Postulated Initiating Events for the IMSR400

Topical Report TR251231-NP-A

Revision 0

June 2026

Abstract

This topical report describes the methodology used to develop a set of postulated initiating events (PIE) for the Integral Molten Salt Reactor (IMSR) design and provides as complete a set of PIE as is possible given the design's maturity. The methodology is not confined to the events that only affect the IMSR Core-unit. The set of PIE discussed in this topical report, and associated references, result from an examination of the complete IMSR facility. This methodology includes the examination of potential off-normal conditions that can lead to potential challenges to one or more of the fundamental safety functions.

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Executive Summary

This topical report describes the methodology used to develop a set of postulated initiating events (PIE) for the Integral Molten Salt Reactor (IMSR) design and provides as complete a set of PIE as is possible given the design's maturity. The methodology is not confined to the events that only affect the IMSR Core-unit. The set of PIE discussed in this topical report, and associated references, result from an examination of the complete IMSR facility. This methodology includes an examination of potential off-normal conditions that can lead to potential challenges to one or more of the fundamental safety functions.

Regulatory finality is being sought on the methodology described in Section III of this topical report. The methodology includes the process that will be used to establish a set of PIE for the IMSR400 and the criteria for classifying individual PIE for evaluation. Regulatory finality on the enclosed list of PIE or the classification of individual PIE is not being requested in this topical report at this time. The presentation of information about the methodology and an application of the methodology provides the opportunity for the regulator to observe the application of the methodology and the resulting outcomes for event classification once the methodology is implemented on the design. Regulatory approval of a final comprehensive list of PIE and the final individual PIE classification will be requested as part of a future license application review.

I. Purpose

The purpose of this topical report is to describe and seek NRC regulatory approval for the methodology used to develop a set of postulated initiating events (PIEs) for the Integral Molten Salt Reactor (IMSR) design, and to provide as complete a set of PIEs as is possible given the design's maturity. The set of PIEs discussed in this topical report are not confined to the events that only affect the IMSR Core-unit and are presented to demonstrate the methodology. The set of PIEs discussed in this topical report and associated references result from an examination of the IMSR facility as a whole. The examination includes the potential off-normal conditions that can lead to potential challenges to one or more of the following fundamental safety functions:

- Controlling reactivity
- Removing heat from the primary system (fuel salt)
- Retaining radionuclides

Regulatory finality is being sought on the methodology that will be used to establish the set of PIE and the criteria for classifying individual PIEs for evaluation. Regulatory finality on the enclosed list of PIEs or the classification of individual PIE is not requested in this topical report.

The discussion of the implementation of the PIE identification methodology and the potential results of the direct application of the methodology are provided in Sections III.4 and III.5 for illustrative purposes. The information in those sections provides the U.S. Nuclear Regulatory Commission (NRC) the opportunity to see clearly how the methodology will be successful in identifying all potential initiating events affecting the operation of the IMSR400 for all plant states and provides the opportunity for the NRC to ask for specific information about the planned design and operation of the IMSR400. Regulatory approval of a final comprehensive list of PIE and the final individual PIE classification will be part of a future license application review.

The design information associated with the IMSR400 reflects the information available for systems as of March 2023. The information was collected from the documents listed in Section VI.

The information in this topical report also addresses the comments received from the Canadian Nuclear Safety Commission (CNSC) and the NRC in their joint report on this topic titled "Joint Report on Terrestrial Energy's Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor" [R-12].

II. Introduction

II.1 Licensing Strategy and Objective

Terrestrial Energy USA's (TEUSA) long-term licensing objective for the commercial deployment of the IMSR design in the U.S. is to first obtain an SDA for the IMSR Core-unit under 10 CFR Part 52, Subpart E. The IMSR Core-unit represents a significant technical portion of the IMSR facility and includes many systems that perform important safety functions. The systems within the Core-unit are reasonably discernible from systems outside the boundaries of the Core-unit. Subsequent sections of this white paper provide additional details about the design envelope of the IMSR Core-unit and its safety interfaces.

TEUSA has developed and submitted a Regulatory Engagement Plan (REP) [R-1] to the NRC. The REP outlines a series of technical documents which TEUSA plans to submit to the NRC for review and comment or review and approval. The TEUSA REP provides additional details regarding TEUSA's licensing activities and objectives.

The identification of PIEs is the first step in the design review and assessment process. It is also a starting point for the safety analysis. A PIE is an event identified in the design that leads to Anticipated Operational Occurrences (AOOs) or accident conditions. Accident conditions include Design Basis Accidents (DBAs) and Beyond Design Basis Accidents (BDBAs). BDBAs include a subset of severe accidents.

There are several sources used to identify the PIEs. The basic sources include Probabilistic Safety Assessment (PSA, hereafter referred to as a Probabilistic Risk Assessment (PRA), engineering judgement, reference lists for the same or similar type of reactor, and operational experience. The operational experience from the Molten Salt Reactor Experiment (MSRE) contains some actual AOOs and experiments which provide insight on DBAs.

The PIEs are further grouped into categories, based on similarity of the plant response or similar initiating failures. The resulting list of PIEs will need to be updated as the design evolves. The set of PIEs will be finalized, and the final classification of PIEs will be confirmed or will be adjusted at the time the result of the complete PRA becomes available. The final set of PIEs will be submitted for review and approval as part of a license application.

II.2 Description of the IMSR400

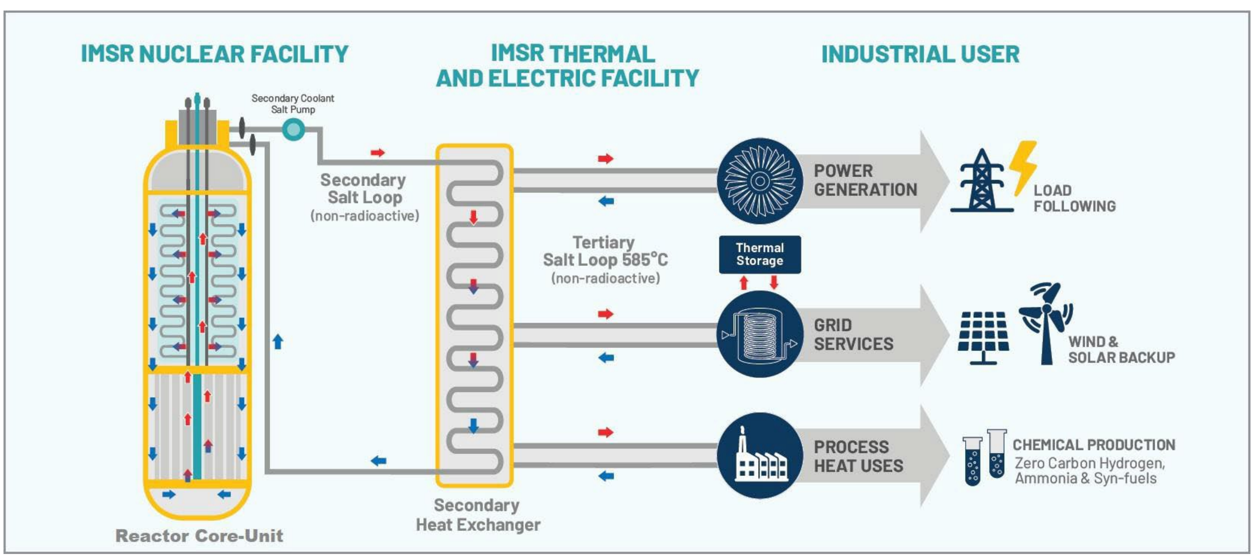
IMSR400, developed by Terrestrial Energy Inc. (TEI), is a near-atmospheric pressure, pool-type, and integral reactor vessel, called the Core-unit, featuring integral primary heat exchangers (PHXs), pumps and extensive inherent and passive safety features. IMSR400 employs a liquid fuel (Fuel Salt) rather than a conventional solid fuel; this liquid contains nuclear fuel and also serves as the primary coolant. It uses graphite as the moderator and operates at low pressure and high temperature (~700 °C) with a rated thermal capacity of 442 MW and provides 195 MWe (net) in electrical power, as well as 585 °C heat for a broad range of potential industrial heat applications. An expanded discussion of the key systems and structures that will be discussed in this topical can be found in the TEUSA White Paper "Core-unit Definition, applicable Structures, Systems, and Components" (TEUSA Document #200310) [R-2] A more detailed presentation of the design details for the systems and structures of the IMSR400 would be found in the specific system reference documents listed in Section VI of this report.

Some of the key factors that support the enhanced safety performance of IMSR400 are as follows:

- IMSR400 has a negative temperature reactivity coefficient of the Fuel Salt [R-13]. If there is a power generation to heat removal mismatch, the increasing Fuel Salt temperature causes a decrease in the reactivity of the system and eventually stabilizes the nuclear reaction such that adverse effects from the reactivity excursion are precluded.
- IMSR400 utilizes a passive heat removal system known as Internal Reactor Vessel Auxiliary Cooling System (IRVACS) [R-14], which, together with the negative temperature reactivity coefficient, is designed to handle extreme events (such as Station Blackout) in a passive operational mode. As a passive system, using thermosyphoning loops, IRVACS is continuously running, even in the Normal Operation (NO) mode. Therefore, IRVACS is always available (rather than requiring activation) for when a PIE which requires it occurs.
- The Fuel Salt, Secondary Coolant Salt and Tertiary Coolant Salt are chemically stable. Therefore, no chemical reactivity is expected.
- Gaseous fission products such as Krypton, Xenon and Tritium are removed from the IMSR400 Core-unit to minimize their available volumes for leakage in accidents and to maintain low pressures in the Core-unit.
- IMSR400 uses a passive Containment for safety, which is a Category A passive system since the Containment structure has no active components.
- The boiling point of Fuel Salt is above 1400°C, much higher than the operating temperature of ~700 °C. This allows a low operating pressure of the core without risk of fuel boiling.

Figure 1 is a flow schematic of the main heat transfer path for the IMSR400. The IMSR400 uses molten fluoride salt, [[ ]] for its primary Fuel Salt. A Secondary Coolant System (SCS), also using a fluoride salt [[ ]], transfers heat away from the Core-unit through the integral PHXs. The SCS, in turn, transfers its heat load to a Tertiary Coolant System (TCS) via the Secondary Heat Exchangers (SHXs), which circulates the heated Tertiary Coolant Salt to a separate building (outside of the nuclear island) where it either transfers heat to Steam Generators (SGs) that generate superheated steam for power generation, or transfers heat to process heat applications.

Figure 1 – Flow Schematic of the Main Heat Transfer Path for the IMSR400 [R-15]



II.3 Scope

The PIE methodology contained in this report represents an evolution of the initial PIE methodology previously submitted in the TEUSA white paper “TEUSA submittal of Postulated Initiating Events for the IMSR®” Revision 2, December 16, 2021 (ML21357A015). The revised methodology addresses some of the comments provided by CNSC and the NRC from their joint review in the document titled "Joint Report on Terrestrial Energy’s Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor,” May 2022 (ML22139A124) [R-12].

This methodology evaluates a single-unit Nuclear Power Plant (NPP) configuration on a generic site (i.e., not site-specific). The methodology for identifying PIEs requires that the following plant operating modes be evaluated:

- **Fuel Storage**: this operating mode refers to the storage of irradiated, unirradiated and decayed Fuel Salt outside of the Core-unit. Locations for fuel storage include the Fuel Salt Storage Tank (FSST), Spent Fuel Storage Tanks (SFSTs), Initial and Makeup Fueling Room and the Flush Tanks[1]. This mode also includes the transfer of irradiated Fuel Salt from the FSST to the SFSTs. A description of the Initial and Makeup Fueling Room is provided in [R-17].
- **Initial Fueling**: this operating mode begins once transfer of Fuel Salt from the FSST to the Core-unit with the Shutdown Rods (SDRs) inserted begins (end of Fuel Storage mode) and ends once the Core-unit is filled to the desired level (start of Shutdown mode). This mode includes the subsequent flushing of the salt transfer lines. The steps followed for Initial Fueling are outlined in [R-16]
- **Shutdown[2]:** this operating mode refers to a filled Core-unit (i.e., filled to the level required for operation) with the SDRs inserted.
- **Startup**: this operating mode begins once the SDRs are removed while the reactor is above the criticality temperature (end of Shutdown mode), resulting in the reactor being shutdown on temperature, and ends once the reactor temperature is brought below the criticality temperature by increasing demand from the Steam Plant (start of At-power mode). Note that Startup can occur either after Initial Fueling or after Shutting Down (i.e., for maintenance). The steps followed for Startup are outlined in [R-13].
- **At-power**: this operating mode refers to an operating Core-unit which generates thermal power that is transferred to the Steam Plant via the SCS and TCS. This mode also includes the periodic addition of makeup Fuel Salt, as described in [R-17]
- **Shutting Down**: this operating mode begins once the reactor is above the criticality temperature (end of At-power mode), resulting in the reactor being shutdown on temperature, and ends once the SDRs are inserted while the reactor is still above the criticality temperature (start of Shutdown mode). During this transition, the Core heat removal switches from the Steam Plant to Process Reactor Auxiliary Cooling System (PRACS), and once heat removal is controlled by PRACS, the SDRs are inserted. The steps followed for Shutting Down are outlined in [R-18].

[1] Flush Tanks are included as a location for fuel storage because after flushing, the flush salt is mixed with the residual irradiated Fuel Salt from the piping/vessels, and this mixture is subsequently transferred to the Flush Tanks. Therefore, this residual irradiated Fuel Salt is being stored in the Flush Tanks.

[2] The Core-unit can shut down with either the SDRs or on high temperature (i.e., exceeding the criticality temperature). The Shutdown mode described here includes shutdown only with the SDRs, based on the normal operation modes going to Shutdown (see Shutting Down) and going from Shutdown (see Startup and Defueling).

- **Defueling**: this operating mode begins once the transfer of Fuel Salt from a Core-unit to the FSST is initiated (end of Shutdown mode, but SDRs remain inserted) and ends once the Core-unit is empty to the extent possible. This mode includes the subsequent flushing of the salt transfer lines. The steps followed for Defueling are outlined in [R-16].
- **Core-swap**: this operating mode involves the replacement of a spent Core-unit with a new Core-unit within the Containment volume. Note that this process can take place at any point after a spent Core-unit has been defueled and occurs in parallel with the other operating modes described above. The steps followed for Core-swap are outlined in [R-19].

Figure 2: Plant operating modes and the transitions between them for normal operation[3]

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The major Structures, Systems and Components (SSCs) which this document covers are the following:

1. SCS
2. TCS
3. Core-unit[4]
4. IRVACS
5. IPS (Integral Pumping System)
6. SHXs

[3] Note that Core-swap can take place at any point after a Core-unit has been defueled and occurs in parallel with the other operating modes shown in **Figure 2**.

[4] Core-unit includes the RV and its contents, which are the graphite core, Primary Pumps, PHXs, Fuel Salt, EHX1 of IRVACS.

7. SGs
8. Steam Plant
9. IrFS (Irradiated Fueling System)
10. FSST Active Cooling System (FACS)
11. IFACS (Irradiated Fuel Auxiliary Cooling System)
12. Initial Fuel System (InFS) and Makeup Fuel System (MFS)
13. Core-swap system
14. PRACS (Process Reactor Auxiliary Cooling System)
15. Core-unit support structures
16. Containment

Additionally, PIEs related to the Instrumentation and Controls (I&C) and plant electrical systems have been considered. The PIEs identified in this report include, as potential causes, the failure of all supporting Systems, Subsystems and Components (SSCs, e.g., failure of HVAC), leading to the failure of a system safety function.

PIEs arising from malevolent attacks and safeguard related events are not covered in this document. Details on these can be found in the Preliminary Safety Analysis Report (PSAR) Annex 1: Security [R-20], PSAR Annex 2: Safeguards [R-21] and the Plant Control and Monitoring System (PCMS) design description [R-22] (for details on cyber-attacks).

This document only considers events within the nuclear island, or events which initiate outside of the nuclear island but then propagate to the nuclear island, such as the external hazards (see section III.4.6). For this document, the Balance of Plant (BOP) is a generic Steam Plant, where only bounding events causing increased or decreased heat removal are considered, as captured in [[ ]], respectively. Specific events within the Steam Plant (e.g., main steam line break, loss of feedwater, loss of condenser cooling, turbine trip) are considered as potential causes of these bounding events. Also, Steam Plant events which impact the Nuclear Plant pressure boundary are also considered (i.e., [[ ]]). Note that the Steam Plant is not required to maintain the control, cool and contain safety function capabilities of the NPP (i.e., the SSCs of the Steam Plant will not be needed to perform any safety functions).

Note that certain PIEs impact the NPP as a whole, which includes safety systems, safety-related systems and non-safety-related systems. Examples of these PIEs include loss of offsite power and internal/external hazards. In terms of external hazards, the IMSR is currently designed as a generic IMSR plant that is designed and qualified against generic external hazards using generic site parameters. TEI used the following IAEA guidance to assist in the development of its list of potential generic external hazards to be evaluated for the IMSR design:

- IAEA Safety Standards Series No. NS-G-1.7, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants [R-24].
- IAEA Safety Standards Series No. NS-G-3.3, Evaluation of Seismic Hazards for Nuclear Power Plants [R-25].
- IAEA Safety Standards Series No. NS-G-1.5, External Events Excluding Earthquakes in the Design of Nuclear Power Plants [R-26].

- IAEA Safety Standards Series No. NS-G-1.11, Protection against Internal Hazards Other than Fires and Explosions in the Design of Nuclear Power Plants [R-27].
- IAEA Safety Standards Series No. NS-G-3.5, Flood Hazard for Nuclear Power Plants on Coastal and River Sites [R-28].
- IAEA Safety Standards Series No. NS-G-3.4, Meteorological Events in Site Evaluation for Nuclear Power Plants [R-29].
- IAEA Safety Guide No. NS-G-3.6, Geotechnical Aspects of Nuclear Power Plant Site Evaluation and Foundations [R-30].

The list of potential internal/external hazards includes environmental events (e.g., flooding, fire, earthquake) and internal system failures (e.g., explosion, missiles). For additional insights into the potential events to be considered, refer to Section III.4.6 of this report. The list will be modified to reflect the hazards present at any future site as part of the license application. Combination events (i.e., events that evaluate the combination of an internal event coupled with an external event or combination of multiple internal or external events) are not included in the scope of this document. A future revision of the PIE document will include credible combinations of individual events, including internal and external hazards, which could lead to anticipated operational occurrences or accident conditions, and shall be considered in the design. The process of identifying combinations of hazards will consider combinations that are either consequential or correlated and will exclude combinations of independent hazards, as per [R-23].

Malevolent attacks and safeguard-related events will be addressed separately under security and safeguards documentation. Note that protection against intentional large aircraft crash is considered in the IMSR design (also included in the protection against malevolent acts scope). Slow-developing degradation in the operating conditions (i.e., ageing) will be addressed in the plant design, equipment qualification program as well as the plant monitoring, maintenance, in-service inspection and test programs.

II.4 Quality Assurance

The Quality Assurance (QA) practices are in place to ensure that this methodology is accurate, complete, and up to date with respect to the design information, regulatory documents, internal analysis documents (i.e., DSA and PRA) and external literature/research and will be implemented in accordance with the process described in this topical report. The general controls used are described in the TEI Management System Manual, with additional information provided below. (Note that the TEI Management System is comparable in scope to 10 CFR 50 Appendix B. While the Quality Assurance Plan for TEUSA has not yet been submitted for review, TEUSA will ensure that the regulatory process described in this topical report will be performed under a quality assurance plan that meets NRC requirements.) Further, this is done through the selection of qualified persons to identify PIEs and the review and verification of the resulting documentation following the applicable management and review controls.

II.4.1 Expertise Requirements

In order to successfully identify a comprehensive set of PIEs, a person or set of people with substantial knowledge of the design and proposed operation of the IMSR400 is chosen to perform the process outlined in the methodology (see section III.1). One person from the Safety Team is assigned as the task lead by the Safety Team Manager and is supported in the effort by the other members of the Safety Team. The task lead will be responsible for creating an update plan for the PIE document and executing this plan (see section III.4.2). Additional qualified people are selected to review (and verify, see section III.4.2) the results of this process. The managers responsible for the technical and engineering disciplines, in consultation with the Safety Team manager, are tasked with the identification of personnel with the appropriate expertise to serve as reviewers of this document. It is the responsibility of the Safety Team Manager to ensure that the expertise of the selected personnel is relevant and sufficient to provide a comprehensive analysis.

