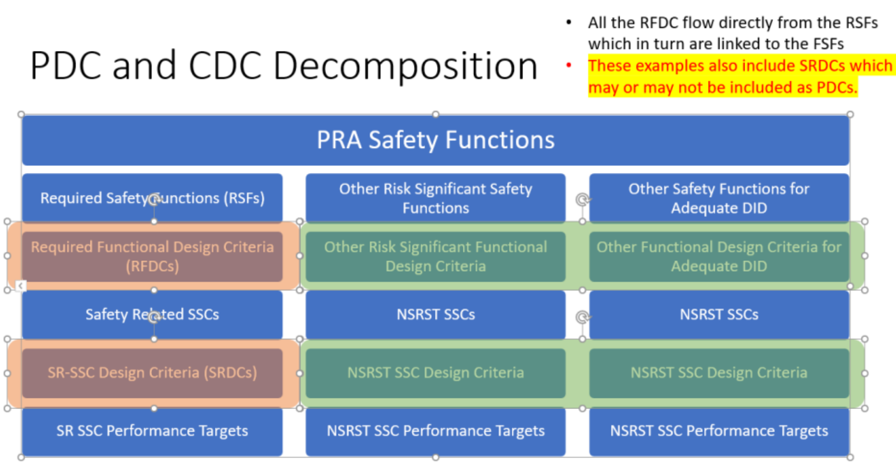

Figure B-2: PDC and CDC Decomposition

B.1.5.2 Non-Safety-Related SSCs Performing Safety Functions Necessary for Adequate Defense-in-Depth

The NEI 18-04 process includes classification of NSRST SSCs resulting from the DID steps discussed in Section 4.2 [1]. The DID steps are not repeated here.

No new NSRST SSCs were identified as a result of the plant capability DID review. The plant capability DID review confirmed the need for B24 passive heat removal function, including the need for preventing RVACS operation for an AOO.

The DID review for risk margins included the review of uncertainty including a cliff-edge effects review. No new NSRST components were identified from the cliff-edge effects review. However, additional NSRST SSCs were identified from the uncertainty DID review. The results are not presented in this report, since none relate to the heat removal function.

The programmatic DID review identified special treatment related to SR and NSRST SSCs, but did not identify any new NSRST SSCs.

This section identifies the non-Safety-Related SSCs that are classified as NSRST because they perform safety functions deemed necessary for adequate defense-in-depth. It should be noted that the SR-SSCs identified Section 5.4 are also key elements of the Plant Capability Defense-in-depth. Supporting documentation for details, calculations, Integrated Decision Process Baseline DID evaluations, etc. that were used to establish SSC functions necessary for adequate DID should be part of the design records and available for NRC audit.

As with the risk-significant SSCs, the SSC classification for DID adequacy is tied to specific LBEs and should be summarized in a table such as the following example.

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
DID-NSRST-SSC$_1$	LBE$_{DID-11}$	?	PSF$_{DID-11}$
	LBE$_{DID-12}$	?	PSF$_{DID-12}$
	…	…	…
	LBE$_{DID-1n}$	?	PSF$_{DID-1n}$
Additional DID-NSRST SSCs…	…	…	…

Comment: Not all NSRST SSCs are related to LBEs, especially if related to scope questions (what is not in the PRA) or uncertainty. For example, radwaste, cover gas system releases, etc. are low dose releases, and not large enough to meet the F-C curve criteria. We could, if needed, make up an LBE (e.g., cover gas releases outside of containment – non-accident conditions), but these would be non-PRA-based LBEs. We should discuss this issue.

B.1.5.3 NSRST SSC Summary

The summary Table 5-3 lists all the NSRST SSCs, the AOOs, DBEs, BDBEs, and the PSFs responsible for preventing and mitigating each of these LBEs. This table summarizes the NSRST

SSCs discussed in 5.5.1 and 5.5.2. There were no operator actions necessary to perform these NSRST functions.

Table B-8: Summary of NSRST SSCs

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
B24 Passive Heat Removal	LBE-LOHS-1: Loss of one of two HRS trains.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-NAFire-1: Sodium fire from one of two HRS trains.	DBE	PSF_{B24-1} PSF_{B24-2} PSF_{B24-3}
	LBE-EMPTrip-1: All four primary EM pumps trip.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-IHX-1: Leak in one of two Intermediate Heat Exchangers.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-SEIS-1: Seismic Event not failing HRS passive cooling.	DBE	PSF_{B24-1} PSF_{B24-2}
	LBE-CG-1: Cover Gas leak outside of containment.	BDBE	PSF_{B24-1} PSF_{B24-2}
	Additional example BDBEs not developed further.		
B21 – Primary EM Pump Trip	LBE-LOHS-1: Loss of one of two HRS trains, EM pump trip successful.	DBE	$PSFB_{21-1}$
	LBE-MAN-1: Manual Shutdown, 1 EM pump fails to trip.	BDBE	$PSFB_{21-1}$
	… repeat LBEs listed for B24 above, as well as the SR table – where EM pump trip is credited.	…	…
RS-NSRST SSC_N	LBE_N	DBE/BDBE	PSF_{RS-N}

The PSFs identified in the last column are listed in Section 5.5.1 above.

A summary table (example below) should be presented that lists all the NSRST SSCs, the AOOs, DBEs, and BDBEs, and the PSFs responsible for preventing and mitigating each of these LBEs. The summary table is a collection of the information in the tables in Sections 5.5.1 and 5.5.2. Operator actions that may be necessary to perform any of these functions should be identified as well as the instrumentation and equipment needed to implement those operator actions.

SR SSC	LBEs	LBE Type (AOO, DBE, or BDBE)	PSF
NSRST SSC_1	LBE_{11}	?	PSF_{11}
	LBE_{12}	?	PSF_{12}
	…	…	…
	LBE_{1n}	?	PSF_{1n}
Additional NSRST SSCs…	…	…	…

The LBE index numbers in the second column should be keyed to LBE indexes identified in Section 3, or alternatively spelled-out. For each PSF identified in the last column, the spelled-out function should be listed.

Comment: Seems like the table above is just a repeat of the previous two tables. Recommend deleting either this or the previous tables (and just refer to this summary table).

B.1.6 Complementary Design Criteria for NSRST SSCs

The Complementary Design Criteria for NSRST SSCs are defined in terms of the success criteria for the PSFs that are represented in the PRA model to prevent and mitigate the LBEs responsible for the safety classification. CDCs associated with the B24 and B21 PSFs listed in Table 5-4 are listed below.

- **B24-1-1:** Each non-safety class HRS train shall have a passive mode with natural circulation sized such that either loop is capable of controlling primary temperature within normal operating limits following an end of cycle scram.
- **B24-1-2:** When a reactor scram occurs, the HRS EM pumps shall be tripped.
- **B24-1-3:** The Heat Rejection System coolant boundary shall be designed such that, when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of a rapidly propagating fracture is minimized.
- **B24-2-1:** The non-safety class HRS shall be designed such that each sodium-to-air heat exchanger unit can be isolated from the remainder of the HRS and drained through heated drain lines to the associated train drain tank while the remaining units continue to function.
- **B24-2-2**: TBD – Need to develop the CDC for Fire Separation of B24 (not yet worded).
- **B24-2-2:** System B24 shall prevent failure of its natural circulation heat removal function caused by sodium freezing.
- **B21-1-1:** When a reactor scram occurs, the PHTS EM pumps shall be tripped.

Note: It is expected that a content of application would include additional CDCs not listed, such as the inspection of intermediate loop coolant boundary and other requirements that are generated from code or regulatory requirements not initially reviewed for the above tabletop review.

