U.S. NRC-CNSC Memorandum of Cooperation

Joint Report on Terrestrial Energy's Methodology for Developing a Postulated Initiating Events List for the Integral Molten Salt Reactor

May 2022

Approved by

Mohamed K. Shams
Digitally signed by Mohamed K. Shams
Date: 2022.05.26 11:30:57 -04'00'

Dr. Mohammed K. Shams, Director
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
United States Nuclear Regulatory Commission

Approved by

Ducros, Caroline
Digitally signed by Ducros, Caroline
DN: C=CA, O=GC, OU=CNSC-CCSN, CN="Ducros, Caroline"
Reason: I am approving this document
Location: your signing location here
Date: 2022-05-27 09:41:05
Foxit Reader Version: 9.7.1

Dr. Caroline Ducros, Director General
Directorate of Advanced Reactor Technologies
Canadian Nuclear Safety Commission

Rinker, Michael
Digitally signed by Rinker, Michael
DN: C=CA, O=GC, OU=CNSC-CCSN, CN="Rinker, Michael"
Reason: I am approving this document
Location: Ottawa, Canada
Date: 2022-05-27 10:00:25
Foxit PhantomPDF Version: 9.7.1

Michael Rinker, Director General
Directorate of Assessment and Analysis
Canadian Nuclear Safety Commission

USNRC ML22139A124 CNSC eDoc 6750192

Preface

On August 15, 2019, the Canadian Nuclear Safety Commission (CNSC) and the United States Nuclear Regulatory Commission (USNRC) signed a joint memorandum of cooperation (MOC) aimed at enhancing technical reviews of advanced reactor and small modular reactor technologies (Ref. 1). This MOC is intended to supplement and strengthen the existing memorandum of understanding between the two parties, signed in August 2017 (Ref. 2). Additional information on international agreements and the CNSC can be found at https://nuclearsafety.gc.ca/eng/resources/international-cooperation/international-agreements.cfm.

Cooperation between the CNSC and the USNRC provides opportunities for both agencies to share scientific information about technical matters that could support more efficient reviews of small modular reactors and advanced reactor technologies. Cooperative activities can be conducted with acknowledgment of differences in Canadian and U.S. regulatory frameworks and licensing processes while leveraging fundamental scientific and engineering findings from other reviews to the extent practicable.

Activities under the MOC are coordinated by a subcommittee of the USNRC-CNSC Steering Committee, called the Advanced Reactor Technologies and Small Modular Reactors (ART-SMR) Subcommittee. The subcommittee approves and prioritizes work plans to accomplish specific cooperative activities under the MOC.

Cooperative activities between both organizations are established and governed under Terms of Reference (see https://nuclearsafety.gc.ca/eng/resources/international-cooperation/international-agreements/cnsc-usnrc-smr-advanced-reactor-moc-tor.cfm) and are designed to do the following:

- Contribute to better use of regulators' resources by leveraging the technical knowledge and resources between the USNRC and the CNSC.
- Enhance the depth and breadth of understanding of the respective staff of the CNSC and USNRC on the counterpart nation's regulatory review activities and requirements.
- Enhance the joint opportunities for learning and understanding the advanced reactor and SMR technologies being reviewed.

Executive Summary

Terrestrial Energy, Inc. (TEI), and Terrestrial Energy USA, Inc. (TEUSA) (collectively, Terrestrial) are engaged in pre-licensing activities (also referred to as pre-application activities) with the Canadian Nuclear Safety Commission (CNSC) and the United States Nuclear Regulatory Commission (USNRC), respectively. As a result of these pre-licensing activities, the topic of postulated initiating events (PIEs) for Terrestrial's Integral Molten Salt Reactor (IMSR) was identified as a collaboration activity under the memorandum of cooperation (MOC) between the CNSC and the USNRC (Ref. 1). This report documents the results of this collaboration between the CNSC and the USNRC, concerning a request by Terrestrial to obtain regulatory feedback on submittals related to this topic.

The regulatory staff reviewed the information provided to date, including the additional actions identified by Terrestrial to complete the development of its PIE methodology and associated PIE list. The regulatory staff noted that the overall IMSR design, its PIE methodology, and the associated PIE list are still evolving. Therefore, the feedback on the soundness of Terrestrial's PIE methodology and completeness of the current PIE list is high-level and does not constitute a regulatory finding. The feedback presented in this report should be considered by Terrestrial for further development of the PIE methodology and PIE list.

The regulatory staff jointly identified the following five key attributes for evaluating the soundness of a PIE methodology: Quality Control; Systematic Process; Scoping of PIEs; Grouping of PIEs; and Classification of PIEs. The regulatory staff's assessment of Terrestrial's methodology against the key attributes, as discussed in Section 4 of this report, and the PIE list is summarized below:

- Terrestrial's plans for the quality control provisions and processes described in the white paper seem adequate. Given the early stage of the PIE methodology development, the PIEs identification process appears to be systematic, logical, and of appropriate scope.
- The grouping, classification, and mitigating methods presented in the white paper appear to be reasonable. It is recognized that they are likely to change as the design matures and the PSA/PRA is fully developed. Regulatory assessment of the grouping and mitigating functions will be performed by the regulators as part of the evaluation of the future DSA and PSA/PRA submittal.