Depending on the stage of the design and the extent of the updates required, the task lead, supporting team members and reviewers cumulatively have familiarity in all or a subset of the following areas [R-31]:

- Licensing
- Plant design details
  - Reactor
  - Spent fuel
  - Structures
  - Mechanical systems
  - Electrical systems
  - Instrumentation and control systems
  - Internal and External Hazards
- Plant operations
  - Concept of operations
  - Plant operating modes
- Reactor physics
- Thermal-hydraulic analysis
- Reliability engineering and/or PRA methods
- Expertise in the selected methods of analysis
- Expertise in disciplines unique to the chosen technology

Note that as the design develops, new information will become available and expertise requirements will change. Therefore, the requirements listed above may not all be utilized at each iteration of this document. The above list is a complete set of engineering disciplines that might be expected throughout the entire design process. For each iteration of this document, the task lead, as supported by the Safety Team Manager, will ensure that the expertise of the individuals involved is appropriate for the scope of the review.

II.4.2 Management and Review Controls

The management and review controls include the processes for collecting information that could result in changes to the PIEs, determining when updates are made and performing review. The general controls used at TEI are described in the Management System Manual [R-32], with additional information provided below.

The process in place for collecting information that could result in changes to the PIE (followed by evaluating that information to determine the necessity for an update) is primarily done using "points of contact", as described in [R-33] and illustrated in Figure 3 below. Points of contact are individuals of a technical discipline (e.g., safety) that are responsible for collecting new information from other disciplines (e.g., physics, mechanical, R&D) and for communicating this information to their own discipline. Each individual within a team is assigned one or more aspects of the design for which they act as point of contacts, so that cumulatively all members within a team establish a communication link to all other disciplines. The points of contact collect information primarily through meetings which the discipline responsible holds to update all points of contact with their new information. Following this routine process, periodic (internal) team meetings are held where team members will update the team with this new information and any associated documentation. In addition to this process, the review and comment process on any new documentation will include all interfacing disciplines (including safety). The reviewers representing these interfacing disciplines will then convey the information during the team meetings, such that the team is up-to-date on the work being done by other disciplines. For the Safety Team, all information which could result in changes to this document will be collected by the Safety Team Manager.

Figure 3: Schematic showing the transfer of information to the safety team using points of contact strategy[5]

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Based on an evaluation of this new information, as well as any external documentation (e.g., regulatory documents, literature from other reactors) and internal safety documentation (i.e., PRA and DSA) since the last PIE update, the Safety Team manager, with support from the Safety Team members, will perform an evaluation to determine if an update to the PIE identification methodology, PIE list or PIE classification is necessary. If an update is deemed necessary, the process of selecting qualified personnel will be initiated by the Safety Team Manager.

Once chosen, the task lead will begin by creating an update plan for the PIE document (see [R-7] for an example of an update plan). The update plan will be aligned with the engineering advancements in the IMSR design since the previous update. The update plan will highlight the areas of the IMSR design that have changed, and which now require updating in the reference document. The plan will include specific references to inputs that are to be used to perform these updates (e.g., design documents, literature, regulatory documents). This plan will also involve the assignment of work to qualified personnel who have access to all relevant background information, and the interfacing disciplines required for each update for details on interdisciplinary interface procedures/requirements). The task lead will also include in the plan the actions for review of the updated documentation. The Safety Team Manager, in consultation with other technical discipline managers and the task lead, will identify the specific reviewer(s) that have the necessary skills to effectively perform the review tasks as outlined in the

[5] Note that this figure is an example for illustrative purposes, there are more disciplines than what is shown.

update plan. The task lead will also be responsible for initiating the document controls described below.

Once the plan has been written, reviewed and approved (following similar procedures to those outlined for the review of the document draft, described below), the task lead will proceed to execute the plan that will result in a draft of the updated document. This draft will be reviewed, as outlined by the plan, by other safety team member(s) and members of interfacing disciplines for completeness and accuracy. The review process, referred to as the review and comment process, will take place through the established document management and control procedures. Each reviewer will be verifying that the information is accurate with respect to the design information and any other relevant references. Note that since no calculations are performed as part of the update process, no associated verification of calculations is required.

During the IMSR400 design, engineering, and pre-licensing phases there are no specific periods defined to update this information but are rather based on the collection and evaluation of new information by the Safety Team Manager and Safety Team, as described above. Once the IMSR400 is licensed, the evolution of the design would be greatly reduced and therefore, plant changes affecting the set of PIEs would be greatly reduced as well. Nonetheless, maintenance of the PIE list by both TEUSA and the plant license holder would be expected, in order to identify new events or update previous ones in terms of their descriptions, mitigations and frequencies. During the life cycle of the plant, this information will be updated periodically. While not a requirement of this methodology, a natural assessment point would seem to be the period following updates to the PRA or following each Core-unit reload (seven years). Nevertheless, if there is a significant change to the plant design or its risk profile, the supporting safety analysis documentation would be modified using the appropriate licensing basis change process established by the regulations.

It is essential that the PIE list is developed and finalized to include input from all interfacing disciplines. During the conceptual design and basic engineering stages, all relevant disciplines have been involved in the review of and feedback on the PIE methodology and PIE list, including DSA, PRA, Licensing, Physics, Thermal-hydraulics, Civil, I&C, R&D, Fire Protection, and system designers. External safety experts from Canada and UK in the DSA and PRA areas were also involved in the review of the IMSR PIE methodology. In the detailed engineering stage, an internal PIE panel will be established for further supporting the developing and finalizing the PIEs list. The PIE panel will include the experienced expertise from relevant disciplines. The panel will thus play a role in the identification, categorization, and/or classification of PIEs.

III. Process for Identifying PIEs

In the design stage of IMSR400 it is important to identify a comprehensive set of PIEs such that, to the extent practical, all foreseeable events are identified and are considered in the design. From the perspective of Safety Analysis, a comprehensive listing of PIEs should be prepared for all permissible plant operating modes to ensure that the analysis of the behavior of the plant is complete. Note that slow-developing degradation in the operating conditions is not considered a PIE. In the current methodology, each identified PIE is categorized into one of seven categories based on their associated primary plant response or similar initiating failures.

After the comprehensive list of PIEs is generated, the events are classified based on their estimated frequency of occurrence (i.e., AOO, DBA and BDBA, see section III.5 for classification criteria, inputs and preliminary results).

III.1 Approach for PIEs Identification

The PIE identification process should be as systematic and complete as possible. The various causes for an initiating event are considered, which include events internal and external to the NPP. For internal events, SSC failures, operator errors and hazards (i.e., human induced or caused by SSC failure/malfunction) which directly or indirectly challenge one or more of the systems required to maintain safety of the plant are considered. For external events, hazards (i.e., human induced or naturally occurring) and events originating in the Steam Plant are considered. External hazards are man-made or naturally occurring to a site and facilities and originate externally to both the site and its processes and over which the site operator may have no or very little control (e.g., earthquake). Internal hazards originate internally and can be man-made or caused by SSC failure/malfunction. As such, the operator may have more control over them. Since this document considers a generic site location, the hazards are based on generic IMSR400 qualification requirements. These events are currently described at a high level and will be broken down further into more specific PIEs once a detailed hazard assessment is complete. The PIEs identified in this report include, as potential causes, the failure of all supporting SSCs (e.g., failure of HVAC, leading to the failure of a system safety function).

The design philosophy for the IMSR is to preclude or limit the influence of human error on plant safety by using fault tolerant, inherent and passive safety features. IMSR is designed to minimize the possibility for human error. The human intervention generally acts as a back-up to automatic plant response in the IMSR design following a PIE. [[

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More details on human-induced events will arise from the human factors review and the PRA. Where design detail is still to be developed, the current PIE methodology uses a bounding or representative event as a placeholder for a more detailed initiator. Continuous and iterative consultation with the System Responsible Engineers (SREs) of the systems being analyzed in this report ensures that all PIEs and their respective mitigations are captured to the extent practicable.

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When identifying PIEs, the various plant operating modes considered include Fuel Storage, Initial Fueling, Shutdown, Startup, At-power, Shutting Down, Defueling and Core-swap. The PRA model currently addresses three steady states (power, shutdown, fuel storage), for which fault schedules were generated and used to update the PIEs in this topical report [R-10]. The fault schedules outline the preventative, protective and mitigative safety measures (at a system level) intended to be claimed in the PRA for each identified initiating event. The PRA will be extended to cover all operating modes mentioned.

The PIE list is non-site-specific currently. Therefore, PIEs that are initiated by external hazards will require re-evaluation once the NPP site is chosen, based on the site evaluation and environmental assessment processes. Additional details regarding the scope considered in PIE identification are described in Section III.4. The identification of external hazards uses the list presented in [R-8], which is based on generic IMSR400 design using generic site parameters.

In this report, the "top-down" approach is employed to identify PIEs, which is similar to a Master Logic Diagram (MLD) used as a PRA tool [R-31]. Note that a general top-down approach was used which considers all plant operating modes, however, future work will involve performing individual top-down assessments as necessary for each plant operating mode and undertaking further bottom-up hazard identification (described below) to ensure that all foreseeable PIEs are identified. The top-down approach starts by specifying [[ ]] events. For example, with the top-level undesired outcome, the second level will be the direct and immediate causes of that outcome. Similarly, the third level will list the direct and immediate causes of the second level, and so on. At the end of this analysis process, the individual PIE would be identified.

To complement the top-down approach, a bottom-up approach (described below) is used to identify new PIEs (i.e., those which the top-down approach did not identify) or update ones previously identified by the top-down approach (i.e., in terms of event causes/mitigations). In this way, the results from both approaches can be integrated. When integrating the results, all events [[ ]] this methodology. This methodology is meant to develop a comprehensive list of all PIEs, no matter their likelihood. The PRA takes the PIE list presented here as an input and performs screening (i.e., removal of events which have low frequencies and/or consequences). (See [R-10] for screening methodology and results.

The bottom-up approach begins at a lower level (i.e., component or major component assembly) and considers how failures may affect the system-level or plant-level function. Examples of this approach include Hazard and Operability Analysis (HAZOP)[R-37], Failure Modes and Effect Analyses (FMEA)[R-38], Hierarchical Task Analysis (HTA) [R-39] [R-40], walkdown (physical/virtual) [R-41] and Human Error Identification (HEI)[R-40]. During the conceptual design stage, an accident list was generated using an approach similar to FMEA, however it did not show much insight (i.e., no new PIEs identified) [R-42]. [[

]] Figure 4 presents a mapping of the IMSR physical design to the functional model [R-42]. As shown in Figure 4, the process was supplemented by high-level Preliminary Hazards Analysis (PHA) and Failure Modes and Effects Analysis (FMEA).

Figure 4: Mapping the IMSR Functional Model to the IMSR Physical Architecture

[[

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The PSA report [R-10], generated later during the basic engineering design stage, contains an FMEA of IRVACS where no new PIEs were discovered, however the event causes/mitigations were used to update the existing events described in this document. [[

.]]

As detailed designs on plant systems become available (i.e., at the component level necessary to conduct a bottom-up analysis), further bottom-up analysis will be performed to aid in PIE identification and analysis. Also note that the referenced PRA report used ORNL Reports [R-43][R-44] as a completeness check for initiating event identification. Collectively, the use of top-down and bottom-up approaches provides assurance that faults and hazards have been comprehensively identified.

Additionally, a report from the Canadian Nuclear Laboratories (CNL) on the Phenomena Identification and Ranking Tables (PIRTs) for severe accidents in Small Modular High-Temperature Gas-Cooled Reactors (HTGRs) [R-45] was reviewed as a potential source of additional information for identification of PIEs. [[.]]

The approach for PIE identification is iterative since the design is constantly evolving. As new information becomes available, which includes but is not limited to regulatory documents, design updates, literature from other reactors and internal analysis documents (i.e., PRA and DSA), this methodology will capture that information and be used during the update process appropriately. Section II.4 provides information on when updates will take place.

III.2 PIEs Identification

According to the top-down approach, an undesired outcome is specified first. For IMSR400, a power reactor, the top event is taken as [[

]]

Figure 5: Main PIEs Identification Top-Down Flowchart of IMSR400 Radioactive Release [[

]]

Figure 6: PIEs Identification Top-Down Flowchart of Internal and External Common Cause Events [[

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Figure 7: PIEs Identification Top-Down Flowchart for Events from Reactivity Insertion inside the RV [[

]]

Figure 8: PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal inside the RV [[

]]

Figure 9: PIEs Identification Top-Down Flowchart for Events from Outside of the RV [[

]]

Figure 10: PIEs Identification Top-Down Flowchart for Events from Mechanical Failure of Boundary outside of the RV [[

]]

Figure 11: PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal Outside of the RV [[

]]

Figure 12 – PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal in the SCS [[

]]

III.3 PIEs Categorization

Based on the top-down flowcharts built in Section III.2, the postulated initiating events for IMSR400 are identified, which includes a total of [[ ]]. The identified events are categorized based on their associated primary plant response (e.g., increase/decrease of Core-unit heat removal) or similar initiating failures (e.g., loss of integrity of piping or vessel). This categorization is done to organize the PIEs, and not for analysis purposes in the PRA and DSA. In the current work, the categories used are the following (based on [R-6]):

1. Unwanted changes in reactivity
2. Increase of Core-unit heat removal
3. Decrease of Core-unit heat removal
4. Loss of integrity of piping or vessel
5. Internal Hazards
6. External Hazards
7. Additional Events

Note that the grouping of PIEs is conducted within the PRA process [R-10] used by Terrestrial Energy and will be conducted within the DSA process. Grouping involves [[

]] for each group. PIEs categorized based on the categories listed above can include multiple bounding events and are not the same as the grouping in the PRA/DSA mentioned above.

III.4 PIE List

Based on the work from Sections III.2 and III.3, a PIE list is generated with [[

.]] Note that the ordering of the PIEs was done chronologically (i.e., in each PIE document revision, additional PIEs were appended to the end of the tables shown below). Therefore, for a certain system, the PIEs related to it may not appear together (e.g., TCS Pump Trip is 3-7, TCS Pump under- speed is 3-41). The PIEs were not reordered to correct this because other documents reference the PIE numbers, so those references would not be correct if the numbering were to change. Additionally, where PIEs were removed or moved to different categories, their numbers were replaced with new PIEs (i.e., new to the document or moved from another category) such that the numbering of existing events was preserved.

[[

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In several entries in the tables below, it is noted that a bounding case will be analyzed. This analysis will be done as the Basic and Detailed Design Engineering work progresses. Note that the bounding cases have not yet been finalized.

III.4.1 Category 1: Unwanted Changes in Reactivity

[[

]]

III.4.2 Category 2: Increase of Core-unit Heat Removal

[[

]]

III.4.3 Category 3: Decrease of Core-unit Heat Removal[[

]]

III.4.4 Category 4: Loss of Integrity of Piping or Vessel [[ ]]

Category 5: Internal Hazards[[

]]

III.4.5 Category 6: External Hazards[[

]]

III.4.6 Category 7: Additional Events

[[

]]

III.5 Classification of the PIEs

After all PIEs are identified, they are classified based on their frequencies and consequences. The purpose of classifying PIEs is to guide the selection of appropriate analytical approaches for each event based on its classification. This classification supports the application of different acceptance criteria—safety criteria, design criteria, and operational criteria—and informs the identification of appropriate mitigating measures. In this report, the PIEs are classified into the following three plant states based only on their frequency[6]:

- AOO: AOOs are considered to represent a group of potentially frequent events or events that might be expected to occur one or more times in the lifetime of a plant. These include all events with frequencies of occurrence equal to or greater than 10^{-2} per reactor year.
- DBA: DBAs are much less likely to occur as compared to AOOs and would generally capture events that are expected to occur once in the lifetime of a large population of plants. These include events with frequencies of occurrence equal to or greater than 10^{-5} per reactor year, but less than 10^{-2} per reactor year.
- BDBA: BDBAs are not expected to occur during the lifetime of a fleet of reactors however, it is necessary to assess the capabilities of the plant to prevent or mitigate such events in the extremely unlikely event that such an event occurs. These include events with frequencies less than 10^{-5} per reactor year.

These frequency ranges are based on CNSC requirements (see [R-5]). Because the NRC does not have established frequency ranges for classifying accidents, and this methodology will also be used in Canada, this methodology will be using the classification ranges that comply with CNSC requirements. Therefore, TEUSA proposes to use the frequency ranges set in the CNSC requirements document for its event classification. The events with a frequency on the border between two classes of events would be conservatively classified into the higher frequency class. It is recognized that assessments of the frequency of occurrence of events close to borderline between classes may be characterized by uncertainty and such events may also be classified into the higher frequency class, depending on their 'spread'. [[

.]]

In the present revision of this methodology, the PIE frequencies and resulting classification were determined first from probabilistic studies. Note that for some events, the classification was based on an

[6] Classification of events based on both frequency and consequence may be done at a later stage, once the appropriate DSA has been conducted.

older version of the design and is therefore subject to change based on a future update to [R-9]. For events not included in the probabilistic studies (i.e., those which were identified after the study was carried out, or those which were screened out during the study[7]), engineering judgement was used with guidance from [R-6] (experience from other reactors). Operator error was also considered when determining frequencies and classifying PIEs.

Frequency of external events (see section III.4.6) is highly dependent on the NPP site and therefore the classification of those events presented here is subject to change based on the site evaluation and environmental assessment processes.

The engineering judgements used in this methodology are the following:

- [[

[7] No screening-out of PIEs was done in this methodology. This methodology is meant to contain a comprehensive list of all possible PIEs, no matter their likelihood. The PRA takes the PIE list presented here as an input and performs screening.

.]]

The current classification of PIEs is listed below as a reflection of the implementation of the methodology presented in this topical report to the current design of the IMSR400. It does not reflect the final classification nor the full set of postulated initiating events but does provide an opportunity to view the comprehensive nature of the process.

Note that for all [[

.]]

IRVACS related PIEs in section III.4.3 [[

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III.5.1 Anticipated Operational Occurrences (AOOs)

[[

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III.5.2 Design Basis Accidents (DBAs)

[[

]]

III.5.3 Beyond Design Basis Accidents (BDBAs)

[[

]]

IV. Conclusions

Implementation of the methodology presented in this topical report identified a total of [[[8]]] which can potentially challenge the safety functions of the reactor facility and release radioactive material to the environment. These PIEs are divided into 7 categories for the future use in DSA and PRA. TEUSA supports the conclusion that the methodology as described in this topical report, as supported by the cited references, provides a comprehensive and systematic process that will lead to a comprehensive set of PIEs for the IMSR400. Further, the methodology includes a process to assure that as the IMSR400 design evolves, the set of PIEs will also evolve in a timely manner to support the continued safe licensing and operation of the IMSR400.

All identified PIEs are also classified into three plant states (AOOs, DBAs, and DBDAs) according to the guidance from [R-6]. Classification was taken from the PRA frequency assessment [R-9] where available for a given event, and where not available, the classification was based on similar events in existing NPPs supplemented by engineering judgement and guidance from [R-6].

Finally, at the time of NRC initial joint review with the CNSC, the NRC concluded that while additional discussion would be required, the NRC had no major concerns with the methodology presented by TEUSA. TEUSA believes that the methodology has been improved resulting from comments given in the Joint Report [R-12], including the incorporation of PRA insights as they have become available. TEUSA also continues to believe that consistent with the Joint Report conclusions, the methodology presented in this topical report remains systematic, logical, and will include the appropriate scope that will reflect the final design and operation of the IMSR400.

The PIE list presented in this topical report contains a comprehensive list of all PIEs that have been identified based on a systematic approach using the current available information, including the IMSR design documentation, reference list for similar type of reactor, hazard identification studies, engineering judgement and operational experience. [[

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[8] The initiating events classified under AOOs, DBAs, BDBAs in total are more than the [[ ]] discrete PIEs because of the identification of the same initiating event in more than one class. For example, a primary heat exchanger blockage can be single or multiple and therefore, can fall under AOO or DBA, respectively.