Table B-9: Summary of NSRST CDCs

NSRST SSC	PRA Safety Function	PSF Success Criterion	Complementary Design Criteria
B24 Passive Heat Removal	Success of passive HRS to prevent damage to radionuclide barriers requires a sufficient number of passive SAHX to remove decay heat plus heat added by primary EM pumps failing to trip.	The success criteria is variable for B24, and depends on the status of the primary EM pumps. Each passive SAHX will remove 2.3 MWth. The number of passive SAHXs operating is compared the heat input into the primary sodium consisting of decay heat (~3 MWths) plus heat added by primary EM pumps failing to trip (1 MWths per pump) to determine success of heat removal by passive SAHXs.	**B24-1-1:** Each non-safety class HRS train shall have a passive mode with natural circulation sized such that either loop is capable of controlling primary temperature within normal operating limits following an end of cycle scram. **B24-1-2:** When a reactor scram occurs, the HRS EM pumps shall be tripped. **B24-1-3:** The Heat Rejection System coolant boundary shall be designed such that, when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of a rapidly propagating fracture is minimized.
	Passive HRS is successful if the exhaust damper is open in the required SAHX.	1 of 1 exhaust damper is opened for each credited SAHX within 1 hour.	**B24-1-1:** Each non-safety class HRS train shall have a passive mode with natural circulation sized such that either loop is capable of controlling primary temperature within normal operating limits following an end of cycle scram.
	One train of HRS is available to passively remove decay heat, plus heat added by the primary EM pumps failing to trip, following a fire caused by a leak/rupture in the other train.	TBD – the fire separation is a combination of fire protection features. Details are not yet designed.	**B24-2-1:** The non-safety class HRS shall be designed such that each sodium-to-air heat exchanger unit can be isolated from the remainder of the HRS and drained through heated drain lines to the associated train drain tank while the remaining units continue to function **B24-2-2**: TBD – Need to develop the CDC for Fire Separation of B24 (not yet worded).
B21 – Primary EM Pump Trip – Thermal Temperature Switch	4 of 4 primary EM pumps successfully trip automatically. Note: EM pump trip can occur from the SR trip feature (e.g., EMP breaker open) or the NSRST SSC (thermal temperature switch).	Note that success criteria for the number of allowable primary EM pump trip failures are not explicitly noted here. Failure of primary EM pumps to trip initiate different loads on the passive HRS or RVACS, so the sequence-specific RVACS criteria developed in the SC chapter includes consideration of EM pump loads as noted above.	**B21-1-1:** When a reactor scram occurs, the PHTS EM pumps shall be tripped.

See comment in 5.5.1 above on CDCs.

The Complementary Design Criteria for NSRST SSCs are defined in terms of the success criteria for the PRA Safety Functions (PSFs) that are represented in the PRA model to prevent and mitigate the LBEs responsible for the safety classification. For example, a PSF safety function might be “Provide adequate heat removal from the reactor following initiating event X” and the success criterion might be “provide a coolant flow rate of Y kg/sec within Z minutes and maintain maximum fuel temperature less than ZZ.” SSCs are classified as NSRST either because the LMP risk significance criteria are met as identified in Section 5.5.1, or the criteria for adequate DID established by the IDP are met as identified in Section 5.5.2. The reliabilities and capabilities that are established in the PRA for the PSFs associated with the SSC trigger the meeting of the risk significance or DID adequacy criteria. These in turn serve to prevent and/or mitigate a specific set of LBEs. Hence the Complementary Design Criteria for the NSRST SSCs are directly tied to the success criteria established in the PRA for the PSFs responsible for the SSC classification as NSRST.

These should be presented in tabular form by listing the SSC, the PSF(s) responsible for its safety classification as NSRST, and the design criteria that are necessary and sufficient to meet the PSF. There may be more than one PSF that is associated with the NSRST classification, and more than one design criterion for each PSF because the SSC may be represented on multiple LBEs.

NSRST SSC	PRA Safety Function	PSF Success Criterion	Complementary Design Criteria
NSRST SSC_1	PSF_{11}	Success criterion for PSF_{11}	Design criterion for PSF_{11}
	PSF_{12}	Success criterion for PSF_{12}	Design criterion for PSF_{12}
	…	…	…
	PSF_{1n}	Success criterion for PSF_{1n}	Design criterion for PSF_{1n}
Additional NSRST SSCs	…	…	…

APPENDIX C Draft Content for SAR Chapter 6 – Safety-Related SSC Criteria and Capability

C.6 Safety-Related SSC Criteria and Capabilities

In Section 5.4 the Safety-Related SSCs were identified and the bases for their classification as such provided. Section 6 provides further detail on the criteria and capabilities of all SR-SSCs in the LMP-based Affirmative Safety Case, consistent with the NEI 18-04 methodology. This further detail includes Safety-Related Design Criteria (SRDC), reliability and capability performance-based targets, and special treatment requirements to provide sufficient confidence that the performance-based targets intended in the design will be achieved in the construction of the plant and maintained throughout the licensed plant life. Section 6 also summarizes design requirements for non-safety-related (NSR) SSCs that provide confidence that the NSR SSCs will not adversely impact the ability of SR-SSCs to support RSFs in the event that a hazard occurs at the DBEHL.

C.6.1 Design Requirements for Safety-Related SSCs (SRDCs)

This section describes the outputs of NEI 18-04 Section 4.1, Task 7 [1]. Details of the analyses and justifications for the development of SRDCs should be in the design records and available for NRC audit.

C.6.1.1 Design Basis External Hazard Levels

DOE-STD-1020 provides criteria and guidance for DOE nuclear facilities for meeting the natural phenomena hazard (NPH) requirements of DOE Order (O) 420.1C, Chg. 1. NPH design categories (NDC) are utilized to establish NPH design criteria for applicable SSCs. NDCs include:

- Seismic Design Categories (SDCs)
- Extreme Wind Design Categories (WDCs)
- Flood Design Categories (FDCs)
- Extreme Precipitation Design Categories (EPDCs)
- Volcanic Design Categories (VDCs)
- ANSI/ANS-2.26-2004 for other NPHs

The design basis external hazard levels (DBEHLs) that may be applicable to SR-SSCs are presented in **Error! Reference source not found.**. Due to their SR designation, NDC-5 (or equivalent) is selected for the DBEHLs, however, the applicability of the DBEHL for the specific SR SSC is reviewed in Section C.6.2.

Table C-1: Design Basis External Hazard Levels (DBEHLs)

Hazard	Design External Hazard Level
Seismic Events	SDC-5: See Early Design Response Spectra (EDRS) in INL-LTD-51865
Extreme Wind Speed	WDC-5: See velocities in INL-LTD-51865
Extreme Precipitation	PDC-5: See rainfall and snowpack in INL-LTD-51865
External Flood	Dry flood area, no requirement
Volcanism	VDC ≥ 3: See administrative controls in INL-LTD-51865
Extreme Temperatures	-47°F to 105°F
Lightning	Flash density (Ng) of 0.5

One general category of design requirements flow from the need to protect the SR-SSCs in the performance of their RSF from design basis external hazards. Each external hazard is characterized by a Design Basis External Hazard Level (DBEHL) (e.g., wind speed). This is discussed in NEI 18-04 Section 3.2.2, Task 6 and the following text from the first page of Section 4 in NEI-18-04 [1].

> It is noted that there will be design requirements to protect all SR-SSCs from any adverse impacts of any DBEHLs. This may lead to design requirements to prevent any adverse impacts from failure of an SSC classified as NST or NSRST that could otherwise prevent an SR SSC from performing its RSFs.

The scope of the DBEHLs include external hazards such as seismic events, wind including tornados and wind generated missiles, external flooding, hazards from external facilities, and internal plant hazards such as internal fires, internal floods, high energy line breaks, and internally generated missiles. These internal plant hazards are frequently described as "area events". Guidance on the scope of hazards may be found in Chapter 3 of the Standard Review Plan (NUREG-0800). The concept is to ensure that hazards with a frequency down to 10-4/plant-year are identified so that design requirements identified in Section 5.4 for the SR-SSCs to protect them against any DBEHL can be specified. Note that the DBEHLs are one of the inputs to the analysis of hazards in the PRA.

The DBEHLs shall be summarized in this section. A tabular form such as shown below is recommended. The determination of the DBEHLs is documented elsewhere in the SAR. This will most likely be in Chapter 2, but will be determined based on ARCAP/TICAP interface discussions and agreements.

Hazard	Design External Hazard Level
Seismic Events	Specify design basis earthquake parameters
Tornado Wind Speed	Specify design basis wind speed
External Flood	Specify design basis flood levels
Internal Fires	Identify fire areas where SR-SSCs are located and fires may occur
Internal Flood	Identify flood areas where SR-SSCs are located and flood may occur
High energy line breaks (HELB)	Identify areas where SR-SSCs are located a HELB may occur
Other hazards that the safety-related SSCs are protected against	Identify areas and specify appropriate parameters

C.6.1.2 Summary of SRDC

The RFDC and safety-related design requirements (SRDC) for the SR-SSCs are presented in Table . See Section B.1.3 for the derivation of the RFDC from the PDC and Section B.1.4 for the applicable LBEs identified for each SR SSC.

Table C-2: Summary of SR SSC RFDCs and SRDCs

SR SSC	Functional Description	RFDC	SRDC
RVACS (Structures)	**Function #1:** The RVACS is the SR decay heat removal pathway. It is utilized in event sequences where heat removal through the secondary system (including both active and passive operation) is unavailable.	Provide sufficient heat removal capability to prevent the release of radionuclides from the fuel (i.e., cladding failure) for applicable LBEs in **Error! Not a valid result for table.**.	**SRDC$_{11}$: Decay Heat Level** – Maximum load from applicable LBEs in **Error! Not a valid result for table.** is full decay heat from a TOP event with successful SCRAM.
			SRDC$_{12}$: Seismic Capability – Maximum seismic load from applicable LBEs in **Error! Not a valid result for table.** is a Cat 3 (0.4g – 0.6g) seismic event with full normal decay heat load. This SRDC is included as it may be beyond the seismic DBEHL.
Reactor Vessel	**Function #1:** The reactor vessel is part of the primary coolant boundary.	Maintain primary sodium inventory for all LBEs.	**SRDC$_{21}$: Structural Integrity** – Maintain structural integrity for predicted temperatures and pressures of all LBEs.