There is no conclusion on the acceptability of the PIE list. The regulatory staff provided feedback in Section 5 of this report on the completeness of the PIE list and identified additional PIEs for consideration.

Table of Contents

List of Acronyms

AOO	Anticipated Operational Occurrence
ANS	American Nuclear Society
ART	Advanced Reactor Technologies
ASME	American Society of Mechanical Engineers
BDBA	Beyond Design Basis Accident
BDBE	Beyond Design Basis Event
CFR	Code of Federal Regulations
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standard Association
DBA	Design Basis Accident
DBE	Design Basis Event
DC	Direct Current
DSA	Deterministic Safety Analysis
IMSR	Integral Molten Salt Reactor
LBE	Licensing Basis Event
LWR	Light Water Reactor
MOC	Memorandum of Cooperation
NEI	Nuclear Energy Institute
NPP	Nuclear Power Plant
PIE	Postulated Initiating Event
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
QA	Quality Assurance
REGDOC	Regulatory Document
RG	Regulatory Guide
SMR	Small Modular Reactor
SRP	Standard Review Plan
SSCs	Structures, Systems, and Components
TEI	Terrestrial Energy, Inc.
TEUSA	Terrestrial Energy USA, Inc.
USA	United States of America
USNRC	United States Nuclear Regulatory Commission
VDR	Vendor Design Review

1. Introduction

Terrestrial Energy, Inc. (TEI), and Terrestrial Energy USA, Inc. (TEUSA) (collectively, Terrestrial) are engaged in pre-licensing activities (also referred to as pre-application activities) with the Canadian Nuclear Safety Commission (CNSC) and the United States Nuclear Regulatory Commission (USNRC), respectively. TEI was founded in 2012, and operates out of offices in Oakville, ON, Canada, and plans to deploy the integral molten salt reactor (IMSR) design in Canada. TEUSA was founded in 2014, as an affiliate of TEI, and operates out of offices in Greenwich, CT, and Charlotte, NC, United States of America (USA). TEUSA entered into agreements with TEI to support TEUSA's development and deployment program for the IMSR in the USA.

As a result of these pre-licensing activities, the topic of postulated initiating events (PIEs) for the IMSR was identified as a collaboration activity under the memorandum of cooperation (MOC) between the CNSC and the USNRC (Ref. 1). This report documents the results of this collaboration between the CNSC and the USNRC, concerning a request by Terrestrial to obtain regulatory feedback on submittals related to this topic. In this report, expectations relating to future submittals from Terrestrial are underlined.

A PIE is an occurrence that challenges plant control and safety systems whose failure could potentially lead to an undesirable end state and/or radioactive material release. Development of PIEs are a key and critical aspect of a designer's (sometimes referred to as vendor) or applicant's safety analysis, including a deterministic safety analysis (DSA), a hazard analysis, and a probabilistic safety assessment (PSA) or a probabilistic risk assessment (PRA).

1.1. Disclaimer

Nothing in this report fetters the powers, duties, or discretion of CNSC or USNRC designated officers, CNSC or USNRC regulatory staff or the respective Commissions regarding making regulatory decisions or taking regulatory action. Nothing in this report is to be construed or interpreted as affecting the jurisdiction and discretion of the CNSC in any assessment of any application for licensing purposes under the *Nuclear Safety and Control Act*, its associated regulations, or the *Canadian Nuclear Safety Commission Rules of Procedure*. Likewise, nothing in this report is to be construed or interpreted as affecting the jurisdiction and discretion of the USNRC in any assessment of any application for licensing purposes under the *Atomic Energy Act* of 1954, as amended, its associated regulations and the USNRC Management Directives. This report does not involve the issuance of a license under Section 24 of the *Nuclear Safety and Control Act* or under Section 103 of the *Atomic Energy Act* of 1954. The conclusions in this collaborative report are those of the CNSC and USNRC staff.

1.2. TEUSA Engagement with the USNRC

In a letter dated October 22, 2020 (Ref. 3), TEUSA submitted to the USNRC a white paper titled "Postulated Initiating Events for the IMSR®". Following this initial submittal, TEUSA submitted revisions to the white paper in letters dated July 8, 2021 (Ref. 4) and December 16, 2021 (Ref. 5). The revisions to the white paper incorporated responses to joint

CNSC/USNRC questions (Refs. 6 & 7). The white paper describes Terrestrial's process used to develop a set of PIEs for the IMSR. As discussed in USNRC's document titled "A Regulatory Review Roadmap for Non-Light Water Reactors" (Ref. 8), white papers submitted to the USNRC for review can be used to: request general feedback, obtain preliminary regulatory responses, or request a more formal regulatory decision (e.g., applicability of a regulatory requirement to the design). USNRC staff's responses to white papers are generally less specific and provide less regulatory certainty than responses for topical reports and formal applications.