The approach for PIE identification is iterative since the design is evolving. As new information becomes available, which includes but is not limited to regulatory documents, design updates, literature from other reactors and internal analysis documents (i.e., PRA and DSA), the PIE document will be updated appropriately.

PIE completeness will be checked during any evolution of the PIE update process. The internal PIE panel will perform the completeness check. The panel will confirm that all relevant technical disciplines have been involved in the development of and feedback on the updated PIE list. including DSA, PRA, Licensing, Physics, Thermal-hydraulics, Civil, I&C, R&D, Fire Protection, and system designers. The panel will also confirm that the most recent and approved versions of technical design documents were employed in the PIE development process and that the updated list reflects the state of the design. The panel will also confirm that the updated PRA was employed to establish the failure modes and failure frequencies so that all PIEs can be properly categorized as AOO, DBA or BDBA. A PIE update process will be triggered at the time of a license application. In addition to the above, as part of the PIE update for an application, the panel will also confirm that the full spectrum of external and internal hazards have been factored into the PIE list that are specific to the selected site.

V. CNSC/NRC Comments on PIE from Joint Report

In May 2022, the NRC and CNSC issued a joint report on the methodology for developing a postulated initiating events list for the Integral Molten Salt Reactor. This section of the topical report provides some insights into how the comments contained in the joint report have been considered or factored into changes to the methodology previously reviewed by both regulators. The focus of this section will be on the comments issued jointly and, on the comments issued specifically by the NRC. The comments issued by CNSC have also been considered in the revisions to the methodology although they will not be specifically discussed in this report.

Joint Feedback Comment #1

"Terrestrial is expected to document in detail, the expertise and qualification of personnel involved in future work on the PIE list development. Terrestrial's future submittal should also address its rules regarding the use of engineering judgement."

Response:

TEUSA notes that the application of the enclosed methodology is not a one-and-done activity. The IMSR400 design will continue to evolve up to the time an application for a license is submitted and even during the review of any license application. Section II.4.1 contains the descriptions of the specific disciplines that could be involved in updates to the PIE list using this methodology. As stated in that section, the technical disciplines listed there may not all be utilized at each iteration of the PIE list. The list is a complete set of engineering disciplines that might be expected throughout the entire design process. For each iteration of the PIE list, the task lead, as supported by the Safety Team Manager, will ensure that the expertise of the individuals involved is appropriate for the scope of the review. It is the responsibility of the Safety Team Manager to ensure that the expertise of the selected personnel is relevant and sufficient to provide a comprehensive analysis. The expertise used to develop the referenced set of PIE in a future license application will be included in that future license application referencing the IMSR400.

Joint Feedback Comment #2

"In future submittals, the regulatory staff will need a description of this program and of the processes used for maintaining configuration control (including software configuration control)."

Response:

This comment refers to the software program PTC Windchill that was described as the means to manage and control changes to documents. The comment discussion focused on the view that Windchill does not constitute a complete configuration management program. The specific details of a complete configuration management program are still being developed, however, when a future license application is submitted to the NRC for review and approval, a quality assurance program (that will include a configuration management program) that meets the requirements of 10 CFR 50 Appendix B will be implemented. The methodology will be implemented, and the PIE list will be developed in accordance with the approved quality assurance program.

Joint Feedback Comment #3

"However, the regulatory staff expect future submittals pertaining to the PIE methodology to include a detailed description of the verification and QA processes. The results of the verification and implementation of QA processes should be available for regulatory evaluation or audit. The PIE methodology should also include processes for collecting the information that could result in changes to the list of PIEs. The process for collecting the information that could result in changes to the methodology could be part of the QA program or be part of the PIE methodology itself."

Response:

The focus of this comment is centered around the procedures that are in place and will be implemented at the time the PIE methodology is implemented to develop a list of PIE that will be included in an application for a license. TEUSA agrees that the process and documentation used for developing the PIE list will need to be in a form that is readily auditable by the regulators. Section II of this topical report outlines the process for collecting information related to design changes or new information that is used to determine when an update of the PIE list would be appropriate. The process for implementing the methodology and changes to the methodology or the PIE list will be conducted within a quality assurance process that will meet NRC requirements.

Joint Feedback Comment #4

"In future submittals, the regulatory staff expect Terrestrial to detail how the iterative process is executed. Terrestrial should also explain its processes to identify and integrate new information during the life cycle of the plant, including the frequency for updating the PIE list."

Response:

The iterative process referred to in this comment is the integration of the PRA insights and other new information into the methodology and how that interactive process could change the list of PIE. Section II.4.2 provides additional detail about the process that will be used to identify new information and the process for initiating an update process for the PIE list. It also contains additional guidance for the frequency for assessing the need to initiate an update process. Note that the information is not a requirement, rather it presents guidance related to the circumstances under which the vendor or a licensee should consider whether new or different initiating events have been identified outside the envelope of initiating events already considered in the existing PIE list or the PIE list included in the current licensing basis of an operating facility.

Joint Feedback Comment #5

"However, as part of future submittals, regulatory staff expect Terrestrial to provide a clear definition of the top event in the "top-down" approach, and to describe the proposed "top-down' and "bottom-up" approaches in detail. Terrestrial is also expected to describe the process used to integrate the results of both approaches; key assumptions used in the methodology, and explain how they complement each other. "

Response:

Section III.1 of the report provides additional guidance into the integration of the "top-down" and "bottom-up" approaches and how those approaches will be used to complement each other. TEUSA does not believe that the regulators expected the methodology or this topical report to include the specific details associated with performing a Failure Modes and Effects Analysis (FMEA) or a Hazard Operability Analysis (HAZOP). These types of assessments are not novel and the procedures for performing them are well understood. The details of these types of assessments performed as a part of the methodology will be available for audit should the regulators wish to review.

The top event used in the 'top-down" approach is listed in Figure 2. Simply, the top event is the prevention or mitigation of a radionuclide release. The top event is consistent with the most significant safety function performed by the IMSR400.

Joint Feedback Comment #6

"…future submittals should include all: hazards and events (internal, external natural and human-induced; radiological sources (reactor core, fresh and spent fuel, radioactive gases); operational modes and transitions (at power operation, low power shutdown startup and other special operating modes; and multi-unit facility, if relevant. In addition, Terrestrial should include a detailed description of the screening criteria and explain how they were used to support the development of the PIE list. As an example, Terrestrial should provide the basis for the specific screening values/criteria regarding health effects and radioactive release."

Response:

Section II of this report provides specific guidance with respect to the scope of the PIE methodology. The guidance covers all the plant operational modes listed in the comment as well as the unique operating conditions of a core-unit replacement, fuel salt defueling, and long-term fuel salt storage. The operating states for postulated events are listed in Sections III.4.1 through III.4.7. The methodology applies to the complete range of internal and external hazards. The scope of internal and external hazards to which the methodology applies are fully displayed in Sections III.4.1 through III.4.7.

As described in Section IV, the methodology will consider internal events having postulated event frequencies larger than 10^-7. CNSC has issued regulatory criteria for classification of postulated event selection. This methodology is written to comply with the CNSC requirements for event classification and TEUSA is proposing to use those criteria for implementation in the U.S. The event classification criteria are found in CNSC document REGDOC 2.4.1, "Deterministic Safety Analysis", May 2014 [R-6]. TEUSA does note that the proposed criteria are more encompassing than the event classification criteria endorsed in the NRC guidance of Regulatory Guide 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non- Light Water Reactors", RG 1.233, June 2020. [R-65] supporting the Licensing Modernization Program. Note that the use of the classification criteria is not applied to external hazard events. The frequency of external events will be based on regulatory guidance established for those events. For example, the design frequency for flooding will be consistent with regulator guidelines for external flooding hazards. The same process will be used for seismic events. This practice is also consistent with the practice endorsed for the LMP process.

The PIE methodology does not use screening criteria for purposes of identifying postulated initiating events that are considered as events for which the IMSR400 must show that the safety functions of control, cool, and contain are successfully performed. Screening criteria are used in the development of the PRA however, those criteria do not apply to this methodology.

Joint Feedback Comment #7

"Regulatory staff expect, as part of future submittals, a detailed description of the process for grouping PIEs, including the rationale for the grouping."

Response:

Section III.3 provides a straightforward and simple explanation for why the grouping categories were selected. PIEs are grouped based on having similar effects on safety and support system availability, temperature and pressure transients, demands on the operator, consequences and success criteria.

Joint Feedback Comment #8

"Terrestrial will be responsible for justifying the chosen frequency ranges for the respective categories."

Response:

As stated in Section IV, the methodology will be using the frequency ranges specified in CNSC REGDOC-2.4.1. These criteria are regulatory requirements set by CNSC. Because this methodology will be used in both Canada and the U.S., TEUSA is adopting the frequency ranges for use in the U.S. TEUSA does note that the frequency ranges are generally consistent with the frequency ranges endorsed by Regulatory Guide 1.233 although the set of postulated events that would be evaluated for beyond design basis events is larger than that endorsed in the regulatory guide. It is important to note that the selection of the frequency ranges in the LMP methodology are completely independent of the evaluation of the frequency of a postulated initiating event that is then placed into the accident categories.

Joint Feedback Comment #9

"…it is expected that in future submittals, the overall methodology used to classify events (including the use of engineering judgment, research and development results, etc.) will be further clarified."

Response:

The approach to integration of new information is presented in Section II.4.2. The guidance for application of engineering judgment is presented in Section III.5.

Joint Feedback Comment #10

"The use of judgement and the treatment of uncertainties in the PIE methodology should be addressed by Terrestrial in future submittals, if requesting approval. This explanation needs to expand on its treatment of modeling uncertainties and uncertainties due to lack of knowledge for some phenomena, and their impact on physical barriers and the PIEs. Such phenomena include: the long-term buildup of fission products in the salts, the potentially highly corrosive behaviour of the fission products, the noble gas fission product transport from the salt into cover gas; the noble metal fission products plate out onto surfaces; and the salt vapor deposition in the cover gas lines.

Response:

A discussion of the treatment of uncertainties is provided in Section III.5 of this report.

As for the treatment of modelling uncertainties listed in the comment, the list of PIE developed by this methodology would capture the worst-case outcomes associated with the phenomena listed in the comment. For example, the buildup of fission products in the salts would have a deleterious effect on the reactivity available in the fuel salt. Such an outcome would be bounded by the events examined by unwanted changes in reactivity. More importantly, because the IMSR400 does not have a fuel salt cleanup system, the buildup of fission products in the fuel salt is evaluated as part of the core physics assessments for the design.

Another example cited was the corrosive behavior of fission products. The design of the IMSR400 already takes into account the chemical nature of the fuel salt and off-gases when the design establishes the operating environments for materials and components in its safety important systems. The structures, systems, and components for the IMSR400 will be qualified to the service conditions in which they would be expected to perform their functions. Setting that aside for a moment, the examples listed would result in either a leak or failure of piping or blockage of a flow path. These types of failures are already considered in the postulated events listed in Sections III.4.1 through III.4.7.

The impacts of the phenomena listed in the comment also bear directly on the radiological source term that would be available for release in the event of a postulated event. The development of the source term is occurring separately outside of the methodology. The demonstration that a particular postulated event meets established regulatory dose criteria is beyond the scope of this topical report.

Joint Feedback Comment #11

"If seeking approval of the PIE list, the following additional information should be provided or made available for audit:…"

Response:

As stated in the report, TEUSA is not seeking approval of the PIE list at this time. As a general response, the documentation used to develop the list under this methodology will be available for audit. Information related to plant operating states considered, effect of support system failures, loss of cooling, loss of electrical power, operator errors and human actions are already included as initiators for postulated events listed in Sections III.4.1 through III.4.7.

The requirement to have the list of PIE undergo an independent review is not supported by any current regulatory guidance or requirements. TEUSA does not believe that such an independent review is needed, especially if the PRA is subject to a third-party review but will consider the need for an independent review at the time it submits its license application.

Joint Feedback Comment #12

"In addition, Terrestrial should clarify whether the following events were considered for the current PIE list:

- Failures of instrumentation and controls (software and hardware) including associated common-cause failures
- Concurrence of hazards (e.g. earthquake and fire, fire and flood, high-winds and external flood).
- Common-cause and multiple independent failures/errors resulting in an initiating event."

Response:

The scope of the methodology is clearly presented in Section II.3. As stated, concurrent external hazards and multiple independent events are not included in the scope of this methodology.

VI. References

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[R-3]. IMSR400-30000-REP-001, Rev. 2, Plant Description.

[R-4]. IMSR400-30000-PPS-001, Rev. 1, Plant Performance Specification for the IMSR400

[R-5]. REGDOC-2.5.2, Regulatory document, “Design of Reactor Facilities: Nuclear Power Plants”, May 2014.

[R-6]. REGDOC-2.4.1, Regulatory document, “Deterministic Safety Analysis”, May 2014.

[R-7]. IMSR400-30800-PLA-001, Rev. 0, Safety Analysis Postulated Initiating Events Update Plan.

[R-8]. IMSR400-30823-ASD-001, Rev. 1, Preliminary Hazard Assessment for Basic Engineering.

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[R-11]. TEUSA, “Terrestrial Energy USA, Inc., Postulated Initiating Events for the IMSR, Revision 2”, US NRC ADAMS Online Database (Docket #: 99902076, Accession #: ML21357A011, TEUSA (Document #: 211216), December 2021.

[R-12]. US NRC-CNSC, “Joint Report on Terrestrial Energy’s Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor”, US NRC ADAMS Online Database (Docket #: 99902076, Accession #: ML22139A124), May 2022.

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[R-16]. IMSR400-22530-ASD-002, Rev. 0, Irradiated Fuel System Design Development.

[R-17]. IMSR400-22500-DD-002, Rev. 0, Makeup Fuel System.

[R-18]. IMSR400-30200-AB-001, Rev. 1, Shutdown States Simulation Analysis Plan.

[R-19]. IMSR400-30000-DD-001, Rev. 0, Core-swap System.

[R-20]. IMSR400-30805-PSAR-016, Rev. 0, Annex 1: Security.

[R-21]. IMSR400-30805-PSAR-017, Rev. 1, Annex 2: Safeguards.

[R-22]. IMSR400-24500-DD-001, Rev. 1, Plant Control and Monitoring System.

[R-23]. CSA 290.17-17, “Probabilistic safety assessment for nuclear power plants”, released April 2017 (revised December 2019).

[R-24]. IAEA, “Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants”, Safety Standards Series No. NS-G-1.7.

[R-25]. IAEA, “Evaluation of Seismic Hazards for Nuclear Power Plants”, Safety Standards Series No. NS-G-3.3.

[R-26]. IAEA, “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, Safety Standards Series No. NS-G-1.5 .

[R-27]. IAEA, “Protection against Internal Hazards Other than Fires and Explosions in the Design of Nuclear Power Plants”, Safety Standards Series No. NS-G-1.11.

[R-28]. IAEA, Flood Hazard for Nuclear Power Plants on Coastal and River Sites, Safety Standards Series No. NS-G-3.5.

[R-29]. IAEA, Meteorological Events in Site Evaluation for Nuclear Power Plants, Safety Standards Series No. NS-G-3.4 .

[R-30]. IAEA, Geotechnical Aspects of Nuclear Power Plant Site Evaluation and Foundations, Safety Guide No. NS-G-3.6.

[R-31]. ADAMS Document Rulemaking: Technology-Inclusive Identification of Licensing Events for Commercial Nuclear Plants - Preliminary Draft Regulatory Guide DG-1413 (June 2022).

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VII. Acronyms

Acronym	Definition
AOO	Anticipated Operational Occurrence
ASEP	Accident Sequence Evaluation Program
AHX	Auxiliary Heat Exchanger
BDBA	Beyond Design Basis Accident
BDBT	Beyond Design Basis Threat
BOP	Balance of Plant
CBDTM	Cause-Based Decision Tree Method
CoA	Code of Accounts
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
DBA	Design Basis Accidents
DBT	Design Basis Threat
DCCS	Defueled Core Cooling System
DiD	Defense-in-Depth
DEC	Design Extension Condition
DSA	Deterministic Safety Analysis
EHX	Emergency Heat Exchanger
FACS	FSST Active Cooling System
FEA	Finite Element Analysis
FHA	Fire Hazard Assessment
FMEA	Failure Modes and Effect Analyses
FSST	Fuel Salt Storage Tank
GHTCS	Gas Holding Tank Cooling System

Acronym	Definition
GRS	Ground Response Spectra
GSS	Guaranteed Shutdown State
GV	Guard Vessel
HAZOP	Hazard and Operability Analysis
HCR/ORE	Human Cognitive Reliability/Operator Reliability Experiment
HEI	Human Error Identification
HEP	Human Error Probability
HRA	Human Reliability Analysis
HTA	Hierarchical Task Analysis
HTGR	High Temperature Gas Reactor
HVAC	Heating, Ventilation, Air Conditioning
HX	Heat Exchanger
IMSR	Integral Molten Salt Reactor
InFS	Initial Fuel System
I&C	Instrumentation and Controls
IFACS	Irradiated Fuel Auxiliary Cooling System
IPS	Integral Pumping System
IrFS	Irradiated Fuel System
IRVACS	Internal Reactor Vessel Auxiliary Cooling System
LRF	Large Release Frequency
MCR	Main Control Room
MFS	Makeup Fuel System
MLD	Master Logic Diagram
MSRE	Molten Salt Reactor Experiment
NPCS	Nuclear Plant Control System

Acronym	Definition
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRV	Nuclear Reactor Vessel
OPP	Overpressure Protection
ORNL	Oak Ridge National Laboratory
PCMS	Plant Control and Monitoring System
PDC	Principal Design Criteria
PDS	Plant Display System
PGA	Peak Ground Acceleration
PHA	Preliminary Hazards Analysis
PHX	Primary Heat Exchanger
PIE	Postulated Initiating Event
PIRT	Phenomena Identification and Ranking Table
PRA	Probabilistic Risk Assessment
PRACS	Process Reactor Auxiliary Cooling System
PSA	Probabilistic Safety Assessment
PSAR	Preliminary Safety Analysis Report
QA	Quality Assurance
RAB	Reactor Auxiliary Building
R&D	Research and Development
REP	Regulatory Engagement Plan
RV	Reactor Vessel
RVFF	Reactor Vessel Failure Frequency
SCA	Secondary Control Area
SCoS	Secondary Control System

Acronym	Definition
SCS	Secondary Coolant System
SD	Shutdown
SDM	Shutdown Mechanism
SDR	Shutdown Rod
SFST	Spent Fuel Storage Tank
SG	Steam Generator
SHX	Secondary Heat Exchanger
SMS	Secondary Monitoring System
SPCS	Steam Plant Control System
SRE	System Responsible Engineer
SSC	Structures, Systems and Component
TB	Turbine Building
TBC	To be confirmed
TBD	To be determined
TCS	Tertiary Coolant System
TEI	Terrestrial Energy Inc.
TEUSA	Terrestrial Energy USA
THERP	Technique for Human Error Rate Prediction
UCE	Upper Containment Enclosure
UCH	Upper Containment Head
VFD	Variable Frequency Drive

TERRESTRIAL
E N E R G Y

March 30, 2026
US Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Project Number: 99902076
TEUSA Letter#: 260330

Subject: Submission of Topical Report on Postulated Initiating Events Methodology for the IMSR400 - Revision C

Document Control Desk,

Please find attached Revision C of the subject topical report for NRC review and approval. This topical report describes the methodology used to develop a set of postulated initiating events (PIE) for the Integral Molten Salt Reactor (IMSR) plant design and provides as complete a set of PIE as is possible given the design's maturity. The PIE methodology discussed in this topical report, and associated references, result from an examination of the complete IMSR plant. This methodology includes an examination of potential off-normal conditions that can lead to potential challenges to one or more of the fundamental safety functions.

Regulatory finality is being sought on the methodology described in this topical report. The methodology includes the process that will be used to establish a set of PIE for the IMSR400 and the criteria for classifying individual PIE for evaluation. Regulatory finality on the enclosed list of PIE or the classification of individual PIE is not being requested at this time. This topical report provides the NRC an opportunity to examine the IMSR plant PIE selection methodology, its application, and the resulting outcomes for event classification once the methodology is implemented. Regulatory approval of the final comprehensive list of PIE and the final individual PIE classification will be requested as part of a future license application review.

