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

Westinghouse eVinci™ Micro-Reactor
Tabletop Exercise Report

Battelle Energy Alliance, LLC (BEA)
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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 Department of Energy (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." 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. This report describes the tabletop exercise conducted with Westinghouse Electric Company to explore the application of the draft TICAP guidance to the safety case for the eVinci™ micro-reactor design. A set of risk-informed, performance-based (RIPB) Principal Design Criteria (PDC) were developed, and feedback from the development of this content informed revisions to the TICAP guidance. In addition to the derivation of the RIPB PDC, this report provides additional context about the eVinci micro-reactor design and safety case and documents the major lessons learned about the TICAP guidance during the eVinci micro-reactor tabletop exercise.

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List of Abbreviations

ANS	American Nuclear Society
AOO	Anticipated Operational Occurrence
ARDC	Advanced Reactor Design Criteria
ASME	American Society of Mechanical Engineers
BDBE	Beyond Design Basis Event
CCS	Canister Containment Subsystem
CDC	Complementary Design Criteria
CDS	Control Drum System
DBE	Design Basis Event
DID	defense-in-depth
DOE	Department of Energy
F-C	Frequency-Consequence
FSF	Fundamental Safety Function
GDC	General Design Criteria
IAEA	International Atomic Energy Agency
IE	Initiating Event
LBE	Licensing Basis Event
LMP	Licensing Modernization Project
LWR	light water reactor
NEI	Nuclear Energy Institute
non-LWR	non-light water reactor
NRC	Nuclear Regulatory Commission
NSRST	Non-Safety-Related with Special Treatment
PCS	Power Conversion Subsystem
PDC	Principal Design Criteria
PRA	Probabilistic Risk Assessment
PSF	PRA Safety Function
RFDC	Required Functional Design Criteria
RG	Regulatory Guide
RIPB	risk-informed and performance-based
RSF	Required Safety Function
SAR	Safety Analysis Report
SRS	Shutdown Rod System
SSCs	Structures, Systems, and Components
TICAP	Technology Inclusive Content of Application Project
TRISO	Tri-structural isotropic

1.0 INTRODUCTION AND BACKGROUND

1.1 TICAP Description

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 Department of Energy (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[2] will help ensure completeness of information submitted to 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 is 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 NRC's current regulatory framework. The initiative recognizes that significant levels of industry input and advocacy are needed in collaboration with 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 Licensing Modernization Project (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 Structures, Systems, and Components (SSCs) and associated risk-informed special treatments; and determination of defense-in-depth (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 provides a list of the products with the subject of this report highlighted. Each of these products is described below.

Figure 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 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 (including this document)—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 prospective site applicants) in order to obtain the maximum independent insights on the proposed processes.*
- 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.

Each TICAP tabletop exercise explored the application of a unique subset of the draft TICAP guidance to a different non-LWR design. The tabletop exercises resulted in four separate tabletop reports that document example SAR content developed using the draft TICAP guidance, additional context about the specific design and safety case necessary to understand the example SAR content, and the major lessons learned for a given exercise.

This report presents the design and safety case details, example SAR content, and lessons learned for the tabletop exercise conducted on the eVinci design in coordination with Westinghouse. The eVinci micro-reactor tabletop exercise explored the development of Principal Design Criteria (PDC) using the draft TICAP guidance.

1.3 Linkage to LMP and TICAP Efforts

NEI 18-04, which documents the LMP process, was used as the basis for developing the Required Safety Functions (RSFs) for the eVinci micro-reactor through the use of the eVinci micro-reactor Probabilistic Risk Assessment (PRA). This guidance was supplemented by the TICAP guidance document, specifically for information related to how the RSFs translate to Required Functional Design Criteria (RFDC)/PDC, and how PDC developed through the Regulatory Guide (RG) 1.232 process (but not through LMP) will be categorized or treated in the SAR (e.g., Non-Safety-Related with Special Treatment [NSRST]).

Additionally, a tabletop exercise was previously conducted for the eVinci micro-reactor to demonstrate the use of the LMP guidance.[3] The eVinci micro-reactor PRA has matured and developed since that time. This report used an updated eVinci micro-reactor PRA as the input for LMP/TICAP, and as such, does not build upon the previous eVinci micro-reactor LMP report (or use it as the starting point for this tabletop exercise).

1.4 eVinci Micro-Reactor Tabletop Exercise Scope, Objectives, and Deliverables

Within the broader TICAP effort, the tabletop exercises had the following high-level objectives:

1. Technically improve the TICAP guidance by obtaining input from advanced reactor developers
2. Maximize the usefulness of the guidance by providing examples for future users
3. Improve the endorsability of the Guidance Document for NRC endorsement

The major objective of the eVinci micro-reactor tabletop exercise was to derive a set of PDC using the RIPB approach outlined in NEI 18-04 and compare this set to the PDC developed using the Advanced Reactor Design Criteria (ARDC) in RG 1.232.[4] This comparison will provide insight regarding how developers and NRC might expect a reactor-specific set of RIPB PDC to differ from the more prescriptive ARDC-derived PDC.