1.3. TEI Engagement with the CNSC

In November 2017, CNSC staff completed Phase 1 of a Vendor Design Review (VDR) for TEI's IMSR design. In May 2018, TEI began Phase 2 of the VDR process. Phase 1 of a VDR seeks to confirm how the vendor is demonstrating intent to meet CNSC's requirements and expectations in their design and safety analysis activities, while Phase 2 goes into further detail, with a focus on identifying any potential fundamental barriers to licensing. Note that the VDR process does not result in regulatory decisions, certify a reactor design or involve the issuance of a license. Moreover, a VDR does not constitute an application with the CNSC.

The VDR is an optional pre-licensing assessment activity that the CNSC offers for a vendor's new nuclear power plant (NPP) design. It provides feedback on a vendor's efforts to address regulatory requirements. It is intended to facilitate the vendor's early identification and resolution of potential issues, particularly those that could result in significant changes to the design. It has a fixed-scope and requires a vendor to address a given set of Focus Areas, important to demonstrating adequate safety, security, and safeguards in a design. VDR Focus Area 10, which looks specifically at the vendor's Safety Analysis, is central to assessing a vendor's methodology for developing PIEs and includes confirmation that the strategy and processes are producing traceable and supportable results.

2. Scope and Objective

The scope of the joint review activity is limited to the information commonly available to both the CNSC and the USNRC. As such, this report focuses on Revision 2 of the white paper (Ref. 9) and the answers to regulators' questions (Refs. 6 & 7).

At the time of writing this report, the overall IMSR design, the associated PIEs, and its methodology, are still evolving. Hence, the objective of this report is to provide high-level feedback on the soundness of Terrestrial's PIE methodology and the current PIE list.

3. Regulatory Framework

In the context of nuclear power, the regulators and designers ask the following three questions to define risk (also known as the "risk triplet"):

- What can go wrong?
- How likely is it?
- What are the consequences?

A PIE list is a starting point to answer the above first question. It provides significant insights for the design process in that it helps to identify design features, establish the design bases, and achieve design risk targets. A PIE is an occurrence that challenges plant control and safety systems whose failure could potentially lead to an undesirable end state and/or radioactive material release. The primary causes of PIEs may be failures of Structures, Systems, and Components (SSCs), operator errors, human-induced events, or natural events.

PIEs are identified based on a preliminary design, experience with similar designs, and engineering judgment. These PIEs are classified according to their likelihood of occurrence and DSAs are performed to ensure that deterministic acceptance criteria based on classification are met. If they are not met, the design is modified, the PIE list is updated, and the process is repeated. Thus, development of the PIEs and the design is an iterative process. The PIE list is revisited after the design is finalized and throughout the plant life to reflect the as-built and as-operated conditions.

It is normal practice to group PIEs based on similarity of the initiating failures, key phenomena, or plant and operator response. The main goal of this grouping is to simplify the safety analysis process by identifying limiting (or bounding) events in each group, for which a safety analysis will be performed to demonstrate the safety of the NPP. The limiting events are the bounding or enveloping scenarios which present the greatest possible challenges to each of the relevant deterministic acceptance criteria.

The PIEs can then be classified in accordance with their associated frequencies. This may include PIE classes such as anticipated operational occurrences (AOOs), postulated accidents, or severe accidents (CNSC classification uses the terms AOOs, design basis accidents (DBAs), and beyond design basis accidents (BDBAs)). This classification allows the application of different acceptance criteria to different classes for the deterministic safety analyses. This provides insights for the second and third questions posed in the risk triplet above. Note that the regulators use different terms to refer to the process of differentiating PIEs. The CNSC refers to the process as "classification" and the USNRC refers to it as "categorization". For the purposes of this report, the term "classification" is used.

3.1. CNSC

The guidelines and requirements for the conduct of the above process, which is used in the design, safety analysis and selection of PIEs, is covered in various CNSC regulatory documents and include the following:

REGDOC-1.1.1, "Site Evaluation and Site Preparation for New Reactor Facilities" (Ref. 10)

This document sets out requirements and guidance for site evaluation and site preparation for new reactor facilities, including considerations related to site-specific PIEs.

REGDOC-1.1.2, "Licence Application Guide: Licence to Construct a Nuclear Power Plant" (Ref. 11)

This document identifies the information that must be presented to the CNSC when applying for a construction license. It covers, among other topics, the required information about the safety analysis and the identification, scope and classification of PIEs.

