CNSC/NRC Feedback – PIE Responses and Revised White Paper

The feedback provided herein is the joint feedback provided by the Canadian Nuclear Safety Commission (CNSC) and U.S. Nuclear Regulatory Commission (NRC) staff regarding the Terrestrial Energy USA (TEUSA) Postulated Initiating Event (PIE) identification methodology as described in TEUSA's Updated Integral Molten Salt Reactor (IMSR®) PIE White Paper (ADAMS Package Accession No. ML21211A518) and Terrestrial Energy, Inc./TEUSA Response to CNSC/NRC Feedback and Questions on IMSR PIE White Paper to Support Joint Regulatory Review (ADAMS Package Accession No. ML21209A989). This feedback was discussed during meetings held on July 22, 2021 and August 16, 2021. The terms "we" or "us" as used in this feedback refers to common feedback between the CNSC and US NRC. In cases where a regulator-specific comment is made, the term "CNSC staff" or "NRC staff" is used.

1. **General Feedback**:

a. Terrestrial should ensure that both TEI and TEUSA use appropriate terms as necessary for each regulator.

b. By the term methodology, we understand Terrestrial to mean the steps and processes used within the vendor's management system to conduct, for example, safety analyses and safety classification activities. Terrestrial presented preliminary work to establish the methodology to support the conceptual design and stated that further refinements are necessary going forward. However, at this point in time it is not clear what work needs to be done to support further refinement of the methodology to support detailed design activities. Terrestrial should present the details of the methodology going forward, including processes to support confidence in the methodology. To provide feedback regarding the methodology, both regulators need to see the detailed steps and processes that make up the methodology or, if the details are not currently available, a description of expected steps and processes. This will demonstrate how the vendor's activities are converging towards a high degree of confidence in the results if the methodology is used to identify and classify PIEs. We expect that the steps and processes are described in sufficient detail before the regulatory staffs can provide detailed feedback on the methodology. Any areas that are not fully developed at this stage should be identified and an expected timeline for completion should be presented.

c. The NRC staff notes that a number of commitments have been made by the vendor that are focused on CNSC Vendor Design Review (VDR) activities. Responses regarding the VDR process need to clarify if (or how) these commitments would also apply to activities in the USA. Some examples are noted in the question-specific feedback provided below.

2. Feedback/Questions on Responses to Joint Questions:

a. Response # 1(a)

i. The revised white paper appears to remove the "bottom-up" portion of the PIE identification methodology because the design isn't developed to the component level necessary to complete a "bottom-up" approach. If Terrestrial wishes to receive feedback from CNSC and NRC regarding the methodology for identifying PIEs, the methodology of performing the "bottom-up" approach should be described in sufficient detail for us to

perform an assessment. The application of the methodology itself can wait until the design has matured to the component level.

ii. The response commits TEI to submitting the "bottom-up" approach to the CNSC as part of the PSA [probabilistic safety assessment] but does not mention the NRC. Will TEUSA follow the same approach as TEI or will there be a different methodology for the NRC to review?

iii. Response to Question 1a states, "The main reason for the choice of top-down methodology was that the design details were still developing at the time of the PIE, making a bottom-up assessment rather difficult, as the level of design resolution did not go down to the component level"

Based on the response and the statements in the white paper (e.g., "[a]t the current stage, the probabilistic studies are not yet completed and so the classification shown in this document is based on engineering judgement and previous similarity with other potential events."), it is noted that the PIE list presented in Section VII of the white paper is not based on the complete methodology as described. Therefore, we cannot make any conclusions regarding the comprehensiveness, completeness, and fidelity of the IMSR® design and PIE list.

iv. The response to Question 1a states, "TEI has committed to the CNSC that a fault-tree analysis and an FMEA [Failure Modes and Effects Analysis] will be part of the PSA for the License to Construct."

There are no commitments (or discussions) made by TEUSA in the white paper, Rev. 1, to perform and integrate FTA, FMEA, and/or any other approaches to finalizing the PIE list. This gives the impression that there is a divergence between the TEI and TEUSA methodologies to identify PIEs. The white paper should make clear if there are differences between the TEI and TEUSA methodologies or if the commitments are intended to apply to TEUSA's interactions with the NRC as well. The NRC staff notes that two or more approaches in combination with the insights from the human reliability analysis (HRA) would provide a more comprehensive and justifiable PIE list.

v. Response to Question 1a states, "Fault trees provide a similar perspective to a bottom-up analysis."