1.5 Report Organization

This report is organized into the following chapters:

- Chapter 1 includes background information on the overall TICAP project and high-level objectives of the eVinci micro-reactor TICAP tabletop exercise.

- Chapter 2 provides background information on the eVinci micro-reactor, including the current status of the design, safety case, and assumptions made to perform the eVinci micro-reactor TICAP tabletop exercise.
- Chapter 3 describes the derivation of the eVinci micro-reactor PDC, both through the RG 1.232 process and using the LMP/TICAP approach. This section also includes a comparison of the PDC derived using each methodology and how the PDC derived using RG 1.232 that no longer appear may be categorized using LMP/TICAP.
- Chapter 4 provides Westinghouse's observations and feedback from using NEI 18-04 and the TICAP guidance to derive eVinci micro-reactor PDC and prepare for the TICAP tabletop exercise.
- Chapter 5 lists references used in the report.

Note that in some instances, the TICAP team has provided additional commentary to clarify aspects of the tabletop exercise, especially in areas where the TICAP guidance developed downstream of the eVinci micro-reactor tabletop exercise. This commentary is provided as footnotes and are indicated by italics.

2.0 DEMONSTRATION OVERVIEW

2.1 Summary of Demonstration Activities

Development of PDC and preparation for the NRC TICAP tabletop exercise began in January 2021. Collaboration through weekly meetings between Westinghouse and Southern Company, as well as work internal to Westinghouse, resulted in the creation of information which was presented at the TICAP tabletop meeting on March 24, 2021. The discussions during the TICAP tabletop meeting focused on the following topics:

1. High-level summary of the eVinci micro-reactor design
2. Use of NEI 18-04 LMP guidance to develop PDC for the eVinci micro-reactor design
3. Comparison of the PDC developed using RG 1.232 and the newly developed PDC using NEI 18-04 and how other design criteria that may no longer be considered PDC could be incorporated into the SAR

2.2 eVinci Micro-Reactor Design Overview

The eVinci micro-reactor, shown in Figure 2, is a high-temperature heat pipe reactor. The core is comprised of a graphite core block with fuel and heat pipe channels. Tri-structural isotropic (TRISO) fuel powers the reactor. The outer layers of the TRISO fuel provide most of the fission product retention capability. A Canister Containment Subsystem (CCS), which encases the entire core, provides supplemental protection against radiological release. Additional structures inside and outside the CCS provide further retention.

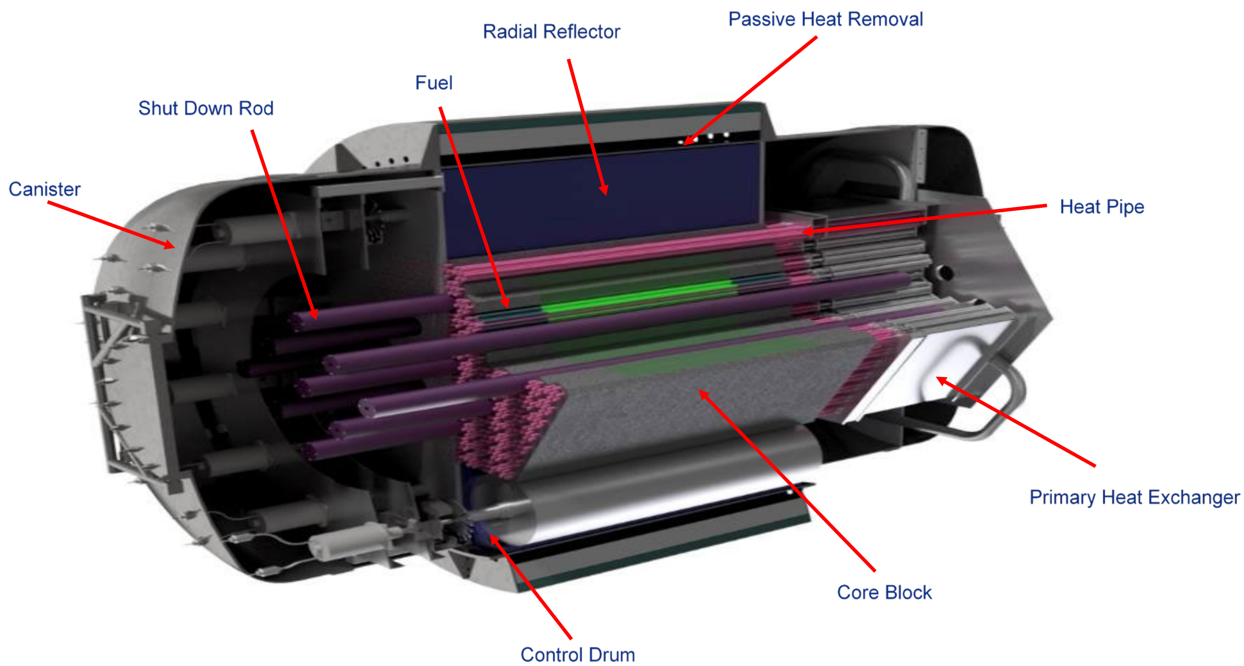

Figure 2. eVinci Micro-Reactor Cutaway View

There are no moving or mechanical parts in the nuclear systems, except for reactivity control drums, which surround the core block. The control drums, which are the primary component of the Control Drum System (CDS), provide reactivity control during all normal operational transients and allow absorber material to passively turn inward toward the core if power is lost, as well as on-demand. A radial neutron reflector surrounds the core block and reactivity control drums.

