Modernization of Technical Requirements
for Licensing of Advanced Non-Light Water Reactors

PRISM Sodium Fast Reactor
Licensing Modernization Project Demonstration

Project Report
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List of Abbreviations

AC	Alternating Current
ACS	Alternate Cooling System
ANS	American Nuclear Society
AOO	Anticipated Operational Occurrence
APM	Asset Performance Management
ASME	American Society of Mechanical Engineers
BDBE*	Beyond Design Basis Event
BOP	Balance of Plant
CCF	Common Cause Failure
CFR	Code of Federal Regulations
CR	Control Rod
DBA	Design Basis Accident
DBE*	Design Basis Event
DC	Direct Current
DID	defense-in-depth
DOE	Department of Energy
DPS	Diverse Protection System
EM	Electromagnetic
ESF	Event Sequence Family
F-C	Frequency-Consequence
GEH	General Electric Hitachi
I&C	Instrumentation and Controls
IAEA	International Atomic Energy Agency
IDP	Integrated Decision-Making Panel
IE	Initiating Event
IEAP	Internal Event At-Power
IHTS	Intermediate Heat Transfer System
IHX	Intermediate Heat Exchanger
IRF	Inherent Reactivity Feedback
LBE*	Licensing Basis Event
LMP	Licensing Modernization Project
LOOP	Loss of Offsite Power
NEI	Nuclear Energy Institute
NGNP	Next Generation Nuclear Plant
non-LWR	non-light water reactor
NRC	Nuclear Regulatory Commission
NSR	Non-Safety-Related with No Special Treatment
NSRST	Non-Safety-Related with Special Treatment
NSSS	Nuclear Steam Supply System
PHTS	Primary Heat Transfer System
PRA	Probabilistic Risk Assessment
PRISM	Power Reactor Inherently Safe Module
PSID	Preliminary Safety Information Document
Q-DCIS	Safety-Related Qualified Distributed Control and Information System
QHO	Quantitative Health Objective
RIPB	risk-informed and performance-based
RPS	Reactor Protection System
RVACS	Reactor Vessel Auxiliary Cooling System
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SR	Safety-Related
SSC	Structures, Systems, and Components
SWR	Sodium-Water Reaction
SWRPS	Sodium-Water Reaction Protection System
TOP	Transient Overpower
U.S.	United States
USS	Ultimate Shutdown System

*These terms have special meanings defined in this document.

1 INTRODUCTION

The Power Reactor Inherently Safe Module (PRISM) Sodium Fast Reactor Demonstration Project described in this document directly supports the Licensing Modernization Project (LMP), a utility-led, Department of Energy- (DOE-) supported effort to propose a technology-inclusive and risk-informed and performance-based (RIPB) methodology that can be used to develop the foundation of the safety case for licensing of advanced non-light water reactors (non-LWRs). The Project's purpose, scope, objectives, and deliverables represent products supporting the LMP effort, and are summarized below.

1.1 Purpose

The purpose of the PRISM Demonstration Project was to exercise key processes as described in the LMP Guidance Document [Reference 1]. Each of the constituent components of the Guidance Document process had been employed in previous DOE and industry initiatives with positive results; the Demonstration performed with General Electric Hitachi (GEH) was the second opportunity to implement the process in the form of the draft LMP Guidance Document.* Given the previous DOE and industry work which is foundational to the LMP, it was not the purpose of the PRISM Demonstration Project to determine whether the proposed process is feasible to implement or to justify the process by producing particular results; affirmative answers to those questions have long been observed and documented as reflected in various documents associated with the MHTGR (DOE's prismatic modular high-temperature gas-cooled reactor), the Next Generation Nuclear Plant (NGNP), and the American Nuclear Society (ANS) design standard on modular helium cooled reactors (ANS53.1). The output of this Demonstration can be used, however, to reduce regulatory uncertainty of the PRISM design licensing through improving the regulatory acceptability of the approach used to develop its associated safety design approach. Additionally, output of the Demonstration provided insights to the PRISM design-specific regulatory strategy.

1.2 Scope

In this demonstration project, specific portions of the Guidance Document that were demonstrated included:

- Selection and quantification of Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs), Design Basis Accidents (DBAs), and Beyond Design Basis Events (BDBEs) (reference Section 3.0 of the Guidance Document)
- Identification of the required safety functions
- Candidate Structures, Systems, and Components (SSCs) safety classifications (reference Section 4.0 of the Guidance Document) and an example of partial defense-in-depth (DID) evaluation (reference Section 5.0 of the Guidance Document)

Section 3.3 of this report describes the design-specific features of the PRISM reactor that were evaluated in the Probabilistic Risk Assessment (PRA) and were included in this demonstration.

*The first LMP Demonstration Project was performed by X-Energy and is documented in the report "Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors High Temperature, Gas-Cooled Pebble Bed Reactor - Licensing Modernization Project Demonstration," Southern Company, August 2018.

Additionally, the Demonstration utilizes a PRA scope that is limited to Internal Events At-Power (IEAPs). Although the PRISM PRA does include a detailed evaluation of all hazards and modes with a bounding quantification for each, the Demonstration scope was limited to IEAP to ensure the process could be carried out within the project timeline.

The LMP process guidance used in this PRISM demonstration was a draft version of the LMP Guidance Document [Reference 1].

1.3 Objectives

The objectives of the PRISM Demonstration were to:

- Introduce the LMP process to GEH.
- Demonstrate key processes of the LMP Guidance Document as applied to the PRISM design.
- Provide an option for GEH to leverage the LMP process to improve the regulatory certainty of GEH's PRISM design and safety case, as best possible at the current state of design, by identifying a credible spectrum of Licensing Basis Events (LBEs) and investigating available SSC groupings that result in acceptable outcomes for the identified LBEs. Underlying this objective is the assertion that use of risk informed, performance-based methods to reach these conclusions is endorsed by Commission policy and compatible with the existing regulatory framework.

1.4 Deliverables

The deliverables of the Demonstration described in this document include:

- LBE selection and quantification, involving AOOs, DBEs, and BDBEs
- Identification of the Required Safety Functions
- Safety Classification of SSCs
- List of Design Basis Accidents
- Partial evaluation of DID

Due to project scope limitations, the portions of the draft Guidance Document involving the specification of special treatments and complete confirmation of DID adequacy (both plant capability adequacy and programmatic adequacy) were outside the scope of this Demonstration.

2 BACKGROUND AND LINKAGE TO LMP

The U.S. commercial nuclear power industry has long sought a broadly applicable, Nuclear Regulatory Commission- (NRC-) accepted, RIPB licensing framework. The increased interest in licensing advanced non-LWRs and given the variety of the designs being pursued have highlighted the importance of pursuing NRC endorsement of a RIPB framework. The foundation work for creating that framework is being advanced by the LMP, a utility-led, DOE-supported effort. This Demonstration is an applied execution of the RIPB processes proposed by the LMP. The LMP, working with the Nuclear Energy Institute (NEI), is currently developing a stand-alone Guidance Document describing the LMP processes for selection, and evaluation of LBEs, SSC safety classification and performance requirements, and evaluation of DID adequacy [Reference 1]. The Guidance Document extracts important regulatory endorsable elements from a series of white papers (WPs) covering the same topics. These WPs provide additional information on the technical bases for the proposed RIPB methodology as well as provide one way of executing the methodology. The Guidance Document is intended to be endorsed by the NRC in the form of a Regulatory Guide for licensing advanced non-LWRs and is planned for release in 2019.

2.1 LMP Documents

Probabilistic Risk Assessment Approach

The PRA draft white paper approach draft document contains the historical background, technical justifications and supporting information, and implementation guidance for creating a PRA computer model fit for providing insights into plant behavior for a given phase of design development. The PRA approach is reactor technology inclusive and makes use of technology inclusive risk metrics. The PRA can be introduced at an early stage of design to incorporate risk insights into early design decisions. However, introduction of the PRA at early design stage is not a requirement and it can be used later in the design process as a confirmatory and as part of presenting the safety case to the regulator. The PRA models are initially limited in scope and of a coarse level of detail as constrained by available supporting information. The scope and level of detail of the PRA models are increased as design and site information are available. The RIPB decisions supported by the PRA and deterministic safety approaches are reviewed and revised as the risk model definition is brought into focus. The PRISM PRA is discussed as an example in this white paper. This document is available as Reference [7] and will be revised as part of the LMP to incorporate feedback from this and other planned LMP demonstrations.

Selection of Licensing Basis Events

Key to building the safety case of any reactor design is identifying, selecting, and evaluating LBE, including the DBAs. The LMP proposed methodology is designed to identify LBEs that reflect the reactor design and technology specific issues and challenges associated with each reactor's safety design approach. A systematic and prescriptive process is used to determine the safety functions required to meet risk targets, whose process provides the developer with options to select the safety-related SSCs that will be used to demonstrate satisfaction of requirements for the Design Basis Accidents. This process builds on the PRA model and is tightly linked with the safety classification of SSCs. The PRISM PRA is discussed as an example in this white paper. This white paper document is available as Reference [8] and will be revised as part of the LMP to incorporate feedback from this and other planned LMP demonstrations.

Safety Classification and Performance Criteria for Structures, Systems, and Components

Criteria are provided to classify SSCs into three safety classes: Safety-Related (SR), Non-Safety-Related with Special Treatment (NSRST), or Non-Safety-Related with no Special Treatment (NSR). Based on the SSC safety functions in the performance of both prevention and mitigation functions, the developer assigns reliability and performance targets which help ensure that selected special treatment requirements are performance-based. This LMP white paper document is available as Reference [9] and will be revised as part of the LMP to incorporate feedback from this and other planned LMP demonstrations.

Risk-Informed and Performance-Based Evaluation of Defense-in-Depth Adequacy

The concept of DID has long been an expressed philosophy of commercial nuclear power design, licensing, and operation. This LMP white paper proposal document seeks to systematically evaluate DID adequacy for the plant capabilities and programs that comprise DID, incorporate needed layers of defense to address uncertainties in the design and operation of the plant, and establish a fixed baseline of DID adequacy. This document is available as Reference [10] and will be revised as part of the LMP to incorporate feedback from this and other planned LMP demonstrations.

3 DEMONSTRATION OVERVIEW

3.1 Summary of Demonstration Activities

During the Demonstration planning phase, a cross-functional, multi-company core team consisting of GEH, Southern Company, and various industry experts was assembled. This team included subject matter experts on PRA, RIPB processes, technical project execution, licensing, and LWR fleet operations. Two training sessions for GEH team members were conducted by the LMP technical leads regarding the three phases of the LMP process. The core GEH team began the project by executing the various tasks described in the LMP Guidance Document. Several teleconference meetings were held between GEH team members and LMP team members where interim results were presented and discussed. The LMP work culminated in a two-day face-to-face presentation of tabletop results at GEH facilities in Wilmington, NC, in October 2018. NRC staff, an NEI representative, and other reactor vendors participated in the second day of the tabletop presentation. During the tabletop presentation GEH personnel described the results of their PRISM LMP analysis and provided design-specific engineering insights.

During the execution of the project, Southern Company and industry consultants provided guidance regarding the application of the LMP RIPB process and led authoring of this report. The outputs, lessons, and conclusions from this Demonstration effort are part of the project closeout phase and are included in this document.

3.2 Prerequisites and Inputs for the Demonstration Project

The demonstrating reasonableness of the selected LBEs using the LMP proposed methodology requires development of a PRA as one of its tasks. GEH teamed with Argonne National Laboratory in 2015 and 2016 to perform research and development of next-generation PRA methodologies for the modernization of an advanced non-light water reactor PRA. This project was sponsored by the DOE.

The modernization project built upon a PRA developed in the early 1990s for the PRISM design. It resulted in a modern advanced non-LWR PRA with a detailed internal events model and a scoping external events analysis over all meaningful plant operating states including at-power and low power/shutdown [Reference 4]. Modeling uncertainty, sensitivity, risk importance measures were presented along with key risk insights. A semi-quantitative multi-unit analysis was also performed. As specified in the LMP PRA white paper, the goal of the PRA in the LMP approach is to support risk-informed decisions associated with each stage of design and licensing. The scope and level of detail of the PRA is developed in stages and corresponds to the scope and level of detail in each stage of design and licensing.

Radioactive sources modeled were the active fuel and spent fuel sources located in the reactor vessel. No other sources were within the PRA scope. It was recognized during the Demonstration that a more complete execution of the LMP methodology would require expanding the scope of the PRA to address other radionuclide sources.

3.3 PRISM Design

Design-specific features of the PRISM reactor were evaluated in the PRA. Some of the more novel features include:

- Two reactors feeding one turbine-generator
- Passive decay heat removal through Reactor Vessel Auxiliary Cooling System (RVACS)
- Passive reactor power suppression by the PRISM core's Inherent Reactivity Feedback (IRF)

3.4 PRA Overview

A Preliminary Safety Information Document (PSID) of the PRISM conceptual design, including a PRA, was submitted to the NRC in 1987 [Reference 2]. During the review of the PRISM PRA the NRC identified that the lack of mechanistic modeling would require additional examination or review [Reference 3]. In 2015 and 2016, GEH, in cooperation with Argonne National Lab performed a DOE-funded modernization of the existing PRISM PRA whose last significant update was in the 1990s [Reference 4], taking the legacy PRA and completely renewing it using state-of-the-art PRA technology. The updated PRISM PRA is based on conceptual design stage information, some of which is subject to change.

The PRISM PRA Project provides a trial use of the U.S. ANS/American Society of Mechanical Engineers (ASME) Non-LWR Trial Use/Pilot Application PRA standard, with specific focus on Full-Power Internal Events. Feedback on the PRA standard was provided to standard working group.