REGDOC-2.4.1, "Deterministic Safety Analysis" (Ref. 12)

This document sets out requirements and guidance for the preparation and presentation of a DSA. It includes information on the identification, selection and scope of PIEs to be analyzed, their classification and acceptance criteria, as well as the safety analysis methods, documentation, review and update.

REGDOC-2.4.2, "Probabilistic Safety Assessment (PSA) for Nuclear Power Plants" (Ref. 13)

This document sets out the requirements of the CNSC with respect to the PSA and touches on the screening criteria for PIEs.

REGDOC-2.4.3, "Nuclear Criticality Safety" (Ref. 14)

This document sets out requirements for nuclear criticality safety and provides guidance on how those requirements may be met, including considerations related to nuclear criticality PIEs.

REGDOC-2.5.2, "Design of Reactor Facilities: Nuclear Power Plants" (Ref. 15)

This document sets out the requirements for the design of new NPPs. It establishes a set of comprehensive design requirements and guidance that are risk-informed and align with accepted national and international codes and practices. It deals with a wide variety of topics including the integration of safety assessments into the design process. As such it provides information on the development of PIEs and how they are used in the safety analysis process.

3.2. USNRC

The guidelines for identifying and characterizing PIEs can be found in the following USNRC regulatory documents:

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (Ref. 16)

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.

Although SRP applies to power reactors with light-water reactor (LWR) technology, the USNRC staff considers the guidance in Section 15.0 regarding transient and accident analyses to generally provide insights to non-LWRs. This guidance is suitable to support preparation of applications for early site permits, design certifications, and combined licenses under Title 10 of the *Code of Federal Regulations* (CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 17) and generally acceptable to support the NRC staff's review of other types of applications under 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 18).

In addition, SRP Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors" provides guidance pertaining to the USNRC staff review of the design-specific and plant-specific PRAs for design certification applications and combined license applications, respectively. SRP Section 19.0 states that the USNRC staff will determine whether the technical adequacy of the PRA is sufficient to justify the specific results and risk insights that are used to support a license application. The applicant's PRA submittal should be consistent with prevailing PRA standards, guidance, and good practices as needed to support its uses and applications and as endorsed by the USNRC. By that, the USNRC staff expects licensing applicants to follow the guidance provided in the consensus PRA standards, specifically, the characteristics and attributes of the initiating event analysis to identify and characterize PIEs.

Trial Regulatory Guide (RG) 1.247, "Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor Risk-Informed Activities" (Ref. 19)

This document endorses, with exceptions, a national consensus PRA standard ASME/ANS RA-S-1.4-2021, "Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants" (Ref. 20). The specific element on initiating event analysis 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. As noted in the RG, although the consensus PRA standards use the terms "requirements", "require", or other mandatory language, which is mirrored in the RG, the use of this language does not impose any regulatory requirements or suggest that these standards are the only way to meet the NRC's statutory and regulatory requirements. Using a systematic and structured approach, those events that have occurred at the plant or have a reasonable probability of occurring can be identified and assessed.

NUREG-1513, "Integrated Safety Analysis Guidance Document" (Ref. 21)

This document provides general guidance to fuel cycle licensees/applicants on how to perform an integrated safety analysis and document the results, and also specifies technology-inclusive guidance for identifying initiating events. In particular, 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" (Ref. 22)

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" (Ref. 23), which provides an acceptable method to identify licensing basis events (LBEs). During the reactor design, an important part of the process is the identification of events that could challenge key safety functions and layers of defense against the release of radioactive materials. NEI 18-04 presents a systematic process for identifying and classifying events and the associated sequences as AOOs, design basis events (DBEs), or beyond design basis events (BDBEs) 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. Note that the definitions of some terms used in NEI 18-04 are different from the same terms used in NRC regulations. For example, the terms "AOO" and "DBE" are similar terms in NEI 18-04 and regulatory guidance but have different definitions. As stated in RG 1.233, "[a]pplicants referencing this RG are expected to use the terminology in NEI 18-04 and, as needed, identify exceptions to and exemptions needed from NRC regulations."

3.3. Common Regulatory Assessment Approach

The development of a PIE methodology and the assessment of its 'soundness' are of significant interest to both regulators and the global regulated sector, as these set the stage for future safety analysis activities. As a result, regulatory staff (from both CNSC and USNRC) identified this topic for joint assessment under the MOC and agreed on five key attributes to assess PIE methodologies. Section 4 of this report defines these key attributes and provides feedback on Terrestrial's methodology for developing the IMSR PIEs, including expectations for further information to be developed, if seeking acceptance of the methodology in either Canada or the USA.