Unlike traditional sodium-cooled reactor designs, in which large volumes of sodium are pumped around the core, the eVinci micro-reactor requires very small amounts of sodium to serve as the coolant, almost all of which is entrained in the wicks of the heat pipes. There are no mechanical pumps, valves, or large diameter primary loop piping. Rather, heat is transferred via conduction and radiative heat transfer through the core block to the heat pipes. Each heat pipe contains a small amount of sodium liquid as the working fluid to move heat from the core to a heat exchanger and is fully encapsulated in a sealed channel. The heat exchanger is in communication with a secondary side Power Conversion Subsystem (PCS), which includes equipment necessary to convert the heat into electricity for transmission.

In the unlikely event that an emergency shutdown is necessary, multiple means to do so are included in the design. The reactivity control drums have the capability to passively shut down the reactor on loss of power. A passively actuated Shutdown Rod System (SRS) provides alternate means of shutdown. Heat removal during an event is accomplished in the same manner as at-power heat removal when the PCS is available. Heat can also be removed from the CCS via buoyancy-driven air, which is channeled from the outside environment. The components of the Passive Heat Removal System are sized such that it is capable of removing heat at a rate greater than that generated by the core shortly after reactor shutdown.

It should be noted that the design utilized in the TICAP tabletop demonstration described herein reflects a point in the design development of the product. The design will evolve as a result of continued design, analysis, and testing. Downstream implications on the TICAP-related activities will be incorporated and packaged as necessary to support regulatory approvals; however, this TICAP tabletop exercise report will not be updated for these design evolutions.

2.3 Prerequisites and Inputs for the Tabletop Exercise

An updated version of the eVinci Micro-Reactor PRA was used as input to the NEI 18-04 guidance methodology to develop PDC relative to that which Westinghouse previously provided a tabletop exercise and report on the LMP process. As such, the information provided in this report is new and different from the previous report. While going through the process, additional analysis needs and areas for further consideration have been identified. Specifically, more work needs to be done to address inherent and intrinsic features of the design and functions, as well as SSCs that are candidates for special treatment. Therefore, this document may not include an exhaustive list of all PDC for the eVinci micro-reactor design, but rather, those that can be developed directly from the utilized PRA model.

Considering the above, the following assumptions have been made either in the utilized PRA or in the use of the PRA to develop PDC:

- LBEs identified include internal events only, i.e., external hazards are not currently considered.
- The utilized PRA is only focused on the operation phase. Other phases of the plant lifecycle (such as transportation) will be considered in future work.
- The utilized PRA does not explicitly model the failure of TRISO fuel beyond manufacturing failures. The position taken is that the TRISO fuel will be a safety-related SSC and will have the required quality standards applied to ensure reliability of the fuel as documented in the TRISO topical report.[5] Because of this, it was not necessary to perform cases that included complete failure of the TRISO fuel (and if this was considered, the frequency of such an event occurring would cause the case to fall well below the Frequency-Consequence [F-C] Targets considered as part of NEI 18-04).
- The utilized PRA reflects the release of radionuclides directly from the fuel only. Additional sources of radionuclides will be included in the final version of the PRA.
- Only a limited number of technical elements in the PRA standard[6] have been exercised in the utilized PRA.
- The PRA represents a single module/reactor.
- The base dose calculations consider an exceedingly small site boundary (<1 m).
- Parametric uncertainties are not considered in the PRA used for the tabletop exercise. Such uncertainties will be captured at the appropriate time in the product development cycle.

3.0 EXPLORATION OF EVINCI PRINCIPAL DESIGN CRITERIA

3.1 Background

The FSFs are technology independent, i.e., the same for all reactor designs.[1]

- Control heat generation
- Control heat removal
- Retain radionuclides

These are used as the base reactor safety functions, before the work to develop RSFs, which are technology specific, is done. The process of developing RSFs and then PDC based on the RSFs is documented in Section 3.3.

3.2 Developing PDC Using an RIPB Approach

The following tasks described in this section come directly from Section 3.2.2 of NEI 18-04 and describe the process used in the guidance to develop RSFs. From there, the RSFs were used to develop PDC consistent with the approach for identifying PDC outlined in the draft TICAP guidance.

3.2.1 Task 1: Propose Initial List of LBEs

During design development, it is necessary to select an initial set of LBEs, which may not be complete but are necessary to develop the basic elements of the safety design. Each initial LBE is defined by an Initiating Event (IE) plus the mitigation systems involved in responding to the IE. Through the NEI 18-04 process, the LBEs are used as the basis to determine which safety functions/SSCs are risk-significant and/or safety-related. The initial identification of LBEs for the eVinci reactor followed two parallel paths:

- A systematic review of available literature associated with initiating events was conducted.
- A structured and multi-disciplinary failure mode and effects analysis was performed on the eVinci design.