The updated PRA included:

- At-power internal events modeling
- An all hazards scoping review to analyze the risk at a high level from external hazards such as earthquakes and high winds
- An all-modes scoping review to understand the risk at a high level from operating modes other than at-power
- Uncertainties and Risk Insights to integrate the results from each of the three phases above

Traditional LWR risk metrics, such as core damage frequency, are not meaningful for advanced reactors such as PRISM because they assume certain LWR core, reactor, and containment design features. Instead, results were carried out to full Level 3 release, using the NRC Quantitative Health Objectives (QHOs).

Mechanistic Source Term

A mechanistic source term computer code was developed to perform the radionuclide release calculations for the PRISM PRA. The code conceptualizes the barriers for radionuclide release from a liquid metal reactor. The code uses several inputs, including the magnitude of fuel

damage, primary sodium conditions, leak rates, and input files containing radionuclide release fractions from the fuel pin to the primary sodium and from the primary sodium to the cover gas.

Multi-Unit Risk

The PRA also included a study aimed at determining the additional risk due to multi-unit events for a PRISM power block with two identical reactor units. The study was patterned after the method outlined in International Atomic Energy Agency (IAEA) draft guidance. The scope included single unit and common cause initiating events which were developed into concurrent event sequences. The results of this study demonstrated that the impact from event sequences involving both reactor modules concurrently is negligible (< 0.1%) compared to the baseline results for the IEAP PRA scope.

This PRA modernization effort was the first step towards GEH's road map for the risk-informed design and construction of the PRISM reactor.

3.4.1 IEAP Scope

The PRA scope for this Demonstration is IEAP. Although the PRISM PRA does include a detailed evaluation of all hazards and modes with a bounding quantification for each, the scope was limited to IEAP to ensure the process could be carried out within the project timeline.

The IEAP model used the Non-LWR PRA Standard [Reference 11] as a guide and generally meets the following technical elements at Capability Category I or greater:

- Initiating Event Analysis
- Event Sequence Analysis
- Success Criteria Development
- Systems Analysis
- Human Reliability Analysis
- Data Analysis
- Event Sequence Quantification
- Mechanistic Source Term Analysis
- Radiological Consequence Analysis
- Risk Integration

3.5 LBE Selection

The LBE selection process follows the approach described in the LMP LBE selection document and Guidance Document [Reference 1]. The proposed Frequency-Consequence (F-C) Target used for the PRISM Demonstration is shown in Figure 1. A design objective of PRISM is to keep the LBEs well within the F-C Target such that the resulting margins can support the eventual demonstration of DID adequacy.

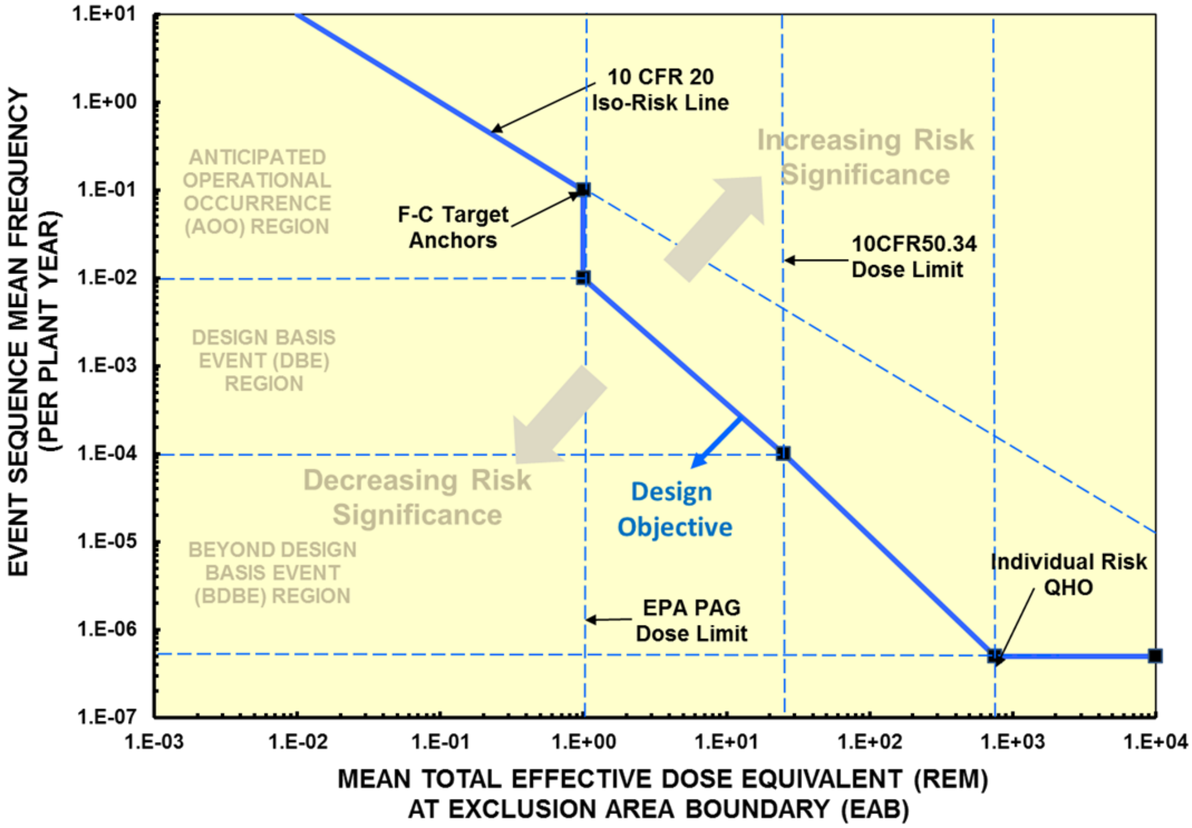

Figure 1. Frequency-Consequence Evaluation Criteria Proposed for LMP from Reference [1]

The LMP LBE selection and evaluation process was implemented as indicated in the tasks on the flow chart shown in Figure 2.* Tasks 7d and higher were not performed during this demonstration.

*One of the outcomes of the first Demonstration was a recommendation to the LMP to revise this flow chart to provide more visibility to the task of identifying the required safety functions. This revised flow chart shown in Figure 2 has been incorporated into the latest draft of the LMP Guidance Document.

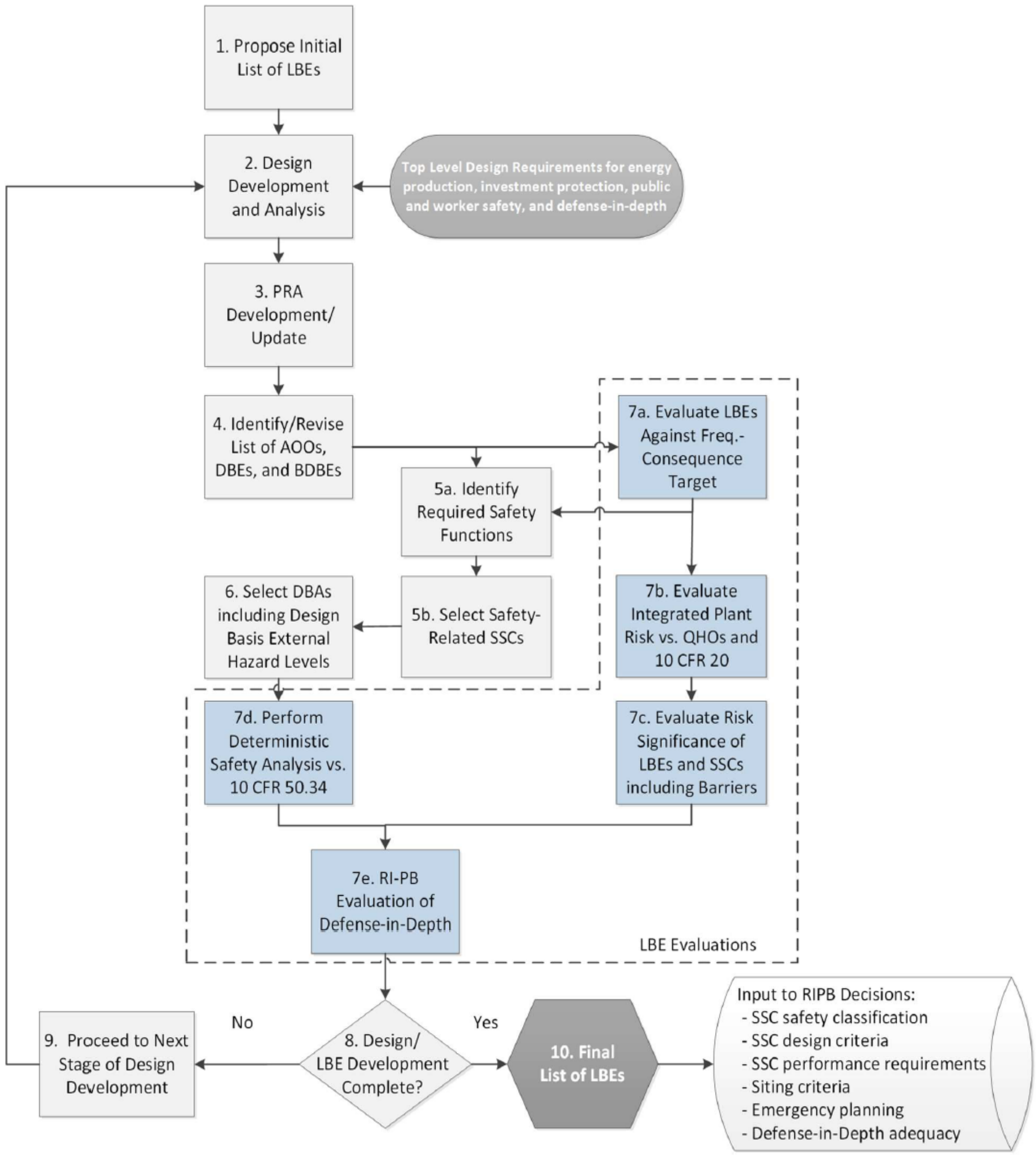

Figure 2. Process for Selecting and Evaluating Licensing Basis Events from Reference [1]

The steps below helped form the foundation for the remainder of the demonstration scope of work. The first priority was to leverage the historical PRISM development work (Tasks 1 and 2) and the recent PRA modernization (Task 3) to perform Tasks 4, 7a, and 7b.

1. Group all event sequences into Event Sequence Families (ESF) to form LBEs
2. Associate detailed failure modes to ESFs
3. Categorize as LBEs—AOOs, DBEs, and BDBEs

4. Visualize LBEs on the F-C chart
5. Assess integrated risk against three cumulative risk targets

3.5.1 Group All Event Sequences into Event Sequence Families

This section describes how all sequences from the PRA were grouped and converted to ESFs. The first part of Task 4 in the Guidance Document applies directly to this section. The Guidance Document provides the following instructions:

> *"The event sequences modeled and evaluated in the PRA are grouped into event sequence families each having a similar initiating event, challenge to the plant safety functions, plant response, end state, and mechanistic source term if there is a radiological release."*

All the information necessary for grouping can be extracted from the PRA.

Each modeled event sequence was enumerated from Initiating Event (IE) to end state through whatever combination of protected, unprotected, and confinement trees the sequence dictates. A total of over 1,000 possible sequences resulted. These sequences were then grouped in accordance with the event sequence family definition which resulted in 591 ESFs for the PRISM IEAP model. Each ESF is a unique combination of the IE, plant response, and end state.

3.5.2 Associate Detailed Failure Modes to ESFs

With the ESFs defined, the quantified results of the PRA can be associated with applicable ESFs.

Out of the 100,000+ detailed failure modes (cutsets) for the baseline IEAP model, 70 of the possible 591 ESFs apply. The screened-out ESFs are those that fall below the truncation threshold established in the PRA model quantification process. These screened-out ESFs are significantly below the lower frequency limit of the F-C chart. The top 10 ESFs in terms of mean frequency are listed in Table 1.

Table 1. Top ESFs

Label	*ESF Frequency Mean per plant-year*	*EAB Mean Dose (rem at 0 – 0.5 miles from plant boundary)*
ESF_a-14	1.7e+00	0
ESF_a-23	1.2e+00	0
ESF_a-35	6.0e-01	0
ESF_a-4	3.9e-01	0
ESF_a-17	1.1e-01	0
ESF_a-13	3.8e-02	0
ESF_a-16	3.4e-02	0
ESF_a-22	2.8e-02	0
ESF_a-3	1.6e-02	0
ESF_a-9	1.4e-02	0

3.5.3 Categorize as LBEs - AOOs, DBEs, BDBEs

The Guidance Document, in Task 4, states that "Each [event sequence family] 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."

It goes on to specify the category assignment criteria based on mean frequency:

- AOOs: LBEs with [mean] frequencies greater than 10^{-2}/plant-year
- DBEs: LBEs with [mean] frequencies between 10^{-4} and 10^{-2}/plant-year
- BDBEs: LBEs with frequencies less than 10^{-4} but with upper bound frequencies greater than [or equal to] $5\times^{-7}$/plant-year

Applying this criteria to the ESFs from the baseline model, a total of 26 LBEs were identified with categorization breaking down as follows:

- AOO: 11
- DBE: 10
- BDBE: 5

The categorization breakdown by IE group is given in Table 2 (an X indicates that at least one LBE for the IE group exists for the given category).

Table 2. ESF Categorization by IE Group

IE Group	*Description*	*AOO*	*DBE*	*BDBE*
BOP	Balance of Plant Transients	X	X	X
IHTS	Intermediate Heat Transport System			X
IHX	Intermediate Heat Exchanger Leaks	X		
LOF	Loss of Flow	X	X	X
LOOP	Loss of Offsite Power	X	X	
NSSS	Nuclear Steam Supply System Transients	X	X	
SGTR	Steam Generator Tube Rupture		X	X
TOP	Transient Overpower	X	X	

Event sequence families with upper bound frequencies less than $5\times^{-7}$/plant-year, although not categorized as LBEs, are retained for tracking purposes. Forty-four "tracked" ESFs remain.