SR SSC	Functional Description	RFDC	SRDC
	Function #2: The reactor vessel is part of the RVACS SR heat removal pathway.	Provide sufficient heat transfer capability such that the RVACS system can prevent the release of radionuclides from the fuel (i.e., cladding failure) for applicable LBEs in **Error! Not a valid result for table.**.	**$SRDC_{22}$: Heat Transfer –** Maintain adequate heat transfer (conductive and radiative) for applicable LBEs in **Error! Not a valid result for table.**.
Guard Vessel	**Function #1:** The guard vessel is part of the RVACS SR heat removal pathway.	Provide sufficient heat transfer capability such that the RVACS system can prevent the release of radionuclides from the fuel (i.e., cladding failure) for applicable LBEs in **Error! Not a valid result for table.**.	**$SRDC_{31}$: Heat Transfer –** Maintain adequate heat transfer (conductive and radiative) for applicable LBEs in **Error! Not a valid result for table.**.
Primary EM Pump Trip	**Function #1:** The primary EMP trip de-energizes the primary EMPs during SCRAM events so that pump heat is not added to the system.	Preserve heat removal capability of RVACS for applicable LBEs in **Error! Not a valid result for table.** by ensuring that primary EM pump heat does not contribute to total system heat load.	**$SRDC_{41}$: Response Time –** Primary pumps must be tripped within designated time for the applicable LBEs in **Error! Not a valid result for table.**.

In the text for Task 7 of Figure 4-1 in NEI-18-04, it is stated:

> "The RFDC, SRDC, the reliability and capability targets for SR and NSRST SSCs, and special treatment requirements for SR and NSRST SSCs define safety-significant aspects of the descriptions of SSCs that should be included in safety analysis reports."

The RFDC are identified in Section 5.3 and the RSFs that they support are identified in Section 5.2. For each of the RFDCs, this section should identify a set of Safety-Related Design Criteria (SRDC) appropriate to the SR-SSCs selected to perform the RSFs. These SRDCs exclude Special Treatment Requirements which are separately covered in Section 6.2. The RFDC, which are expressed in the form of functions and involve collections of SSCs and intrinsic capabilities of the reactor, may be viewed as a bridge between the RSF and the SRDCs. The SRDCs are more detailed requirements for specific SR-SSCs in performance of the RSF functions in specific DBAs. Examples of SRDCs that were developed for the MHTGR are found in Appendix A of the LMP SSC Report*.

* Southern Company, "Modernization of Technical Requirements for Licensing of Advanced Non Light Water Reactors: Safety Classification and Performance Criteria for Structures, Systems, and Components", Document Number SC 29980 102 Rev 1, March 1, 2020

For the Safety-Related Design Criteria (SRDC), the following information is presented in tabular form as shown in the table below.

- First column has the SSC name
- Second column has a short SSC functional description
- Third column has the RFDC that the SR SSC supports. Most likely there is only one RFDC associated with each SR SSC but if there is more than one all should be listed. Note that the links from the SR-SSCs back to the LBEs that define the RSFs are provided in Chapter 5.
- Fourth column lists the SRDC. There may be more than one SRDC for each SR SSC.

SR SSC	Functional Description	RFDC	SRDC
SR SSC1	Functional Description SR SSC1	RFDCx	SRDC11
			SRDC12
			…
			SRDC1n
Additional SR-SSCs	…	…	…

C.6.1.3 Summary of DBEHL-related Requirements for NSR SSCs

Table contains DBEHL-related requirements for NSR SSCs, which are necessary for the protection of RSFs and SR-SSCs. For RVACS, successful performance depends on the preservation of an adequate flow path and area. Therefore, failure of the reactor building, which would result in RVACS structure and flow path distortion, must be prevented for the DBEHLs and non-DBEHL events outlined in Table .

Table C-3: Summary of NSR SSC DBEHL-related Requirements

NSR SSC	Protected RSF and SR-SSCs	DBEHL	NSR SSC Design Requirement
Reactor Building[1]	RSF: Removal Core Heat SR SSC: RVACS (structures)	DBEHL[1]	Seismic DBEHL
		DBEHL[2]	Extreme Winds DBEHL
		DBEHL[3]	Extreme Precipitation DBEHL
		DBEHL[4]	Volcanism DBEHL
		Non-DBEHL[1]	Seismic Cat 3

[1] The reactor building includes any components within, such as casks or cranes, whose restraint or support system failure could also impact RVACS structure.

Chapter 6 also identifies DBEHL-related design requirements for non-SR-SSCs. These design requirements are to support the special safety functions that are applied to the non-SR-SSCs to prevent adverse impacts on the ability of the SR-SSCs to perform the RSFs. An example is requirement for anchorage to prevent a non-safety-related SSC to fail in such a manner that would impact a SR SSC and cause it to fail to perform its RSF.

It is important to note that the non-SR-SSCs covered in these requirements are not for the SSC functions that they normally perform but for the special function of preventing any adverse impact on the capability of any SR SSC in the performance of the RSF. The DBEHLs include external hazards such as seismic events as well as internal plant hazards such as internal fires and floods, turbine missiles, and high energy line breaks. When a non-SR SSC is required to protect the SR-SSCs in their ability to perform their RSFs, such non-SR-SSCs are not necessarily NSRST. The NSRST classifications are based on the PSFs these SSCs perform to prevent and mitigate event sequences and not these special functions of a structural nature that are focused on protecting the SR-SSCs.

For the non-safety-related SSCs that have design requirements to protect the SR-SSCs in the performance of the RSFs in response to a DBEHL, the following information in tabular form should be provided, as illustrated in the example below.

- First column identifies the NSR SSC
- Second column identifies the RSF and SR SSC(s) that are protected
- Third column identifies the DBEHL(s) that are associated with these requirements.
- Fourth column identifies the specific design requirement for the function to protect the SR-SSCs for each of the DBEHLs. Note that this function is different than the PSFs for the same NSR SSCs.

NSR SSC	Protected RSF and SR-SSCs	DBEHL	NSR SSC Design Requirement
NSR SSC1	RSF / SR SSCX	DBEHL1	NSR DC11
		DBEH2	NSR DC12
			…
		DBEHLn	NSR DC1n
Additional NSR SSCs	…	…	…

C.6.2 Special Treatment Requirements for SR-SSCs

Special treatment refers to those requirements that provide increased assurance beyond normal industrial practices that SSCs perform their design basis function. All safety-significant SSCs (including SR and NSRST SSCs) include the following special treatments:

- Development of a Reliability Assurance Program
- Design requirements related to SSC capabilities to mitigate challenges from applicable LBEs
- Development of a Maintenance Program that assures targets for SSC availability and effectiveness of maintenance to meet SSC reliability targets
- Applicable Licensee Event Reports

Additional special treatment requirements for SR-SSCs are outlined in Table .

Table C-4: Special Treatment Requirements for SR-SSCs

SR SSC	Functional Description	Required Functional Design Criteria	Technical Specifications	Seismic Design Basis	Seismic Qualification Testing	Protection Against Design Basis External Events	Equipment Qualification Testing	Materials Surveillance Testing	Pre-Service and In-Service Inspection	In-Service Monitoring
RVACS (structures)	**Function #1:** The RVACS is the SR decay heat removal pathway. It is utilized in event sequences where heat removal through the secondary system (including both active or passive operation) is unavailable.	✓	✓	✓		✓	✓	✓	✓	✓
Reactor Vessel	**Function #1:** The reactor vessel is part of the primary coolant boundary.	✓	✓	✓			✓	✓	✓	
	Function #2: The reactor vessel is part of the RVACS SR heat removal pathway.	✓	✓	✓			✓	✓	✓	
Guard Vessel	**Function #1:** The guard vessel is part of the RVACS SR heat removal pathway.	✓	✓	✓			✓	✓	✓	

SR SSC	Functional Description	Required Functional Design Criteria	Technical Specifications	Seismic Design Basis	Seismic Qualification Testing	Protection Against Design Basis External Events	Equipment Qualification Testing	Materials Surveillance Testing	Pre-Service and In-Service Inspection	In-Service Monitoring
EM Pump Trip	**Function #1:** The primary EMP trip de-energizes the primary EMPs during SCRAM events so that pump heat is not added to the system.	✓	✓	✓	✓		✓	✓	✓	✓

NEI 18-04 adopted the definition of special treatment that is provided in Regulatory Guide 1.201 which was developed for implementing 10 CFR 50.69.