Terrestrial Energy USA, Inc. (TE USA) prepared Revision A of the topical report and submitted it to the NRC for review and approval in December 2024. The NRC initiated an audit review of the topical report and provided a set of questions for clarification. TEUSA and the NRC met on Aug 7, 2025, to discuss the planned resolution of the NRC items. The NRC indicated that the responses were adequate, resolved their questions, and requested that some of the response language be included in the topical report. Even though the NRC audit was not complete, TEUSA provided Revision B of the topical report to reflect resolution of known audit items. After submission of Revision B, the NRC provided additional feedback. This Revision C reflects the resolution of all known audit items.

Portions of the enclosed topical report revision are proprietary, and TE USA requests that the NRC withhold it from public disclosure in accordance with the provisions of 10 CFR 2.390. Enclosure 1 contains the proprietary version of the topical report, and Enclosure 2 contains the non-proprietary version. Enclosure 3 provides an affidavit supporting the withholding request.

TEUSA is prepared to actively engage with the NRC on the materials provided. If you have any questions or need any additional information, please contact David O'Keefe at dokeefe@terrestrialenergy.com or by phone at 646-687-8212, extension 422.

Sincerely,

Signed by:
Simon Irish
17A65B40752E40B

Simon Irish
Chief Executive Officer
Terrestrial Energy USA, Inc.

Enclosures:
Enclosure 1: Topical Report on Postulated Initiating Events for the IMSR400 Revision C - Proprietary
Enclosure 2: Topical Report on Postulated Initiating Events for the IMSR400 Revision C - non-Proprietary
Enclosure 3: Unsworn Declaration Supporting Request for Withholding from Public Disclosure

Cc:
Project Manager, DANU
Branch Chief, DANU

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

TERRESTRIAL ENERGY USA, INC. – FINAL SAFETY EVALUATION OF TOPICAL REPORT TITLED: "POSTULATED INITIATING EVENTS FOR THE IMSR400," REVISION C (EPID NO.: L-2025-TOP-0000)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor: Terrestrial Energy USA, INC. (TEUSA)

Sponsor Address: 2730 W. Tyvola Rd., Suite 100, Charlotte, NC 28217

Project No.: 99902076
Submittal Date: December 27, 2024

Submittal Agencywide Documents Access and Management System (ADAMS) Accession No.: ML25006A141

Brief Description of the Topical Report:

By letter dated December 27, 2024, Terrestrial Energy USA, Inc. (TEUSA or the applicant) submitted a Topical Report (TR) titled: "Postulated Initiating Events for the IMSR400," Revision A, (Agencywide Documents Access and Management System (ADAMS) Accession No. ML25006A141), for the U.S. Nuclear Regulatory Commission (NRC or the Commission) staff's review. By email dated March 31, 2025, the NRC staff informed TEUSA that the TR contained sufficient information for the NRC staff to initiate its detailed technical review (ML25083A115). TEUSA subsequently submitted Revisions B and C of the TR on October 1, 2025, and March 30, 2026, respectively (ML25274A145 and ML26092A409).

In support of the review, the NRC staff conducted a regulatory audit in accordance with the approved audit plan (ML25139A596) and documented the results in an audit report (ML26098A165). This safety evaluation (SE) is based on the information provided in Revision C of the TR. The TR describes TEUSA's methodology for developing a set of postulated initiating events (PIEs) for the Integral Molten Salt Reactor (IMSR) design and provides a preliminary set of PIEs consistent with the design's maturity.

TEUSA requested the NRC staff's review and approval of the methodology described in the TR. The methodology includes the process that will be used to establish a set of PIEs for the IMSR400 and the criteria for classifying an individual PIE for evaluation. TEUSA has not requested approval of the enclosed list of PIEs or the classification of individual PIEs in this TR. Approval of the final comprehensive list of PIEs and the final individual PIE classification will be requested as part of a future license application review. The development of these will be within the scope of an approved quality assurance program (QAP), a description of which TEUSA will submit to NRC for review and approval as part of future pre-application engagements.

REGULATORY EVALUATION

The identification of initiating events that form the basis for design basis accidents (DBAs) and associated consequence analyses is addressed through the regulatory framework governing nuclear facility licensing. Under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," internal and external hazards are encompassed within appendix A, "General Design Criteria (GDC) for Nuclear Power Plants," which establish the minimum requirements for the principal design criteria (PDC) for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission. The GDC are considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the PDC for such other units. Regulatory Guide 1.232, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors," Revision 0 (ML17325A611) (Reference 1), provides guidance for non-light water reactor (LWR) designers, applicants and licensees to develop PDCs, as required by the applicable NRC regulations for nuclear power plants. These requirements also exist under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," where applicants must address such hazards through the safety analysis report and site-specific information required by 10 CFR 52.47, "Application for renewal," and 10 CFR 52.79, "Contents of applications; technical information in final safety analysis report."

For its evaluation of TEUSA's methodology, the NRC staff used the following applicable guidance. Conformance with NRC guidance is one way of demonstrating compliance with the regulations or demonstrating technical acceptability.

- **NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (ML052340514) (Reference 2)**

  NUREG-0800 (SRP) section 15.0, "Introduction – Transient and Accident Analyses," provides guidance to review and ensure that the applicant's selection and assembly of the plant transient and accident analyses represent a sufficiently broad spectrum of transients and accidents or initiating events for LWR technology. The NRC staff considers the guidance in section 15.0 regarding transient and accident analyses to generally provide insights for non-LWRs.

  SRP section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors," provides guidance pertaining to the NRC staff's review of the design-specific and plant-specific probabilistic risk assessments (PRA) for design certification applications and combined license applications. The applicant's PRA submittal should be consistent with prevailing PRA standards, guidance, and good practices as needed to identify and characterize PIEs. The NRC staff considers the guidance in section 19.0 regarding the identification hazards to generally provide insights for non-LWRs.

- **Trial regulatory guide (RG) 1.247, "Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor Risk-Informed Activities" (ML21235A008) (Reference 3)**

  This document endorses PRA standard The American Society of Mechanical Engineers/American Nuclear Society (ASME/ANS) RA-S-1.4-2021, "Probabilistic Risk

Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants.” The initiating event analysis element in the PRA standard provides guidance and PRA supporting requirements to identify and characterize events that challenge plant operation during any plant operating state and require successful mitigation by plant equipment and personnel to prevent or to mitigate a release of radioactive material.

- **NUREG-1513, “Integrated Safety Analysis Guidance Document” (ML011440260) (Reference 4)**

  This document provides general guidance to fuel cycle licensees/applicants on how to perform an integrated safety analysis and document the results, and specifies technology-inclusive guidance for identifying initiating events. Specifically, it identifies acceptable methods for conducting a comprehensive and systematic search for initiating events and accident sequences.

- **RG 1.233, “Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors” (ML20091L698) (Reference 5)**

  This document endorses the principles and methodology in Nuclear Energy Institute (NEI) 18-04, “Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development,” which provides an acceptable method to identify licensing basis events (LBEs). NEI 18-04 presents a systematic process for identifying and classifying events and the associated sequences as anticipated operational occurrences (AOOs), design basis events, or beyond design basis events for non-LWRs. The outcome of the selection and evaluation of LBEs can be used to identify design features of the plant that are necessary and sufficient to ensure that risk goals are achieved, and licensing requirements are met.

- **DG-1413, “Technology-Inclusive Identification of Licensing Events for Commercial Nuclear Plants” (ML22257A173) (Reference 6)**

  This document provides the NRC staff’s technology-inclusive guidance for identifying initiating events, delineating event sequences, and identifying licensing events that can be used to inform the design and licensing bases and the content of applications for commercial nuclear plants.

TECHNICAL EVALUATION

Introduction

Note: [[ ]] denotes proprietary information.

In October 2020, TEUSA and Terrestrial Energy, Inc. (TEI) (hereafter collectively referred to as Terrestrial) were engaged in pre-licensing activities with the NRC and the Canadian Nuclear Safety Commission (CNSC), respectively, related to the IMSR design. PIEs for the IMSR were identified as a collaboration topic under the memorandum of cooperation between the NRC and the CNSC (Reference 7). Consequently, in May 2022, the NRC and CNSC (hereafter referred to as the regulators) issued a joint report, "Joint Report on Terrestrial Energy's Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor" (ML22139A124) (Reference 9), documenting the results of this collaboration in response to a request by Terrestrial for regulatory feedback on a white paper, "TEUSA submittal of Postulated Initiating Events for the IMSR," Revision 2 (ML21357A015), describing the process used to develop a set of PIEs for the IMSR design.

A PIE is an occurrence that challenges plant control and safety systems and whose failure could result in an undesirable end state and/or a release of radioactive material. The development of PIEs is a fundamental element of an applicant's safety analysis, including the deterministic safety analysis (DSA), hazard analysis, and PRA.

Based on the high-level information available at that time and the additional actions identified by Terrestrial to complete the methodology, the regulators jointly concluded that the resulting methodology would likely be technically sound and capable of generating a comprehensive set of PIEs. Given the early stage of the design, the PIE identification methodology was determined to be systematic, logical, and of appropriate scope. The regulators also identified additional information that should be considered by Terrestrial in further enhancement of the methodology and to be addressed in future licensing actions. The grouping, classification, and mitigation approaches presented in the white paper were considered reasonable, with the recognition that they are expected to evolve as the design matures and the PRA is developed.

With respect to the PIE list presented in the white paper, the regulators did not make a determination on acceptability because the design was still evolving. The regulators indicated that additional detail would be required in a future submittal to determine whether the PIE list is comprehensive and acceptable for approval.

Following these pre-licensing activities and in response to the comments in the joint report, TEUSA submitted a TR to the NRC on December 27, 2024, requesting the NRC's approval of the methodology described in the TR. The methodology includes the process that will be used to establish the set of PIEs for the IMSR400 and the criteria for classifying individual PIEs for evaluation. The methodology addresses events affecting the systems, structures and components (SSCs) included in the IMSR facility; it is not limited to the IMSR core unit. The methodology includes an evaluation of potential off-normal conditions that could challenge one or more fundamental safety functions.

The TR also documents how the comments contained in the joint report were considered and incorporated into revisions to the methodology previously reviewed by the regulators. Both the jointly issued comments and those issued specifically by the NRC staff were addressed and are discussed in the TR.

TEUSA included in the TR, the existing PIE list and the individual PIE classification commensurate with the current maturity of the design to demonstrate the output of the methodology. TEUSA has not requested the NRC's approval of this information at this time. The NRC's approval of a final, comprehensive PIE list and final PIE classifications will be requested by TEUSA as part of a future license application.

TR section I summarizes the purpose of the TR. TR section II provides an introduction of the licensing strategy and objective, description of the IMSR400, scope, and quality assurance (QA) practices in place for the methodology. TR section III describes the process for identifying the

PIEs and their classification criteria and provides a preliminary list of PIEs and their classifications. TR section IV provides TEUSA's conclusions regarding implementation of the methodology. TR section V addresses the comments provided in the joint report from the NRC and the CNSC.

NRC Staff's Evaluation of TEUSA's PIE Methodology for the IMSR400

The NRC staff evaluated the approach described in this TR to determine the acceptability of the approach for developing a set of PIEs for the IMSR400 design and the criteria for classifying individual PIEs for evaluation. The NRC staff's evaluation is based on TR, Revision C, as summarized above. In the joint report on TEUSA's white paper describing the methodology for developing PIEs, the regulators identified the following five key attributes for evaluating the soundness of a PIE methodology: 1) quality control; 2) systematic process; 3) scoping of PIEs; 4) grouping of PIEs; and 5) classification of PIEs. The NRC staff's review of the TR was conducted using these attributes.

1. Attribute 1: Quality Control

This attribute focuses on ensuring that the PIE methodology is effectively integrated with the designer's QA and configuration control processes. As the design and the list of PIEs evolve, appropriate quality controls are necessary to provide confidence in the results of the methodology and to prevent errors from propagating into downstream analyses and decisions. Quality controls apply to multiple activities, including safety analysis and the development of the PIE list. The NRC staff's review under this attribute emphasizes those aspects of quality control relevant to the PIE methodology, including documentation and traceability, verification and validation of results, definition of roles and responsibilities, and confirmation of personnel qualifications.

Quality Assurance and Controls for PIE Methodology

TEUSA provided information pertaining to quality controls in TR section II.4, "Quality Assurance." In the TR, TEUSA stated that QA practices are established to ensure that the PIE methodology is accurate, complete, and current with respect to design information, regulatory documents, internal analyses, and external literature and research. TEUSA stated that these practices will be implemented in accordance with the processes described in the TR and supported by general controls described in the TEI Management System Manual, which is comparable to 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." TEUSA further stated that the regulatory process described in the TR will be performed under a QA plan that meets NRC requirements and will include the use of qualified personnel to identify PIEs and the review and verification of resulting documentation under applicable management and review controls.

The NRC staff finds that the described QA framework, including the use of qualified personnel and the application of management and review controls, is generally consistent with accepted QA principles for ensuring the technical adequacy, traceability, and reproducibility of analyses supporting PIE identification. These elements are important for ensuring that the methodology is applied in a systematic and controlled manner. However, the NRC staff notes that the TR does not provide details for the NRC staff to verify that the QAP fully complies with the requirements of 10 CFR Part 50, Appendix B.

Based on the information provided, the NRC staff concludes that TEUSA has described a QA approach that is generally consistent with the intent of establishing adequate controls over the PIE identification process. The NRC staff finds this approach acceptable for the purpose of supporting the methodology described in the TR.

Because the NRC staff's approval is limited to the PIE methodology, the adequacy and implementation of the QAP, including compliance with 10 CFR Part 50, Appendix B, will need to be demonstrated as part of a future application. Accordingly, the NRC staff will defer its detailed review of the QAP and its implementation to a later stage when QA information is submitted.

Expertise Requirements

In TR section II.4.1, "Expertise Requirements," TEUSA stated that personnel with substantial knowledge of the design and proposed operation of the IMSR will be selected to perform the PIE methodology. TEUSA stated that a task lead is responsible for developing and executing an update plan for the PIE document, and that additional qualified personnel will review the results. Managers for the relevant technical and engineering disciplines are responsible for identifying personnel with appropriate expertise to serve as reviewers. The safety team manager is responsible for ensuring that the selected personnel possess relevant and sufficient expertise to support a comprehensive evaluation.

The NRC staff finds that TEUSA has defined roles and responsibilities for implementing, updating, and reviewing the PIE methodology, including the use of personnel with relevant expertise, assignment of a task lead for maintaining the PIE document, and the involvement of qualified reviewers and discipline managers. The NRC staff also notes that TEUSA has designated the safety team manager as the individual responsible for ensuring that personnel possess appropriate expertise to support the evaluation. These elements establish clear accountability, incorporate qualified technical input, and provide for independent review and management oversight, which are consistent with accepted QA and engineering practices.
Therefore, the NRC staff concludes that the expertise requirements and associated management and review controls are adequately defined to support consistent and technically sound implementation and updating of the PIE methodology and are acceptable.

Management and Review Controls

In TR section II.4.2, "Management and Review Controls," TEUSA described a process for collecting and evaluating information that may affect the PIE list. TEUSA stated that this process relies on discipline-specific "points of contact" responsible for collecting new information from interfacing disciplines and communicating that information within their own discipline.
Information is collected primarily through discipline meetings and periodic team meetings, during which updates and supporting documentation are shared. In addition, the review and comment process for new documentation includes all interfacing disciplines, and reviewers communicate relevant information to the team to ensure consistency across disciplines. For the safety team, the safety team manager is responsible for collecting information that could result in changes to the PIE documentation.

TEUSA stated that, based on the evaluation of new information, external documentation, and internal safety documentation, the safety team manager, with support from the safety team, determines whether updates to the PIE identification methodology, PIE list, or PIE classification are necessary. If updates are needed, the safety team manager initiates the selection of qualified personnel to perform the work.

TEUSA also stated that the task lead develops an update plan aligned with engineering changes to the IMSR design since the previous update. The plan identifies affected design areas, specifies reference inputs (e.g., design documents, literature, regulatory guidance), assigns work to qualified personnel, identifies interfacing disciplines, and establishes review actions. The safety team manager, in coordination with other discipline managers and the task lead, identifies reviewers with appropriate skills. After the plan is approved, the task lead executes the plan and produces a draft update. The draft is to be reviewed by safety team members and interfacing disciplines using established document control procedures to verify completeness and accuracy with respect to design information and relevant references.

The NRC staff concludes that TEUSA has sufficiently described a structured process for the identification, collection, and evaluation of new information that may affect the PIE documentation, including the use of discipline-specific points of contact, periodic interdisciplinary interactions, and management oversight by the safety team manager. The process sufficiently defines controls for initiating and implementing updates, including the development of an update plan aligned with design changes, identification of affected systems and inputs, assignment of qualified personnel, and performance of interdisciplinary reviews. In addition, the use of established document control and review procedures provides a mechanism to verify the technical accuracy, completeness, and consistency of updates with design and supporting references. Collectively, these elements establish a systematic and controlled framework for maintaining the PIE documentation. Therefore, the NRC staff concludes that the process is reasonable and acceptable.

Update Frequency and Lifecycle Controls

TEUSA stated that during the IMSR400 design, engineering, and pre-licensing phases, updates are not performed on a fixed schedule but are triggered by the collection and evaluation of new information by the safety team manager and safety team. TEUSA further stated that, once the design approval is issued, design evolution and associated PIE changes would be reduced because the design is complete; however, under the PIE maintenance process, updates to the PIE list are expected to identify new events or revise existing ones. TEUSA stated that PIE information will be updated periodically over the life of the plant. TEUSA identified natural assessment points such as updates to the PRA or following each core-unit reload (7 years).
TEUSA further stated that significant changes to plant design or risk profile would be addressed through the applicable licensing basis change process.

The NRC staff concludes that the described approach provides reasonable triggers for maintaining the currency of the PIE list. Although no specific update interval is defined, updates are initiated as needed by plant personnel under the maintenance and control program. In addition, updates are expected to occur periodically, such as following PRA updates required by 10 CFR 50.71, “Maintenance of records, making of reports,” or after each core reload.
Collectively, these triggers provide a sound and reasonable basis for maintaining the PIE list.

Interdisciplinary Review

TEUSA stated that during the conceptual design and basic engineering stages, relevant disciplines, including DSA, PRA, licensing, physics, thermal-hydraulics, civil, instrumentation and controls (I&C), research and development, fire protection, and system design, were involved in reviewing the PIE methodology and PIE list. During detailed engineering, TEUSA plans to establish an internal PIE panel composed of experienced personnel from relevant disciplines to support the identification, categorization, and classification of PIEs. TEUSA stated that the internal PIE panel will include experienced expertise from relevant technical disciplines and will be responsible for performing completeness checks. The panel will confirm that all relevant disciplines have been involved in the development of, and provided feedback on, the updated PIE list. The panel will also verify that the most recent approved versions of technical design documents were used in the PIE development process and that the updated list reflects the current design. In addition, the panel will confirm that the updated PRA has been used to identify failure modes and estimate failure frequencies, ensuring that all PIEs are appropriately categorized as AOOs, DBAs, and beyond design basis accidents (BDBAs). Furthermore, as part of the PIE update for an application, the panel will confirm that the full spectrum of internal and external hazards specific to the selected site has been considered in the PIE list.

The NRC staff finds that TEUSA’s process reasonably incorporates the involvement of relevant technical disciplines throughout the design stages and includes the establishment of an internal PIE panel to perform completeness and consistency checks during detailed engineering. The NRC staff also finds that these elements, interdisciplinary input, use of current design information, incorporation of PRA insights, and formal completeness checks, provide a systematic and technically grounded approach for ensuring that the PIE list is comprehensive, properly categorized, and consistent with the design. Therefore, the NRC staff concludes that the described process provides an adequate basis for ensuring the technical completeness and consistency of the PIE identification and classification and is acceptable.

The NRC Staff’s Evaluation Findings for Attribute 1

Based on its review of the quality control information provided in the TR and confirmation obtained through the audit, the NRC staff finds that TEUSA has reasonably described how quality control aspects relevant to the PIE methodology will be implemented, including documentation control, verification of results, definition of roles and responsibilities, interdisciplinary review, and use of qualified personnel. The NRC staff finds that the expertise requirements and management and review controls are reasonably characterized and provide confidence that the PIE methodology can be implemented in a manner that supports technically sound and consistent results.