With the LBEs identified and categorized, there is now a manageable set of events to analyze that represent a much larger population of PRA event sequences. The grouping process in terms of event counts is summarized below.

3.5.4 Visualize LBEs on the F-C Chart

Task 7a involves the visualization of the LBEs developed above on an F-C chart. The chart for the PRISM IEAP scope is displayed below and confirms that all LBEs are within the F-C Target.

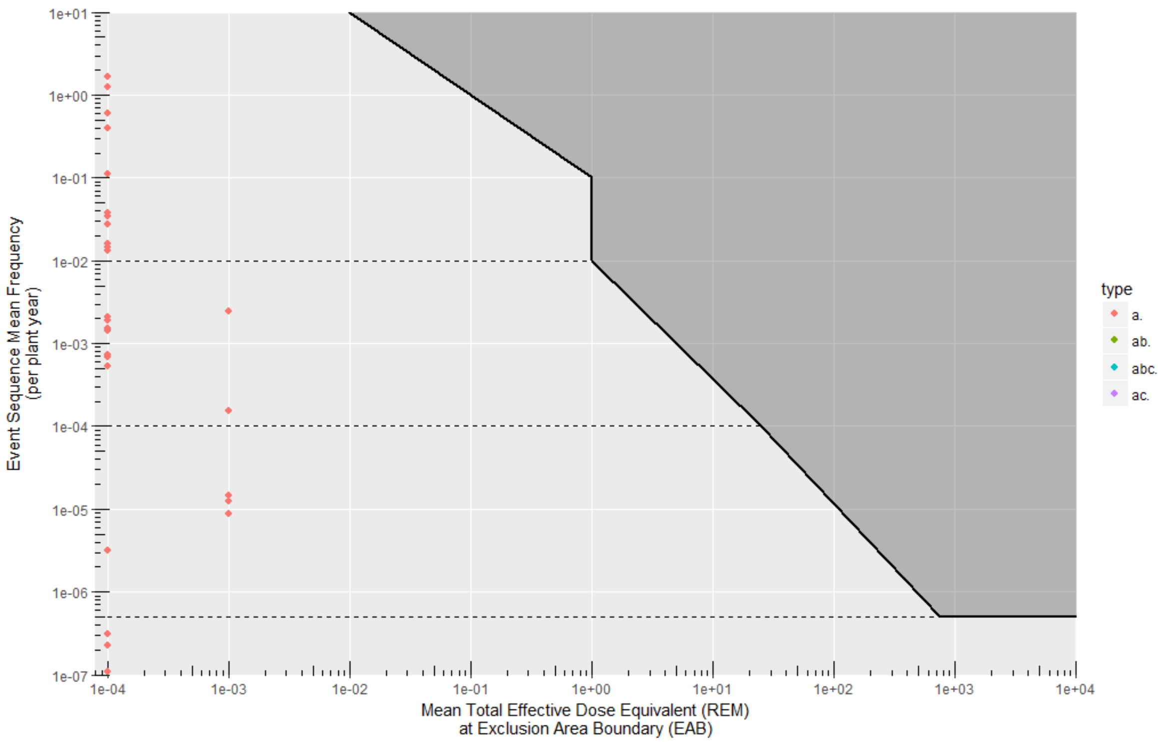

Figure 3. PRISM LBEs Plotted Against the LMP F-C Target

There are several important observations associated with this plot:

- There are large margins between the LBE mean-value points and the target line. The mean-value points are two to three orders of magnitude apart in risk, and the highest consequence LBEs are over two orders of magnitude from the design goal, 1-rem Protective Action Guides criterion for sheltering and/or evacuation actions.
- The LBEs plotted with a dose of 10^{-3} are for non-fuel damage LBEs and the dose values are not based on Mechanistic Source Term analysis. Placement was based on engineering judgement and is for demonstration purposes only.
- No uncertainty upper and lower bars are presented for any of the LBEs. No uncertainty (frequency or consequence) analysis was performed during this Demonstration. The PRISM PRA included uncertainty analysis, but these were not resolved for individual ESFs and LBEs. However, based on the large margin between the points and the target line and previous integrated uncertainty analysis performed in the PRA, these LBEs including uncertainties are not expected to challenge the target line.

- The Demonstration scope does not include seismic events or other external hazards nor shutdown events. Inclusion of these events will likely result in additional LBEs being added to the F-C chart.

3.5.4.1 LMP Process Feedback for LBE Selection

The LMP LBE selection process as described in tasks 4, 7a, and 7b of the Guidance Document was shown to be applicable to PRISM. There was sufficient breadth in the PRA to identify a spectrum of event sequences in each of the AOO, DBE, and BDBE categories with varying releases in terms of sources, pathways, magnitude, and timing.

3.5.5 Assess Integrated Risk Against Three Cumulative Metrics

This task evaluates the integrated risk of the plant against three cumulative risk targets:

- Cumulative Dose Exceedance Frequency
- Cumulative Early Fatality Risk
- Cumulative Latent Fatality Risk

3.5.5.1 Dose Target

The dose target is defined as follows in the Guidance Document:

> *"The total frequency of exceeding a site boundary dose of 100 mrem from all LBEs shall not exceed 1/plant-year…"*

PRISM's total frequency for this metric is: 10^{-7}/plant-year, which is well below the threshold.

3.5.5.2 Early Fatality Target

The Early Fatality target is defined as follows in the Guidance Document:

> *"The average individual risk of early fatality within 1 mile of the Exclusion Area Boundary (EAB) from all LBEs shall not exceed 5×10^{-7}/plant-year…"*

PRISM's total risk for this metric is $\ll 5\times10^{-7}$/plant-year.

3.5.5.3 Latent Fatality Target

The Latent Fatality target is defined as follows in the Guidance Document:

> *"The average individual risk of latent cancer fatalities within 10 miles of the EAB from all LBEs shall not exceed 2×10^{-6}/plant-year…"*

PRISM's total risk for this metric is $\ll 2\times10^{-6}$ per plant-year.

3.6 SSC Classification

This section describes how the PRISM SSCs were classified into one of the following three LMP safety classification categories:

1. Safety-Related
2. Non-Safety-Related with Special Treatment
3. Non-Safety-Related with No Special Treatment

To perform the classification, the following LMP tasks are carried out:

- LBE Selection Tasks
  - Task 5a: Identify Required Safety Functions
  - Task 5b: Select/Revise Safety-Related SSCs
  - Task 7c: Evaluate Risk Significance of LBEs and SSCs Including Barriers
- Safety Classification Tasks
  - Task 3: Determine required and safety-significant functions
  - Task 4a/5a: Evaluate for SR SSCs
  - Task 4b/5b: Evaluate for NSRST SSCs
  - Task 4c/5c: Evaluate for NST SSCs

As evident in the task list above, there are several tasks necessary to form the basis for the classification activity. This process is illustrated in Figure 4.

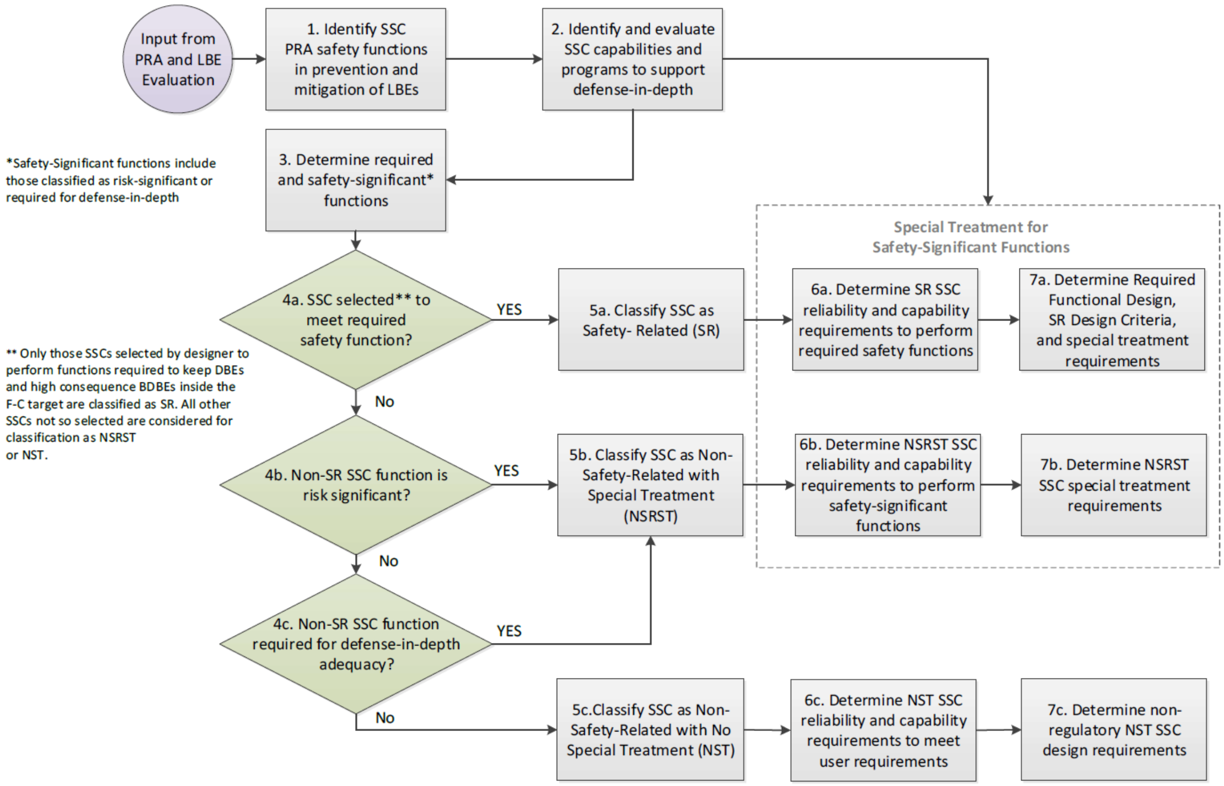

Figure 4. SSC Classification Process

Ultimately, a set of SSCs is selected that maintains all LBEs[*] within the F-C Target.

The PRISM PRA IEAP model—a modern PRA that meets applicable portions of the Non-LWR Standard—is capable of providing quantitative case studies that empirically demonstrate LBE (and associated LBE/ESF) position vs. target given different combinations of credited functions/SSCs. This allows a straightforward and repeatable classification of SSCs. This repeatability is important since the plant design/PRA may change during the design stage. For example, when external hazards are brought in to the LMP process, the IEAP-based SSC classification will need to be re-run to capture changes that may result.

These PRA case studies (referred to as "sensitivity studies" by PRA analysts) end up exchanging event frequency among DBEs/BDBEs and their related non-LBE ESFs. The NGNP SSC Classification White Paper provides a discussion on the relationships between LBEs illustrated in Figure 5.

[*]The guidance specifies keeping only DBEs and high consequence BDBEs within the target. All LBEs is mentioned here because each DBE/BDBE has associated LBEs and non-LBE ESFs that will increase in frequency when successful SSCs in the DBE/BDBE sequence are assumed to not be available. This is a technical clarification since LBEs only change frequency, they never change consequence. If consequence does change, it is a different LBE/ESF per the grouping definitions in the guidance and the Non-LWR Standard (event sequence family).

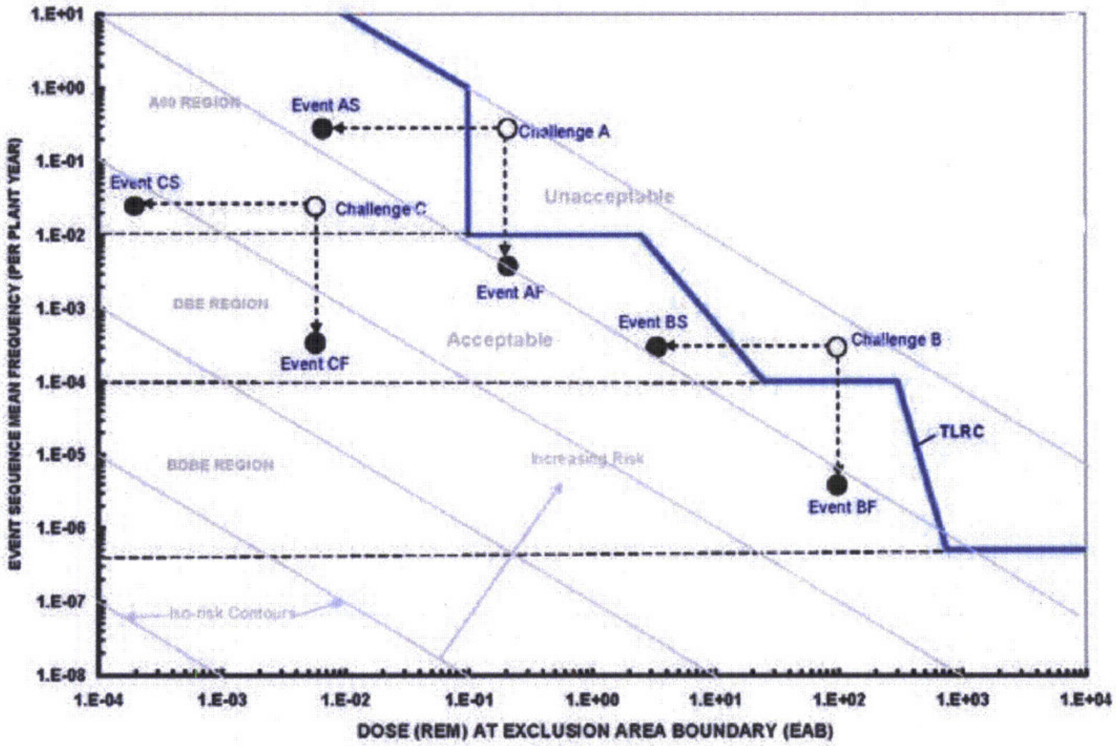

Figure 5. Impact of Safety-Classified SSCs in Prevention and Mitigation of LBEs (Figure 1 from NGNP White Paper)

It explains:

> *"SSC AS is an example of an SSC whose successful performance mitigates (ensures) the consequences of an Event AS and remains below the TLRC thus preventing AOO (Challenge A).*
>
> *SSC AF is an example of an SSC whose successful performance prevents the frequency of a corresponding DBE (Event AF), whose consequences exceed the AOO dose criteria, from moving into the AOO region."*

It also explains that:

> *"By varying the LBE frequency along the path from point AF to challenge A, one may simulate degradation of the SSC(s) in comparison to what was predicted in the PRA, or one may investigate the impact of uncertainties in the assumed reliabilities of the SSCs."*

The simulation described can be performed using PRA sensitivity studies. Applying sensitivities can show how the baseline PRA and its LBEs are impacted by crediting or not crediting a safety function or SSC.