Following the completion of these activities, the two lists of potential events were combined. The initiators were then grouped into event categories based on similar expected plant responses. Based on the remaining three initiating events and possible mitigation systems, 36 initial LBEs were identified. The following mitigative functions were considered in defining the initial LBEs:

- Reactor Shutdown (success/failure)
- Passive Heat Removal (success/failure)
- Canister Integrity (nominal leakage/excessive leakage/failure)

3.2.2 Task 2: Design Development and Analysis

This task is outside of the scope of the tabletop exercise.

3.2.3 Task 3: PRA Development/Update

The utilized PRA was built following the high-level structure of the American Nuclear Society (ANS)/American Society of Mechanical Engineers (ASME) PRA standard for non-LWRs.[6] The 36 initial LBEs developed in Task 1 were run through the PRA. As described above, these initial LBEs are defined in terms of successes and failures of SSCs that perform safety functions. These safety functions are the PRA Safety Functions (PSFs) for the eVinci micro-reactor design:

- Control heat generation
- Control heat removal
- Retain radionuclides

Note that by direct comparison, the eVinci PSFs are the same as the FSFs.[A]

3.2.4 Task 4: Identify/Revise List of Anticipated Operational Occurrences, Design Basis Events, and Beyond Design Basis Events

Figure 3 documents the results from the PRA and radiological consequences analysis as compared to the F-C Targets.

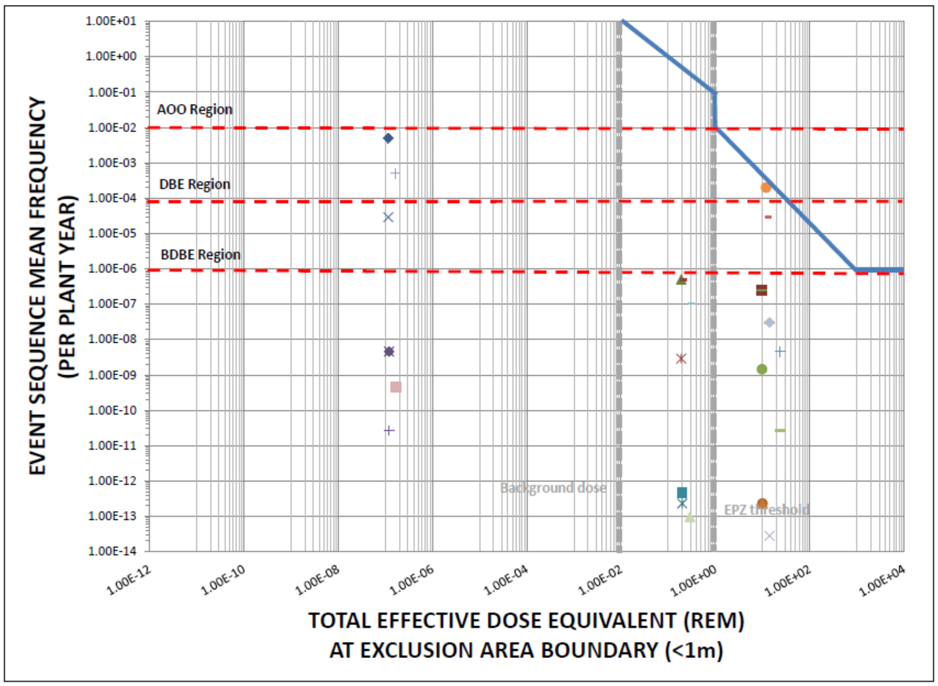

Figure 3. eVinci Micro-Reactor Results vs. F-C Target

[A] *Note from TICAP Team: Although there are considerable similarities between the FSFs and the PSFs identified by the Westinghouse team as part of this tabletop exercise, it is the opinion of the TICAP team that there are important differences such that the eVinci Micro-Reactor PSFs would not be identical to the FSFs. Notably, the PSFs modeled in the eVinci Micro-Reactor PRA reflect design-specific considerations that are not included in the FSFs, such as success criteria dependent upon eVinci Micro-Reactor design details. The safety functions identified during Task 1 (listed in Section 3.2.1) include these considerations; as such, these functions more closely align with the TICAP team's expectations for PSFs.*

Figure 4 further refines the results in Figure 3, highlighting only those sequences that fall into the frequencies associated with Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs), and Beyond Design Basis Events (BDBEs) per NEI 18-04.