4. Joint CNSC-USNRC Assessment of Terrestrial's Methodology

As a result of the joint efforts described in Section 3.3 of this report, regulatory staff identified five key attributes for evaluating the 'soundness' of a PIE methodology. Note that there is a close relationship between the five attributes and that a consideration used for assessing the PIE methodology could inform more than one attribute. Those five attributes were applied to Terrestrial's PIE methodology as discussed below. Sections 4.1 through 4.5 of this report include the purpose for each attribute, joint assessment of material provided by Terrestrial, and any additional information the regulatory staff would expect to see in future submittals. It is also emphasized that applicants must demonstrate compliance with the regulatory requirements for the country for which it is seeking approval and should use terms consistent with the country's regulatory framework (e.g., PRA vs PSA).

4.1. Attribute 1: Quality Control

4.1.1. Purpose

The purpose of this attribute is to ensure that the PIE methodology closely interfaces with the designer's quality control provisions and processes (this includes configuration control). As the design and the PIEs evolve, quality controls are necessary to increase confidence in the result of the methodology and to prevent errors from cascading into other processes. Quality controls are applicable to many processes, including the safety analysis which includes the development of the PIE list. The focus here is on the aspects of quality controls that are relevant to the PIE list, to ensure they are well-integrated into the methodology. This includes areas such as documentation, verification of results, description of roles and responsibilities, and verification of personnel qualification.

4.1.2. Joint Feedback

Terrestrial provided some information pertaining to quality controls in its PIE white paper. For example, Terrestrial stated that the IMSR PIE analysis followed its internal safety analysis procedure (Ref. 24). Terrestrial also clarified that the PIE methodology follows the relevant portions of the company's Management System Manual (Ref. 25), and explained that in many respects, it mirrors the overarching requirements contained in 10 CFR 50 Appendix B (Ref. 26) and ASME NQA-1 (Ref. 27). Terrestrial stated that the Terrestrial Management System aligns with various relevant Canadian Standard Association (CSA) standards and that it satisfies the management system requirements in the relevant CNSC regulatory documents. Furthermore, it stated that the content of the Management System Manual meets the twelve management principles outlined in CSA N286-12 (Ref. 28) and refers to those Terrestrial processes and practices used to control various activities associated with the evolution of the IMSR. Regulatory staff note that the industry standards used by Terrestrial for quality control must align with the licensing country's regulatory framework. Although the quality assurance (QA) program cited in the white paper has not been submitted, based on the information provided, it seems that appropriate steps are being taken to ensure that quality controls are in place as part of the PIE methodology. Terrestrial indicated that the content and acceptability of its QA program will be the topic of a future submittal.

The white paper provides a discussion of the roles and responsibilities for Terrestrial's conduct of the PIE list development process. Terrestrial indicated that for the conceptual and early preliminary design, it has used a qualified and experienced safety analyst, supervised by a senior safety manager for the development and update of the PIE list. In general, the disciplines, knowledge, experience, and responsibility required to perform, update, review, and verify the PIE related work to date seem to be appropriate given the preliminary status of design development. 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 submittals should also address its rules regarding the use of engineering judgement.

As stated in the white paper, Terrestrial uses a software called PTC Windchill to manage and control changes to its documents, however, this does not constitute a complete configuration management program. Therefore, the regulators expect that a configuration control program will be used to support development of the design and the PIE list, and to ensure that the list will represent the as-designed, as-intended-to-operate plant. In future submittals, regulatory staff will need a description of this program and of the processes used for maintaining configuration control (including software configuration control).

In the white paper, Terrestrial explained that all documents, and changes to them, are subject to further verification and that the "personnel executing the verification process are required to have knowledge and expertise in the area to be verified. The role of the verifier is to examine the analysis and documentation for errors or inconsistencies with previous classification documents and relevant design documents." Terrestrial further stated that, "[o]nce the verification is complete, the task leader will forward the revised document to a reviewer. The role of the reviewer is to review the final product and judge the appropriateness and completeness of the work." This is conducted in accordance with Terrestrial's internal document on design verification (Ref. 29). Terrestrial explained in the white paper that the "extent of independent verification [e.g., self-assessments, third-party assessments, etc.], will depend on the safety significance and complexity of the work."

Based on Revision 2 of the white paper and Terrestrial's responses to regulators' questions, Terrestrial's proposed verification and review process seems reasonable. However, 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.

4.2. Attribute 2: Systematic Process

4.2.1. Purpose

The purpose of this attribute is to assess the designer's overall process for the development of PIEs. One important objective of a systematic process is to increase confidence that the overall methodology will identify all foreseeable initiating events and produce a list of PIEs as complete as possible. In this attribute, the regulators assess whether the methodology's steps are logical, methodical, and integrated with the DSA and PSA/PRA. The regulators also ensure that the approaches and processes applied are well-established and that the methodology includes provisions to identify, characterize, and account for uncertainties.

4.2.2. Joint Feedback

The identification of PIEs is the starting point for the safety analysis of the design, including the DSA, hazard analysis, and PSA/PRA. In Revision 2 of the white paper, Terrestrial explained that there is an interconnection between the PIEs and the PSA/PRA. While the PSA/PRA uses the PIEs as an input to its assessment, it may also expand or reduce the PIE list. Terrestrial stated that the development of the PIE list is an iterative process, and the list is a design tool used to identify potential events as early as possible in the design process, so that the appropriate mitigating systems and/or human actions can be incorporated. 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.