Three types of sensitivity studies are carried out to support the classification of SSCs:

1. Safety Functions Studies

2. SSC Set Studies
3. Risk Significance Studies

3.6.1 Safety Function Studies

3.6.1.1 PRISM PRA Safety Functions and Required Safety Function

As illustrated in Figure 6, the following PRA Safety Functions for PRISM were identified in the PRISM PRA:

1. Reactivity Control
2. Core Flow
3. Heat Removal from primary sodium
4. Confinement*

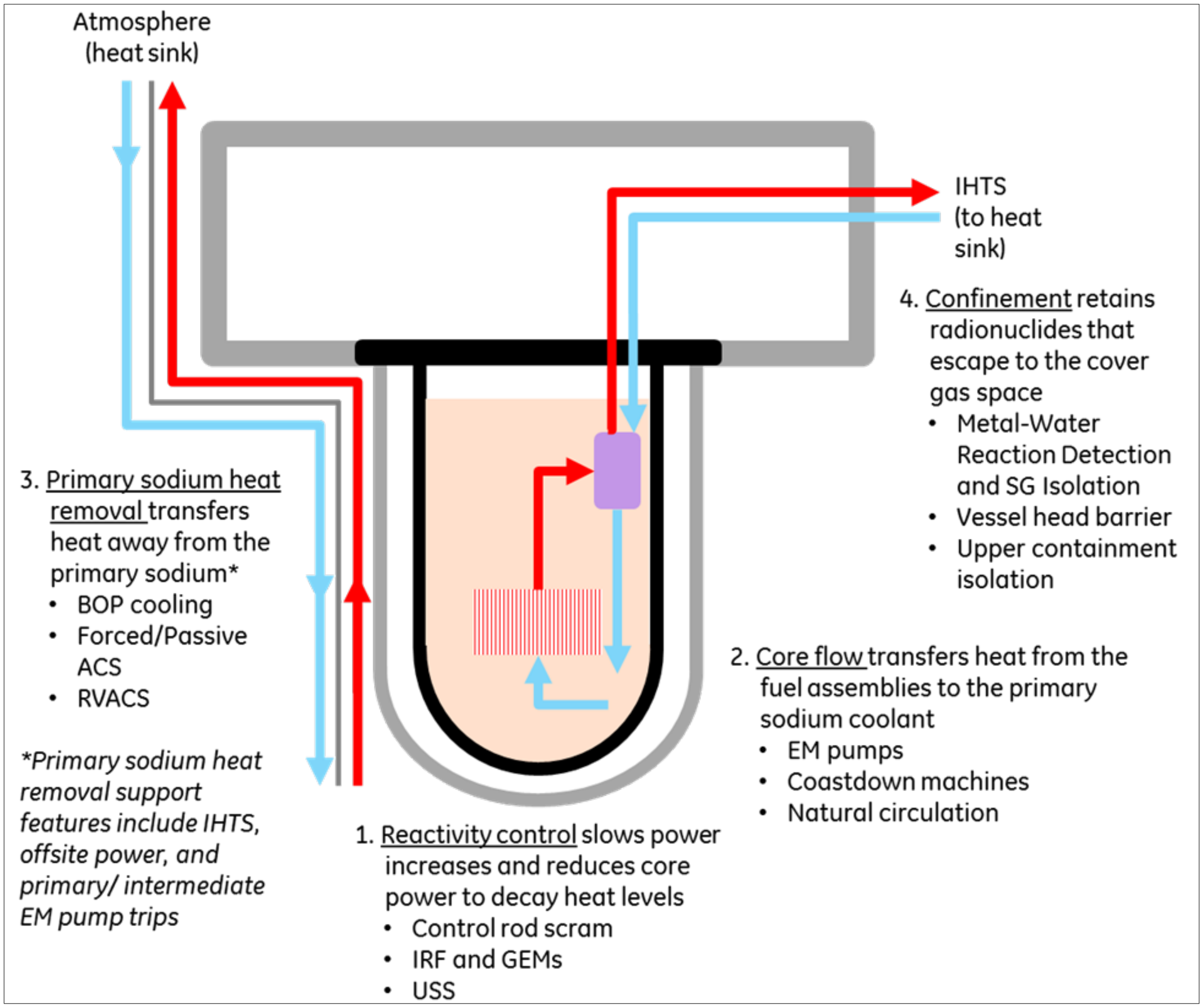

Figure 6. PRISM PRA Safety Functions

*Radionuclide retention in vessel gas space and containment building

A "required safety function" is one that must be fulfilled to meet the dose requirements for the DBAs using conservative assumptions. In Task 4A, each of the DBEs and any high consequence BDBEs (i.e., those with doses above 10 Code of Federal Regulations (CFR) 50.34 limits) are examined to determine which SSCs are available to perform the RSFs. The designer then selects one specific combination of available SSCs to perform each RSF that covers all the DBEs and high consequence BDBEs. These specific SSCs are classified as SR in Task 5A and are the only ones included in the DBA analysis of the DBAs. All the remaining SSCs are processed further in Tasks 4B and 4C. In the guidance, Required Safety Function is defined as:

> *"A PRA Safety Function that is required to be fulfilled to maintain the consequence of one or more DBEs or the frequency of one or more high consequence BDBEs inside the F-C Target."*

3.6.1.2 Sensitivity Cases

LBE Selection Task 5a provides the requirements for the safety function studies:

> *"In Task 5a the full set of DBEs are examined to identify the safety functions that are necessary and sufficient to meet the F-C Target for all DBEs and high consequence BDBEs, and to conservatively ensure that 10 CFR 50.34 dose requirements can be met."*

Sensitivities were constructed to show which of the four PRA Safety Functions were necessary and sufficient to meet the F-C Target:

- Case 1
  - Credited: Reactivity Control, Heat Removal, Core Flow
  - Not Credited: Confinement
- Case 2
  - Credited: Reactivity Control, Heat Removal
  - Not Credited: Confinement, Core Flow
- Case 3
  - Credited: Heat Removal
  - Not Credited: Confinement, Core Flow, Reactivity Control
- Case 4
  - Credited: Confinement, Core Flow, Reactivity Control
  - Not Credited: Heat Removal

The study results show that Cases 1 and 2 are within the Target while Cases 3 and 4 exceed the Target. These results were expected since the Core Flow function is only applicable to loss of flow events where control rod insertion fails (unprotected) and the Confinement function only lowers the consequences of fuel damage events but does not affect frequency. Not crediting Reactivity Control (Case 3) has a significant effect since control rods and IRF are included under this function. This hypothetical scenario therefore has no mechanism to control core heat generation which negates crediting the full set of Heat Removal functions. Not crediting Heat

Removal (Case 4) also has a major impact because there is no mechanism to remove core heat from even the more benign sequences.

Based on these four sensitivity cases, the following required safety functions* are proposed for this PRISM demonstration:

- Reactivity Control
- Heat Removal

These required safety functions are illustrated in Figure 7 (shaded boxes).

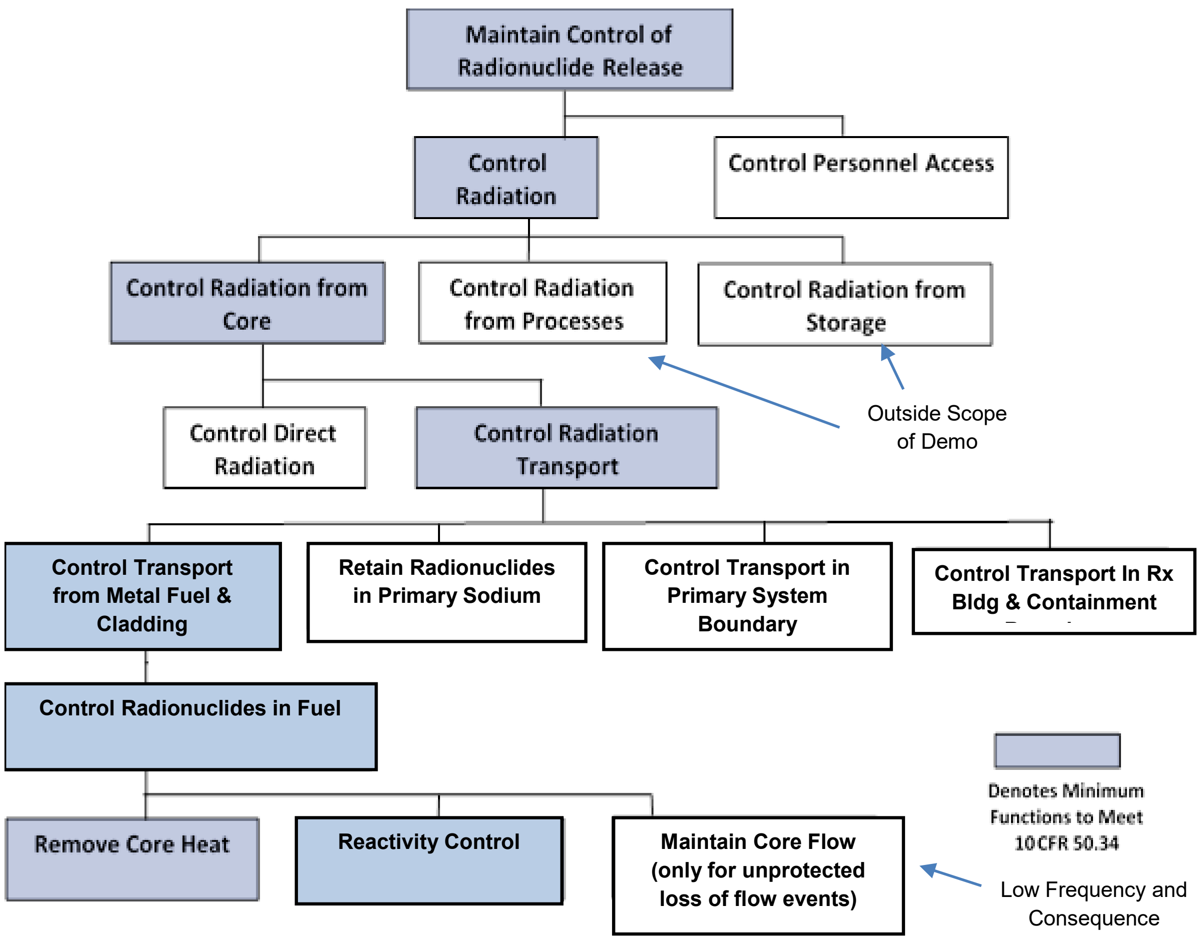

Figure 7. PRISM Safety Functions and Required Safety Functions

3.6.2 SSC Set Studies

LBE Selection Task 5b provides the requirements for the SSC set studies:

*Results based solely on the PRISM PRA IEAP model. The DID process is designed to make up for PRA uncertainties, PRA scope limitations, and PRA capability limitations and has an opportunity to challenge/change these results. Additionally, as the PRA matures commensurate with the design, these results may change as new details, new hazards, new methods, etc. emerge.

> *"For each of these required safety functions identified in Task 5a, a decision is made on which SSCs that perform these required safety functions and are found to be available on all the DBEs should be classified as safety-related … Safety-related SSCs are also selected for any required safety function associated with any high consequence BDBEs in which the reliability of the SSC is required to keep the event in the BDBE frequency region. The remaining SSCs that are not classified as safety-related are considered in other evaluation tasks including …"*

A key phrase for Task 5b is *"a decision is made on which SSCs that perform these required safety functions and are found to be available on all the DBEs."* In the PRISM design there are numerous SSCs that can fulfill the two required safety functions, but only a subset is available during all DBEs (and high consequence BDBEs). The Steam Generator Alternate Cooling System (ACS), for example, is capable of fulfilling the success criteria for the heat removal function; however, during certain IEs and event sequences, this system will not be available due to loss of electrical power, loss of the Intermediate Heat Transport System (IHTS), Steam Generator (SG) tube rupture, etc.

The definitions for safety classification categories provided in Section 4.0 of the guidance provides more details on performing this task:

> *"SSCs selected by the designer from the SSCs that are available to perform the required safety functions to mitigate the consequences of DBEs to within the LBE FC Target … SSCs selected by the designer and relied on to perform required safety functions to prevent the frequency of BDBE with consequences greater than the 10 CFR 50.34 dose limits from increasing into the DBE region and beyond the F-C Target."*

As discussed earlier, the PRISM model is capable of being directly queried to show the effect of different assumptions on the position of LBEs/ESFs relative to the F-C Target. For Task 5b, a series of sensitivities was constructed to determine which SSCs should be classified as safety-related in accordance with the definition above.

These studies are performed in two phases: System-Function Level Studies and SSC Level Studies. The System-Function Level phase screens-out potentially large collections of SSCs that cannot fulfill Task 5b even if all supporting SSCs were credited. The second phase examines the supporting SSCs for the systems-functions that can meet the Task 5b requirements.