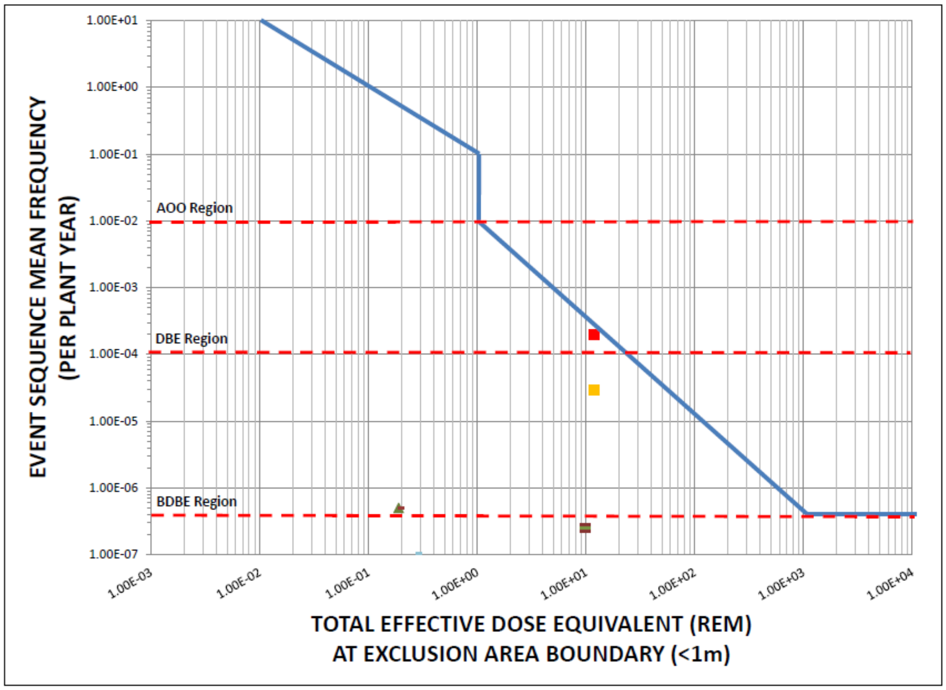

Figure 4. eVinci Micro-Reactor Results vs. F-C Target (NEI 18-04 Boundaries)

Note that the base dose calculations consider an exceedingly small site boundary (<1 m) with a corresponding conservatively large atmospheric dispersion factor.

Based on Figure 4, the following six LBEs were identified:

- DBE—Red square: CDS successful in shutting down reactor
- BDBE—Yellow square: CDS fails, SRS successful in shutting down reactor
- BDBE—Brown square: IE 1, successful heat removal, CCS failed
- BDBE—Gray dash: IE 2, successful heat removal, CCS failed
- BDBE—Green triangle: IE 1, successful heat removal, CCS leakage
- BDBE—Brown dash: IE 2, successful heat removal, CCS leakage

3.2.5 Task 5a: Identify Required Safety Functions

RSFs are those functions necessary and sufficient to meet the F-C Target for all DBEs and high-consequence BDBEs. High-consequence BDBEs are defined as those BDBEs with consequences that exceed the F-C Target. Figure 5 documents the portions of the F-C Target figure where RSFs are needed (see the yellow highlighted regions). Note that although not required per NEI 18-04, Westinghouse has decided to shade the AOO region to the left of the F-C curve (see the orange highlighted region). There are no sequences that fall into this region in the utilized PRA. However, if a sequence were to end up in this region in the final PRA, Westinghouse would also consider using this sequence to define RSFs.

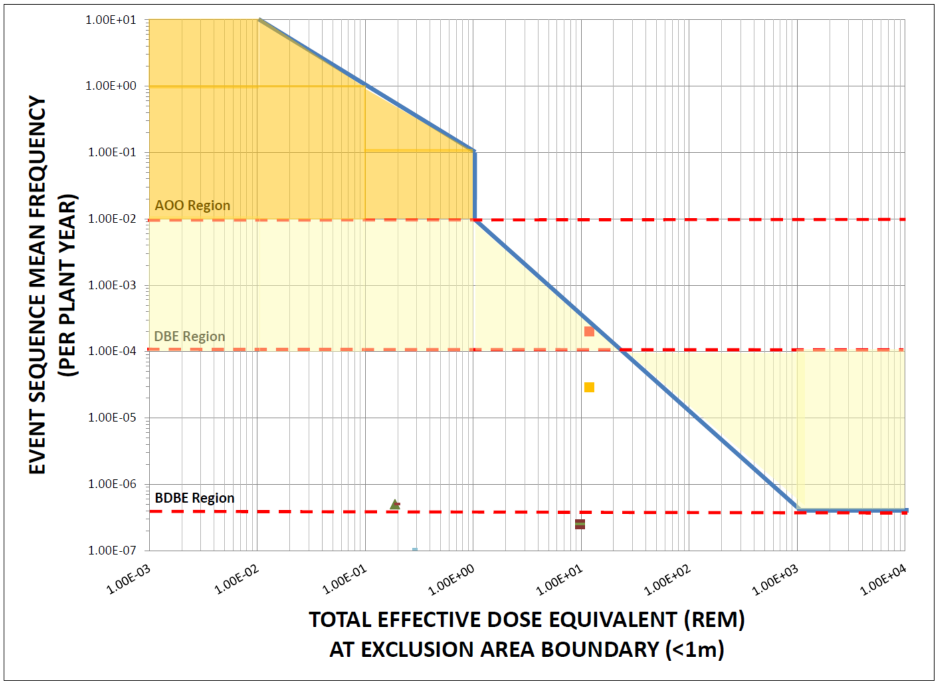

Figure 5. Regions to Consider for RSFs

Based on Figure 5, RSFs are only needed for the LBE indicated by the red square (CDS successful in shutting down reactor). One RSF has been identified for this LBE—reactivity control/shutdown reactor.