> "…special treatment refers to those requirements that provide increased assurance beyond normal industrial practices that structures, systems, and components (SSCs) perform their design basis functions." [1]

Anything that is done beyond procuring commercial grade equipment to provide increased assurance in the capability and reliability of the SSC falls into the category of special treatment. Hence, all the design requirements provided in Section 6.1 are part of the special treatment. This section identifies the additional special treatments that are applied to SR-SSCs. Candidate special treatments (STs) for consideration are identified in Table 4-1 of NEI 18-04.

As noted in Section 4.4.5 of NEI 18-04 the selection of STs for all safety significant SSCs (SR and NSRST) are informed by a set of targets for the reliability and availability of the SSCs in their prevention functions as well as targets for the capability of the SSCs in the performance of their mitigation functions. These specific targets should not be stated in the SAR but should be available in the plant records for NRC audit purposes. The focus of this section in the application is to produce the resulting special treatment requirements.

For the selected STs the license application should identify the treatments in the license application with details available for NRC audit in the license application.

The STs should be summarized in tabular form by listing each SR SSC, providing a brief performance-based functional description and identifying which ST has been selected for each SR SSC.

SR SSC	Functional Description	SR SSC Special Treatments
SR SSC1	Short SSC functional description for SR SSC1	SR SSC1 Special Treatment No. 1
		SR SSC1 Special Treatment No. 2
		…
		SR SSC1 Special Treatment No. n
Additional NSR SSCs	…	…

C.6.3 System Description of SR-SSCs

This section provides system descriptions for SR-SSCs. These descriptions include the specific design features for SR-SSCs that are responsible for meeting the SRDC and fulfilling their RSFs to mitigate the DBAs. This description should include features that demonstrate system capability and reliability for both prevention and mitigation of LBEs, as applicable.

Note: The content provided below is for RVACS, based on the draft DOE submittal document. It is expected the level of detail in a final content of application would be expanded to include additional details important to the requirements discussed above.

C.6.3.1 RVACS Description

Emergency decay heat removal is normally performed by the two HRS secondary sodium loops. If normal AC electrical power is available, then the primary EMPs and secondary EMPs in each HRS loop may all be electrically powered such that heat transport of reactor decay heat to the atmosphere heat sink involves forced flow of primary sodium, secondary sodium in both HRS loops, and natural circulation of air through the SAHXs. Operation of the SAHX air blowers will result in overcooling.

In the HRS heat removal pathway is unavailable, the design incorporates a RVACS that is a completely passive natural circulation air cooling system for the guard vessel. The RVACS is always in operation providing an additional heat transport pathway to the air atmosphere heat sink. Figure and Figure provide idealized illustrations of the RVACS concept. Decay heat from the core is transported to the inner surface of the reactor vessel by natural circulation of primary sodium. Heat is thermally conducted through the reactor vessel wall and is transported across the reactor vessel-guard vessel annular gap through thermal radiation and natural convection of the enclosed argon gas. Heat is thermally conducted through the guard vessel wall and heats the air inside of the hot air riser through convective heat transfer to the rising air. The collector cylinder forming the outer wall of the hot air riser absorbs thermal radiation from the guard vessel and heats up. The heated collector cylinder surface transfers additional heat to the rising hot air through convective heat transfer. The outer surface of the collector cylinder is thermally insulated to minimize preheating of the cooler air flowing downward through the cold air downcomer. The air flowrate is driven by natural circulation due to a chimney effect. The hot air in the riser is less dense than the cold air in the downcomer. The density difference creates a gravity head that drives the flow at a quasi-steady air velocity for which the gravity head is balanced by frictional and form losses along the air flow path.

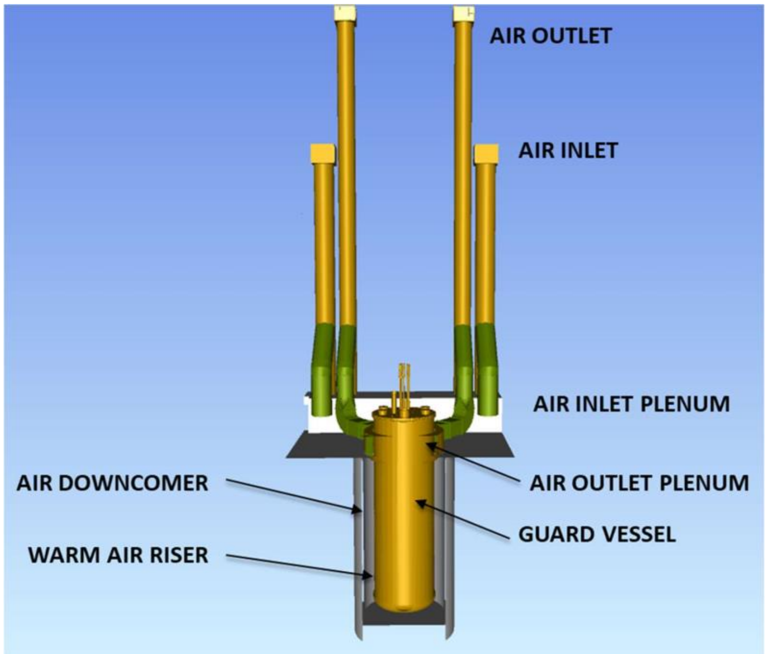

Figure C-1: RVACS Configuration

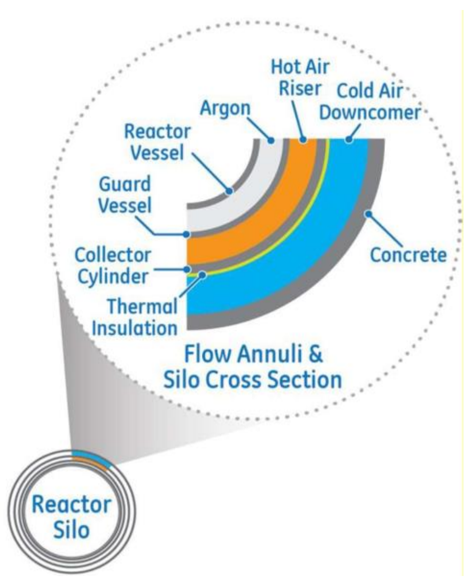

Figure C-2: Illustration of RVACS Configuration Surrounding Guard and Reactor Vessels

As a completely passive system that is always in operation, RVACS does not have distinct operational modes. However, its heat removal capabilities are directly correlated to the temperature of the reactor vessel and primary system. Therefore, during transient event sequences with elevated primary sodium temperatures, RVACS heat removal performance increases substantially relative to its heat removal during normal full-power reactor operation.

RVACS performance depends not only on the RVACS structure but also the guard vessel, reactor vessel, and natural circulation in the primary system. For the assurance of successful RVACS operation, the RVACS structure, guard vessel, and reactor vessel are designed based on applicable codes TBD.

RVACS requires no operator actions or the movement of any components. In-service monitoring and inspection are used to maintain system reliability. Inspections of the RVACS flow pathways and reactor and guard vessel surfaces are performed during plant shutdowns. Monitoring of the system inflow and outflow during reactor operation is displayed to the reactor operators, with alarms to signify abnormal flow patterns. Pre-service testing of the primary system natural circulation characteristics is used to verify flow predictions.

In regard to system interface requirements, RVACS does not require electrical power or other support systems. Before plant operation can commence, the closure of all system inspection ports must be verified to prevent flow bypasses or other flow distortion.

As the RVACS inlets, outlets, and associated piping runs are exposed to the environment, they are qualified for harsh environments. In addition, RVACS structures near the guard vessel are qualified for the associated high temperatures and radiation doses.

This description should include:

- Simplified schematic diagram
- Narrative design descriptions that address the design aspects relevant to the performance of the RSFs systems including:
    - the system purpose in the context of supporting the RSFs
    - significant functional performance in the context of supporting the RSFs
    - system location and environmental conditions
    - key design features relevant to performance of RSFs
    - seismic and industry (e.g. ASME, IEEE) code classifications and the design codes applicable to the SR SSC,
    - description of system operation including a description of the performance modes of operation of the system relevant to the RSFs.
    - identification of operator actions needed to implement the RSFs

- controls and displays needed to accomplish RSFs
- logic circuits and interlocks needed to support RSFs
- electric power, support systems, and interface requirements needed to support the RSFs
- equipment to be qualified for harsh environments as needed to meet SR SSC special treatment requirements defined in Section 6.2

6.3.2, 6.3.3, et al.: Descriptions of the remainder of the SR-SSCs are provided.

APPENDIX D Draft Content for SAR Chapter 7 – NSRST/SS Criteria and Capability

D.7 NSRST/SS Criteria and Capability

This chapter provides the details and background for NSRST SSC Criteria and Capability. In Section 5.5 the NSRST SSCs were identified and the bases for their classification as such provided. Section 7 provides further detail on the criteria and capabilities of all NSRST SSCs in the LMP-based Affirmative Safety Case, consistent with the NEI 18-04 methodology. This further detail includes NSRST design criteria, reliability and capability performance-based targets, and special treatment requirements to provide sufficient confidence that the performance-based targets intended in the design will be achieved in the construction of the plant and maintained throughout the licensed plant life.