Terrestrial indicated that, up until now, PIEs for the IMSR have been identified using a "Top-Down" approach, supplemented by engineering judgment and operating experience from the molten salt reactor experiment (MSRE). Terrestrial plans to update the PIE list while progressing the design work. Terrestrial provided a brief explanation on the "Top-Down" approach and stated that this approach will continue to be used until the PIE list is finalized. Terrestrial also stated, in response to regulators' questions, that a "Bottom-Up" approach will be used for verification of the PIE list.

In the white paper, Terrestrial indicated that the first step of the "Top-Down" approach is to specify an undesired outcome as the top event. For the IMSR, this top event is defined as "*Unwanted movement of radioactive materials*". Regulatory staff acknowledge that the first step in the development of a "Top-Down" approach consists in defining the "top undesired event", which is a very important step as this would shape the entire safety analysis. Hence, a careful choice of the top event is important to the success of this analysis. If it is too general, the analysis becomes unmanageable; if it is too specific, the analysis may not encompass the desired scope. Regulatory staff concluded that Terrestrial's formulation of the top event may lead to misunderstandings regarding the scope, and extent to which the investigation of the causes of this top event is conducted. As an example, this formulation may imply that malevolent acts or safeguards related events could be considered as part of the safety analysis (when such events are normally considered as part of the security assessment). Therefore, Terrestrial should include a clear description of the top event to avoid confusion.

The overall PIE identification process planned by Terrestrial appears to be systematic and logical. <u>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 as part of the methodology, and explain how they complement each other.</u>

4.3. Attribute 3: Scoping of PIEs

4.3.1. Purpose

The purpose of this attribute is to establish confidence in the designer's scope of PIEs and safety assessment activities, to develop a PIE list that is as comprehensive and as complete as possible. Considerations in assessing this attribute include a verification that the designer accounted for all potential events or occurrences (e.g., failures, malfunctions, accidents, errors, hazards) for the entire facility. This includes, but is 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 combination or interaction between events and reactor units
- plant operating modes, states, conditions, and configurations (whether normal or abnormal), and transitions between them

In addition to the above information, justification or rationale for excluding PIEs is necessary to demonstrate that the scope of the PIEs is acceptable.

4.3.2. Joint Feedback

Terrestrial stated that the scope for its current PIE list includes failures or malfunctions of SSCs, as well as operator errors, common-cause failures, internal hazards, external hazards, human-induced events, natural events, and events that might cause radioactive release for both inside and outside the reactor vessel. Terrestrial also stated that "all significant sources of radioactive material, including the reactor core, the off-gas handling and storage system, new fuel salt handling, core swap, and irradiated fuel salt handling and storage," associated with the design, have been considered.

Terrestrial indicated that the PIE list is non-site-specific at this time and also indicated that more details on human-induced events will arise from the human factors review and the PSA/PRA. Terrestrial also indicated that, where design detail is still to be developed, the current PIE methodology used a bounding or representative event as a placeholder for a more detailed initiator. Also, as stated in response to regulators' questions, "TEI will look at all operating states. [The] [m]odel currently addresses three steady states (power, shutdown, fuel storage). However, it will need extending to cover transitions (e.g., core-unit filling, start-up, shutdown, defuel, core-swap, etc.). Extension of the model to consider transitions between nominal steady states requires development and documentation of PRA methodology for intermediate operating states."

Terrestrial stated that the scope of the submitted PIE assessment considers a single unit nuclear power plant configuration, however, the business plan for the IMSR design is evolving towards a two-unit per site configuration, and a PIE assessment will be performed once the multi-plant configuration and the PSA/PRA are completed. Terrestrial also indicated that if there are already other reactors on site or a determination is made that the selected site will be for a multi-unit site, a multi-unit PSA/PRA would be performed, and a comprehensive list of PIEs will be developed for the entire site.

Terrestrial indicated that PIEs with a frequency of less than $5x10^{-7}$ are considered so rare that they would not need to be considered when assessing the capabilities of the plant to respond to those postulated events. Therefore, Terrestrial indicated that such extremely rare severe external events (e.g., large meteorite strike) were not included in the PIE list.

The PIE scope identified by Terrestrial and its plan for developing a more detailed PIE list, as presented in the responses to regulators' questions, seem appropriate given the maturity and stage of the design. Regulatory staff agree that the scope of <u>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, start-up 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.</u>

4.4. Attribute 4: Grouping of PIEs

4.4.1. Purpose

The purpose of this attribute is to assess how PIEs having similar characteristics are grouped together. The main goal of event grouping is to simplify the safety analysis process by identifying limiting (or bounding) events in each group, thereby reducing the overall number of analyses required to demonstrate the safety of the NPP. A limiting event bounds or envelops scenarios which present the greatest possible challenges to each of the relevant acceptance criteria. Considerations in assessing this attribute include items such as how PIEs are grouped and how safety and mitigating functions are considered.