However, because TEUSA has not submitted its QAP documentation for the NRC staff’s review, the NRC staff does not make findings on the adequacy of the QA and configuration management program as part of this SE. The NRC staff notes that a future QAP, when submitted for the NRC staff’s review, must demonstrate compliance with the requirements of 10 CFR Part 50, Appendix B, and may do so by conforming to the guidance in RG 1.28, “Quality Assurance Program Criteria (Design and Construction),” (Reference 8) by providing detailed documentation of personnel qualifications and QA controls for future PIE updates.

2. Attribute 2: Systematic Process

This attribute focuses on the designer's overall process for developing PIEs. A systematic process is expected to provide confidence that the methodology identifies all reasonably foreseeable initiating events and produces a PIE list that is reflective of the design during the design phase and is comprehensive at initial fuel loading. The NRC staff's review considers whether the process steps are logical, structured, and integrated with the DSA and PRA. This includes evaluating whether the approaches and processes are technically sound and whether the process includes provisions to identify, characterize, and appropriately account for uncertainties.

In TR section III, "Process for Identifying PIEs," TEUSA stated that a comprehensive list of PIEs is developed for all permissible plant operating modes to ensure completeness in the analysis of plant behavior. TEUSA stated that each identified PIE is categorized into one of seven categories based on the associated primary plant response or similar initiating failures. After the comprehensive list of PIEs is generated, the events are classified based on estimated frequency of occurrence into AOOs, DBAs, and BDBAs.

In the sections below, the NRC staff evaluates the proposed systematic process for identifying PIEs to determine whether the process provides a structured and comprehensive basis for supporting subsequent analyses. The categorizing (grouping) and classifying of PIEs are addressed under Attributes 4 and 5, respectively.

Approach for PIE Identification

In TR section III.1, "Approach for PIEs Identification," TEUSA stated that the PIE identification process is intended to be systematic and as complete as practicable. TEUSA stated that the causes of initiating events include both internal and external hazards. Internal hazards originate within the plant and may be human-induced or caused by SSC failures or malfunctions. Internal events include SSC failures, operator errors, and hazards (human-induced or caused by SSC malfunction) that directly or indirectly challenge one or more plant safety functions. External hazards originate externally to the site and its processes and are hazards over which the operator has little or no control (e.g., earthquakes). External events include human-induced or naturally occurring events as well as events originating in the steam plant.

TEUSA stated that important Type B initiating events, which are caused by human actions such as mispositioning or incorrect operation of equipment that inadvertently trips components or generates false control signals, are evaluated and reviewed as part of the PIE identification process.

TEUSA stated that the identification of hazards is based on generic IMSR400 qualification requirements and parameters because the methodology is currently based on a generic (non-site-specific) site. TEUSA stated that these hazards are described at a high level and will be further refined into more specific PIEs once a detailed site hazard assessment is completed. In addition, since the methodology and PIE list is currently based on a generic site, PIEs initiated by external hazards will require reevaluation once a site is selected, using the site evaluation and environmental assessment processes.

TEUSA stated that a deductive, top-down approach similar to a master logic diagram (MLD) is used to identify PIEs. This approach considers all plant operating modes and evaluates plant-level challenges that could lead to undesirable consequences. TEUSA also indicated that future work will include conducting mode-specific top-down assessments. To complement the top-down approach, TEUSA used an inductive, bottom-up approach to identify new PIEs and refine previously identified events. The bottom-up approach evaluates how lower-level failures may affect

system- and plant-level functions. TEUSA applies failure modes and effects analysis (FMEA) as the primary bottom-up technique. During the design stage, TEUSA developed an FMEA for passive systems to confirm that no active failures or dependencies on supporting systems would cause the passive system to fail and that system failures would not generate additional PIEs. TEUSA stated that during the detailed engineering stage, additional bottom-up analyses will be performed as more detailed system design information becomes available. The TR provides examples of the application of MLD and FMEA in the IMSR PIE identification process.

In addition, TEUSA stated that industry and research sources, including Oak Ridge National Laboratory (ORNL) reports (e.g., ORNL-TM-732 and ORNL/TM-2019/1246), are used as completeness checks for initiating event identification. TEUSA stated that the PIE identification approach is iterative because the plant design continues to evolve. As new information becomes available, including regulatory guidance, design updates, operating experience from other reactors, and internal safety analyses (e.g., PRA and DSA), this information will be incorporated into the PIE update process.

The NRC staff finds that TEUSA's approach of using deductive and inductive approaches to systematically identify PIEs across all plant operating modes is technically sound and adequate. The top-down approach ensures that plant-level challenges and mode-specific hazards are considered, while the bottom-up approach evaluates how lower-level system failures, including passive system interactions, could propagate to plant-level events. The NRC staff notes that TEUSA also considers important Type B human errors, external hazards, and uses industry and research references to verify the completeness of initiating event identification. This provides reasonable assurance that the PIE list is comprehensive and complete.

The NRC staff further notes that TEUSA's methodology is iterative, allowing the incorporation of new design information, regulatory guidance, operating experience, and internal safety analyses (e.g., PRA and DSA) as they become available. This ensures that the PIE identification process remains current and technically robust as the design matures.

Based on this evaluation, the NRC staff concludes that TEUSA's use of deductive and inductive approaches, consideration of internal and external hazards, inclusion of human-induced events, and iterative updates provide a technically sound, systematic, and comprehensive basis for identifying PIEs. Therefore, the proposed methodology for PIE identification is acceptable.

PIE Identification

TR section III.2, "PIEs Identification," describes the application of the top-down MLD assessment used to identify PIEs. TEUSA specifies a top event for the IMSR400 design that considers all radiological sources within the plant, including reactor and non-reactor sources. The assessment evaluates internal events, internal hazards, external events, external hazards, common-cause hazards, release pathway challenges, plant responses, and resulting PIEs.

TEUSA also describes the application of bottom-up FMEA to complement the MLD process and provides example extracts from the preliminary FMEA worksheets to illustrate the type of information evaluated during PIE identification in section III.1 of the TR, as described above.

The NRC staff concludes that the use of MLD and FMEA techniques for PIE identification is consistent with generally accepted engineering and risk assessment practices. Although TEUSA provided the preliminary MLD flowcharts and FMEA worksheets as illustrative examples of how these techniques are implemented and documented; per the scope of review requested by TEUSA, a detailed review of its content and deliverables is outside the scope of this TR. Accordingly, the NRC staff does not draw conclusions regarding the specific inputs or results of the MLD and FMEA.

The NRC Staff's Evaluation Findings for Attribute 2

Identification of PIEs is a fundamental starting point for nuclear power safety assessment and risk evaluation. Therefore, a reasonably complete set of initiating events is necessary to determine challenges to plant safety functions and to support the selection and evaluation of LBEs, including AOOs, DBAs, and BDBAs.

The NRC staff finds that TEUSA's systematic process uses multiple complementary perspectives and techniques, including a top-down MLD approach and a bottom-up FMEA approach, consideration of human-induced initiating events, and the incorporation of generic operating experience and relevant data. This blended approach provides reasonable assurance that risk-significant and foreseeable initiating events are identified and evaluated.

Accordingly, the NRC staff concludes that the PIE identification process proposed by TEUSA is systematic, logical, and technically sound, and provides a reasonable and acceptable basis for developing a comprehensive set of PIEs to support subsequent safety and risk analyses.

3. Attribute 3: Scoping of PIEs

This attribute focuses on the scope of PIE identification and safety assessment activities used to develop a comprehensive PIE list. The NRC staff's review considers whether the applicant has adequately accounted for all relevant events and occurrences (e.g., failures, malfunctions, accidents, human errors, and hazards) applicable to the entire facility and its operating and operational states. The objective is to establish confidence that the PIE list is comprehensive and appropriately scoped. The scope of relevant events and occurrences include, but are not limited to:

- all potential radioactive sources;
- site-specific and non-site-specific events or hazards;
- internal and external events (natural, common-cause failures, and human-induced events);
- common-cause events affecting multiple reactor units (if applicable);
- potential combinations or interactions between events and reactor units; and
- plant operating modes, states, conditions, and configurations (whether normal or abnormal), and transitions between them.

In addition to the above considerations, justification or rationale for excluding PIEs should be documented to demonstrate that the scope of the PIEs is reasonable and acceptable.

Scope of the PIE Methodology

As discussed in TR section II, the proposed methodology evaluates a single-unit nuclear power plant (NPP) configuration located at a generic site. The methodology considers the evaluation of the following plant operating modes:

- Fuel storage
- Initial fueling
- Shutdown
- Startup
- At-power
- Shutting down
- Defueling
- Core-swap

TEUSA stated that PIEs associated with I&C and plant electrical systems are also considered. The identified PIEs include, as potential causes, failures of supporting systems, subsystems, and components that could lead to the loss of a safety function (e.g., failure of heating, ventilation, air conditioning (HVAC) system).

Based on its review and the information presented in the TR, the NRC staff concludes that by incorporating and evaluating a broad range of operating modes and including potential failures of critical supporting SSCs, the methodology addresses variability in plant configuration and operational states, ensuring that PIE identification is comprehensive and not biased toward a single operating condition. Accordingly, the NRC staff concludes that the current scope is reasonable and acceptable for demonstrating the implementation of the methodology and for supporting the preliminary identification of initiating events.

Nuclear Island and Balance of Plant Scope

The TR states that the methodology considers events occurring within the nuclear island and events that originate outside the nuclear island but propagate to it, including external hazards. The balance of the plant is modeled generically as a steam plant. Only bounding steam plant events that result in increased or decreased heat removal are considered. Specific steam plant events (e.g., main steam line break, loss of feedwater, loss of condenser cooling, turbine trip) are treated as potential causes of these bounding events. Steam plant events that could affect the nuclear plant pressure boundary are also considered.

The NRC staff concludes that limiting the scope to bounding steam plant effects while focusing on impacts to nuclear island safety functions is reasonable for a generic PIE identification methodology and is consistent with the TEUSA licensing framework. The NRC staff finds that the applicant has reasonably described the events considered in the initial evaluation, which limits the scope to bounding steam plant effects while focusing on impacts to nuclear island safety functions. Because the TR mainly addresses the methodology for PIE identification rather than establishing a complete set of PIEs, the NRC staff finds that this scoped approach is acceptable for demonstrating a technically justified and systematic basis for PIE identification in a generic design context and is consistent with the TEUSA licensing approach, which includes TEUSA's ongoing pre-licensing activities with the NRC staff to establish the safety case, design criteria, and regulatory pathway for licensing the IMSR within the existing U.S. regulatory structure.

Plant-Wide and Hazard-Initiated PIEs

The TR states that certain PIEs affect the entire NPP, including safety-related and non-safety-related systems, for example, loss of offsite power. Other internal and external hazards that may affect the entire NPPs include environmental events (e.g., flooding, fire, earthquake) and internal system failures (e.g., explosions, missiles). In the TR, external hazards are addressed using generic site parameters consistent with the IMSR400 design basis. Combination events involving multiple internal and/or external hazards are not included within the current scope of the preliminary PIE list. Incorporating combinations of events does not impact the PIE methodology; however, TEUSA has stated that a future revision of the PIE TR will address credible combinations of events, including those that are consequential or correlated.

The NRC staff concludes that TEUSA's approach of considering internal and external hazards within a generic site framework reasonably provides a systematic basis for identifying PIEs at this stage of design development. By limiting the current evaluation to individual hazards, the methodology still captures key safety-significant events without introducing complexity in early design. The NRC staff notes that the assessment of credible hazard combinations, as described by TEUSA, is not necessary to evaluate the methodology for PIE identification, but will be needed to ensure completeness of the PIE list and consistency with licensing expectations.

Protection Against Malevolent Acts and Aging Effects

The TR states that protection against an intentional large aircraft crash is addressed in the IMSR400 design under the scope of protection against malevolent acts. The TR also states that slow-developing degradation mechanisms (e.g., aging effects) are addressed through plant design features, equipment qualification, monitoring, maintenance, in-service inspection, and testing programs.

The NRC staff concludes that the TR's treatment of malevolent acts and aging mechanisms through design and programmatic controls, outside of the PIE methodology is reasonable and consistent with established practices (e.g., the use RG 1.217, "Guidance for the Assessment of Beyond-Design-Basis Aircraft Impacts," to address regulations such as 10 CFR 50.150[1], "Aircraft impact assessment").

Hazard Scope and Operating States

TR section II defines the scope of the PIE methodology and provides guidance applicable to all plant operating modes, including unique operating conditions such as core-unit replacement, fuel salt defueling, and long-term fuel salt storage. The applicable operating states for postulated events are identified in TR section III.4.1 through section III.4.7. The methodology applies to the full range of identified internal and external hazards within the defined scope.

The NRC staff concludes that the TR defines the scope of hazards and operating states to which the PIE methodology applies in a manner consistent with the IMSR400 design. The TR reasonably establishes the boundaries within which internal and external hazards are evaluated

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[1] Pursuant to the sunsetting provision in 10 CFR 50.150(d), "[10 CFR 50.150] shall cease to have effect on April 8, 2027, unless the NRC determines that the cessation deadline should be extended to a date not more than 5 years in the future after offering the public an opportunity to provide input on the costs and benefits of this section and considering that input. The NRC will publish a document in the *Federal Register* announcing its determination and revising or removing this section accordingly."

and identifies the operating conditions relevant to postulated events. Based on this information, the NRC staff finds that the defined scope is sufficiently comprehensive to support the systematic identification of potential initiating events and to ensure that the methodology is applied across all plant conditions.

Frequency Considerations

As described in TR section V, TEUSA stated that the methodology considers internal events with postulated frequencies greater than 10^{-7} per year, while frequencies of external events will be based on applicable guidance. The applicant also noted that this approach is consistent with the licensing modernization project process.

The NRC staff concludes that the proposed approach for addressing event frequencies is reasonable and consistent with accepted practices, as discussed in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition”; RG 1.233, which endorses the LMP; and RG 1.247, which endorses the non-LWR PRA standard.

Screening Criteria

The PIE identification methodology does not apply screening criteria to exclude PIEs from consideration in demonstrating the performance of the fundamental safety functions (control, cool, and contain). TEUSA stated that screening criteria are used in the development of the PRA, but such screening does not apply to the PIE identification methodology.

The NRC staff concludes that because TEUSA applies screening only within the PRA and not within the PIE identification process, the PIE identification methodology is acceptable and supports the development of a comprehensive set of initiating events in a conservative and technically sound manner.

The NRC Staff’s Evaluation Findings for Attribute 3

Based on its review, the NRC staff finds that the scope of the proposed PIE methodology clearly defines the plant configuration, operating modes, hazard types, and system interfaces considered in the identification of PIEs. The methodology appropriately addresses internal and external hazards, plant-wide events, supporting SSC failures, and applicable operating states, and it establishes a clear relationship between the PIE identification process and PRA development.

Accordingly, the NRC staff concludes that the scope of the PIE identification methodology is systematic, sufficiently comprehensive for a generic site application, and provides a reasonable and acceptable basis for identifying initiating events to support subsequent safety and risk evaluations.

4. Attribute 4: Grouping of PIEs

This attribute focuses on how PIEs with similar characteristics are grouped for analysis. The objective of event grouping is to simplify the safety analysis process by identifying limiting (or bounding) events within each group, thereby reducing the number of analyses needed to demonstrate compliance with acceptance criteria. A limiting event bounds the scenarios that present the greatest challenges to the applicable acceptance criteria. The NRC staff's review considers how PIEs are categorized, how limiting events are selected, and how safety and mitigating functions are addressed in the grouping process.

PIE Categorization

TEUSA stated that the top-down approach described in TR section III.2, resulted in the preliminary identification of **[[** **]]** for the IMSR400 design. The applicant further stated that these events were categorized according to its associated primary plant response (e.g., increase or decrease in core-unit heat removal) or by similar initiating failures (e.g., loss of piping or vessel integrity). The applicant clarified that this categorization is intended solely to organize the identified PIEs and is not used directly for PRA or DSA modeling purposes. The categories used are the following:

1) Unwanted changes in reactivity
2) Increase of core-unit heat removal
3) Decrease of core-unit heat removal
4) Loss of integrity of piping or vessel
5) Internal hazards
6) External hazards
7) Additional events.

The applicant stated that grouping of the PIEs for analytical purposes involves **[[**

]]

TEUSA also stated that the categorization presented in the TR may include multiple bounding events within a single category and may not align with the event grouping structure used in the PRA.

The NRC Staff's Evaluation Findings for Attribute 4

The NRC staff reviewed the applicant's approach to categorizing PIEs and concluded that organizing a large number of identified initiating events by primary plant response or similar failure mechanisms is a reasonable and systematic method for managing the completeness and traceability of the PIE identification process. The NRC staff notes that the categorization is used as an organizational tool and is distinct from the grouping of events performed within the PRA and DSA models.

The NRC staff further determines that distinguishing between internal hazards, external hazards, and additional events provides a clear high-level structure for the identified event set and supports subsequent risk-informed and deterministic evaluations. The NRC staff notes that analytical grouping within the PRA and DSA based on similar safety function impacts, system availability, operator demands, and success criteria is consistent with accepted risk assessment practices. It should be noted that the NRC staff did not make any findings regarding the acceptability of the IMSR400 PIE list or the resulting groupings presented in the TR.

Based on its review, the NRC staff concludes that the applicant's PIE categorization approach provides a logical and traceable organizational framework for the identified initiating events and is acceptable for supporting subsequent safety and risk evaluations.

5. Attribute 5: Classification of PIEs

This attribute focuses on how PIEs are classified based on their associated frequencies and consequences. The objective is to establish confidence in the designer's classification approach and justification of PIE frequencies. Classification supports the application of appropriate acceptance criteria, including safety, design, and operational criteria, as well as the identification of mitigating measures. The NRC staff's review considers how event classifications and frequency ranges are justified and demonstrated, how probabilities of combined system failures are evaluated, and how uncertainties are characterized and treated.

Classification of PIEs

The applicant stated that, for each PIE, the safety analyses (e.g., PRA and DSA) will determine which mitigating systems and safety functions are credited, based on the safety classification of the systems involved and the classification of the PIEs (i.e., AOO, DBA, or BDBA). The applicant indicated that, unless specifically identified, the listed PIEs do not require reactor shutdown via the shutdown rods to achieve a safe state. The applicant further stated that preventive measures and monitoring capabilities are identified where applicable and that, for credible events identified through the PRA and DSA, monitoring is assumed to be available to detect event occurrence.

The applicant described the frequency-based classification framework as follows:

- **AOOs:** Events with frequencies greater than or equal to 10^{-2} per reactor year.
- **DBAs:** Events with frequencies greater than or equal to 10^{-5} per reactor year and less than 10^{-2} per reactor year.
- **BDBAs:** Events with frequencies less than 10^{-5} per reactor year.

The applicant stated that PIEs are classified based on frequency and consequences to support the selection of appropriate analytical approaches and the application of corresponding safety, design, and operational acceptance criteria. The applicant further stated that, because the NRC staff has not established specific frequency ranges for accident classification applicable to this design and because the methodology may also be applied internationally, the proposed frequency ranges are based on CNSC requirements. Events with frequencies near classification boundaries are conservatively assigned to the higher frequency category, particularly where uncertainty exists.

The applicant stated that: **[[**

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The applicant stated that, in the current revision of the methodology, PIE frequencies and classifications were initially derived from probabilistic studies. For events not included in those studies or screened from them, the classification was based on engineering judgment informed by operating experience from other reactors. Operator errors were considered in determining event frequencies and classifications. The applicant noted that the classification of external hazards is site-dependent and therefore subject to change based on future site and environmental evaluation.

The NRC Staff's Evaluation Findings for Attribute 5

The NRC staff reviewed the applicant's proposed methodology for establishing and classifying PIEs and finds it reasonable, with appropriate consideration of uncertainty. Final PIE identification and classification are design- and site-specific and will be subject to further NRC staff's review as part of a future license application. In addition, the specific PIE list and individual event classifications were not included within the scope of the NRC staff's review of this TR.

The NRC staff concludes that the use of defined frequency ranges and treatment of uncertainty described in TR section III.5, "Classification of the PIEs", including the use of the 5th and 95th percentiles, to classify events as AOOs, DBAs, or BDBAs and provides a structured and transparent framework for determining the level of analysis and applicable acceptance criteria. The NRC staff further concludes that conservatively assigning events near classification boundaries to the higher frequency category is reasonable and appropriately accounts for uncertainties.