3.6.2.1 System-Function Level Studies

Each required safety function is represented in the PRISM event sequence analysis by one or more event tree headers, as indicated in Table 3.

Table 3. Required Safety Functions

Safety Function	*FT Top Event*	*Description*
Reactivity Control	Top_CR	Scram signal and control rod (CR) insertion
Reactivity Control	Top_IRF	IRF and GEMs
Reactivity Control	Top_USS	Ultimate Shutdown System (USS) control rod insertion
Heat Removal	Top_SGDry	Arrest of SG sodium water reaction
Heat Removal	Top_BOP	Balance of Plant (BOP) cooling
Heat Removal	Top_FACS	Forced air Auxiliary Cooling System
Heat Removal	Top_xPump	Tripping of Primary and Intermediate electromagnetic (EM) pumps
Heat Removal	Top_PACS	Passive ACS
Heat Removal	Top_RVACS	RVACS cooling
Heat Removal	Top_IHTS	IHTS to move heat

Five studies were carried out to determine which of these systems/functions (which are collections of SSCs) can "mitigate the consequences of DBEs [based on their associated LBEs/ESFs] to within the LBE FC-Target." Three cases examined different combinations of Heat Removal systems, while two looked at Reactivity Control combinations.

After running the cases, the following systems/functions listed in Table 4 are retained for further examination at the SSC level.

Table 4. Required Systems/Functions

System Functions	*Description*
Top_RVACS	RVACS passive cooling
Top_CR	Control Rod Insertion
Top_IRF	Inherent Reactivity Feedback
Top_xPump	EM pump trip

3.6.2.2 SSC Level Studies

To complete LBE Selection Task 5b (from LMP Guidance Document Figure 3-2), the following process was followed at the SSC level:

1. Determine the SSCs that support the retained system level functions
2. Run model cases to determine the set of SSCs that "are found to be available on all the DBEs [and BDBEs]" and "mitigate the consequences of DBEs [and BDBEs] to within the LBE FC Target"

3.6.2.2.1 Determine Supporting SSCs

For each retained system level function, there are SSCs (and human actions) that are modeled under the system tops–these are the "SSCs that perform [the] required safety functions …" In a PRA model, such a list can become quite extensive when support systems such as electrical are considered. Therefore, a decision was made to screen out certain supporting system functions that were not considered necessary to "mitigate … within the LBE F-C Target." (This qualitative assessment was validated quantitatively when the SSC cases were run.)

For example, certain digital Instrumentation and Controls (I&C) functions are powered by the vital 120-VAC electrical system, which can receive its power from multiple sources including the 125-VDC system (batteries) or the 480-VAC system (ultimately powered by offsite power or the standby gas turbines). Only the vital alternating current (AC) and direct current (DC) SSCs were included with the 480-VAC and beyond SSCs screened-out.

Table 5 shows an excerpt of SSC to system function alignment.

Table 5. Supporting SSCs

PRA Basic Event	*Top CR*	*Top IHTS*	*Top IRF*	*Top RVACS*	*Top xPump*
B21-B22-XHE-FO-EM-PWR					Y
B21-Fuel-IRF			Y		
B21-LCB-EMCB1A/B/C/D					Y
B22-_PF-0001		Y			
B22-_SG-0001		Y			
B22-ACV-Drain/Vent		Y			
B22-EM-1A/B		Y			
B22-IHX-1A/1B		Y			
B22-LCB-EMCB1A/B					Y
C12-CRs/CRDs	Y				
C12-MOTs	Y				
C63-B22-CCFSOFTWARE_S		Y			

3.6.2.2.2 Determine SSC Set

Similar to the safety function and system function level cases, SSC sensitivity cases were run to determine the set of SSCs that "are found to be available on all the DBEs [and BDBEs]" and "mitigate the consequences of DBEs [and BDBEs] to within the LBE FC-Target."

Four SSC cases were sufficient to determine the credited set of SSCs. The selected SR SSCs can be grouped into the following high-level categories:

- Digital I&C logic and load drivers (Reactor Protection System [RPS], Diverse Protection System [DPS], and Safety-Related Qualified Distributed Control and Information System [Q-DCIS])
- Control rods and drives and associated operator actions
- EM pump supply breakers and associated operator actions
- 120-VAC equipment
- 125-VDC equipment
- Reactor vessel and internals
- RVACS
- Supporting structures

3.6.2.3 Classify Credited SSCs as Safety-Related

SSC Classification Tasks 4A and 5A (from Figure 4-1 of the Guidance Document) are described as follows:

> *"In Task 4A, each of the DBEs and any high consequence BDBEs (i.e., those with doses above 10 CFR 50.34 limits) are examined to determine which SSCs are available to perform the required safety functions.* ***The designer then selects one specific combination of available SSCs to perform each required safety function that mitigates the DBEs and prevents the high consequence BDBEs. These specific SSCs are classified as SR in Task 5A*** *and are the only ones credited in the Chapter 15 safety analysis of the DBAs. All the remaining SSCs are processed further in Steps 4B and 4C."*

The portion in bold above is the focus of this section.

The process identifies three categories of classification:

- Safety-Related
  - SSCs selected by the designer to perform required safety functions to mitigate the consequences of DBEs to within the F-C Target, and to mitigate DBAs to meet the dose limits of 10 CFR 50.34 using conservative assumptions
  - SSCs selected by the designer to perform required safety functions to prevent the frequency of BDBEs with consequences greater than 10 CFR 50.34 dose limits from increasing into the DBE region and beyond the F-C Target
- Non-Safety-Related with Special Treatment
  - Non-safety-related SSCs relied on to perform risk significant functions. Risk significant SSCs are those that perform functions that keep LBEs from exceeding the F-C Target or make significant contributions to the cumulative risk metrics selected for evaluating the total risk from all analyzed LBEs.
  - Non-safety-related SSCs relied on to perform functions requiring special treatment for DID adequacy
- Non-Safety-Related with No Special Treatment
  - All other SSCs

This process outlines three critical tasks after the required functions are identified. The first task is to determine which SSCs are selected to meet the required safety function for each DBE. These SSCs are then classified as safety-related. The next two tasks involve determining if the SSC should be classified as NSRST.

Available sets of SSCs which could perform the three required safety functions are identified. The LMP process does not attempt to determine which of the options should be chosen, as this is a designer's choice. The designer may consider many different parameters when selecting the safety-related SSCs, such as economic cost, regulatory uncertainty, and difficulty of performance requirements.

Under LBE Selection Task 5b, "one specific combination of available SSCs" was selected that keeps all LBEs/ESFs within the F-C Target. This set is therefore classified as safety-related for the purposes of this demonstration.

Included in this set are both explicitly modeled SSCs and those implicitly modeled. PRAs, especially those performed in the design stage, will have several plant features that are assumed, but not explicitly modeled. For example, for the RVACS heat removal function, there is an implicit assumption that the Primary Heat Transfer System (PHTS) is intact and natural circulation is removing heat from the core and transferring it to the reactor vessel walls where RVACS subsequently transfers the heat to the environment.

3.6.3 SSC Risk Significance

SSC Classification Task 4b/5b evaluate for NSRST SSCs based on the SSC risk significance determined in LBE Selection Task 7c. As described in Task 4b/5b, each SR SSC is risk significant because, by definition, they are necessary to keep one or more LBEs/ESFs inside the F-C Target. The balance of SSCs (not classified as SR) are evaluated in Task 4b/5b, however, because it is "possible that some non-SR SSCs will meet the criteria for risk significance."

3.6.3.1 Risk Significance Evaluation

As described in the guidance:

> *"A risk significant SSC function is one that is necessary to keep one or more LBEs within the F-C Target or is significant [(within 1%)] in relation to one of the LBE cumulative evaluation risk metric limits."*

To evaluate both metrics in this specification, collections of non-SR SSC were simulated as failed in the PRA model. The resultant LBE/ESF placement relative to the F-C Target was then evaluated for the case. In addition, the cumulative impact was also assessed against the integrated risk targets.

These studies resulted in zero risk significant non-safety SSCs as all met the F-C Target and integrated criteria.

3.6.3.2 Classify Risk Significant SSCs as NSRST

Based on the SSC risk significance evaluations, no SSC is classified as NSRST at this point in the LMP process. During the DID adequacy evaluation, consideration will be given to whether any SSCs should be classified as NSRST to meet DID adequacy criteria.

3.7 Design Basis Accidents

3.7.1 Define DBAs

LBE Selection Task 6 is where the definition of DBAs takes place. The LMP guidance states under Task 6:

> *"For each DBE identified in Task 4, a deterministic DBA is defined that includes the required safety function challenges represented in the DBE but assumes that the required safety functions are performed exclusively by safety-related SSCs and all non-safety SSCs that perform these same functions are assumed to be unavailable."*

Note: Task 6 also identifies Design Basis External Events. This is outside the scope of this demonstration which is limited to IEAP.

DBEs were identified in LBE Selection Task 4. Each DBE sequence (event sequence family) was converted to a DBA sequence in accordance with Task 6. Each is displayed in Table 6 along with its IE Group.

Table 6. DBEs

DBE ID	*IE Group*
ESF_a-2	BOP
ESF_a-11	LOF
ESF_a-12	LOF
ESF_a-15	LOOP
ESF_a-20	NSSS
ESF_a-21	NSSS
ESF_a-26	SGTR
ESF_a-30	SGTR
ESF_a-32	TOP
ESF_a-33	TOP

Each DBE sequence (event sequence family) is described below and then converted to a DBA sequence in accordance with Task 6. Note that a given DBA can represent more than one DBE when crediting only SR SSCs results in the same sequence.

DBA-01

DBE: ESF_a-2

DBE Description

BOP IE with successful Control Rod Insertion and IHTS heat transport and failure of Forced Air ACS. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. Passive ACS then fails to supplement the heat removal function. Finally, RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA Description

BOP IE with successful Control Rod Insertion. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA-02

DBEs: ESF_a-11 / ESF_a-12

ESF_a-11 DBE Description

Partial LOF IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS from the remaining running pumps. Passive ACS then fails to supplement the heat removal function. Finally, RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

ESF_a-12 DBE Description

Partial LOF IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS from the remaining running pumps. Passive ACS then successfully supplements the heat removal function and RVACS removes the remaining heat load from PHTS and no fuel damage occurs. There is no release from non-fuel sources.

DBA Description

Partial LOF IE with successful Control Rod Insertion. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS from the remaining running pumps. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA-03

DBE: ESF_a-15

DBE Description

LOOP IE (affects both units) with successful Control Rod Insertion and IHTS heat transport. BOP cooling is assumed unavailable due to the initiator. Forced Air ACS relies is possible (standby power) but fails. All four PHTS EM pumps and two IHTS EM pumps trip as a result of the initiator and thus no pump heat is added to decay heat in the PHTS. Passive ACS then fails to supplement the heat removal function. Finally, RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA Description

LOOP IE with successful Control Rod Insertion. All four PHTS EM Pumps and two IHTS EM Pumps trip as a result of the initiator and thus no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA-04

DBEs: ESF_a-20 / ESF_a-21

ESF_a-20 DBE Description

NSSS Fault IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. Passive ACS then fails to supplement the heat removal function. Finally, RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

ESF_a-21 DBE Description

NSSS Fault IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. Passive ACS then successfully supplements the heat removal function and RVACS removes the remaining heat load from PHTS and no fuel damage occurs. There is no release from non-fuel sources.

DBA Description

NSSS Fault IE with successful Control Rod Insertion. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

DBA-05

DBEs: ESF_a-26 / ESF_a-30

ESF_a-13 DBE Description

SGTR IE with successful Control Rod Insertion. Sodium-Water Reaction (SWR) is not arrested due to fail of the SWR Protection System. IHTS heat transport, ACS, and BOP is assumed failed due to non-arrested SWR. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. No fuel damage occurs. There is an assumed release from the activated IHTS sodium through the ruptured SG tube through the pressure relief exhaust on the shell side of the SG.

ESF_a-30 DBE Description

SGTR IE with successful Control Rod Insertion. SWR is arrested by isolating water sources to the SG and drying-out remaining water in the SG via blowdown. IHTS heat transport successfully moves heat to Forced Air ACS which fulfills the heat removal function regardless of decay heat and pump heat loads. No fuel damage occurs. There is an assumed release from the activated IHTS sodium through the ruptured SG tube through the pressure relief exhaust on the shell side of the SG.

DBA Description

SGTR IE with successful Control Rod Insertion. SWR is not arrested due to failure of the SWR Protection System. IHTS heat transport, ACS, and BOP are assumed failed due to non-arrested SWR. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is an assumed release from the activated IHTS sodium through the ruptured SG tube through the pressure relief exhaust on the shell side of the SG.

DBA-06

DBEs: ESF_a-32 / ESF_a-33

ESF_a-32 DBE Description

TOP IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. Passive ACS then fails to supplement the heat removal function. Finally, RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

ESF_a-33 DBE Description

TOP IE with successful Control Rod Insertion and IHTS heat transport. BOP cooling and Forced Air ACS fail. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. Passive ACS then successfully supplements the heat removal function and RVACS removes the remaining heat load from PHTS and no fuel damage occurs. There is no release from non-fuel sources.

DBA Description

TOP Fault IE with successful Control Rod Insertion. All four PHTS EM pumps and two IHTS EM pumps trip which ensures no pump heat is added to decay heat in the PHTS. RVACS successfully fulfills the heat removal function and no fuel damage occurs. There is no release from non-fuel sources.

3.7.2 Safety Analysis of DBAs

This task (LBE Selection Task 7d) is outside the scope of this demonstration project.