Note that the utilized PRA does not propagate random uncertainties, as the model/epistemic uncertainties associated with the early design stage are currently dominating. With this perspective, all the assumptions made during the development of the PRA have been reviewed for their potential uncertainty impact, and then appropriate sensitivities have been developed to capture the uncertainty. Each LBE can therefore be represented by multiple points in the F-C diagram which capture the associated uncertainties.

Parametric uncertainties are not considered in the utilized PRA. Multiple sensitivities tracking design alternatives and variations in data are presented in the PRA that provide an uncertainty span to each dose case.

Due to the uncertainty discussed above, applying uncertainty bands at this stage would not provide any meaningful results. This will be done in future iterations when the design input is more final.

Note that both NEI 18-04 and the TICAP guidance instruct that the RSFs should support the FSFs. Therefore, Westinghouse has also included decay heat removal and containment of radioactive material as RSFs.[B]

Due to the simplistic design of the eVinci micro-reactor plant, the RSFs are the same as the PSFs, which are the same as the FSFs.[C]

3.2.6 Development of RFDC/PDC

The draft TICAP guidance defines the PDC as the RFDC. The RFDC/PDC are derived from the RSFs as described in NEI 18-04. Based on the previously defined RSFs (including the FSFs), the following are determined to be PDC for eVinci:

- Reactivity control/shutdown reactor
    - Reactivity control system (Based on ARDC Appendix C, Criterion 26)

      A reactivity control system shall provide: (1) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the specified acceptable system radionuclide release design limits and the reactor system design limits are not exceeded and safe shutdown is achieved and maintained during normal operation, including anticipated operational occurrences. (2) A means of inserting negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the capability to cool the core is maintained and a means of shutting down the reactor and maintaining, at a minimum, a safe shutdown condition following a postulated accident. (3) A means for holding the reactor shutdown under conditions which allow for interventions such as fuel loading, inspection and repair shall be provided.

- Decay heat removal
    - Passive residual heat removal (Based on ARDC Appendix C, Criterion 34)

      A passive system to remove residual heat shall be provided. For normal operations and anticipated operational occurrences, the system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core to an ultimate heat sink at a rate such that specified acceptable system radionuclide release design limits are not exceeded. During postulated accidents, the system safety function shall provide effective cooling.

- Containment of radioactive material

B *Note from TICAP Team: The guidance in Section 3.3.4 of NEI 18-04 states that RSFs are defined starting with the FSFs, but it continues on to state that the FSFs "are refined as necessary into reactor technology-specific safety functions that reflect the reactor concept and unique characteristics of the reactors." As such, it is not necessary for each FSF to have a corresponding RSF (provided that the design-specific analyses confirm that the performance objectives of the FSFs can be met with the set of design-specific RSFs). Based on the eVinci Micro-Reactor analyses discussed in this tabletop exercise, it is not necessary for either decay heat removal or containment of radioactive material to be identified as an RSF.*

C *Note from TICAP Team: As discussed in Footnotes A and B, from the perspective of the TICAP team, the FSFs, the design-specific PSFs, and the RSFs for the eVinci Micro-Reactor would each be comprised of a unique set of functions (even if some of the functions are similar and/or related) based upon the analyses discussed in this tabletop exercise.*

- Functional containment design (Based on ARDC Appendix C, Criterion 16)

  A reactor functional containment shall be provided to control the release of radioactivity to the environment and to ensure that the functional containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

Beyond the RSFs determined through the NEI 18-04 process using the PRA, there may be additional design features that require some type of safety-related classification/special treatment as they are inherently assumed to be needed. A review of the special treatment items will occur later, and the classification will be addressed at a later time. Inherent/intrinsic features may lead to the creation of additional PDC.

3.3 Developing PDC using Advanced Reactor Design Criteria Regulatory Guidance

Westinghouse previously defined PDC for the eVinci micro-reactor using RG 1.232. Based on that guidance, a number of PDC were developed and are listed in this section. For simplicity in this report, only the titles of the PDC are included in the list. Each title is associated with one of the General Design Criteria (GDC) or ARDC (see criterion number in parentheses). In some instances, the PDC matches the GDC/ARDC text directly, and in others, the GDC/ARDC were used as a basis, but the PDC was revised to be applicable for the eVinci micro-reactor design specifically. The process of developing PDC using the RIPB LMP/TICAP approach is documented in Section 3.2. Those criteria that were derived using both the RG 1.232 and the NEI 18-04 processes are listed first.

As an academic exercise, the PDC developed based on RG 1.232 were surveyed to better understand the differences between PDC from RG 1.232 and a set of reactor-specific RIPB PDC. The PDC developed using RG 1.232 were binned into several categories, each of which describing how the requirements would be considered as part of the LMP/TICAP methodology in the case that the RIPB approach did not identify the requirement as an RFDC/PDC. The list below illustrates that although the TICAP approach to identifying PDC may not characterize a number of the requirements contained within the ARDC as RFDC/PDC, these requirements (or similar, risk-informed requirements) would be discussed in the SAR as other topics, such as Special Treatments.