The NRC staff notes that deriving event frequencies primarily from probabilistic analyses and supplementing those results with engineering judgment and operating experience, where necessary, is consistent with risk-informed regulatory practices. The NRC staff determines that it is appropriate that operator errors are identified and considered in frequency determinations and that external hazard classifications are recognized as site-dependent.

The NRC staff concludes that the proposed methodology for classifying PIEs, including the defined frequency ranges, treatment of uncertainty, and integration with PRA and DSA, provides a systematic and reasonable basis for classifying initiating events. The approval of the final PIE list and individual classifications will be addressed in a future application-specific review.

CONCLUSION

Based on its review of the TR and supporting documentation, the NRC staff concludes that the applicant has proposed a systematic, technically sound, and reasonable methodology for the identification, scoping, categorization, and classification of PIEs for the IMSR400 design.

Because the NRC staff's approval is limited to the methodology described in the TR, certain aspects relevant to finalizing the PIE list and classifying individual PIE have not yet been fully addressed and are outside the scope of this review. Accordingly, the user of the methodology described in the TR should address these aspects when finalizing the PIE list and performing classification. The NRC staff will defer its review and conclusions on these matters until the relevant information is submitted for review. These aspects, discussed in the technical evaluation section, are summarized below:

- A QA plan that meets NRC regulations should be developed and submitted for the NRC staff's review.
- The maintenance and update interval should be defined once plant operating and maintenance procedures are available.
- The internal PIE panel process for performing completeness checks should be established.
- Human-induced events should be identified consistently with plant operating and maintenance procedures when available.
- Inputs to the MLD and FMEA should be technically appropriate and adequately supported.
- The plant operating modes described in the TR should be confirmed when final design information becomes available.
- Evaluation of credible hazard combinations should be addressed in future updates based on final design and site-specific information.
- The treatment of malevolent acts and aging mechanisms is outside the scope of this PIE methodology but should be addressed in other programs.
- As stated in the TR, during the detailed design stage, event classification should be performed using the 5^{th} and 95^{th} percentile confidence levels for component failure data.

The NRC staff concludes that the methodology includes appropriate quality control elements, such as documentation control, verification of results, defined roles and responsibilities, interdisciplinary review, and use of qualified personnel, which provide confidence that the PIE process can be implemented consistently. The NRC staff notes that QA and configuration management documentation has not been submitted and will be reviewed in future PIE updates.

The NRC staff concludes that the systematic process, employing complementary top-down (MLD) and bottom-up (FMEA) techniques, consideration of human-induced initiating events, and incorporation of generic operating experience, provides reasonable assurance that risk-significant and foreseeable PIEs are identified and evaluated. The scope appropriately addresses internal and external hazards, plant-wide events, SSC failures, and relevant operating states, providing a sufficiently comprehensive basis for subsequent safety and risk analyses.

The NRC staff concludes that categorizing PIEs by primary plant response or similar failure mechanisms provides a clear, logical framework to manage completeness and traceability. The use of defined frequency ranges to classify PIEs as AOOs, DBAs, or BDBAs, including the treatment of uncertainty and site-dependent external hazards, provides a transparent and structured basis for applying acceptance criteria. Since the NRC staff's approval is sought only for the methodology and classification criteria the final PIE list and individual classification result will be addressed in future reviews once submitted to the NRC.

Overall, the NRC staff concludes that the applicant's methodology provides a systematic, traceable, and technically robust framework for developing a comprehensive set of PIEs and supporting subsequent safety and risk evaluations for the IMSR400 design. The NRC staff further concludes that the proposed methodology provides reasonable assurance that, if implemented as described, foreseeable PIEs would be systematically identified and appropriately evaluated and classified as AOOs, DBA, and BDBAs to support plant safety and risk assessments.

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9. U.S. NRC, Joint Report on Terrestrial Energy's Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor, Washington D.C., May 2022 (ML22139A124).

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Date: April 27, 2026

TERRESTRIAL
ENERGY

Postulated Initiating Events for the IMSR400

Topical Report

Revision C

March 2026

Abstract

This topical report describes the methodology used to develop a set of postulated initiating events (PIE) for the Integral Molten Salt Reactor (IMSR) design and provides as complete a set of PIE as is possible given the design's maturity. The methodology is not confined to the events that only affect the IMSR Core-unit. The set of PIE discussed in this topical report, and associated references, result from an examination of the complete IMSR facility. This methodology includes the examination of potential off-normal conditions that can lead to potential challenges to one or more of the fundamental safety functions.

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Executive Summary

This topical report describes the methodology used to develop a set of postulated initiating events (PIE) for the Integral Molten Salt Reactor (IMSR) design and provides as complete a set of PIE as is possible given the design's maturity. The methodology is not confined to the events that only affect the IMSR Core-unit. The set of PIE discussed in this topical report, and associated references, result from an examination of the complete IMSR facility. This methodology includes an examination of potential off-normal conditions that can lead to potential challenges to one or more of the fundamental safety functions.

Regulatory finality is being sought on the methodology described in Section III of this topical report. The methodology includes the process that will be used to establish a set of PIE for the IMSR400 and the criteria for classifying individual PIE for evaluation. Regulatory finality on the enclosed list of PIE or the classification of individual PIE is not being requested in this topical report at this time. The presentation of information about the methodology and an application of the methodology provides the opportunity for the regulator to observe the application of the methodology and the resulting outcomes for event classification once the methodology is implemented on the design. Regulatory approval of a final comprehensive list of PIE and the final individual PIE classification will be requested as part of a future license application review.

VIII. Purpose

The purpose of this topical report is to describe and seek NRC regulatory approval for the methodology used to develop a set of postulated initiating events (PIEs) for the Integral Molten Salt Reactor (IMSR) design, and to provide as complete a set of PIEs as is possible given the design's maturity. The set of PIEs discussed in this topical report are not confined to the events that only affect the IMSR Core-unit and are presented to demonstrate the methodology. The set of PIEs discussed in this topical report and associated references result from an examination of the IMSR facility as a whole. The examination includes the potential off-normal conditions that can lead to potential challenges to one or more of the following fundamental safety functions:

- Controlling reactivity
- Removing heat from the primary system (fuel salt)
- Retaining radionuclides

Regulatory finality is being sought on the methodology that will be used to establish the set of PIE and the criteria for classifying individual PIEs for evaluation. Regulatory finality on the enclosed list of PIEs or the classification of individual PIE is not requested in this topical report.

The discussion of the implementation of the PIE identification methodology and the potential results of the direct application of the methodology are provided in Sections III.4 and III.5 for illustrative purposes. The information in those sections provides the U.S. Nuclear Regulatory Commission (NRC) the opportunity to see clearly how the methodology will be successful in identifying all potential initiating events affecting the operation of the IMSR400 for all plant states and provides the opportunity for the NRC to ask for specific information about the planned design and operation of the IMSR400. Regulatory approval of a final comprehensive list of PIE and the final individual PIE classification will be part of a future license application review.

The design information associated with the IMSR400 reflects the information available for systems as of March 2023. The information was collected from the documents listed in Section VI.

The information in this topical report also addresses the comments received from the Canadian Nuclear Safety Commission (CNSC) and the NRC in their joint report on this topic titled "Joint Report on Terrestrial Energy's Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor" [R-12].

IX. Introduction

a. Licensing Strategy and Objective

Terrestrial Energy USA's (TEUSA) long-term licensing objective for the commercial deployment of the IMSR design in the U.S. is to first obtain an SDA for the IMSR Core-unit under 10 CFR Part 52, Subpart E. The IMSR Core-unit represents a significant technical portion of the IMSR facility and includes many systems that perform important safety functions. The systems within the Core-unit are reasonably discernible from systems outside the boundaries of the Core-unit. Subsequent sections of this white paper provide additional details about the design envelope of the IMSR Core-unit and its safety interfaces.

TEUSA has developed and submitted a Regulatory Engagement Plan (REP) [R-1] to the NRC. The REP outlines a series of technical documents which TEUSA plans to submit to the NRC for review and comment or review and approval. The TEUSA REP provides additional details regarding TEUSA's licensing activities and objectives.

The identification of PIEs is the first step in the design review and assessment process. It is also a starting point for the safety analysis. A PIE is an event identified in the design that leads to Anticipated Operational Occurrences (AOOs) or accident conditions. Accident conditions include Design Basis Accidents (DBAs) and Beyond Design Basis Accidents (BDBAs). BDBAs include a subset of severe accidents.

There are several sources used to identify the PIEs. The basic sources include Probabilistic Safety Assessment (PSA, hereafter referred to as a Probabilistic Risk Assessment (PRA), engineering judgement, reference lists for the same or similar type of reactor, and operational experience. The operational experience from the Molten Salt Reactor Experiment (MSRE) contains some actual AOOs and experiments which provide insight on DBAs.

The PIEs are further grouped into categories, based on similarity of the plant response or similar initiating failures. The resulting list of PIEs will need to be updated as the design evolves. The set of PIEs will be finalized, and the final classification of PIEs will be confirmed or will be adjusted at the time the result of the complete PRA becomes available. The final set of PIEs will be submitted for review and approval as part of a license application.

b. Description of the IMSR400

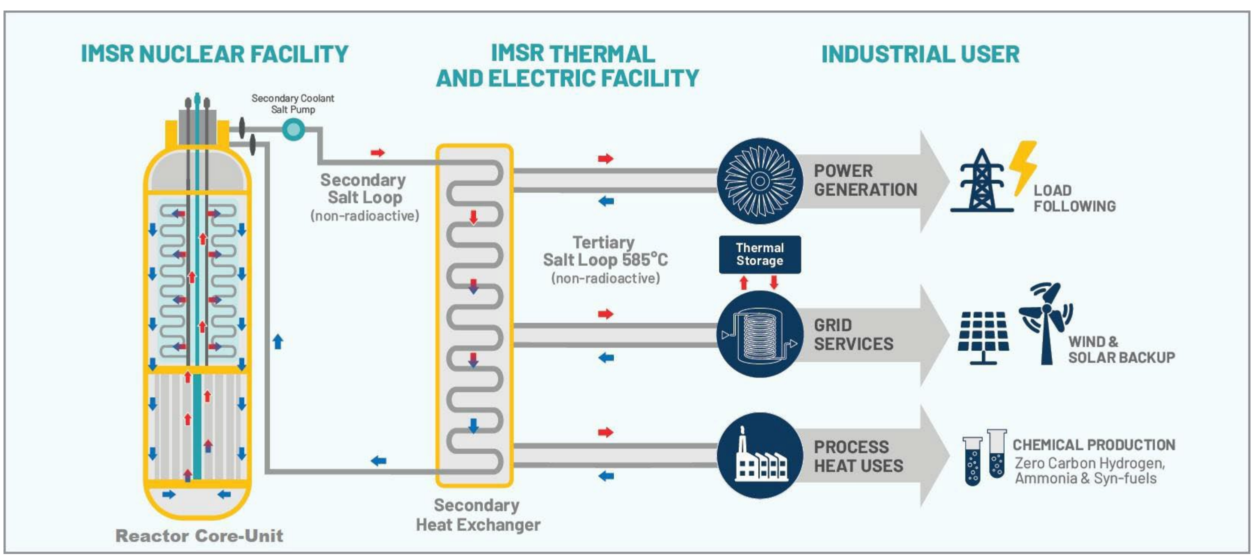
IMSR400, developed by Terrestrial Energy Inc. (TEI), is a near-atmospheric pressure, pool-type, and integral reactor vessel, called the Core-unit, featuring integral primary heat exchangers (PHXs), pumps and extensive inherent and passive safety features. IMSR400 employs a liquid fuel (Fuel Salt) rather than a conventional solid fuel; this liquid contains nuclear fuel and also serves as the primary coolant. It uses graphite as the moderator and operates at low pressure and high temperature (~700 °C) with a rated thermal capacity of 442 MW and provides 195 MWe (net) in electrical power, as well as 585 °C heat for a broad range of potential industrial heat applications. An expanded discussion of the key systems and structures that will be discussed in this topical can be found in the TEUSA White Paper "Core-unit Definition, applicable Structures, Systems, and Components" (TEUSA Document #200310) [R-2] A more detailed presentation of the design details for the systems and structures of the IMSR400 would be found in the specific system reference documents listed in Section VI of this report.

Some of the key factors that support the enhanced safety performance of IMSR400 are as follows:

- IMSR400 has a negative temperature reactivity coefficient of the Fuel Salt [R-13]. If there is a power generation to heat removal mismatch, the increasing Fuel Salt temperature causes a decrease in the reactivity of the system and eventually stabilizes the nuclear reaction such that adverse effects from the reactivity excursion are precluded.
- IMSR400 utilizes a passive heat removal system known as Internal Reactor Vessel Auxiliary Cooling System (IRVACS) [R-14], which, together with the negative temperature reactivity coefficient, is designed to handle extreme events (such as Station Blackout) in a passive operational mode. As a passive system, using thermosyphoning loops, IRVACS is continuously running, even in the Normal Operation (NO) mode. Therefore, IRVACS is always available (rather than requiring activation) for when a PIE which requires it occurs.
- The Fuel Salt, Secondary Coolant Salt and Tertiary Coolant Salt are chemically stable. Therefore, no chemical reactivity is expected.
- Gaseous fission products such as Krypton, Xenon and Tritium are removed from the IMSR400 Core-unit to minimize their available volumes for leakage in accidents and to maintain low pressures in the Core-unit.
- IMSR400 uses a passive Containment for safety, which is a Category A passive system since the Containment structure has no active components.
- The boiling point of Fuel Salt is above 1400°C, much higher than the operating temperature of ~700 °C. This allows a low operating pressure of the core without risk of fuel boiling.

Figure 1 is a flow schematic of the main heat transfer path for the IMSR400. The IMSR400 uses molten fluoride salt, [[ ]] for its primary Fuel Salt. A Secondary Coolant System (SCS), also using a fluoride salt [[ ]], transfers heat away from the Core-unit through the integral PHXs. The SCS, in turn, transfers its heat load to a Tertiary Coolant System (TCS) via the Secondary Heat Exchangers (SHXs), which circulates the heated Tertiary Coolant Salt to a separate building (outside of the nuclear island) where it either transfers heat to Steam Generators (SGs) that generate superheated steam for power generation, or transfers heat to process heat applications.

Figure 1 – Flow Schematic of the Main Heat Transfer Path for the IMSR400 [R-15]



c. Scope

The PIE methodology contained in this report represents an evolution of the initial PIE methodology previously submitted in the TEUSA white paper “TEUSA submittal of Postulated Initiating Events for the IMSR®” Revision 2, December 16, 2021 (ML21357A015). The revised methodology addresses some of the comments provided by CNSC and the NRC from their joint review in the document titled "Joint Report on Terrestrial Energy’s Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor,” May 2022 (ML22139A124) [R-12].

This methodology evaluates a single-unit Nuclear Power Plant (NPP) configuration on a generic site (i.e., not site-specific). The methodology for identifying PIEs requires that the following plant operating modes be evaluated:

- **Fuel Storage**: this operating mode refers to the storage of irradiated, unirradiated and decayed Fuel Salt outside of the Core-unit. Locations for fuel storage include the Fuel Salt Storage Tank (FSST), Spent Fuel Storage Tanks (SFSTs), Initial and Makeup Fueling Room and the Flush Tanks[1]. This mode also includes the transfer of irradiated Fuel Salt from the FSST to the SFSTs. A description of the Initial and Makeup Fueling Room is provided in [R-17].
- **Initial Fueling**: this operating mode begins once transfer of Fuel Salt from the FSST to the Core-unit with the Shutdown Rods (SDRs) inserted begins (end of Fuel Storage mode) and ends once the Core-unit is filled to the desired level (start of Shutdown mode). This mode includes the subsequent flushing of the salt transfer lines. The steps followed for Initial Fueling are outlined in [R-16]
- **Shutdown[2]:** this operating mode refers to a filled Core-unit (i.e., filled to the level required for operation) with the SDRs inserted.
- **Startup**: this operating mode begins once the SDRs are removed while the reactor is above the criticality temperature (end of Shutdown mode), resulting in the reactor being shutdown on temperature, and ends once the reactor temperature is brought below the criticality temperature by increasing demand from the Steam Plant (start of At-power mode). Note that Startup can occur either after Initial Fueling or after Shutting Down (i.e., for maintenance). The steps followed for Startup are outlined in [R-13].
- **At-power**: this operating mode refers to an operating Core-unit which generates thermal power that is transferred to the Steam Plant via the SCS and TCS. This mode also includes the periodic addition of makeup Fuel Salt, as described in [R-17]
- **Shutting Down**: this operating mode begins once the reactor is above the criticality temperature (end of At-power mode), resulting in the reactor being shutdown on temperature, and ends once the SDRs are inserted while the reactor is still above the criticality temperature (start of Shutdown mode). During this transition, the Core heat removal switches from the Steam Plant to Process Reactor Auxiliary Cooling System (PRACS), and once heat removal is controlled by PRACS, the SDRs are inserted. The steps followed for Shutting Down are outlined in [R-18].

[1] Flush Tanks are included as a location for fuel storage because after flushing, the flush salt is mixed with the residual irradiated Fuel Salt from the piping/vessels, and this mixture is subsequently transferred to the Flush Tanks. Therefore, this residual irradiated Fuel Salt is being stored in the Flush Tanks.

[2] The Core-unit can shut down with either the SDRs or on high temperature (i.e., exceeding the criticality temperature). The Shutdown mode described here includes shutdown only with the SDRs, based on the normal operation modes going to Shutdown (see Shutting Down) and going from Shutdown (see Startup and Defueling).

- **Defueling**: this operating mode begins once the transfer of Fuel Salt from a Core-unit to the FSST is initiated (end of Shutdown mode, but SDRs remain inserted) and ends once the Core-unit is empty to the extent possible. This mode includes the subsequent flushing of the salt transfer lines. The steps followed for Defueling are outlined in [R-16].
- **Core-swap**: this operating mode involves the replacement of a spent Core-unit with a new Core-unit within the Containment volume. Note that this process can take place at any point after a spent Core-unit has been defueled and occurs in parallel with the other operating modes described above. The steps followed for Core-swap are outlined in [R-19].

Figure 2: Plant operating modes and the transitions between them for normal operation[3]

[[

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The major Structures, Systems and Components (SSCs) which this document covers are the following:

17. SCS
18. TCS
19. Core-unit[4]
20. IRVACS
21. IPS (Integral Pumping System)
22. SHXs

[3] Note that Core-swap can take place at any point after a Core-unit has been defueled and occurs in parallel with the other operating modes shown in **Figure 2**.

[4] Core-unit includes the RV and its contents, which are the graphite core, Primary Pumps, PHXs, Fuel Salt, EHX1 of IRVACS.

23. SGs
24. Steam Plant
25. IrFS (Irradiated Fueling System)
26. FSST Active Cooling System (FACS)
27. IFACS (Irradiated Fuel Auxiliary Cooling System)
28. Initial Fuel System (InFS) and Makeup Fuel System (MFS)
29. Core-swap system
30. PRACS (Process Reactor Auxiliary Cooling System)
31. Core-unit support structures
32. Containment

Additionally, PIEs related to the Instrumentation and Controls (I&C) and plant electrical systems have been considered. The PIEs identified in this report include, as potential causes, the failure of all supporting Systems, Subsystems and Components (SSCs, e.g., failure of HVAC), leading to the failure of a system safety function.

PIEs arising from malevolent attacks and safeguard related events are not covered in this document. Details on these can be found in the Preliminary Safety Analysis Report (PSAR) Annex 1: Security [R-20], PSAR Annex 2: Safeguards [R-21] and the Plant Control and Monitoring System (PCMS) design description [R-22] (for details on cyber-attacks).

This document only considers events within the nuclear island, or events which initiate outside of the nuclear island but then propagate to the nuclear island, such as the external hazards (see section III.4.6). For this document, the Balance of Plant (BOP) is a generic Steam Plant, where only bounding events causing increased or decreased heat removal are considered, as captured in [[ ]], respectively. Specific events within the Steam Plant (e.g., main steam line break, loss of feedwater, loss of condenser cooling, turbine trip) are considered as potential causes of these bounding events. Also, Steam Plant events which impact the Nuclear Plant pressure boundary are also considered (i.e., [[ ]]). Note that the Steam Plant is not required to maintain the control, cool and contain safety function capabilities of the NPP (i.e., the SSCs of the Steam Plant will not be needed to perform any safety functions).