3.8 Defense in Depth Overview

The final key part of the LMP RIPB framework addressed in the Demonstration is the RIPB evaluation of DID adequacy. The reasons for including a DID evaluation as part of the LMP framework are discussed below.

- It is desirable for the reactor developer and the plant operator to take ownership of establishing DID adequacy because the key RIPB decisions that influence plant capabilities and programs that are responsible for achieving DID adequacy must be introduced early in the design.
- Historical references on DID by the NRC [Reference 12] and the IAEA [Reference 13] are rooted in terms that were developed for operating LWRs and have questionable applicability to advanced non-LWRs. Hence a technology inclusive language for defining and evaluating DID is needed.
- By documenting the basis for DID adequacy as part of the safety case it is considered less likely that there would be costly back fits imposed by the regulator and more likely that the regulator would appreciate the DID capabilities.
- The LMP approach to DID includes criteria for deciding the sufficiency of DID that aim to avoid an open-ended process for evaluating DID. The approach is based on the Layers of Defense concept recommended in Reference [13] which acknowledges both physical barriers and functional barriers to prevent the uncontrolled release of radioactive material.

An overview of the key elements of the approach to defining DID, which is built on earlier efforts to address this topic for the PBMR and NGNP projects, is provided in Figure 8. The LMP approach to establishing DID adequacy is integrated into each of the other key elements of the LMP framework. There are important DID roles in each major element of the framework including:

- Designer development of the safety design approach
- Development and analysis of information from the design and design specific PRA development
- Selection and evaluation of LBEs
- Establishing the adequacy of margins in the evaluation of risk significance of LBEs, safety functions, and SSCs
- SSC safety classification and development of SSC performance requirements

- Establishing the appropriate special treatment based on the insights gained from the PRA LBE development and SSC classification

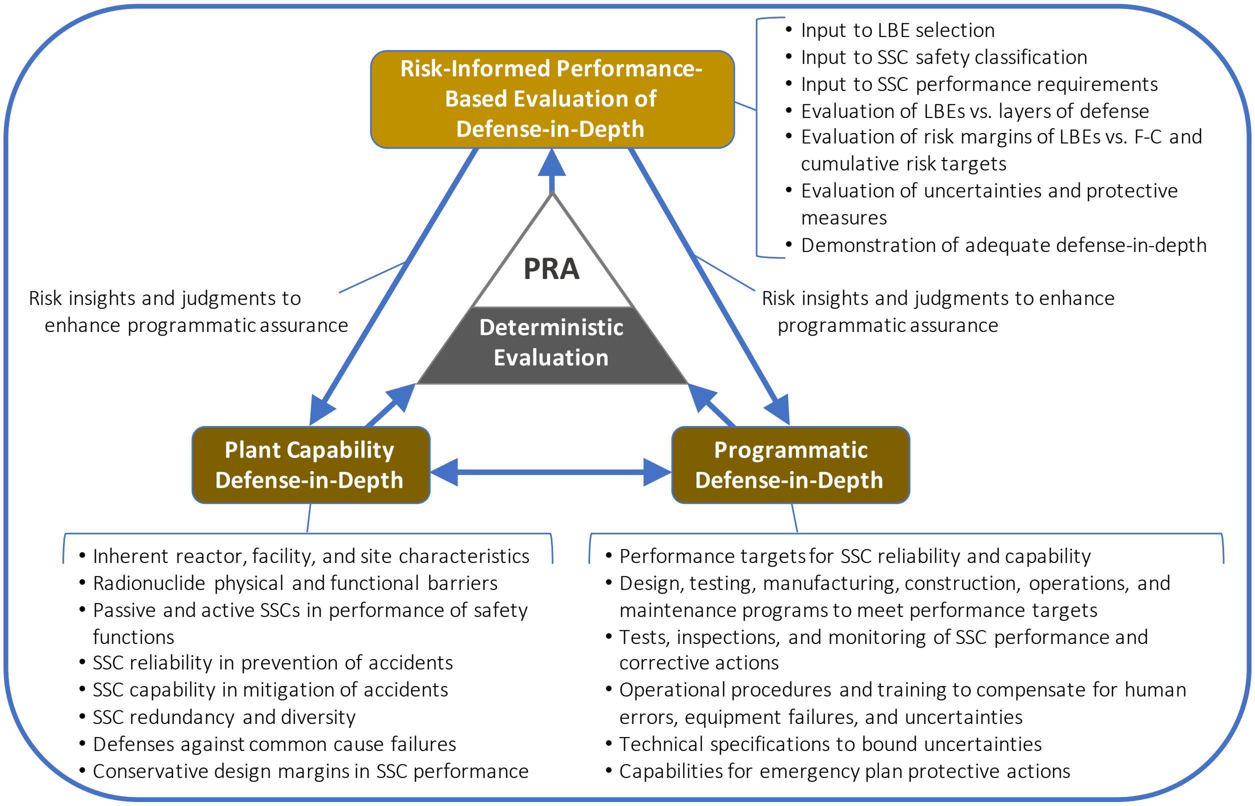

Figure 8. LMP Framework for Establishing DID Adequacy

To address the key question of "When is enough, enough?" a set of criteria are included as summarized in Table 7 for application in establishing DID adequacy for a plant at a suitable level of design completion. When implemented, these criteria track the five key layers of defense in the prevention and mitigation of accidents and include both quantitative and qualitative criteria for establishing DID adequacy. These criteria ensure that the frequencies and consequences of LBEs are maintained in the appropriate categories and exhibit sufficient margins against the F-C Target and the cumulative risk criteria. The adequacy is evaluated at each stage of design, licensing, construction, and operation by an Integrated Decision Panel, comprised initially of those responsible for selecting and evaluating the safety design approach and eventually by the owner operator. These DID evaluations are documented and available for review and audit by the regulator.

As part of this LMP Demonstration project, a first pass through the DID adequacy process was performed. The Heat Removal required safety function received most of the focus during this review. Although no formal Integrated Decision-Making Panel (IDP) was performed, the documentation that resulted from this first pass can support a demonstration IDP. Note: no programmatic DID was performed.

Figure 9 provides the flow chart representing the DID process.

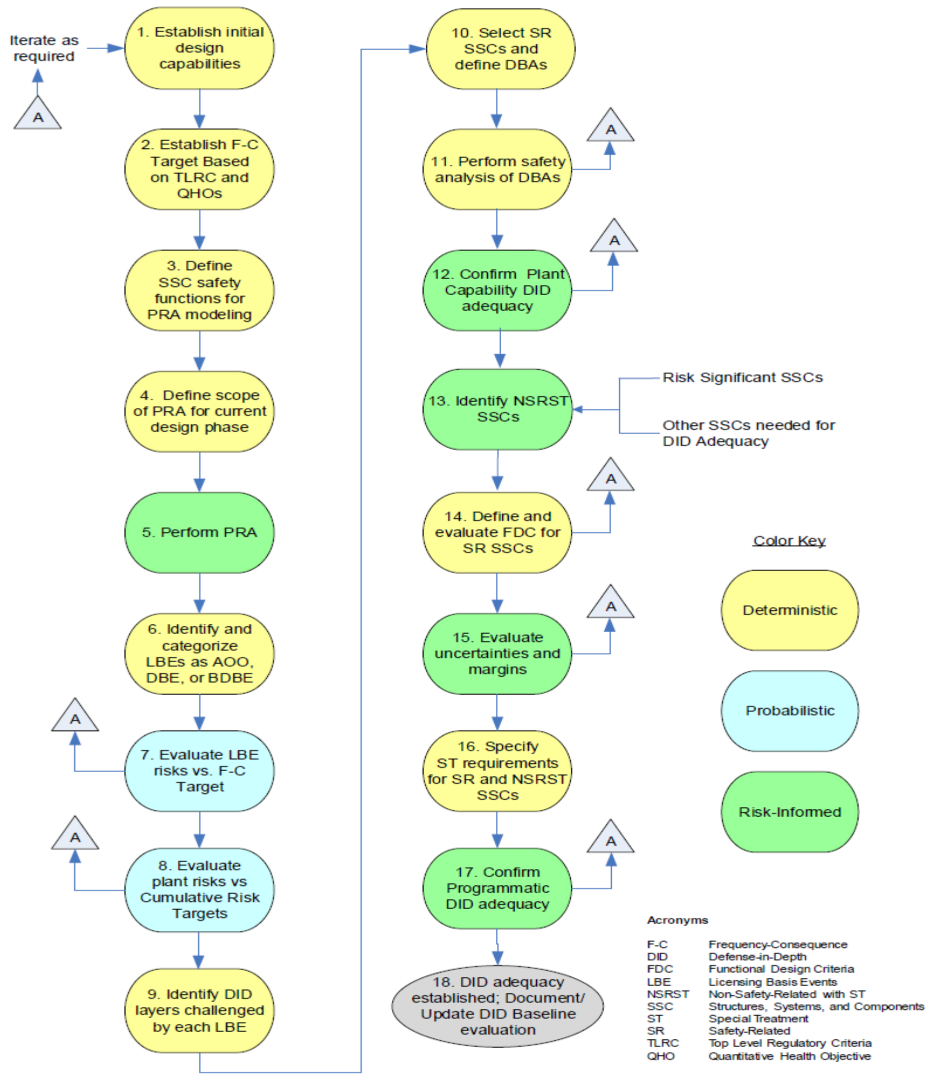

Figure 9. DID Process

A preliminary DID adequacy evaluation was performed. Each layer in Table 7 is analyzed for the current stage of PRISM design with recommendations provided for the identified gaps.

Table 7. Guidelines for Establishing the Adequacy of Overall Plant Capability Defense-in-Depth

<table>
<tr><th rowspan="2">Layer[a]</th><th colspan="2">Layer Guideline</th><th colspan="2">Overall Guidelines</th></tr>
<tr><th>Quantitative</th><th>Qualitative</th><th>Quantitative</th><th>Qualitative</th></tr>
<tr><td>1) Prevent off-normal operation and AOOs</td><td colspan="2">Maintain frequency of plant transients within designed cycles; meet owner requirements for plant reliability and availability</td><td rowspan="5">Meet F-C Target for all LBEs and cumulative risk metric targets with sufficient margins</td><td rowspan="5">No single design or operational feature, no matter how robust, is exclusively relied upon to satisfy the five layers of defense</td></tr>
<tr><td>2) Control abnormal operation, detect failures, and prevent DBEs</td><td>Maintain frequency of all DBEs $< 10^{-2}$/plant-year</td><td>Minimize frequency of challenges to SR SSCs</td></tr>
<tr><td>3) Control DBEs within the analyzed design basis conditions and prevent BDBEs</td><td>Maintain frequency of all BDBEs $< 10^{-4}$/plant-year</td><td>No single design or operational feature relied upon to meet quantitative objective for all DBEs</td></tr>
<tr><td>4) Control severe plant conditions and mitigate consequences of BDBEs</td><td rowspan="2">Maintain individual risks from all LBEs < QHOs with sufficient margins</td><td rowspan="2">No single barrier or plant feature relied upon to limit releases in achieving quantitative objectives for all BDBEs</td></tr>
<tr><td>5) Deploy adequate offsite protective actions and prevent adverse impact on public health and safety</td></tr>
</table>

3.8.1 Box 1: Establish Initial Design Capabilities

Refer to Section 3.2.1 above.

3.8.2 Box 2: Establish F-C Target Based on TLRC and QHOs

The F-C Target along with its basis is documented in the LMP Guidance Document. The F-C Target is shown above in Figure 1.

3.8.3 Box 3: Define SSC Safety Functions for PRA Modeling

The following PRA Safety Functions for PRISM were identified in the PRISM PRA:

1. Reactivity Control
2. Core Flow
3. Heat Removal from primary sodium
4. Confinement

These functions are allocated to passive and active SSCs through the use of event trees in the PRA. Table 8 shows the relationship between safety function and the headers in the event trees. These headers are then mapped to SSCs through the PRA fault trees.

Table 8. SSC Safety Functions

Safety Function	*Top*	*Description*
Reactivity Control	Top_CR	Scram signal and control rod insertion
Reactivity Control	Top_IRF	IRF and GEMs
Reactivity Control	Top_USS	USS control rod insertion
Heat Removal	Top_SGDry	Arrest of SG sodium water reaction
Heat Removal	Top_BOP	BOP cooling
Heat Removal	Top_FACS	Forced air Auxiliary Cooling System (ACS)
Heat Removal	Top_xPump	Tripping of Primary and Intermediate EM pumps
Heat Removal	Top_PACS	Passive ACS
Heat Removal	Top_RVACS	RVACS cooling
Heat Removal	Top_IHTS	IHTS to move heat
Core Flow	Top_Coast	Primary EM Pump coastdown
Confinement	Top_Bypass	Bypass
Confinement	Top_Ves	Vessel head intact
Confinement	Top_Cnt	Containment isolation

In LBE Selection Task 5a, Reactivity Control and Heat Removal were determined to be the required safety functions for PRISM. Core Flow and Confinement, in this task, were shown to be not required for meeting the F-C Target.

3.8.4 Box 4: Define Scope of PRA for Current Design Phase

The PRA scope for this demonstration is IEAP. Although the PRISM PRA does include a detailed evaluation of all hazards and modes with a bounding quantification for each, the scope was limited to IEAP to ensure the process could be carried out within the project timeline. Expansion to a fuller scope should be considered in the future.

3.8.5 Box 5: Perform PRA

The selection of LBEs requires development of a PRA as one of its tasks. GEH teamed with Argonne National Laboratory in 2015 and 2016 to perform research and development of next-generation PRA methodologies for the modernization of an advanced non-light water reactor PRA. This project was sponsored by the DOE.

The modernization project built upon a PRA developed in the early 1990s for the PRISM design. It resulted in a modern advanced non-LWR PRA with a detailed internal events model and a scoping external events analysis over all meaningful plant operating states including at-power and low power/shutdown. Modeling uncertainty, sensitivity, risk importance measures were

presented along with key risk insights. A semi-quantitative multi-unit analysis was also performed.