4.4.2. Joint Feedback

The white paper presents an initial PIE list with expected mitigation methods for each PIE. It included 105 PIEs which were arranged into 7 groups for future use in the IMSR safety analysis. Combinations of events were not considered in the list, but Terrestrial stated that they will be part of the PSA/PRA. Likewise, Terrestrial stated that the DSA will identify bounding events for each group, and that the list of PIEs will evolve and reflect the combinations of failures, errors, or other initiating events, as the design matures.

Based on the information provided, Terrestrial's PIE grouping and mitigating methods presented in the white paper appear to be reasonable. The regulatory staff note that this grouping might change as the design matures and the PSA/PRA and preliminary safety analyses are completed. Regulatory assessment of the grouping and mitigating functions will also be performed as part of the future DSA and PSA/PRA submittal(s). <u>Regulatory staff expect, as part of future submittals, a detailed description of the process for grouping PIEs, including the rationale for the grouping.</u>

4.5. Attribute 5: Classification of PIEs

4.5.1. Purpose

The purpose of this attribute is to assess how PIEs have been classified in accordance with their associated frequencies. This helps to establish confidence in the designer's classification and justification of PIE frequencies. Considerations in assessing this area include items such as how event classification and frequency ranges are justified and demonstrated. It also includes how the probabilities of combined system failures are considered and how uncertainties are treated.

4.5.2. Joint Feedback

Terrestrial classified the PIEs into AOOs, DBAs, and BDBAs, based on their frequencies. The use of this classification is consistent with past practice in Canada and is similar to USNRC "categories". The frequency bands assigned by Terrestrial to each class are based on CNSC requirements (Ref. 12). USNRC staff notes that the event frequency ranges presented by Terrestrial are typical when compared to USNRC's guidance in RG 1.233 (Ref. 22) for non-LWRs and NUREG-0800 (Ref. 16) for LWRs. Since the IMSR is a non-LWR design and Terrestrial has not committed to following RG 1.233, <u>Terrestrial will be responsible for justifying the chosen frequency ranges for the respective categories</u>. It should be noted that RG 1.233 is only one acceptable means for non-LWRs to demonstrate compliance with USNRC regulations. USNRC staff will review the justification for the ranges when it is presented in future submittals.

Regulatory staff noted that the classifications in the white paper were done using experience from other reactor types or engineering judgement. Regulatory staff have no major concerns with this given the state of design development; however, <u>it is expected that in future submittals, the overall methodology used to classify events (including the use of engineering judgement, research and development results, etc.) will be further clarified.</u>

Terrestrial explained in response to regulator's joint questions that the future PSA/PRA will address the uncertainty associated with the event frequency, using sensitivity and uncertainty analyses. As such, this is not discussed in the current version of the white paper. <u>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 behavior of the fission products; the noble gas fission products transport from the salt into cover gas; the noble metal fission products plate out onto surfaces; and the salt vapor deposition in cover gas lines.</u>

While regulatory staff need additional information to fully assess the methodology for classifying events based on frequency, no major concerns were identified with the information that was presented by Terrestrial.

5. Feedback on PIE list

Terrestrial asked regulatory staff to provide feedback on the PIE list presented in Section IX of the white paper. A list of PIEs is not part of a methodology itself, but rather results from the application of that methodology. Terrestrial's PIE list is based on the current stage of the design; however, it is acknowledged by Terrestrial and the regulators that the list will likely change as the design matures and the PSA/PRA is developed. As such, the following regulatory feedback is general in nature and represents high-level observations about the proposed PIE list (i.e., it is not intended to be a detailed review of the PIEs identified).

<u>If seeking approval of the PIE list, the following additional information should be provided or made available for audit:</u>

- The assumptions, due to the lack of as-built and as-operated details, that influence the PIE list.
- An independent review of the PIE list.
- Associated plant operating state(s) or mode(s) for each PIE (e.g., start-up, at-power, shutdown).
- Insights on the effects of support systems' failures on other systems (e.g., dependency matrices).
- Detailed information regarding operator errors and human-induced events.
- Impacts of human actions and recoveries on the PIE list.

- Analysis of other PIEs such as loss of direct current (DC) power and loss of heating, ventilation, or air conditioning.

<u>In addition, Terrestrial should clarify whether the following events were considered for the current PIE list:</u>

- 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.