Note that certain PIEs impact the NPP as a whole, which includes safety systems, safety-related systems and non-safety-related systems. Examples of these PIEs include loss of offsite power and internal/external hazards. In terms of external hazards, the IMSR is currently designed as a generic IMSR plant that is designed and qualified against generic external hazards using generic site parameters. TEI used the following IAEA guidance to assist in the development of its list of potential generic external hazards to be evaluated for the IMSR design:

- IAEA Safety Standards Series No. NS-G-1.7, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants [R-24].
- IAEA Safety Standards Series No. NS-G-3.3, Evaluation of Seismic Hazards for Nuclear Power Plants [R-25].
- IAEA Safety Standards Series No. NS-G-1.5, External Events Excluding Earthquakes in the Design of Nuclear Power Plants [R-26].

- IAEA Safety Standards Series No. NS-G-1.11, Protection against Internal Hazards Other than Fires and Explosions in the Design of Nuclear Power Plants [R-27].
- IAEA Safety Standards Series No. NS-G-3.5, Flood Hazard for Nuclear Power Plants on Coastal and River Sites [R-28].
- IAEA Safety Standards Series No. NS-G-3.4, Meteorological Events in Site Evaluation for Nuclear Power Plants [R-29].
- IAEA Safety Guide No. NS-G-3.6, Geotechnical Aspects of Nuclear Power Plant Site Evaluation and Foundations [R-30].

The list of potential internal/external hazards includes environmental events (e.g., flooding, fire, earthquake) and internal system failures (e.g., explosion, missiles). For additional insights into the potential events to be considered, refer to Section III.4.6 of this report. The list will be modified to reflect the hazards present at any future site as part of the license application. Combination events (i.e., events that evaluate the combination of an internal event coupled with an external event or combination of multiple internal or external events) are not included in the scope of this document. A future revision of the PIE document will include credible combinations of individual events, including internal and external hazards, which could lead to anticipated operational occurrences or accident conditions, and shall be considered in the design. The process of identifying combinations of hazards will consider combinations that are either consequential or correlated and will exclude combinations of independent hazards, as per [R-23].

Malevolent attacks and safeguard-related events will be addressed separately under security and safeguards documentation. Note that protection against intentional large aircraft crash is considered in the IMSR design (also included in the protection against malevolent acts scope). Slow-developing degradation in the operating conditions (i.e., ageing) will be addressed in the plant design, equipment qualification program as well as the plant monitoring, maintenance, in-service inspection and test programs.

d. Quality Assurance

The Quality Assurance (QA) practices are in place to ensure that this methodology is accurate, complete, and up to date with respect to the design information, regulatory documents, internal analysis documents (i.e., DSA and PRA) and external literature/research and will be implemented in accordance with the process described in this topical report. The general controls used are described in the TEI Management System Manual, with additional information provided below. (Note that the TEI Management System is comparable in scope to 10 CFR 50 Appendix B. While the Quality Assurance Plan for TEUSA has not yet been submitted for review, TEUSA will ensure that the regulatory process described in this topical report will be performed under a quality assurance plan that meets NRC requirements.) Further, this is done through the selection of qualified persons to identify PIEs and the review and verification of the resulting documentation following the applicable management and review controls.

i. Expertise Requirements

In order to successfully identify a comprehensive set of PIEs, a person or set of people with substantial knowledge of the design and proposed operation of the IMSR400 is chosen to perform the process outlined in the methodology (see section III.1). One person from the Safety Team is assigned as the task lead by the Safety Team Manager and is supported in the effort by the other members of the Safety Team. The task lead will be responsible for creating an update plan for the PIE document and executing this plan (see section III.4.2). Additional qualified people are selected to review (and verify, see section III.4.2) the results of this process. The managers responsible for the technical and engineering disciplines, in consultation with the Safety Team manager, are tasked with the identification of personnel with the appropriate expertise to serve as reviewers of this document. It is the responsibility of the Safety Team Manager to ensure that the expertise of the selected personnel is relevant and sufficient to provide a comprehensive analysis.

Depending on the stage of the design and the extent of the updates required, the task lead, supporting team members and reviewers cumulatively have familiarity in all or a subset of the following areas [R-31]:

1. Licensing
2. Plant design details
   a. Reactor
   b. Spent fuel
   c. Structures
   d. Mechanical systems
   e. Electrical systems
   f. Instrumentation and control systems
   g. Internal and External Hazards
3. Plant operations
   a. Concept of operations
   b. Plant operating modes
4. Reactor physics
5. Thermal-hydraulic analysis
6. Reliability engineering and/or PRA methods
7. Expertise in the selected methods of analysis
8. Expertise in disciplines unique to the chosen technology

Note that as the design develops, new information will become available and expertise requirements will change. Therefore, the requirements listed above may not all be utilized at each iteration of this document. The above list is a complete set of engineering disciplines that might be expected throughout the entire design process. For each iteration of this document, the task lead, as supported by the Safety Team Manager, will ensure that the expertise of the individuals involved is appropriate for the scope of the review.

ii. Management and Review Controls

The management and review controls include the processes for collecting information that could result in changes to the PIEs, determining when updates are made and performing review. The general controls used at TEI are described in the Management System Manual [R-32], with additional information provided below.

The process in place for collecting information that could result in changes to the PIE (followed by evaluating that information to determine the necessity for an update) is primarily done using "points of contact", as described in [R-33] and illustrated in Figure 3 below. Points of contact are individuals of a technical discipline (e.g., safety) that are responsible for collecting new information from other disciplines (e.g., physics, mechanical, R&D) and for communicating this information to their own discipline. Each individual within a team is assigned one or more aspects of the design for which they act as point of contacts, so that cumulatively all members within a team establish a communication link to all other disciplines. The points of contact collect information primarily through meetings which the discipline responsible holds to update all points of contact with their new information. Following this routine process, periodic (internal) team meetings are held where team members will update the team with this new information and any associated documentation. In addition to this process, the review and comment process on any new documentation will include all interfacing disciplines (including safety). The reviewers representing these interfacing disciplines will then convey the information during the team meetings, such that the team is up-to-date on the work being done by other disciplines. For the Safety Team, all information which could result in changes to this document will be collected by the Safety Team Manager.

Figure 3: Schematic showing the transfer of information to the safety team using points of contact strategy[5]

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Based on an evaluation of this new information, as well as any external documentation (e.g., regulatory documents, literature from other reactors) and internal safety documentation (i.e., PRA and DSA) since the last PIE update, the Safety Team manager, with support from the Safety Team members, will perform an evaluation to determine if an update to the PIE identification methodology, PIE list or PIE classification is necessary. If an update is deemed necessary, the process of selecting qualified personnel will be initiated by the Safety Team Manager.

Once chosen, the task lead will begin by creating an update plan for the PIE document (see [R-7] for an example of an update plan). The update plan will be aligned with the engineering advancements in the IMSR design since the previous update. The update plan will highlight the areas of the IMSR design that have changed, and which now require updating in the reference document. The plan will include specific references to inputs that are to be used to perform these updates (e.g., design documents, literature, regulatory documents). This plan will also involve the assignment of work to qualified personnel who have access to all relevant background information, and the interfacing disciplines required for each update for details on interdisciplinary interface procedures/requirements). The task lead will also include in the plan the actions for review of the updated documentation. The Safety Team Manager, in consultation with other technical discipline managers and the task lead, will identify the specific reviewer(s) that have the necessary skills to effectively perform the review tasks as outlined in the

[5] Note that this figure is an example for illustrative purposes, there are more disciplines than what is shown.

update plan. The task lead will also be responsible for initiating the document controls described below.

Once the plan has been written, reviewed and approved (following similar procedures to those outlined for the review of the document draft, described below), the task lead will proceed to execute the plan that will result in a draft of the updated document. This draft will be reviewed, as outlined by the plan, by other safety team member(s) and members of interfacing disciplines for completeness and accuracy. The review process, referred to as the review and comment process, will take place through the established document management and control procedures. Each reviewer will be verifying that the information is accurate with respect to the design information and any other relevant references. Note that since no calculations are performed as part of the update process, no associated verification of calculations is required.

During the IMSR400 design, engineering, and pre-licensing phases there are no specific periods defined to update this information but are rather based on the collection and evaluation of new information by the Safety Team Manager and Safety Team, as described above. Once the IMSR400 is licensed, the evolution of the design would be greatly reduced and therefore, plant changes affecting the set of PIEs would be greatly reduced as well. Nonetheless, maintenance of the PIE list by both TEUSA and the plant license holder would be expected, in order to identify new events or update previous ones in terms of their descriptions, mitigations and frequencies. During the life cycle of the plant, this information will be updated periodically. While not a requirement of this methodology, a natural assessment point would seem to be the period following updates to the PRA or following each Core-unit reload (seven years). Nevertheless, if there is a significant change to the plant design or its risk profile, the supporting safety analysis documentation would be modified using the appropriate licensing basis change process established by the regulations.

It is essential that the PIE list is developed and finalized to include input from all interfacing disciplines. During the conceptual design and basic engineering stages, all relevant disciplines have been involved in the review of and feedback on the PIE methodology and PIE list, including DSA, PRA, Licensing, Physics, Thermal-hydraulics, Civil, I&C, R&D, Fire Protection, and system designers. External safety experts from Canada and UK in the DSA and PRA areas were also involved in the review of the IMSR PIE methodology. In the detailed engineering stage, an internal PIE panel will be established for further supporting the developing and finalizing the PIEs list. The PIE panel will include the experienced expertise from relevant disciplines. The panel will thus play a role in the identification, categorization, and/or classification of PIEs.

X. Process for Identifying PIEs

In the design stage of IMSR400 it is important to identify a comprehensive set of PIEs such that, to the extent practical, all foreseeable events are identified and are considered in the design. From the perspective of Safety Analysis, a comprehensive listing of PIEs should be prepared for all permissible plant operating modes to ensure that the analysis of the behavior of the plant is complete. Note that slow-developing degradation in the operating conditions is not considered a PIE. In the current methodology, each identified PIE is categorized into one of seven categories based on their associated primary plant response or similar initiating failures.

After the comprehensive list of PIEs is generated, the events are classified based on their estimated frequency of occurrence (i.e., AOO, DBA and BDBA, see section III.5 for classification criteria, inputs and preliminary results).

a. Approach for PIEs Identification

The PIE identification process should be as systematic and complete as possible. The various causes for an initiating event are considered, which include events internal and external to the NPP. For internal events, SSC failures, operator errors and hazards (i.e., human induced or caused by SSC failure/malfunction) which directly or indirectly challenge one or more of the systems required to maintain safety of the plant are considered. For external events, hazards (i.e., human induced or naturally occurring) and events originating in the Steam Plant are considered. External hazards are man-made or naturally occurring to a site and facilities and originate externally to both the site and its processes and over which the site operator may have no or very little control (e.g., earthquake). Internal hazards originate internally and can be man-made or caused by SSC failure/malfunction. As such, the operator may have more control over them. Since this document considers a generic site location, the hazards are based on generic IMSR400 qualification requirements. These events are currently described at a high level and will be broken down further into more specific PIEs once a detailed hazard assessment is complete. The PIEs identified in this report include, as potential causes, the failure of all supporting SSCs (e.g., failure of HVAC, leading to the failure of a system safety function).

The design philosophy for the IMSR is to preclude or limit the influence of human error on plant safety by using fault tolerant, inherent and passive safety features. IMSR is designed to minimize the possibility for human error. The human intervention generally acts as a back-up to automatic plant response in the IMSR design following a PIE. [[

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More details on human-induced events will arise from the human factors review and the PRA. Where design detail is still to be developed, the current PIE methodology uses a bounding or representative event as a placeholder for a more detailed initiator. Continuous and iterative consultation with the System Responsible Engineers (SREs) of the systems being analyzed in this report ensures that all PIEs and their respective mitigations are captured to the extent practicable.

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When identifying PIEs, the various plant operating modes considered include Fuel Storage, Initial Fueling, Shutdown, Startup, At-power, Shutting Down, Defueling and Core-swap. The PRA model currently addresses three steady states (power, shutdown, fuel storage), for which fault schedules were generated and used to update the PIEs in this topical report [R-10]. The fault schedules outline the preventative, protective and mitigative safety measures (at a system level) intended to be claimed in the PRA for each identified initiating event. The PRA will be extended to cover all operating modes mentioned.

The PIE list is non-site-specific currently. Therefore, PIEs that are initiated by external hazards will require re-evaluation once the NPP site is chosen, based on the site evaluation and environmental assessment processes. Additional details regarding the scope considered in PIE identification are described in Section III.4. The identification of external hazards uses the list presented in [R-8], which is based on generic IMSR400 design using generic site parameters.

In this report, the “top-down” approach is employed to identify PIEs, which is similar to a Master Logic Diagram (MLD) used as a PRA tool [R-31]. Note that a general top-down approach was used which considers all plant operating modes, however, future work will involve performing individual top-down assessments as necessary for each plant operating mode and undertaking further bottom-up hazard identification (described below) to ensure that all foreseeable PIEs are identified. The top-down approach starts by specifying [[ ]] events. For example, with the top-level undesired outcome, the second level will be the direct and immediate causes of that outcome. Similarly, the third level will list the direct and immediate causes of the second level, and so on. At the end of this analysis process, the individual PIE would be identified.

To complement the top-down approach, a bottom-up approach (described below) is used to identify new PIEs (i.e., those which the top-down approach did not identify) or update ones previously identified by the top-down approach (i.e., in terms of event causes/mitigations). In this way, the results from both approaches can be integrated. When integrating the results, all events [[ ]] this methodology. This methodology is meant to develop a comprehensive list of all PIEs, no matter

their likelihood. The PRA takes the PIE list presented here as an input and performs screening (i.e., removal of events which have low frequencies and/or consequences). (See [R-10] for screening methodology and results.

The bottom-up approach begins at a lower level (i.e., component or major component assembly) and considers how failures may affect the system-level or plant-level function. Examples of this approach include Hazard and Operability Analysis (HAZOP)[R-37], Failure Modes and Effect Analyses (FMEA)[R-38], Hierarchical Task Analysis (HTA) [R-39] [R-40], walkdown (physical/virtual) [R-41] and Human Error Identification (HEI)[R-40]. During the conceptual design stage, an accident list was generated using an approach similar to FMEA, however it did not show much insight (i.e., no new PIEs identified) [R-42]. [[

]] Figure 4 presents a mapping of the IMSR physical design to the functional model [R-42]. As shown in Figure 4, the process was supplemented by high-level Preliminary Hazards Analysis (PHA) and Failure Modes and Effects Analysis (FMEA).

Figure 4: Mapping the IMSR Functional Model to the IMSR Physical Architecture

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The PSA report [R-10], generated later during the basic engineering design stage, contains an FMEA of IRVACS where no new PIEs were discovered, however the event causes/mitigations were used to update the existing events described in this document. [[

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As detailed designs on plant systems become available (i.e., at the component level necessary to conduct a bottom-up analysis), further bottom-up analysis will be performed to aid in PIE identification and analysis. Also note that the referenced PRA report used ORNL Reports [R-43][R-44] as a completeness check for initiating event identification. Collectively, the use of top-down and bottom-up approaches provides assurance that faults and hazards have been comprehensively identified.

Additionally, a report from the Canadian Nuclear Laboratories (CNL) on the Phenomena Identification and Ranking Tables (PIRTs) for severe accidents in Small Modular High-Temperature Gas-Cooled Reactors (HTGRs) [R-45] was reviewed as a potential source of additional information for identification of PIEs. [[.]]

The approach for PIE identification is iterative since the design is constantly evolving. As new information becomes available, which includes but is not limited to regulatory documents, design updates, literature from other reactors and internal analysis documents (i.e., PRA and DSA), this methodology will capture that information and be used during the update process appropriately. Section II.4 provides information on when updates will take place.

b. PIEs Identification

According to the top-down approach, an undesired outcome is specified first. For IMSR400, a power reactor, the top event is taken as [[

]]

Figure 5: Main PIEs Identification Top-Down Flowchart of IMSR400 Radioactive Release [[

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Figure 6: PIEs Identification Top-Down Flowchart of Internal and External Common Cause Events [[

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Figure 7: PIEs Identification Top-Down Flowchart for Events from Reactivity Insertion inside the RV [[

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Figure 8: PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal inside the RV [[

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Figure 9: PIEs Identification Top-Down Flowchart for Events from Outside of the RV [[

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Figure 10: PIEs Identification Top-Down Flowchart for Events from Mechanical Failure of Boundary outside of the RV [[

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Figure 11: PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal Outside of the RV [[

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Figure 12 – PIEs Identification Top-Down Flowchart for Events from Loss of Heat Removal in the SCS [[

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c. PIEs Categorization

Based on the top-down flowcharts built in Section III.2, the postulated initiating events for IMSR400 are identified, which includes a total of [[ ]]. The identified events are categorized based on their associated primary plant response (e.g., increase/decrease of Core-unit heat removal) or similar initiating failures (e.g., loss of integrity of piping or vessel). This categorization is done to organize the PIEs, and not for analysis purposes in the PRA and DSA. In the current work, the categories used are the following (based on [R-6]):

8. Unwanted changes in reactivity
9. Increase of Core-unit heat removal
10. Decrease of Core-unit heat removal
11. Loss of integrity of piping or vessel
12. Internal Hazards
13. External Hazards
14. Additional Events

Note that the grouping of PIEs is conducted within the PRA process [R-10] used by Terrestrial Energy and will be conducted within the DSA process. Grouping involves [[

]] for each group. PIEs categorized based on the categories listed above can include multiple bounding events and are not the same as the grouping in the PRA/DSA mentioned above.

d. PIE List

Based on the work from Sections III.2 and III.3, a PIE list is generated with [[

.]] Note that the ordering of the PIEs was done chronologically (i.e., in each PIE document revision, additional PIEs were appended to the end of the tables shown below). Therefore, for a certain system, the PIEs related to it may not appear together (e.g., TCS Pump Trip is 3-7, TCS Pump under- speed is 3-41). The PIEs were not reordered to correct this because other documents reference the PIE numbers, so those references would not be correct if the numbering were to change. Additionally, where PIEs were removed or moved to different categories, their numbers were replaced with new PIEs (i.e., new to the document or moved from another category) such that the numbering of existing events was preserved.

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In several entries in the tables below, it is noted that a bounding case will be analyzed. This analysis will be done as the Basic and Detailed Design Engineering work progresses. Note that the bounding cases have not yet been finalized.

i. Category 1: Unwanted Changes in Reactivity

[[

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ii. Category 2: Increase of Core-unit Heat Removal

[[

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iii. Category 3: Decrease of Core-unit Heat Removal[[

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iv. Category 4: Loss of Integrity of Piping or Vessel [[ ]]

Category 5: Internal Hazards[[

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v. Category 6: External Hazards[[

]]

vi. Category 7: Additional Events

[[

]]

e. Classification of the PIEs

After all PIEs are identified, they are classified based on their frequencies and consequences. The purpose of classifying PIEs is to guide the selection of appropriate analytical approaches for each event based on its classification. This classification supports the application of different acceptance criteria—safety criteria, design criteria, and operational criteria—and informs the identification of appropriate mitigating measures. In this report, the PIEs are classified into the following three plant states based only on their frequency[6]:

- AOO: AOOs are considered to represent a group of potentially frequent events or events that might be expected to occur one or more times in the lifetime of a plant. These include all events with frequencies of occurrence equal to or greater than 10^{-2} per reactor year.
- DBA: DBAs are much less likely to occur as compared to AOOs and would generally capture events that are expected to occur once in the lifetime of a large population of plants. These include events with frequencies of occurrence equal to or greater than 10^{-5} per reactor year, but less than 10^{-2} per reactor year.
- BDBA: BDBAs are not expected to occur during the lifetime of a fleet of reactors however, it is necessary to assess the capabilities of the plant to prevent or mitigate such events in the extremely unlikely event that such an event occurs. These include events with frequencies less than 10^{-5} per reactor year.