3.8.6 Box 6: Identify and Categorize LBEs as AOOs, DBEs, or BDBEs

ESFs were identified by grouping the PRISM event sequences based on IE, plant response, end state, and several other characteristics. The results from the PRA (cutsets) were then matched to these ESFs to allow calculation of ESF frequency. This frequency was then used to categorize certain ESFs as LBEs and further as AOOs, DBEs, or BDBEs. LBE Selection Task 4 provides an expanded discussion on the development and categorization process and the LBE results.

3.8.7 Box 7: Evaluate LBE Risks Vs. F-C Target

The visualization of LBEs against the F-C Target was performed in LBE Selection Task 7a. This plot is reproduced as Figure 10.

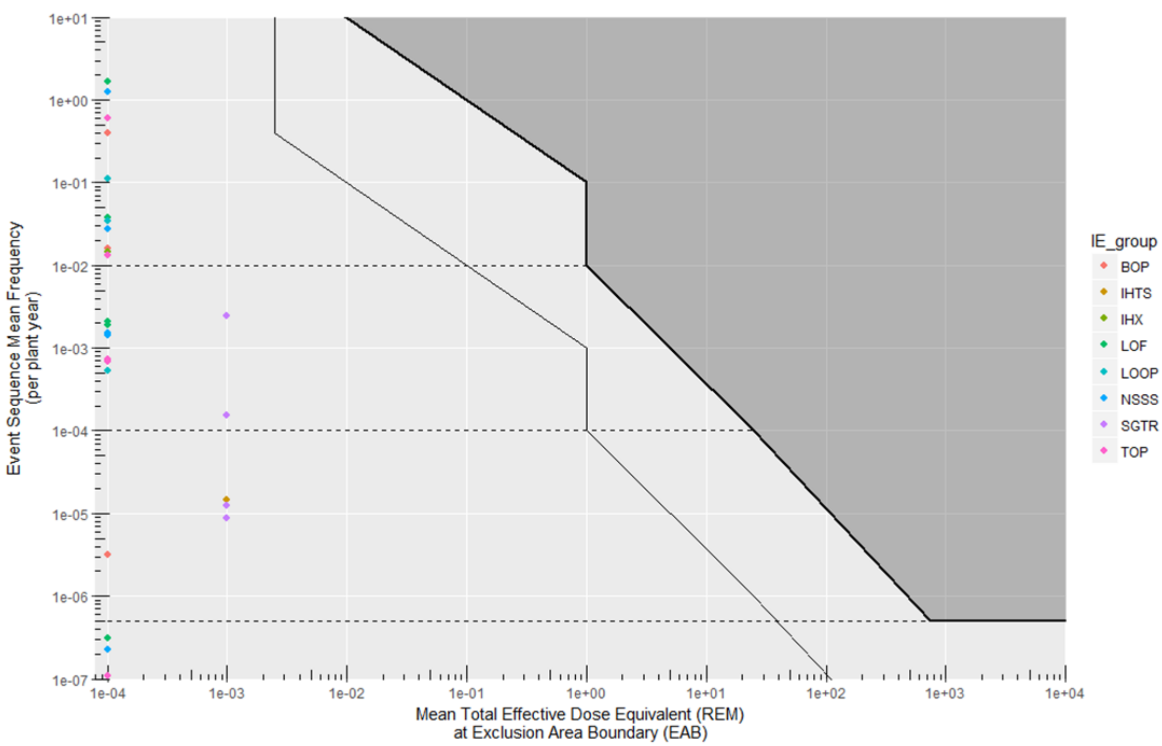

Figure 10. LBEs Plotted

Included in this plot is the LBE risk significance threshold line that was defined in the LMP guidance. As can be seen, no LBEs are risk significant for PRISM IEAP scope. The collection of SGTR and IHTS LBEs with non-zero consequences can be qualitatively assessed as having significant margin to the F-C Target point for each. These are non-fuel release LBEs that involve potential activated release from secondary sodium. It should be noted that the consequence for these LBEs were not included in the PRA's mechanistic source term and radiological consequence analyses. During the PRA, only fuel release scenarios were analyzed. Developing more realistic consequence estimates for non-fuel release scenarios has been identified as a future need for the PRISM PRA to supporting the LMP process.

3.8.8 Box 8: Evaluate Plant Risks Vs. Cumulative Risk Targets

LBE Selection Task 7b evaluated the integrated PRISM risk against the three cumulative risk targets. The results from this task show that there is significant margin between IEAP risk and the targets.

3.8.9 Box 9: Identify DID Layers Challenged by Each LBE

For this demonstration project, an introductory analysis and discussion for each layer is provided in Box 12.

3.8.10 Box 10: Select Safety-Related SSCs and Define DBAs

Select SR SSCs

SR SSCs were determined during the SSC Classification phase under Tasks 4a/5a. These SSCs can be grouped into the following high-level categories:

- Digital I&C logic and load drivers (RPS, DPS, Q-DCIS)
- Control rods and drives and associated operator actions
- EM pump supply breakers and associated operator actions
- 120-VAC equipment
- 125-VDC equipment
- Reactor vessel and internals
- RVACS

Define DBAs

Refer to Section 3.7.1.

3.8.11 Box 11: Perform Safety Analysis of DBAs

Refer to Section 3.7.2.

3.8.12 Box 12: Confirm Plant Capability DID Adequacy

> *"At this step, there is sufficient information, even during the conceptual engineering phase, to evaluate the adequacy of the plant capabilities for DID using information from the previous steps and guidelines for establishing the adequacy of DID. This step is supported by the results of the systematic evaluation of LBEs using the layers of defense process outlined in Figure 5-3 in Box 9. As part of the DID adequacy evaluation, each LBE is evaluated to confirm that risk targets are met without exclusive reliance on a single element of design, single program, or single DID attribute."*

A preliminary DID adequacy evaluation was performed (although not a formal IDP). Each layer in Table 5-2 of Reference 1 (Table 7 in this report) was analyzed for the current stage of PRISM design with recommendations provided for the identified gaps.

It is noted that examples are given where classification of a non-safety-related SSC as safety significant could be made to address DID adequacy. However, in a more complete execution of the DID adequacy evaluation process, the Integrated Decision Process may take some other action to achieve DID adequacy. When these examples are given, note that LMP does not automatically require classification of SSC as safety significant in order to achieve DID adequacy. Refer to Section 5 of the Guidance Document for more details.

3.8.12.1 Layer 1: Prevent Off-Normal Operation and AOOs

Guidelines

- Maintain frequency of plant transients within designed cycles
- Meet owner requirements for plant reliability and availability

A design objective of PRISM is to maximize generation output while optimizing maintenance costs. Through an Asset Performance Management (APM) integrated plant software platform, a combination of maintenance optimization analytics and latent stage equipment failure mode detection analytics would help minimize off-normal operation beyond typical Gen II performance. APM maintenance optimization analytics would determine the optimal use of preventive and predictive activities to prevent off-normal operation. Predictive analytics could detect numerous failure modes in the incipient stage (e.g. bearing failure, stator failure) which allows transfer to redundant equipment without challenging plant operation.

With the use of generation risk assessment models to help inform APM plant transient frequency can be predicted and features important to generation risk identified during plant design. This feedback helps risk-inform the design from an owner costs perspective while also contributing to Layer 1 prevention guidelines.

Recommendations
No SSCs need to be considered classified as safety significant to ensure DID adequacy for Layer 1. APM (or a more traditional risk asset management program) would help carry out typical industrial and special treatment requirements specified by the LMP process for PRISM.

3.8.12.2 Layer 2: Control abnormal operation, detect failures, and prevent DBEs

Guidelines

- Quantitative: Maintain frequency of all DBEs < 10^{-2}/plant-year
- Qualitative: Minimize frequency of challenges to safety-related SSCs

Key to examining this layer is the list of DBEs and SR SSCs identified in earlier phases of the LMP process.

Maintain frequency of all DBEs < 10^{-2}/plant-year
Using the SGTR DBEs as an example, the following features are key to keeping these DBEs less than 10^{-2}/plant-year:

- SG tubes and related structures (prevent SGTR IE)
- Sodium-Water Reaction Protection System (SWRPS) acoustic SSCs (detect incipient SGTR IE)
- SWRPS mitigation SSCs (prevent potentially higher consequence non-fuel release)

Minimize Frequency of SR SSC Challenges

The following SR SSC groups were defined previously:

- Digital I&C logic and load drivers (RPS, DPS, Q-DCIS)
- Control rods and drives and associated operator actions
- EM pump supply breakers and associated operator actions
- 120-VAC equipment
- 125-VDC equipment
- Reactor vessel and internals
- RVACS

The first six categories are challenged when an IE analyzed in the PRA occurs. This is because IEs involve a need for reactor scram or shutdown which will challenge the SR features of control rod insertion and EM pump trip along with their associated digital I&C and vital AC/DC supports.

RVACS, unlike the other SSC categories, is not challenged by the occurrence of the IE. For analyzed sequences, RVACS is only challenged after IHTS has failed to transport heat to the BOP or ACS or when the BOP/ACS fail. Therefore, the following are examples of SSCs that the IDP may consider as safety significant in order to address DID adequacy:

- IHTS features supporting heat transport including the IHXs
- Forced air cooling mode of ACS and supporting 480-VAC electrical equipment
- Steam Generator shell and tubes (not including feed water supply and steam supply to turbine)
- SWRPS

3.8.12.3 Layer 3: Control DBEs Within the Analyzed Design Basis Conditions and Prevent BDBEs

Guidelines

- Quantitative: Maintain frequency of all BDBEs < 10^{-4}/plant-year
- Qualitative: No single design or operational feature relied upon to meet quantitative objective for all DBEs

Prevent BDBEs

For the quantitative portion of this layer, BDBEs are examined.

There are five BDBEs identified for this demonstration of PRISM. All BDBEs are being kept below 10^{-4}/plant-year due to features already credited as SR or already recommended as NSRST under a Layer 2. Therefore, there is no new feature to recommend consideration as safety significant.

No Single Feature

For the Heat Removal function, ACS is available to support a subset of the DBEs, while RVACS is available to support all the DBEs. Therefore, no single design or operational feature is relied upon to meet the quantitative objective for all DBEs. To state this another way, since ACS is available to fulfil the heat removal safety function for many of the DBE sequences, RVACS is not exclusively relied upon to meet the quantitative objective for all DBEs.

3.8.12.4 Layer 4/5: Severe plant conditions and offsite protective actions

Guidelines

- Quantitative: Maintain individual risks from all LBEs < QHOs with sufficient margins
- Qualitative: No single barrier or plant feature relied upon to limit releases in achieving quantitative objectives for all BDBEs

Individual Risks

The integrated plant risk metrics calculated in LBE Selection Task 7b show that PRISM has a very large margin (several orders of magnitude) between predicted risk and target risk. The quantitative guideline is therefore considered met for Layers 4 and 5.

No single barrier

For the Heat Removal function:

- The fuel cladding is available to support all the DBEs
- The sodium pool is available to support all the DBEs

Therefore, no single design or operational feature is relied upon for the heat removal required safety function. No single barrier, outside of the fuel cladding, is relied upon to limit releases below QHO limits. The integrated metrics can be met, based on currently modeling, even if the Confinement safety function is assumed failed (all fuel releases assumed to bypass confinement).

3.8.12.5 Overall Guidelines

Guidelines

- Quantitative: Meet F-C Target for all LBEs and cumulative risk metric targets with sufficient margins
- Qualitative: No single design or operational feature, no matter how robust, is exclusively relied upon to satisfy the five layers of defense

Meet F-C and Cumulative Risk Targets

As demonstrated in LBE Selection Tasks 7a and 7b, all targets are met with substantial margin. Margin can currently be observed qualitatively using the plots provided in these Tasks.

Five Layers

As discussed under Layer 3, no single design feature is relied upon to satisfy the five layers of defense. Operational features were not examined as part of this example.

3.8.13 Box 13: Identify Non-Safety-Related with Special Treatment SSCs

Box 13 calls back to SSC Classification Task 4c and related guidance in Guidance Document Sections 4.3 and 5.6.2. In Section 4.3 the need to classify SSCs required for DID adequacy is specified:

> *"Any SSCs that do not meet the risk significance criteria will be classified as safety significant only if the integrated decision making process determines that some form of special treatment is necessary to establish the adequacy of DID."*

Although a formal IDP process is outside the scope of this demonstration project, the probable outcomes of IDP based on the DID adequacy analysis in Box 12 are discussed below.

The following features identified as safety significant in Box 12 are considered candidates to be classified as NSRST as one approach to achieve DID adequacy:

- SG shell and tubes
- IHTS features supporting heat transport
- Forced air cooling mode of ACS and supporting 480-VAC electrical equipment
- SWRPS detection and mitigation SSCs

3.8.14 Box 14: Define and Evaluate Functional Design Criteria for SR SSCs

The definition and evaluation of Functional Design Criteria is outside the scope of this demonstration.

3.8.15 Box 15: Evaluate Uncertainties and Margins

Although the evaluation of LBE uncertainties is outside the scope of this project, the PRISM PRA provided an extensive examination of uncertainties. A simple but systematic process was developed to determine the sources of uncertainty in the PRISM PRA model. It involved gathering sources of uncertainty, identifying the area of the model affected by the uncertainty, and characterizing the type of uncertainty as shown in Figure 11.