It is important to note that this academic exercise represents a snapshot in time when the eVinci micro-reactor design and safety case information was at a relatively early stage of development, as was the draft TICAP guidance, such that the list below represents some of the earliest thinking on non-LWR PDC within the LMP/TICAP methodology. A significant number of interactions with the regulator on this topic will occur as part of the TICAP effort and eVinci micro-reactor regulatory engagement. In some instances, assumptions had to be made such that the list below does not necessarily reflect actual Westinghouse design, safety, and/or licensing decisions. Finally, this activity was only performed as part of the tabletop exercise to develop insights and would not be conducted by a designer developing a SAR using the TICAP guidance.

PDC derived via both RG 1.232 and LMP/TICAP processes

- Functional containment design (ARDC[D] Appendix C, Criterion 16)
- Reactivity control systems (ARDC Appendix C, Criterion 26)
- Passive residual heat removal (ARDC Appendix C, Criterion 34)

PDC derived via RG 1.232 that could be considered as Special Treatments Implemented via Plant Programs via TICAP

- Quality standards and records (GDC[E] 1; ARDC Appendix A, Criterion 1)
- Fire protection (ARDC Appendix A, Criterion 3)
- Environmental and dynamic effects design bases (ARDC Appendix A, Criterion 4)
- Protection system reliability and testability (GDC 21; ARDC Appendix A, Criterion 21)
- Inspection of passive residual heat removal system (ARDC Appendix C, Criterion 36)
- Testing of passive residual heat removal system (ARDC Appendix C, Criterion 37)
- Monitoring fuel and waste storage (ARDC Appendix A, Criterion 63)
- Monitoring radioactivity releases (ARDC Appendix A, Criterion 64)

PDC derived via RG 1.232 that could be considered with Special Treatment Implementation via an element that is not a Plant Program via TICAP

None have been identified in this category at this time for the eVinci micro-reactor.

PDC derived via RG 1.232 that could be defined as Safety-Related Design Criteria via TICAP

- Design bases for protection against natural phenomena (GDC 2; ARDC Appendix A, Criterion 2)
- Reactor design (ARDC Appendix C, Criterion 10)
- Reactor inherent protection (ARDC Appendix A, Criterion 11)
- Suppression of reactor power oscillations (ARDC Appendix A and C, Criterion 12)
- Instrumentation and control (ARDC Appendix A and C, Criterion 13)
- Protection system functions (ARDC Appendix C, Criterion 20)
- Protection system failure modes (ARDC Appendix B, Criterion 23)
- Protection system requirements for reactivity control malfunctions (ARDC Appendix C, Criterion 25)
- Reactivity limits (ARDC Appendix A, Criterion 28)
- Protection against anticipated operational occurrences (GDC 29; ARDC Appendix A, Criterion 29)
- Fuel storage and handling and radioactivity control (ARDC Appendix A, Criterion 61)
- Prevention of criticality in fuel storage and handling (ARDC Appendix A, Criterion 62)
- Sodium/water reaction prevention/mitigation (ARDC Appendix B, Criterion 74)

D The ARDC can be found in RG 1.232.

E The GDC can be found in 10 CFR 50, Appendix A.

- Sodium/helium system interfaces (ARDC Appendix B, Criterion 74)

PDC derived via RG 1.232 that could be considered design criteria that will need to be resolved with the evolution of the eVinci micro-reactor PRA model via TICAP

- Sodium leakage detection and reaction prevention and mitigation (ARDC Appendix B, Criterion 71; ARDC Appendix B, Criterion 73)
- Transportation (New requirement to address considerations associated with a mobile reactor)

PDC derived via RG 1.232 for which the categorization and treatment via TICAP is not readily apparent

- Sharing of structures, systems, and components (GDC 5; ARDC Appendix A, Criterion 5)
- Local control (ARDC Appendix A, Criterion 19)
- Protection system independence (GDC 22; ARDC Appendix A, Criterion 22)
- Separation of protection and control systems (GDC 24; ARDC Appendix A, Criterion 24)

4.0 OBSERVATIONS AND CONCLUSIONS

4.1 Observations and Lessons Learned

Throughout the process of using the NEI 18-04 and TICAP guidance documents to develop PDC, Westinghouse had the following observations to share with the TICAP team. These observations identify areas of confusion or concern, suggestions for improvement in the process, as well as places where Westinghouse chose to depart from the draft TICAP guidance.

- Through the process, there are many types of "safety functions" (i.e., FSFs, PSFs, and RSFs) and "design criteria" (i.e., RFDC, PDC, Complementary Design Criteria [CDC], and Safety Related Design Criteria) defined. Having so many definitions could be confusing and cumbersome. Especially for the eVinci micro-reactor, which has a simple design, many of these items ended up being similar, particularly at this early stage of design. For example, using the eVinci PRA, the FSFs, PSFs, and RSFs were the same.[F] Consider whether the terminology/number of different terms can be simplified or reduced.
- The guidance is not clear on whether all FSFs need to be considered RSFs and need at least one PDC associated with each FSF. The guidance includes the following statements:
    - Section 5.2 of the TICAP guidance for RSFs states that a summary level justification for why the reactor-specific RSFs adequately support the FSFs should be included.
    - NEI 18-04 states, "RSFs are defined starting with generic Fundamental Safety Functions (FSFs) defined by the International Atomic Energy Agency (IAEA)* of controlling heat generation, controlling heat removal, and retaining radionuclides."