Section 6.3.1 above summarizes design requirements for NSR SSCs that provide confidence that the NSR SSCs will not adversely impact the ability of SR-SSCs to support RSFs in the event that a hazard occurs at the DBEHL.

From the TICAP Guidance:

In Section 5.5 the Non-Safety-Related with Special Treatment (NSRST) SSCs were identified. Section 7 provides further detail on the role of each NSRST SSC in the LMP-based Affirmative Safety Case, consistent with the NEI 18-04 methodology. Complementary Design Criteria for NSRST SSCs are covered in Section 5.5.4. The remaining criteria and capabilities for NSRST SSCs include reliability and capability performance targets, and special treatment requirements to provide sufficient confidence that the performance targets will be achieved and maintained throughout the life of the licensed plant.

As noted in Section 4.4.5 of NEI 18-04 the selection of STs for all safety significant SSCs (SR and NSRST) are informed by a set of targets for the reliability and availability of the SSCs in their prevention functions as well as targets for the capability of the SSCs in the performance of their mitigation functions. These specific targets should not be stated in the license application but should be available in the plant records for NRC audit purposes. Hence this section should be limited to an affirmative statement that targets for the reliability and capability of NSRST SSCs were established via the IDP and these were made to inform the selection of the STs identified in the following section.

Note: The discussion in Section D.7.1 is not currently in the draft TICAP guidance document. The section is included to develop a parallel between Chapters 6 and 7 in the development of special treatments for NSRST SSCs.

D.7.1 Design Requirements for NSRST SSCs

Table 7-1 provides a summary of the NSRST SSC CDCs and associated design criteria. Details of the analysis for the development of the Table D-1 summary are available in the VTR design record. The design requirements are derived from the LBE evaluations summarized Section 5.5 and supported by the DID evaluations discussed in Section 4.2.

Table D-1: Summary of SR NSRST CDCs and Design Criteria

SR SSC	Functional Description	CDC	NSRST SSC Design Criteria
Intermediate Heat Exchanger	B24-1: Intermediate Heat Exchanger including tubing transfer heat from the primary coolant to the intermediate loop sodium following a reactor trip or transient.	**B24-1-3:** The HRS coolant boundary shall be designed such that, when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of a rapidly propagating fracture is minimized.	Similar to SR SRDC22 on heat transfer: **Heat Transfer –** Maintain adequate heat transfer (conductive and radiative) for applicable LBEs in **Error! Not a valid result for table.** through the IHX to the HRS.
Heat Rejection System	B24-2: HRS passively removes heat from the intermediate loop to air following a reactor trip or transient.	**B24-1-1:** Each non-safety class HRS train shall have a passive mode with natural circulation sized such that either loop is capable of controlling primary temperature within normal operating limits following an end of cycle scram.	Similar to SR SRDC22 on heat transfer: **Heat Transfer –** Maintain adequate heat transfer (conductive and radiative) for applicable LBEs in **Error! Not a valid result for table.** through the IHX to the HRS.
		B24-1-2: When a reactor scram occurs, the HRS EM pumps shall be tripped.	Similar to SR SRDC22 on heat transfer: **Heat Transfer –** Maintain adequate heat transfer (conductive and radiative) for applicable LBEs in **Error! Not a valid result for table.** through the IHX to the HRS.
		B24-1-3: The HRS coolant boundary shall be designed such that, when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of a rapidly propagating fracture is minimized.	Similar to SRDC21: **Structural Integrity –** Maintain structural integrity for predicted temperatures and pressures of all LBEs.
		B24-2-1: The non-safety class HRS shall be designed such that each sodium-to-air heat exchanger unit can be isolated from the remainder of the HRS and drained through heated drain lines to the associated train drain tank while the remaining units continue to function.	TBD
		B24-2-2: System B24 shall prevent failure of its natural circulation heat removal function caused by sodium freezing.	TBD

SR SSC	Functional Description	CDC	NSRST SSC Design Criteria
Primary EM Pumps	B21-1: EM Pump Thermal Shutdown Device trips the primary EM pump when the primary coolant temperature exceeds the design temperature (TBD).	**B21-1-1:** When a reactor scram occurs, the PHTS EM pumps shall be tripped.	TBD

Comment: Please note this Section is not in the COA Guidance. The following text are based on the similar wording provided in 6.1

This section describes the outputs of NEI 18-04 Section 4.4 [1] for NSRST SSCs. Details of the analyses and justifications for the development of design criteria should be in the design records and available for NRC audit. It includes design requirements derived from LBEs, and requirements derived from DID evaluations.

Note: NEI 18-04 Table 5-1 summarizes section 4.4 by discussing RFDC, which are for all SSCs (not just for SR-SSCs). The Section then lists the following for design criteria: "Selection of PB reliability, availability, and capability targets for safety-significant SSCs." It may be that for NSRST, the table above will list the design criteria as reliability criteria or other items listed in NEI Table 5-1 [1].

D.7.2 Special Treatment Requirements for NSRST SSCs

Special treatment refers to those requirements that provide increased assurance beyond normal industrial practices that SSCs perform their non-safety function. All NSRST SSCs (including SR and NSRST SSCs) include the following special treatments:

- Development of a Reliability Assurance Program
- Design requirements related to SSC capabilities to mitigate challenges from applicable LBEs
- Development of a Maintenance Program that assures targets for SSC availability and effectiveness of maintenance to meet SSC reliability targets

Additional special treatment requirements for NSRST SSCs are outlined in Table D-2.

Table D-2: Special Treatment Requirements for NSRST SSCs

SR SSC	Functional Description	NSRST Design Criteria	Technical Specifications	Seismic Design Basis	Seismic Qualification Testing	Protection Against Design Basis External Events	Equipment Qualification Testing	Materials Surveillance Testing	Pre-Service and In-Service Inspection	In-Service Monitoring
HRS	B24-1: Intermediate Heat Exchanger including tubing transfer heat from the primary coolant to the intermediate loop sodium following a reactor trip or transient.	✓					✓	✓		✓
HRS	B24-2: HRS passively removes heat from the intermediate loop to air following a reactor trip or transient.	✓					✓		✓	
Primary EM Pumps	B21-1: EM Pump Thermal Shutdown Device trips the primary EM pump when the primary coolant temperature exceeds the design temperature (TBD).	✓					✓		✓	

From the TICAP Guidance:

This section documents the special treatment requirements for NSRST SSCs.

NEI 18-04 adopted the definition of special treatment that is provided in Regulatory Guide 1.201 which was developed for implementing 10 CFR 50.69.

> *"…special treatment refers to those requirements that provide increased assurance beyond normal industrial practices that structures, systems, and components (SSCs) perform their design basis functions."* [1]

Anything that is done beyond procuring commercial grade equipment to provide increased assurance in the capability and reliability of the SSC falls into the category of special treatment. Section 6.1 identified NSR SSC design requirements associated with protecting SR-SSCs from design basis external hazards. Hence, if a NSR SSC identified in Section 6.1.3 is also an NSRST SSC, then all the design requirements provided in Section 6.1 are part of the NSRST's special treatment. This section identifies the additional special treatments that are applied to NSRST SSCs.

For the selected STs the license application should identify the treatments in the license application with details available for NRC audit in the license application.

The STs should summarized in tabular form simply by listing each NSRST SSC, providing a brief functional description and identifying which ST has been selected for each NSRST SSC.

NSRST SSC	Functional Description	NSRST SSC Special Treatments
NSRST SSC_1	Short SSC functional description for NSRST SSC_1	NSRST SSC_1 Special Treatment No. 1
		NSRST SSC_1 Special Treatment No. 2
		…
		NSRST SSC_1 Special Treatment No. n
Additional NSRST SSCs	…	…

D.7.3 System Descriptions for NSRST SSCs

This section provides a brief description of each SR SSC, including key details related to the RSFs and applicable codes and standards. Although this level of detail has not yet been completed for HRS as part of VTR, a preliminary assessment of applicable codes and standards is provided above. It is expected that the level of detail would be adjusted for a final content of application.

D.7.3.1 HRS

The HRS transfers reactor-generated heat from the PHTS directly to the atmosphere via the SAHXs. The HRS performs this function while providing an adequate flow rate for maintaining reactor temperature conditions within limits preventing damage to the reactor vessel, fuel, and reactor internals during normal power operation, during shutdown (decay heat removal), and under upset conditions, which includes functioning using off-site or on-site power supplies. In addition, this system will provide cooling under natural circulation without freezing.