6. Joint Regulatory Staff Conclusions

The regulatory staff reviewed the information provided to date, including the additional actions identified by Terrestrial to complete the development of its PIE methodology and associated PIE list. The regulatory staff noted that the overall IMSR design, its PIE methodology, and the associated PIE list are still evolving. Therefore, the feedback on the soundness of Terrestrial's PIE methodology and completeness of the current PIE list is high-level and does not constitute a regulatory finding. The feedback presented in this report should be considered by Terrestrial for further development of the PIE methodology and PIE list.

The regulatory staff's assessment of Terrestrial's methodology against the key attributes, as discussed in Section 4 of this report, and the PIE list is summarized below:

- Terrestrial's plans for the quality control provisions and processes described in the white paper seem adequate. Given the early stage of the PIE methodology development, the PIEs identification process appears to be systematic, logical, and of appropriate scope.
- The grouping, classification, and mitigating methods presented in the white paper appear to be reasonable. It is recognized that they are likely to change as the design matures and the PSA/PRA is fully developed. Regulatory assessment of the grouping and mitigating functions will be performed by the regulators as part of the evaluation of the future DSA and PSA/PRA submittal.
- There is no conclusion on the acceptability of the PIE list. The regulatory staff provided feedback in Section 5 of this report on the completeness of the PIE list and identified additional PIEs for consideration.

7. References

1. USNRC, ADAMS Accession No. ML19275D578, "Memorandum of Cooperation on Advanced Reactor and Small Modular Reactor Technologies between the United States Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission", August 15, 2019
2. USNRC, ADAMS Accession No. ML19168A017, "Memorandum of Understanding between the United States Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission for the Exchange of Technical Information and Cooperation in Nuclear Safety Matters", August 2017

3. USNRC, ADAMS Package Accession No. ML20318A178, "TEUSA submittal of Postulated Initiating Events for the IMSR®", October 22, 2020
4. USNRC, ADAMS Package Accession No. ML21211A518, "TEUSA submittal of Postulated Initiating Events for the IMSR®", Revision 1, July 8, 2021
5. USNRC, ADAMS Package Accession No. ML21357A015, "TEUSA submittal of Postulated Initiating Events for the IMSR®", Revision 2, December 16, 2021
6. USNRC, ADAMS Package Accession No. ML21209A989, "TEI/TEUSA Response to CNSC/NRC Feedback and Questions on IMSR® Postulated Initiating Events White Paper to Support Joint Regulatory Review", July 7, 2021
7. USNRC, ADAMS Accession No. ML21357A013, "Terrestrial Energy Responses to 2nd Round of CNSC/NRC Feedback on IMSR® Postulated Initiating Events", December 16, 2021
8. USNRC, ADAMS Accession No. ML17312B567, "A Regulatory Review Roadmap for Non-Light Water Reactors", December 2017
9. USNRC, ADAMS Accession No. ML21357A011 (Public) and A012 (Proprietary), Postulated Initiating Events for the IMSR®, Revision 2, December 16, 2021
10. CNSC, REGDOC-1.1.1, "Site Evaluation and Site Preparation for New Reactor Facilities", February 2022
11. CNSC, REGDOC-1.1.2, "Licence Application Guide: Licence to Construct a Nuclear Power Plant", August 2019
12. CNSC, REGDOC-2.4.1, "Deterministic Safety Analysis", May 2014
13. CNSC, REGDOC-2.4.2, "Probabilistic Safety Assessment (PSA) for Nuclear Power Plants", May 2014
14. CNSC, REGDOC-2.4.3, "Nuclear Criticality Safety", September 2020
15. CNSC, REGDOC-2.5.2, "Design of Reactor Facilities: Nuclear Power Plants", May 2014
16. USNRC, NUREG-0800 Chapters 15 and 19, ADAMS Accession Nos. ML070710376 and ML15089A068, respectively, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition", June 1996
17. USNRC, Title 10 of the Code of Federal Regulations (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants"
18. USNRC, 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities"
19. USNRC, ADAMS Accession No. ML21235A008, Trial Regulatory Guide (RG) 1.247, "Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor Risk-Informed Activities", March 2022
20. ASME/ANS RA-S-1.4-2021, "Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants", 2021
21. USNRC, NUREG-1513, ADAMS Accession No. ML011440260, "Integrated Safety Analysis Guidance Document"
22. USNRC, RG 1.233, ADAMS Accession No. ML20091L698, "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", June 2020

23. NEI 18-04, ADAMS Accession No. ML19241A472, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development"
24. TEI, IMSR400-30711-PRO-004, "Procedure: Safety Analysis", June 2016
25. TEI, IMSR400-30710-MAN-001, "Manual: Management System - Terrestrial Energy", December 2020
26. USNRC, 10 CFR 50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants"
27. ASME NQA-1-2015, "Quality Assurance Requirements for Nuclear Facility Applications"
28. CSA Group, CSA N286-12, "Management system requirements for nuclear facilities", 2012 (reaffirmed in 2017)
29. TEI, IMSR400-30711-PRO-008, "Procedure: Design Verification", December 2018