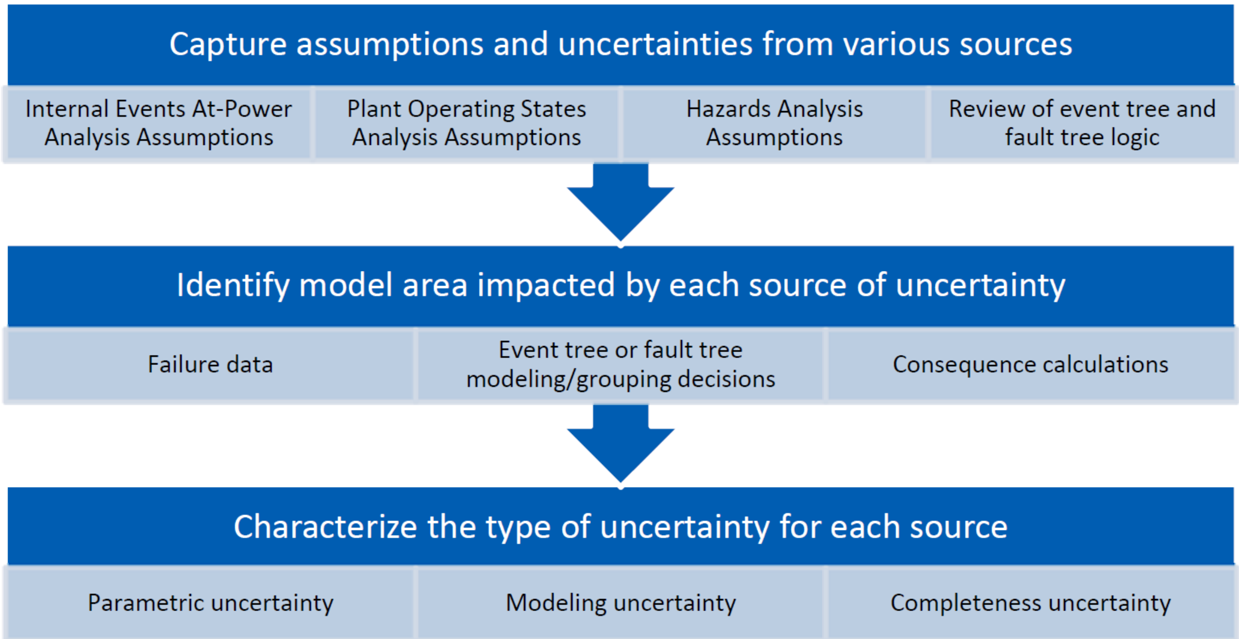

Figure 11. PRA Uncertainty

3.8.16 Box 16: Specify Special Treatment Requirements for SR and NSRST SSCs

The development of special treatment requirements is outside the scope of this demonstration.

3.8.17 Box 17: Confirm Programmatic DID Adequacy

Since this Box requires information from Box 16, it is also outside the scope of this demonstration.

3.8.18 Box 18: DID Adequacy Established; Document/Update DID Baseline Evaluation

The discussion in Box 12 provided a preview of what an IDP based DID adequacy analysis might look like. Establishing DID adequacy is outside the scope of this demonstration, however.

4 CONCLUSIONS

4.1 Overall Conclusions

The Demonstration Project met the objectives and deliverables as discussed in pre-demonstration meetings and summarized in this report.

1. Introduce the LMP process to GEH.

   Through two training sessions and several other team interactions, the LMP team was able to explain the LMP process to the GEH PRISM Demonstration participants.

2. Demonstrate select processes of the LMP Guidance Document as applied to the PRISM design.

   Significant progress was made to demonstrate the selection of LBEs based on information obtained from the PRISM PRA for event sequences, combined with performance-based targets for frequency and radiological dose, reflecting the PRISM conceptual design and additional efforts to estimate offsite radiological doses for each LBE. The process of defining the required safety functions using PRISM examples was also demonstrated. Options for selecting safety-related SSCs for each required safety function were identified in these examples. However, it should be noted that classification of SSCs as safety-related will ultimately be made by the designer. An introduction to the process of evaluating plant capability DID adequacy was also reviewed. Other elements of the DID adequacy determination were not exercised within the bounds of the Demonstration Project.

   Based on the scope and design basis of this Demonstration Project and follow-on presentations and conversations, the process described in the LMP Guidance Document was shown to provide a systematic, practical, and reproducible framework for selection of LBEs, defining required safety function, and classification of SSCs.

3. Provide an option for GEH to leverage the LMP process to improve the regulatory certainty of GEH's PRISM design and safety case, as best possible at the current state of design, by identifying a credible suite of Licensing Basis Events and investigating available structure, system, and component groupings that result in acceptable outcomes for the identified LBEs. Underlying this objective is the assertion that use of risk informed, performance-based methods to reach these conclusions are endorsed by Commission policy and compatible with the existing regulatory framework.

   The Demonstration provided insights into how the technology-inclusive, RIPB LMP process can be leveraged in the licensing process to provide:

   a: A flexible, systematic, and technically defendable process for developing the foundation for a PRISM safety case

   b. Minimized unnecessary regulatory burden

   c. Once the LMP proposed methodology is endorsed, reduced regulatory uncertainty, specifically in the areas of LBE selection, identification of required safety functions, SSC classification, and DID adequacy

GEH may select the LMP Demonstration Project, and this associated report, to serve as an input into GEH's PRISM on-going design efforts and to inform their regulatory engagement strategy.

Additionally, some design options were identified as part of the Demonstration. While no decisions were made during this Demonstration, an understanding of the RIPB processes proved valuable in identifying the steps needed to evaluate the safety-risk associated with various design selections and the tradeoffs needed from other stakeholders to achieve broader designer objectives.

In summary, this Demonstration shows the LMP processes have the potential to reduce regulatory uncertainty by providing a systematic, reproduceable, practical and transparent process, as well as criteria, for addressing key and fundamental safety questions and informing design decisions.

4.2 Other Observations

4.2.1 General

For the LMP to be fully effective, organizations should provide internal training on the LMP process, and ensure the appropriate members are sufficiently involved.

- Decision makers beyond the core engineering staff should use/embrace and be sufficiently knowledgeable of the LMP process to ensure regulatory/licensing success.
- It is important for the team following the LMP approach to have key, cross-functional engineering design and licensing team members and decision makers in charge of safety function development and the selection of SSC safety classification.

LMP provides a RIPB framework for making decisions that impact the safety design approach and technical basis for licensing activities. Based on the Demonstration, GEH believes that the usefulness and benefits of the LMP RIPB process will increase over time as the design completion and PRA update integration processes are performed.

The LMP approach to functional design criteria complements more deterministic approaches to develop Principle Design Criteria. Additional effort is needed to define the relationship of the LMP process with existing reactor General Design Criteria, Advanced Reactor Design Criteria, and other licensing requirements. These are topics currently being discussed as the Guidance Document and associated NRC interactions move forward.

RIPB decisions in the LMP framework are made by the designer integrated decision process for eventual approval by the regulator. This exercise of the LMP framework initially demonstrated that the RIPB process successfully:

- Provides a process for selecting and evaluating LBEs including the selection of DBAs as defined by user selected safety-related SSCs for the performance of required safety functions.

- Provides criteria for establishing risk significant and safety significant SSCs. Based on insights from the PRISM Demonstration, it is likely that for GEH's PRISM, most risk significant SSCs will be contained within the set of safety-related SSCs because none of the SSCs beyond the SR SSCs are expected to meet the LMPs criteria for risk significance.
- Enables the designer to establish requirements for the SSC reliabilities and capabilities to prevent and mitigate LBEs that will flow down to the special treatment requirements for safety significant (SR and NSRST SSCs).
- Gives the designer ownership of the responsibility to evaluate the adequacy of DID whose documentation will be available for review and audit by the NRC.
- With the Guidance Document, provides flexibility to the designer to meet other top-level requirements (e.g. performance, cost, risk, etc.).

Once DID adequacy evaluations are finalized in a future project, reliability, and performance programmatic DID requirements (e.g. technical specifications, reliability assurance programs, limits of operation, surveillance requirements, etc.) can be constructed for all the SR. NSRST SSCs will also have treatment requirements established which will be customized by the developer and can be as simple as monitoring reliability performance against a target. Larger LBE margins to the F-C Target can lead to the derivation of less stringent performance requirements than what has been typically done for existing light water reactors.

4.2.2 Comparison to Historical PRISM PSID Results

Historical Analyzed Events

A comparison was made between the DBEs described in the PRISM PSID [Reference 2] and the LBEs identified in this Demonstration project and is presented in Table 9. The Demonstration project results generally aligned with some of the PSID DBEs falling outside of (below) the LBE cutoff while other PSID DBEs were evaluated as BDBEs in the Demonstration project. Note that Fuel Handling and Storage Accidents, which were evaluated in the PSID, were not evaluated as part of the Demonstration project.

Table 9. Historical Comparison of Event Selection

PSID Event	*LMP Demo LBE Category*
Reactor scram, to envelope the design duty cycles for normal operation and anticipated scram events	AOO
Normal scram transients with flow coastdown	DBE
Reactivity addition with scram and flow coastdown	DBE
Loss of IHTS at full flow	BDBE
Reactivity addition at full flow without scram	Non-LBE
Loss of IHTS at full flow without scram	Non-LBE
Loss of flow with flow coastdown without scram	Non-LBE
Reactivity addition and loss of flow with flow coastdown without scram	Coincident IEs - not evaluated
Loss of flow and IHTS with flow coastdown without scram	Non-LBE
Reactivity addition and loss of power with flow coastdown without scram	Coincident IEs - not evaluated
Degraded RVACS and loss of IHTS with flow coastdown without scram	Non-LBE

Note: Non-LBE ESF—the frequency of this event sequence was below the cutoff for LBEs
Coincident IEs—simultaneous IEs fall well below PRA IE screening criteria

Possible LMP Process Optimizations

Following completion of the Demonstration project and in response to feedback provided by GEH participants and others, LMP team members identified several possible enhancements to the LMP Guidance Document and/or associated documents:

1. While the evaluation of external events was not part of the GEH PRISM Demonstration project, discussions amongst GEH and LMP team members revealed a possible need for more clarity in the LMP Guidance Document or associated white papers regarding how external events are included in the LMP process.
2. More clarity regarding how to model failure probability of passive systems may be needed in the LMP whitepapers. The PRA standard requires a quantitative uncertainty analysis of phenomena to quantify the failure probability of passive systems but examples in the PRA white paper may help in the future if funded as part of the project or picked up in a future standard on the topic. It is noted that NEI 18-04 does not require assuming complete failure of passive SSCs or inherent features. However, NEI 18-04 does require SSC failure mode determinations by the developer as part of safety case development, and also requires the definition of Required Safety Functions and plant features responsible for fulfilling them. Detailed guidance regarding the determination and treatment of passive and active SSC failure modes is outside the scope of NEI 18-04 and associated whitepapers. This topic is covered in other available references, including the ASME/ANS-RA-S-1.4, *Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants* [Reference 11], NUREG-0800, *Standard Review Plan for the Review of Safety*

Analysis Reports for Nuclear Power Plants: LWR Edition—Severe Accidents, Chapter 19 [Reference 14], and other regulatory guidance such as NUREG-1855, *Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision-making* [Reference 15].

3. The PRA white paper should clarify that a larger group of technical experts, as well as a wider range of data sources interrogated in the maturation of the PRA, are needed in order to establish adequate data certainty. The clarification should recognize the different types of deterministic insights into plant performance that can be part of the validation of the safety case as well as PRA adequacy case.
4. Consider providing more training in the PRA/LBE development area for non-PRA participants involved in the LMP integrated decision process so that they may better understand how the LBEs are formed and how LBEs can be traced back to individual PRA sequences and, thus, can make more informed judgements.
5. It may be beneficial to add guidance in the white paper and a reference in the Guidance Document regarding the need to identify the implicitly modelled components as part of the SSC classification process. While this consideration was always understood to be part of the process it was not definitively discussed.
6. Developing clear and comprehensive expectations in the white paper(s) to ensure a knowledgeable interdisciplinary team is capable of performing an effective integrated decision-making process.
7. A generic question arose about the DID adequacy guidelines in Table 5-2 of NEI 18-04:*

   "As it stands, the guidance for assessing defense-in-depth, especially Table 5-2 (page 82 of LMP version N), requires assessing SSCs based on whether their failure changes an event frequency category. This particular analysis is based only on frequency, not consequence. Dose/Consequence is not taken into account, nor is the F-C curve. This may lead to counterintuitive results. A frequency might just change enough to fall into another category, while still having zero or very low dose or consequence. This may mean that higher classification/special treatment may be put on an array of SSCs for little to no apparent reason. The DID approach is deterministic."

   The LMP Team provides the following response: NEI 18-04, Figure 5-4 "Integrated Process for Incorporation and Evaluation of Defense-In-Depth" and supporting text reflects the tasks in the LMP process, including Task 12 for plant capability DID, prior to concluding DID adequacy (Task 18). Evaluation of LBEs, including zero/low consequence LBEs against the F-C curve, are taken into account in SSC classification decisions. DID change evaluation in Task 18 considers reasons for frequency as well as consequences, and SSC classification as NSRST is not an automatic, prescribed action within the process. SSC classification action depends

* To provide a context for the question, it is noted that, due to constraints on available resources, the LMP's DID methodology was not fully executed during this tabletop exercise.

on IDP outcome. Adding special treatment to a non-safety-related SSC is just one option available to achieve DID adequacy.

In the limited time available for the DID part of the RIPB demonstration project, GEH chose to focus on application of the guidelines in Table 5-2 for addressing the adequacy of Plant Capability DID. In the demonstration, GEH identified several SSCs that could be classified as NSRST for the heat removal required safety function as a means of fulfilling the DID adequacy guidelines. Options other than classifying SSCs as NSRST that could be identified with a more complete execution of all of the DID methodology parts that were not explored as they were outside the scope of the demonstration.

It is recommended that text changes to NEI 18-04, Section 5.6.2 (and conforming changes) be made to clarify application of Table 5-2 and improve alignment with the Tasks summarized in Figure 5-4.

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