The HRS consists of two secondary sodium loops that transfer thermal energy from the two IHXs of the PHTS to the ten SAHXs in which heat is rejected to the atmosphere heat sink. Each loop (Figure 7-1) incorporates two EM sodium pumps in a parallel flow configuration in the cold leg, surge tank with argon cover gas to accommodate thermal expansion of secondary sodium, instrumentation and controls (I&Cs), a secondary sodium purification system (SSPS), and a drain tank into which the secondary sodium can be drained, stored, and recharged back into the loop. Each secondary sodium loop is independent of the other and is connected to the tube side of one IHX and five SAHXs. The HRS provides heat transport from the PHTS to the atmosphere heat sink under all normal operating conditions. The HRS responds to the PCS to satisfy coolant temperature and flow requirements for stable reactor operating and test conditions.

In addition, the HRS is configured to provide a passive partial cooling capability through natural circulation if the EM sodium pumps and SAHX air blowers are not available. This would be the case for a normal reactor trip or if normal and standby AC power were not available, for example. The IHXs are located well below grade level while the SAHXs are located above grade level. Each secondary sodium loop out to the SAHXs for that loop provides a pathway for removal of decay heat that provides good control of secondary and primary temperatures. Heat rejection would occur under natural draught air flow conditions through SAHXs. Each SAHX module sodium inlet and outlet pipe can be isolated in the event of detection of a sodium leak inside of the SAHX.

The VTR SAHXs (Figure D-2) will be optimized for reduction of heat loss during standby operations, along with ensuring that factory fabrication minimizes on-site required labor, and with normal reliability, accessibility, maintainability, inspectability, and constructability requirements. Using the FFTF unit design as a conceptual baseline ensures that the design will work, but optimization is expected during the design process.

The SAHXs are physically located in the heat rejection facilities. The SAHXs are arranged in parallel modules with three parallel SAHXs in one module and two parallel SAHXs in the other module. The two modules are in series with the hot leg of their respective HRS piping loop that runs from the respective SAHX, through the intermediate sodium pumps, through the respective IHX, and back to the SAHXs. They transfer the heat load from the reactor to the atmosphere using sodium-to-air heat transfer components. Figure D-3 provides an elevation view of the HRS.

The HRS includes passive means of decay heat removal and passive containment features. The HRS is designed such that decay heat removal can be accomplished utilizing the normal heat removal train described above, or natural circulation providing the motive force for sodium flow. Using natural circulation flow, the HRS is designed with the capability to transfer at least 3.5% rated core thermal power per train from the PHTS to the atmosphere during shutdown and refueling modes. The system will be designed to prevent failure of its natural circulation heat removal function caused by sodium freezing.

Draft

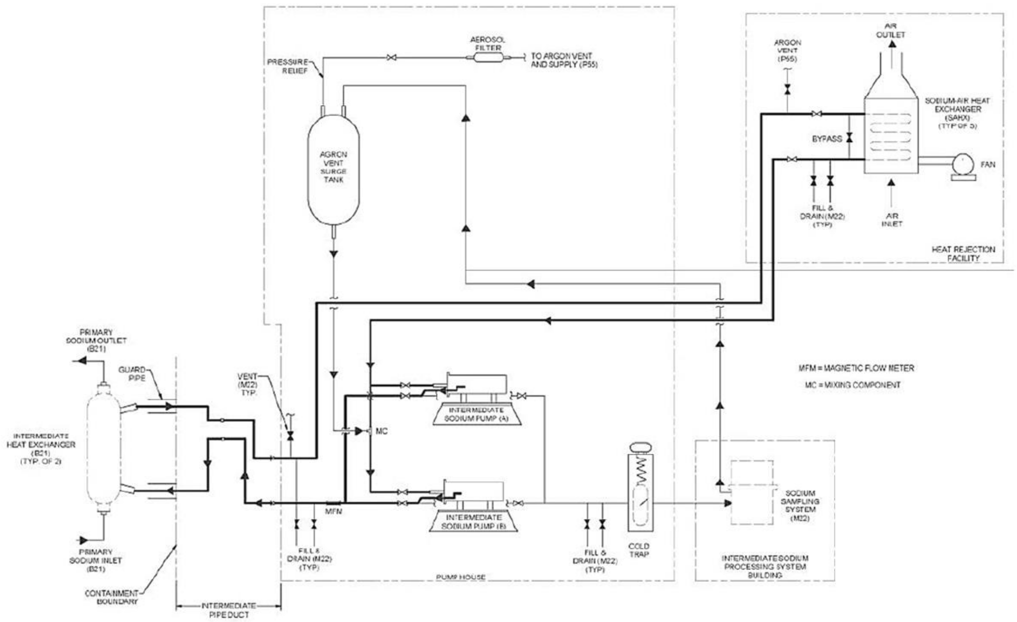

Figure 17. VTR HRS simplified flow diagram.

Figure D-1: VTR HRS Simplified Flow Diagram

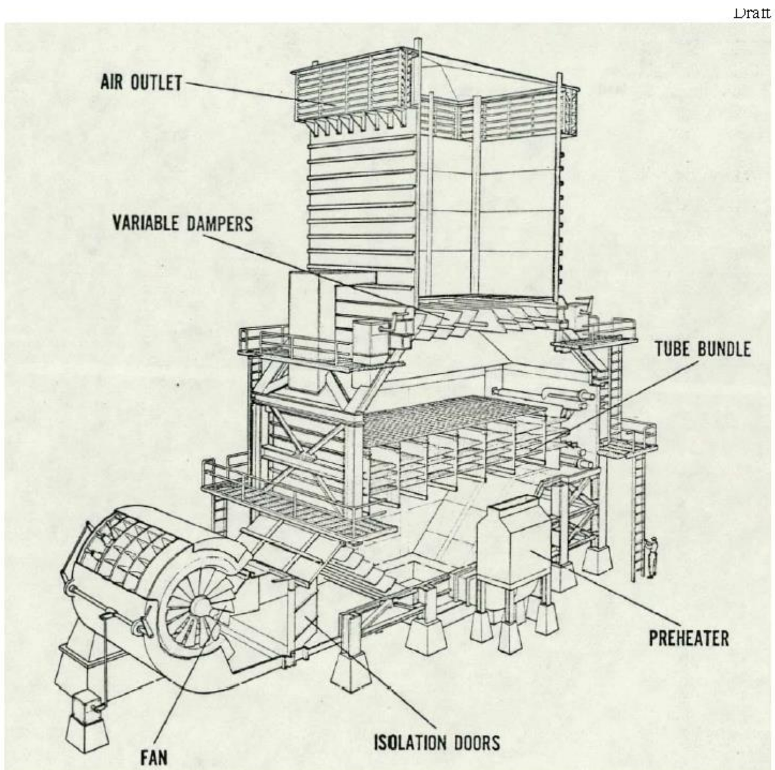

Figure 18. Illustration of FFTF 33 MWth air dump heat exchanger.

Figure D-2: Illustration of FFTF 33 MWth Air Dump Heat Exchanger

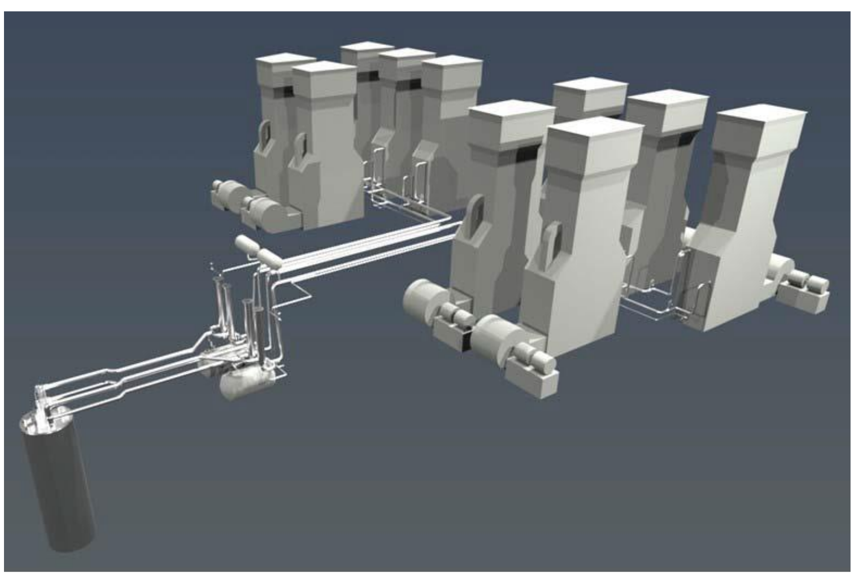

Figure D-3: Elevation View of HRS Components

From the TICAP Guidance:

This section provides system descriptions for NSRST SSCs. These descriptions include the specific design features for NSRST SSCs that are responsible for meeting their safety significant functions identified in the LBEs responsible for the classification as NSRST. This description should include features that demonstrate system capability and reliability for both prevention and mitigation of LBEs, as applicable. It is expected that these system descriptions are generally less detailed than those provided for SR-SSCs in Section 6.3.