These frequency ranges are based on CNSC requirements (see [R-5]). Because the NRC does not have established frequency ranges for classifying accidents, and this methodology will also be used in Canada, this methodology will be using the classification ranges that comply with CNSC requirements. Therefore, TEUSA proposes to use the frequency ranges set in the CNSC requirements document for its event classification. The events with a frequency on the border between two classes of events would be conservatively classified into the higher frequency class. It is recognized that assessments of the frequency of occurrence of events close to borderline between classes may be characterized by uncertainty and such events may also be classified into the higher frequency class, depending on their 'spread'. [[

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In the present revision of this methodology, the PIE frequencies and resulting classification were determined first from probabilistic studies. Note that for some events, the classification was based on an

[6] Classification of events based on both frequency and consequence may be done at a later stage, once the appropriate DSA has been conducted.

older version of the design and is therefore subject to change based on a future update to [R-9]. For events not included in the probabilistic studies (i.e., those which were identified after the study was carried out, or those which were screened out during the study[7]), engineering judgement was used with guidance from [R-6] (experience from other reactors). Operator error was also considered when determining frequencies and classifying PIEs.

Frequency of external events (see section III.4.6) is highly dependent on the NPP site and therefore the classification of those events presented here is subject to change based on the site evaluation and environmental assessment processes.

The engineering judgements used in this methodology are the following:

- [[

[7]No screening-out of PIEs was done in this methodology. This methodology is meant to contain a comprehensive list of all possible PIEs, no matter their likelihood. The PRA takes the PIE list presented here as an input and performs screening.

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The current classification of PIEs is listed below as a reflection of the implementation of the methodology presented in this topical report to the current design of the IMSR400. It does not reflect the final classification nor the full set of postulated initiating events but does provide an opportunity to view the comprehensive nature of the process.

Note that for all [[

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IRVACS related PIEs in section III.4.3 [[

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i. Anticipated Operational Occurrences (AOOs)

[[

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ii. Design Basis Accidents (DBAs)

[[

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iii. Beyond Design Basis Accidents (BDBAs)

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XI. Conclusions

Implementation of the methodology presented in this topical report identified a total of [[[8]]] which can potentially challenge the safety functions of the reactor facility and release radioactive material to the environment. These PIEs are divided into 7 categories for the future use in DSA and PRA. TEUSA supports the conclusion that the methodology as described in this topical report, as supported by the cited references, provides a comprehensive and systematic process that will lead to a comprehensive set of PIEs for the IMSR400. Further, the methodology includes a process to assure that as the IMSR400 design evolves, the set of PIEs will also evolve in a timely manner to support the continued safe licensing and operation of the IMSR400.

All identified PIEs are also classified into three plant states (AOOs, DBAs, and DBDAs) according to the guidance from [R-6]. Classification was taken from the PRA frequency assessment [R-9] where available for a given event, and where not available, the classification was based on similar events in existing NPPs supplemented by engineering judgement and guidance from [R-6].

Finally, at the time of NRC initial joint review with the CNSC, the NRC concluded that while additional discussion would be required, the NRC had no major concerns with the methodology presented by TEUSA. TEUSA believes that the methodology has been improved resulting from comments given in the Joint Report [R-12], including the incorporation of PRA insights as they have become available. TEUSA also continues to believe that consistent with the Joint Report conclusions, the methodology presented in this topical report remains systematic, logical, and will include the appropriate scope that will reflect the final design and operation of the IMSR400.

The PIE list presented in this topical report contains a comprehensive list of all PIEs that have been identified based on a systematic approach using the current available information, including the IMSR design documentation, reference list for similar type of reactor, hazard identification studies, engineering judgement and operational experience. [[

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[8] The initiating events classified under AOOs, DBAs, BDBAs in total are more than the [[ ]] discrete PIEs because of the identification of the same initiating event in more than one class. For example, a primary heat exchanger blockage can be single or multiple and therefore, can fall under AOO or DBA, respectively.

The approach for PIE identification is iterative since the design is evolving. As new information becomes available, which includes but is not limited to regulatory documents, design updates, literature from other reactors and internal analysis documents (i.e., PRA and DSA), the PIE document will be updated appropriately.

PIE completeness will be checked during any evolution of the PIE update process. The internal PIE panel will perform the completeness check. The panel will confirm that all relevant technical disciplines have been involved in the development of and feedback on the updated PIE list. including DSA, PRA, Licensing, Physics, Thermal-hydraulics, Civil, I&C, R&D, Fire Protection, and system designers. The panel will also confirm that the most recent and approved versions of technical design documents were employed in the PIE development process and that the updated list reflects the state of the design. The panel will also confirm that the updated PRA was employed to establish the failure modes and failure frequencies so that all PIEs can be properly categorized as AOO, DBA or BDBA. A PIE update process will be triggered at the time of a license application. In addition to the above, as part of the PIE update for an application, the panel will also confirm that the full spectrum of external and internal hazards have been factored into the PIE list that are specific to the selected site.

XII. CNSC/NRC Comments on PIE from Joint Report

In May 2022, the NRC and CNSC issued a joint report on the methodology for developing a postulated initiating events list for the Integral Molten Salt Reactor. This section of the topical report provides some insights into how the comments contained in the joint report have been considered or factored into changes to the methodology previously reviewed by both regulators. The focus of this section will be on the comments issued jointly and, on the comments issued specifically by the NRC. The comments issued by CNSC have also been considered in the revisions to the methodology although they will not be specifically discussed in this report.

Joint Feedback Comment #1

"Terrestrial is expected to document in detail, the expertise and qualification of personnel involved in future work on the PIE list development. Terrestrial's future submittal should also address its rules regarding the use of engineering judgement."

Response:

TEUSA notes that the application of the enclosed methodology is not a one-and-done activity. The IMSR400 design will continue to evolve up to the time an application for a license is submitted and even during the review of any license application. Section II.4.1 contains the descriptions of the specific disciplines that could be involved in updates to the PIE list using this methodology. As stated in that section, the technical disciplines listed there may not all be utilized at each iteration of the PIE list. The list is a complete set of engineering disciplines that might be expected throughout the entire design process. For each iteration of the PIE list, the task lead, as supported by the Safety Team Manager, will ensure that the expertise of the individuals involved is appropriate for the scope of the review. It is the responsibility of the Safety Team Manager to ensure that the expertise of the selected personnel is relevant and sufficient to provide a comprehensive analysis. The expertise used to develop the referenced set of PIE in a future license application will be included in that future license application referencing the IMSR400.

Joint Feedback Comment #2

"In future submittals, the regulatory staff will need a description of this program and of the processes used for maintaining configuration control (including software configuration control)."

Response:

This comment refers to the software program PTC Windchill that was described as the means to manage and control changes to documents. The comment discussion focused on the view that Windchill does not constitute a complete configuration management program. The specific details of a complete configuration management program are still being developed, however, when a future license application is submitted to the NRC for review and approval, a quality assurance program (that will include a configuration management program) that meets the requirements of 10 CFR 50 Appendix B will be implemented. The methodology will be implemented, and the PIE list will be developed in accordance with the approved quality assurance program.

Joint Feedback Comment #3

"However, the regulatory staff expect future submittals pertaining to the PIE methodology to include a detailed description of the verification and QA processes. The results of the verification and implementation of QA processes should be available for regulatory evaluation or audit. The PIE methodology should also include processes for collecting the information that could result in changes to the list of PIEs. The process for collecting the information that could result in changes to the methodology could be part of the QA program or be part of the PIE methodology itself."

Response:

The focus of this comment is centered around the procedures that are in place and will be implemented at the time the PIE methodology is implemented to develop a list of PIE that will be included in an application for a license. TEUSA agrees that the process and documentation used for developing the PIE list will need to be in a form that is readily auditable by the regulators. Section II of this topical report outlines the process for collecting information related to design changes or new information that is used to determine when an update of the PIE list would be appropriate. The process for implementing the methodology and changes to the methodology or the PIE list will be conducted within a quality assurance process that will meet NRC requirements.

Joint Feedback Comment #4

"In future submittals, the regulatory staff expect Terrestrial to detail how the iterative process is executed. Terrestrial should also explain its processes to identify and integrate new information during the life cycle of the plant, including the frequency for updating the PIE list."

Response:

The iterative process referred to in this comment is the integration of the PRA insights and other new information into the methodology and how that interactive process could change the list of PIE. Section II.4.2 provides additional detail about the process that will be used to identify new information and the process for initiating an update process for the PIE list. It also contains additional guidance for the frequency for assessing the need to initiate an update process. Note that the information is not a requirement, rather it presents guidance related to the circumstances under which the vendor or a licensee should consider whether new or different initiating events have been identified outside the envelope of initiating events already considered in the existing PIE list or the PIE list included in the current licensing basis of an operating facility.

Joint Feedback Comment #5

"However, as part of future submittals, regulatory staff expect Terrestrial to provide a clear definition of the top event in the "top-down" approach, and to describe the proposed "top-down' and "bottom-up" approaches in detail. Terrestrial is also expected to describe the process used to integrate the results of both approaches; key assumptions used in the methodology, and explain how they complement each other. "

Response:

Section III.1 of the report provides additional guidance into the integration of the "top-down" and "bottom-up" approaches and how those approaches will be used to complement each other. TEUSA does not believe that the regulators expected the methodology or this topical report to include the specific details associated with performing a Failure Modes and Effects Analysis (FMEA) or a Hazard Operability Analysis (HAZOP). These types of assessments are not novel and the procedures for performing them are well understood. The details of these types of assessments performed as a part of the methodology will be available for audit should the regulators wish to review.

The top event used in the 'top-down" approach is listed in Figure 2. Simply, the top event is the prevention or mitigation of a radionuclide release. The top event is consistent with the most significant safety function performed by the IMSR400.

Joint Feedback Comment #6

"…future submittals should include all: hazards and events (internal, external natural and human-induced; radiological sources (reactor core, fresh and spent fuel, radioactive gases); operational modes and transitions (at power operation, low power shutdown startup and other special operating modes; and multi-unit facility, if relevant. In addition, Terrestrial should include a detailed description of the screening criteria and explain how they were used to support the development of the PIE list. As an example, Terrestrial should provide the basis for the specific screening values/criteria regarding health effects and radioactive release."

Response:

Section II of this report provides specific guidance with respect to the scope of the PIE methodology. The guidance covers all the plant operational modes listed in the comment as well as the unique operating conditions of a core-unit replacement, fuel salt defueling, and long-term fuel salt storage. The operating states for postulated events are listed in Sections III.4.1 through III.4.7. The methodology applies to the complete range of internal and external hazards. The scope of internal and external hazards to which the methodology applies are fully displayed in Sections III.4.1 through III.4.7.

As described in Section IV, the methodology will consider internal events having postulated event frequencies larger than 10^-7. CNSC has issued regulatory criteria for classification of postulated event selection. This methodology is written to comply with the CNSC requirements for event classification and TEUSA is proposing to use those criteria for implementation in the U.S. The event classification criteria are found in CNSC document REGDOC 2.4.1, "Deterministic Safety Analysis", May 2014 [R-6]. TEUSA does note that the proposed criteria are more encompassing than the event classification criteria endorsed in the NRC guidance of Regulatory Guide 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non- Light Water Reactors", RG 1.233, June 2020. [R-65] supporting the Licensing Modernization Program. Note that the use of the classification criteria is not applied to external hazard events. The frequency of external events will be based on regulatory guidance established for those events. For example, the design frequency for flooding will be consistent with regulator guidelines for external flooding hazards. The same process will be used for seismic events. This practice is also consistent with the practice endorsed for the LMP process.

The PIE methodology does not use screening criteria for purposes of identifying postulated initiating events that are considered as events for which the IMSR400 must show that the safety functions of control, cool, and contain are successfully performed. Screening criteria are used in the development of the PRA however, those criteria do not apply to this methodology.

Joint Feedback Comment #7

"Regulatory staff expect, as part of future submittals, a detailed description of the process for grouping PIEs, including the rationale for the grouping."

Response:

Section III.3 provides a straightforward and simple explanation for why the grouping categories were selected. PIEs are grouped based on having similar effects on safety and support system availability, temperature and pressure transients, demands on the operator, consequences and success criteria.

Joint Feedback Comment #8

"Terrestrial will be responsible for justifying the chosen frequency ranges for the respective categories."

Response:

As stated in Section IV, the methodology will be using the frequency ranges specified in CNSC REGDOC-2.4.1. These criteria are regulatory requirements set by CNSC. Because this methodology will be used in both Canada and the U.S., TEUSA is adopting the frequency ranges for use in the U.S. TEUSA does note that the frequency ranges are generally consistent with the frequency ranges endorsed by Regulatory Guide 1.233 although the set of postulated events that would be evaluated for beyond design basis events is larger than that endorsed in the regulatory guide. It is important to note that the selection of the frequency ranges in the LMP methodology are completely independent of the evaluation of the frequency of a postulated initiating event that is then placed into the accident categories.

Joint Feedback Comment #9

"…it is expected that in future submittals, the overall methodology used to classify events (including the use of engineering judgment, research and development results, etc.) will be further clarified."

Response:

The approach to integration of new information is presented in Section II.4.2. The guidance for application of engineering judgment is presented in Section III.5.

Joint Feedback Comment #10

"The use of judgement and the treatment of uncertainties in the PIE methodology should be addressed by Terrestrial in future submittals, if requesting approval. This explanation needs to expand on its treatment of modeling uncertainties and uncertainties due to lack of knowledge for some phenomena, and their impact on physical barriers and the PIEs. Such phenomena include: the long-term buildup of fission products in the salts, the potentially highly corrosive behaviour of the fission products, the noble gas fission product transport from the salt into cover gas; the noble metal fission products plate out onto surfaces; and the salt vapor deposition in the cover gas lines.

Response:

A discussion of the treatment of uncertainties is provided in Section III.5 of this report.

As for the treatment of modelling uncertainties listed in the comment, the list of PIE developed by this methodology would capture the worst-case outcomes associated with the phenomena listed in the comment. For example, the buildup of fission products in the salts would have a deleterious effect on the reactivity available in the fuel salt. Such an outcome would be bounded by the events examined by unwanted changes in reactivity. More importantly, because the IMSR400 does not have a fuel salt cleanup system, the buildup of fission products in the fuel salt is evaluated as part of the core physics assessments for the design.

Another example cited was the corrosive behavior of fission products. The design of the IMSR400 already takes into account the chemical nature of the fuel salt and off-gases when the design establishes the operating environments for materials and components in its safety important systems. The structures, systems, and components for the IMSR400 will be qualified to the service conditions in which they would be expected to perform their functions. Setting that aside for a moment, the examples listed would result in either a leak or failure of piping or blockage of a flow path. These types of failures are already considered in the postulated events listed in Sections III.4.1 through III.4.7.

The impacts of the phenomena listed in the comment also bear directly on the radiological source term that would be available for release in the event of a postulated event. The development of the source term is occurring separately outside of the methodology. The demonstration that a particular postulated event meets established regulatory dose criteria is beyond the scope of this topical report.

Joint Feedback Comment #11

"If seeking approval of the PIE list, the following additional information should be provided or made available for audit:…"

Response:

As stated in the report, TEUSA is not seeking approval of the PIE list at this time. As a general response, the documentation used to develop the list under this methodology will be available for audit. Information related to plant operating states considered, effect of support system failures, loss of cooling, loss of electrical power, operator errors and human actions are already included as initiators for postulated events listed in Sections III.4.1 through III.4.7.

The requirement to have the list of PIE undergo an independent review is not supported by any current regulatory guidance or requirements. TEUSA does not believe that such an independent review is needed, especially if the PRA is subject to a third-party review but will consider the need for an independent review at the time it submits its license application.

Joint Feedback Comment #12

"In addition, Terrestrial should clarify whether the following events were considered for the current PIE list:

- Failures of instrumentation and controls (software and hardware) including associated common-cause failures
- Concurrence of hazards (e.g. earthquake and fire, fire and flood, high-winds and external flood).
- Common-cause and multiple independent failures/errors resulting in an initiating event."

Response:

The scope of the methodology is clearly presented in Section II.3. As stated, concurrent external hazards and multiple independent events are not included in the scope of this methodology.

XIII. References

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[R-25]. IAEA, "Evaluation of Seismic Hazards for Nuclear Power Plants", Safety Standards Series No. NS-G-3.3.

[R-26]. IAEA, “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, Safety Standards Series No. NS-G-1.5 .

[R-27]. IAEA, “Protection against Internal Hazards Other than Fires and Explosions in the Design of Nuclear Power Plants”, Safety Standards Series No. NS-G-1.11.

[R-28]. IAEA, Flood Hazard for Nuclear Power Plants on Coastal and River Sites, Safety Standards Series No. NS-G-3.5.

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XIV. Acronyms

Acronym	Definition
AOO	Anticipated Operational Occurrence
ASEP	Accident Sequence Evaluation Program
AHX	Auxiliary Heat Exchanger
BDBA	Beyond Design Basis Accident
BDBT	Beyond Design Basis Threat
BOP	Balance of Plant
CBDTM	Cause-Based Decision Tree Method
CoA	Code of Accounts
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
DBA	Design Basis Accidents
DBT	Design Basis Threat
DCCS	Defueled Core Cooling System
DiD	Defense-in-Depth
DEC	Design Extension Condition
DSA	Deterministic Safety Analysis
EHX	Emergency Heat Exchanger
FACS	FSST Active Cooling System
FEA	Finite Element Analysis
FHA	Fire Hazard Assessment
FMEA	Failure Modes and Effect Analyses
FSST	Fuel Salt Storage Tank
GHTCS	Gas Holding Tank Cooling System

Acronym	Definition
GRS	Ground Response Spectra
GSS	Guaranteed Shutdown State
GV	Guard Vessel
HAZOP	Hazard and Operability Analysis
HCR/ORE	Human Cognitive Reliability/Operator Reliability Experiment
HEI	Human Error Identification
HEP	Human Error Probability
HRA	Human Reliability Analysis
HTA	Hierarchical Task Analysis
HTGR	High Temperature Gas Reactor
HVAC	Heating, Ventilation, Air Conditioning
HX	Heat Exchanger
IMSR	Integral Molten Salt Reactor
InFS	Initial Fuel System
I&C	Instrumentation and Controls
IFACS	Irradiated Fuel Auxiliary Cooling System
IPS	Integral Pumping System
IrFS	Irradiated Fuel System
IRVACS	Internal Reactor Vessel Auxiliary Cooling System
LRF	Large Release Frequency
MCR	Main Control Room
MFS	Makeup Fuel System
MLD	Master Logic Diagram
MSRE	Molten Salt Reactor Experiment
NPCS	Nuclear Plant Control System

Acronym	Definition
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRV	Nuclear Reactor Vessel
OPP	Overpressure Protection
ORNL	Oak Ridge National Laboratory
PCMS	Plant Control and Monitoring System
PDC	Principal Design Criteria
PDS	Plant Display System
PGA	Peak Ground Acceleration
PHA	Preliminary Hazards Analysis
PHX	Primary Heat Exchanger
PIE	Postulated Initiating Event
PIRT	Phenomena Identification and Ranking Table
PRA	Probabilistic Risk Assessment
PRACS	Process Reactor Auxiliary Cooling System
PSA	Probabilistic Safety Assessment
PSAR	Preliminary Safety Analysis Report
QA	Quality Assurance
RAB	Reactor Auxiliary Building
R&D	Research and Development
REP	Regulatory Engagement Plan
RV	Reactor Vessel
RVFF	Reactor Vessel Failure Frequency
SCA	Secondary Control Area
SCoS	Secondary Control System

Acronym	Definition
SCS	Secondary Coolant System
SD	Shutdown
SDM	Shutdown Mechanism
SDR	Shutdown Rod
SFST	Spent Fuel Storage Tank
SG	Steam Generator
SHX	Secondary Heat Exchanger
SMS	Secondary Monitoring System
SPCS	Steam Plant Control System
SRE	System Responsible Engineer
SSC	Structures, Systems and Component
TB	Turbine Building
TBC	To be confirmed
TBD	To be determined
TCS	Tertiary Coolant System
TEI	Terrestrial Energy Inc.
TEUSA	Terrestrial Energy USA
THERP	Technique for Human Error Rate Prediction
UCE	Upper Containment Enclosure
UCH	Upper Containment Head
VFD	Variable Frequency Drive