  As interpreted by the Westinghouse team, these statements imply that all FSFs should be RSFs, or there should be at least one RSF that is derived from each FSF; however, the TICAP team stated that this was not the intention of these statements and that a plant could have fewer RSFs than FSFs or not address each FSF with an RSF. This should be clarified in the guidance moving forward.

- One of the main goals of the LMP and TICAP guidance is to be flexible enough to be able to be used for any advanced reactor design. To do this, the guidance is fairly generic and allows for the designer to make risk-informed decisions based on the specifics of its reactor design. However, in some ways, this made it difficult to follow and use the guidance, especially for a simple design like the eVinci micro-reactor. For example, it was not clear when additional PDC should be defined (that were not derived from the PRA), how uncertainty was to be applied, what to do with cases that landed in the more risk-significant areas of the F-C curve, and which design criteria require special treatment. It was not obvious what the NRC expectations will be for an application when a licensee uses this guidance, so it was hard to discern what more to include beyond the minimum derived from the use of the PRA. One suggestion is to include some specific examples/templates in

[F] *Note from TICAP Team: As discussed in Footnotes A through C, from the perspective of the TICAP team, the FSFs, the design-specific PSFs, and the RSFs for the eVinci Micro-Reactor would each be comprised of a unique set of functions (even if some of the functions are similar and/or related) based upon the analyses discussed in this tabletop exercise.*

the guidance, such as for PDC text for PDC tied to the FSFs.[G] These examples would not be requirements that have to be followed but could provide additional guidance for those designers that consider using them.

- Through preparing materials to present in the tabletop exercise, Westinghouse started going down the path of defining CDC in addition to PDC, but there was some outstanding confusion on the two terms and how each is used, especially when looking at previous examples. The term PDC refers to design criteria, i.e., a several-sentence description of requirements for the reactor design. PDC do not describe how the criteria is met or which SSC performs the safety functions required by the PDC. However, the examples of CDC that were discussed with the TICAP team focused on secondary or backup systems to perform a specific safety function. This is confusing, as, based on the name, it would appear that the CDC should also be system-independent design criteria and not specific systems that are available as alternative systems to perform the PDC. This needs further clarification and more detailed guidance moving forward.
- There are supplemental documents meant to provide additional guidance to that in NEI 18-04 and the TICAP guidance, such as training slides and examples.[7], [8], [9], [10] Knowing that this additional material is available and should be used in order to correctly apply the risk-informed process was confusing and somewhat cumbersome. A suggestion is combining these into one document (or two—one for LMP and one for TICAP) so that users do not need to go back and forth between various documents and would not miss valuable information if they were only reviewing the main guidance report.

4.2 Conclusions

As documented herein, Westinghouse was able to use the NEI 18-04 and TICAP guidance to develop PDC for the eVinci micro-reactor design using the existing early design phase PRA. In comparison to the PDC previously developed for the eVinci micro-reactor using the RG 1.232 process, it is evident that the new risk-informed approach has led to significantly fewer PDC and allows for the remaining design criteria to be handled in other ways, such as being categorized as NSRST. Westinghouse presented this information to NRC in a tabletop exercise on March 24, 2021. NRC provided a number of written comments to the TICAP team after the tabletop was completed, which will be taken into consideration in moving forward with TICAP guidance documents. The areas of the TICAP guidance refined by this exercise (as well as the other exercises) will be summarized in the final project report.

[G] *Note from TICAP Team: Although the draft TICAP guidance was still evolving during the performance of the eVinci Micro-Reactor tabletop exercise, the TICAP approach for identifying PDC was not intended to require that applicants identify one PDC for each FSF. In the case of the eVinci TICAP tabletop exercise, the Westinghouse team found at least one risk-significant LBE; therefore, there is at least one RSF. However, in the case that there are no adverse LBE outcomes, then there are no RSFs, meaning that there are no RFDC/PDC.*

5.0 REFERENCES

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

[2] TICAP Content of Application Guidance, DRAFT, January 14, 2021.

[3] EMR_LTR_190010, “Westinghouse eVinci^{TM} Micro-Reactor Licensing Modernization Project Demonstration,” (ML19227A322) August 12, 2019.

[4] Regulatory Guide 1.232 “Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors,” U.S. Nuclear Regulatory Commission, 2018.

[5] EPRI-AR-1, “Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance,” May 2019.

[6] ASME/ANS RA-S-1.4-2020, “Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants,” (updated for NRC endorsement, Fall 2020).

[7] Slides, “Technology Inclusive Content of Application Project (TICAP), Principal Design Criteria (PDC) and Complementary Design Criteria (CDC),” TICAP-NRC Working Meeting, August 27, 2020.

[8] INL/EXT-20-60394, “Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: Selection of Licensing Basis Events,” Revision 0, March 2020.

[9] INL/EXT-20/60396, “Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: Safety Classification and Performance Criteria for Structures, Systems, and Components,” Revision 0, March 2020.

[10] Slides, “Basic Training in Licensing Modernization Project Methodology,” January 14, 2020.