7.3.1 Description for NSRST SSC 1

This description should include:

- Simplified schematic diagram
- Narrative design descriptions that address the design aspects relevant to the performance of the safety significant functions systems including:
    - the system purpose in the context of supporting the safety significant functions
    - significant functional performance-based characteristics in performing safety significant functions
    - system location
    - key design features relevant to performance of safety significant functions
    - seismic and industry (e.g. ASME, IEEE) code classifications and the design codes applicable to the NSRST SSC
    - description of system operation including a description of the performance modes of operation of the system relevant to the safety significant functions
    - identification of any operator actions needed to implement safety significant functions
    - controls and displays needed to support safety significant functions
    - logic circuits and interlocks needed to support safety significant functions
    - electric power, support systems, and interface requirements needed to support the safety significant functions
    - equipment to be qualified for harsh environments as needed to meet SR SSC special treatment requirements defined in Section 7.2

7.3.2, 7.3.3, et al.: Descriptions of the remainder of the NSRST SSCs are provided.

Comments:

- It is not clear we need all of the above bullets. Maybe want to check this to be “as applicable”. For example, in our HRS, we do not need electric power, cooling water, and support systems.

APPENDIX E Presentation During the Tabletop - VTR Design Description

Versatile Test Reactor (VTR) Design Overview for TICAP Tabletop

Jason Andrus
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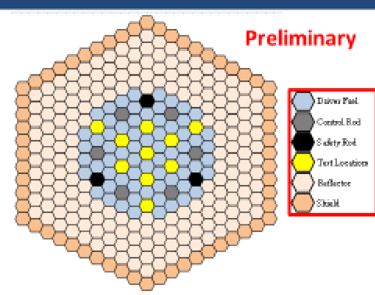
Idaho National Laboratory

3/04/2021

Note: All information regarding VTR technology selection and site location is **preliminary**. The decision for technology and site location is determined via DOE acquisition processes that have not yet been completed.

Status: Required Testing Mission

Parameter	Target
High neutron flux	≥ 4 x 10^{15} n/cm^2-s
High fluence	≥ 30 dpa/yr
High test volume in the core	≥ 7 L (multiple locations)
Representative testing height	0.6 ≤ L ≤ 1 m
Flexible test environment	Rabbit and loops (Na, Pb, LBE, He, Salt)
Advance instrumentation and sensors	In situ, real-time data
Experiment life cycle	Proximity to other infrastructure
Driver fuel life cycle management	Existing facilities as much as possible



ASSUMPTIONS – pending AoA and NEPA:

- Mature technology: sodium-cooled pool-type reactor
- Metallic alloy fuel (HALEU, LEU+Pu, DU-Pu)
- Novel testing capabilities
- Start date: 2026.

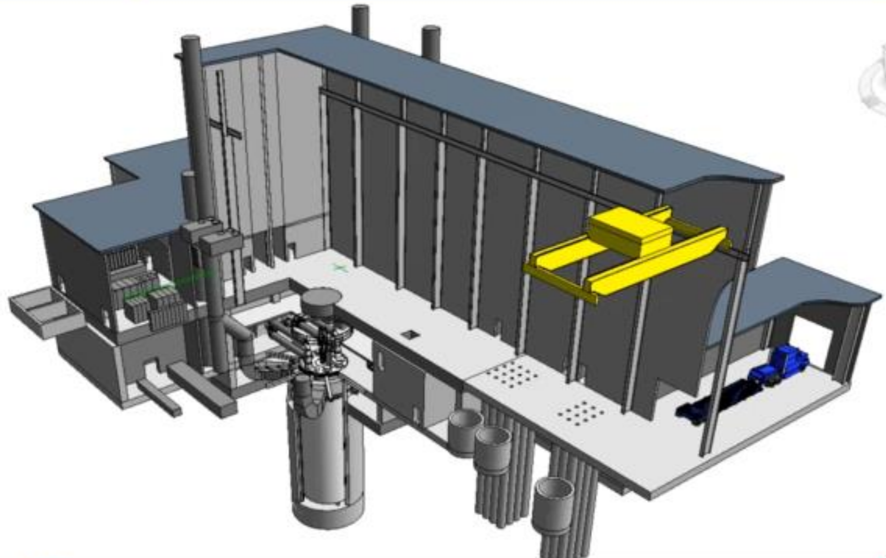
Preliminary

2

VTR General Arrangement

VTR General Arrangement

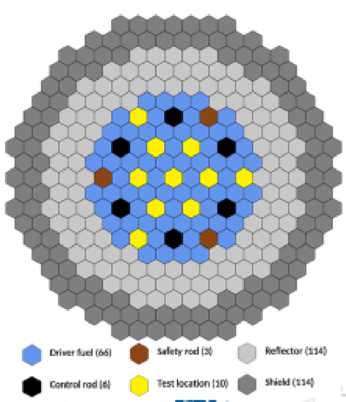
VTR General Arrangement

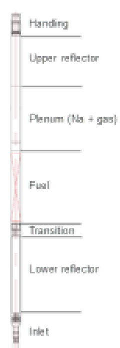


Preliminary

Current Reference VTR Core

- The most current VTR core design description is summarized in the Conceptual Design Report.
  - Driver fuel assembly contains 217 wire-wrapped fuel pins inside of a hexagonal flow duct. The reference fuel is U 20Pu-10Zr ternary metallic fuel.





Design characteristics

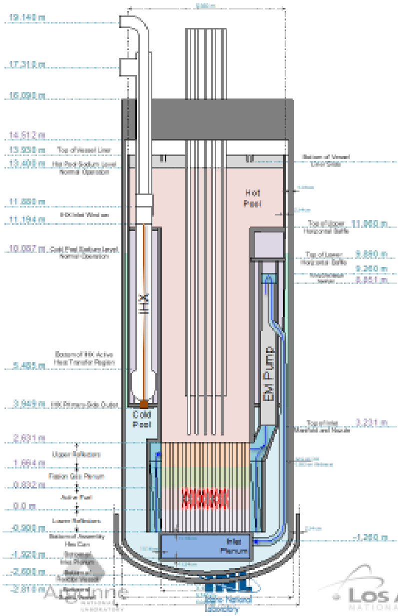
Parameter	Value
Assembly Pitch	12.0 cm
Fuel Height	80 cm
Plenum Height	80 cm
Inter-Assembly Gap	0.3 cm
Duct Thickness	0.3 cm
Duct Inside Flat-to-Flat	11.1 cm
Pins Per Assembly	217
Pin Diameter	0.625 cm
Cladding Thickness	0.05 cm
Fuel smeared Density	75%
Wire Wrap Diameter	0.1094 cm
Wire Wrap Axial Pitch	20.32 cm
Pitch-to-Diameter Ratio	1.183
Coolant Volume Fraction	35.50%
Fuel Volume Fraction	29.70%
Bond Volume Fraction	9.89%
Structure Volume Fraction	25.00%

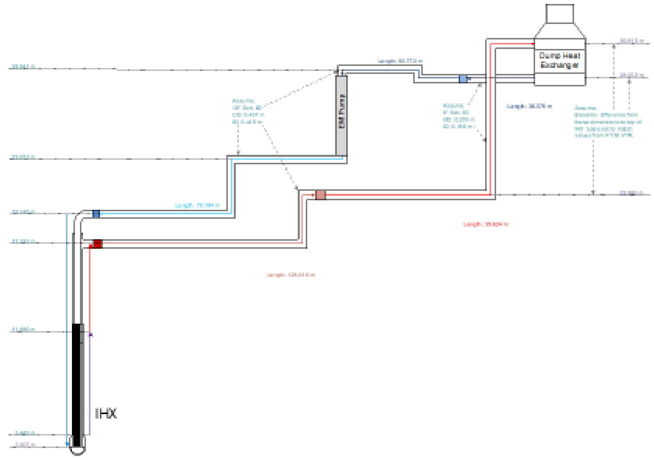
Performance characteristics

Parameter	Value
Power	300 MW_{th}
Fresh Fuel Height	80 cm
# Fuel Assemblies	66
Cycle Length	100 EFPD
# Batches	5
Plutonium wt%	19.4%
Test Peak Fast Flux	4.17×10^{15} n/cm^2-s
Absolute Peak Fast Flux	4.35×10^{15} n/cm^2-s
Max. Assembly Power	6.1 MW_{th}
Burnup Reactivity Swing	2124 pcm
Fuel Charge/Cycle	596.2 kg HM
Average Discharge Burnup	540.6 GWd/t

Preliminary

Reactor Vessel





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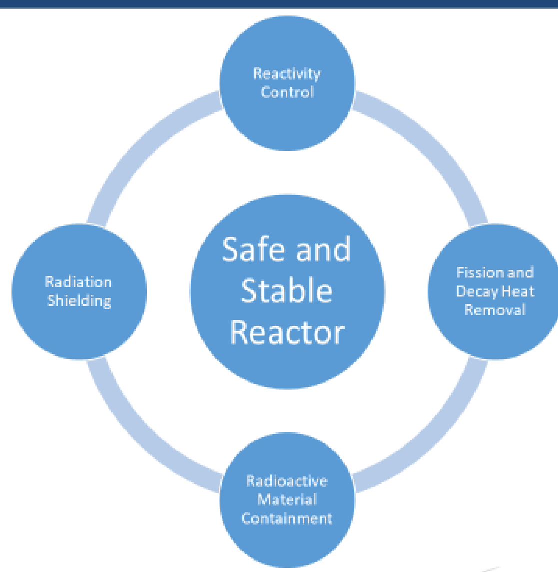
6

General Reactor Safety Functions

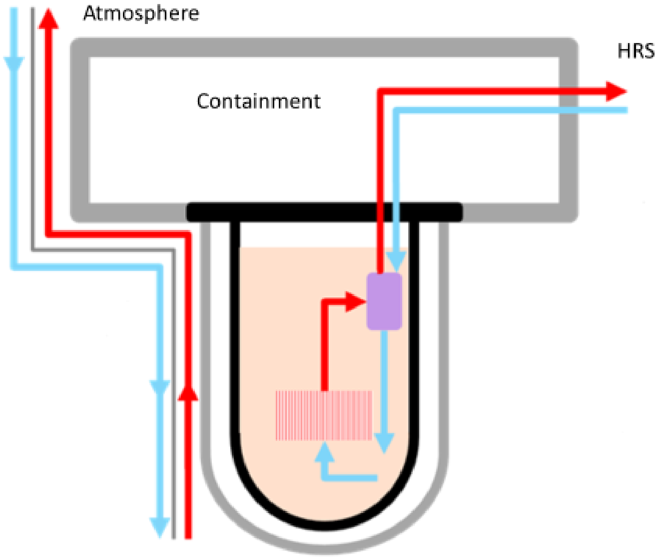


Preliminary

7

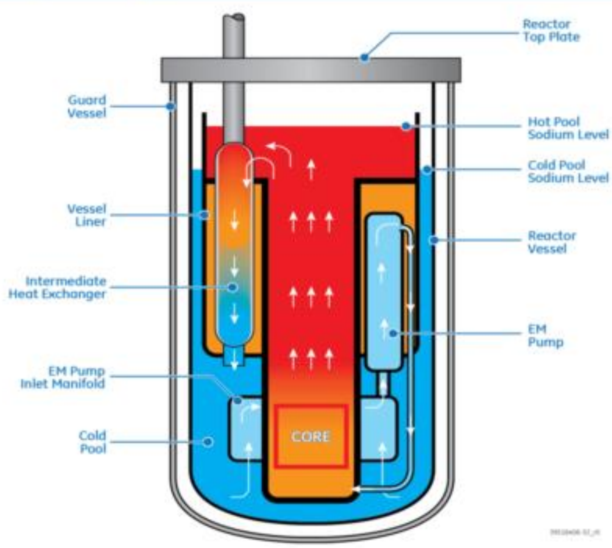
VTR Safety Functions

1. Reactivity controls: Control rods, inherent reactivity feedback (IRF), Safety shutdown rods.
2. Core flow: electromagnetic (EM) pumps, Coastdown machines
3. Primary sodium heat removal: Forced/passive HRS cooling, RVACS
4. Containment: Vessel head barrier, Head access area



8

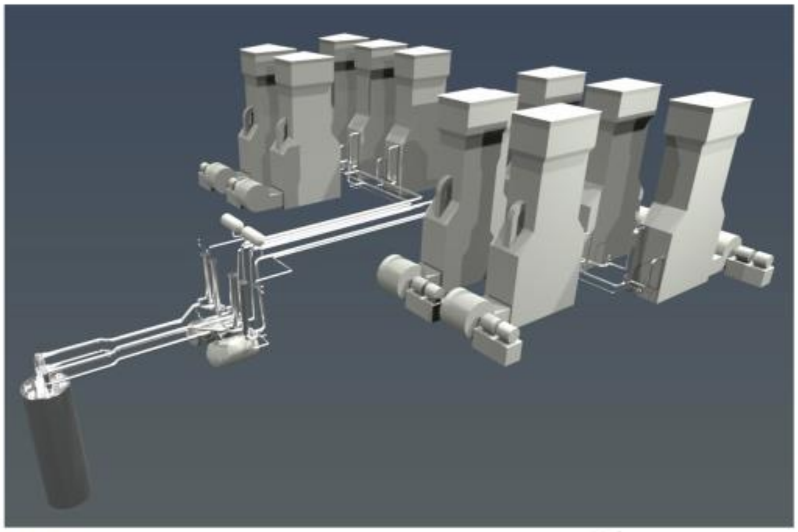
Primary Heat Transport System



Preliminary

9

VTR Heat Removal

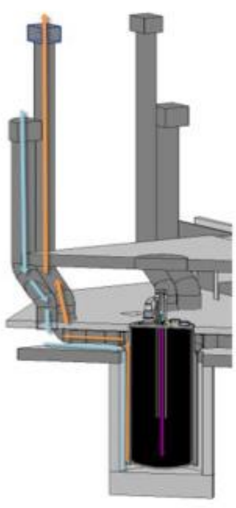


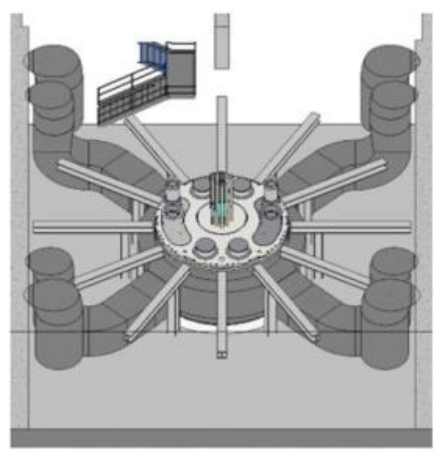
Preliminary

10

Reactor Vessel Auxiliary Cooling System (RVACS)

- Passive natural circulation air cooling system for the reactor vessel.
- Normal operations ~0.7 megawatt thermal (MWth) heat transfer
- Accident conditions ~2.8 MWth heat transfer





Preliminary

11

Reactor Vessel Auxiliary Cooling System (RVACS)

- Passive natural circulation air cooling system for the reactor vessel.
- Normal operations ~0.7 megawatt thermal (MWth) heat transfer
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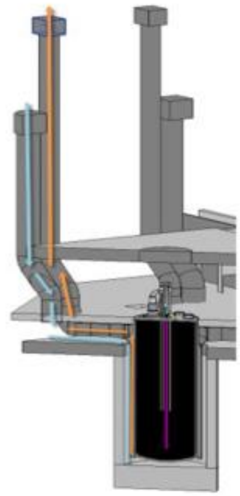
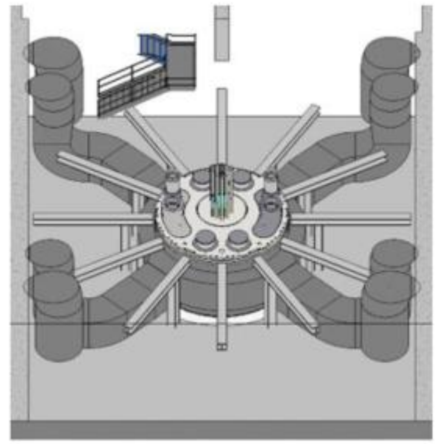




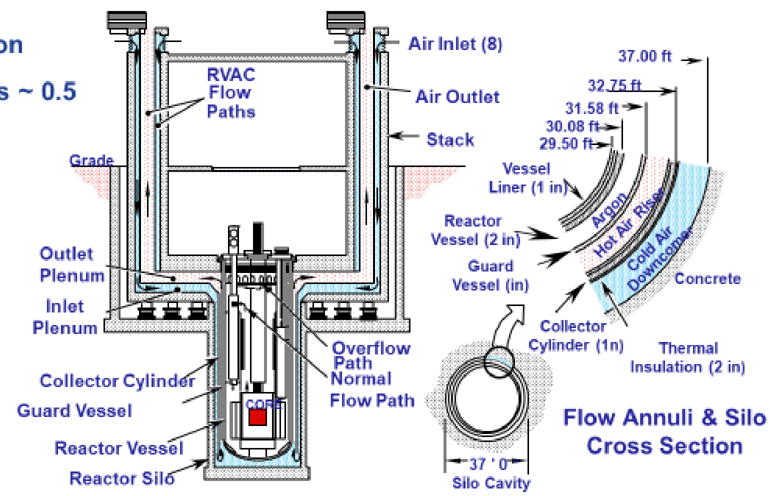
Preliminary

11

PRISM: Reactor Vessel Cooling System

Always on

Removes ~ 0.5 MWt



Slide Courtesy of GE-Hitachi