This statement is correct but not always true. A "qualitative" fault-tree analysis can be used to identify the additional failures but not the initiators nor pre-accident human-induced initiating events.

b. Response #1(b)

i. The response to Question 1b states, "With each PIE iteration, the number of events becomes larger: not so much because completely different events have been added, but more because detailed events are added under each overall category."

It is unclear why the detailed events are added to the PIE list. Later in the process, should all detailed events be grouped or combined for the event sequence analysis? Normally, the systematically identified individual initiating events (IEs) are grouped using a

systematic process for a more manageable list and for input to the event sequence analysis.

ii. Response to Question 1b states, “The safety analysis will choose bounding events for each PIE or group of PIEs to reduce the impact of design detail.”

Define the term “bounding events,” e.g., frequency-based, consequence-based, site-specific based, etc.

iii. Response to Question 1b states, “The two methods will result in a consolidated list of PIEs by the time of application for a License to Construct.”

The process to consolidating the two methods is not provided. TEUSA should include the integration step in the white paper as part of the methodology.

c. Response #1(c)

i. Response to Question 1c states, “There was no screening of events performed during the PIE. The focus of the PIE was on internal events and on a “standard” list of external events relative to a Canadian generic site. However, extremely rare severe external events (e.g., large meteorite strike) were not included.” In addition, the white paper states, “Events with a frequency likelihood less than 5E-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.”

ii. During the meeting, the NRC suggested that TEUSA review ASME/ANS [American Society of Mechanical Engineers/ American Nuclear Society] RA-S-1.4-2021, Section 4.3.11, “Hazards Screening Analysis” to determine if it is applicable for the IMSR design.

iii. Response to Question 1c states, “TEI is currently preparing a case on the frequency of failure of passive components and systems, which will factor in such failure mechanisms and their prevention.”

iv. We are interested in viewing these cases when they are developed and used to support future licensing activities. There are currently no NRC endorsed techniques for assessing passive structures, systems, and components (SSCs) reliability/frequency (except piping, heat exchangers, etc.).

v. Response to Question 1c states, “In the report, we did classify events as AOO [anticipated operational occurrence], DBA [design basis accident], BDBA [beyond design-basis accident] based on experience with other reactors, and engineering judgement.”

We understand from the white paper that the engineering judgement used to classify the events is presented as a starting point and not the results of following the complete methodology. The overall methodology used to classify events (including the use of engineering judgement, research and development results, etc.) needs to be further clarified.

d. Response #1(d)

i. We understand that FMEA is not used at this preliminary stage of design development, but if it is part of the methodology, it should be explained in enough detail for the reviewers to

understand how TEI and TEUSA use it and provide an assessment. The response also only seems to refer to future use of FMEA in the PSA (for CNSC). Does this indicate that there is a difference between the TEI and TEUSA methodologies?

ii. Response to Question 1d states, "Also as previously noted, a fault-tree analysis [FTA] will be part of the PSA for the License to Construct. Fault trees provide a similar perspective to a bottom-up analysis."

    Fault tree analysis (performed in PRA) is a graphical tool to model the causes of system failures. It uses Boolean logic to combine a series of basic events to generate cutsets and quantify top event probability. It is basically a top-down approach initiated with a top event. The use of FTA in the PIE identification methodology as a bottom-up analysis should be presented in enough detail to permit CNSC/NRC assessment, if our feedback is desired.

e. Response #1(e)

i. The response doesn't commit to a specific requirement regarding the makeup or skillset of an analyst (or team of analysts), but instead simply states what was done at this preliminary stage. Our original question was related to any panel or skillset requirements per the methodology. Provide the requirements per the methodology that drive the makeup of analysts (or team of analysts) and the processes that support them. The NRC staff notes that diverse expertise and experience brought by a team or panel is preferred (see guidance for maintenance rule, Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.69, LMP, etc.). For example, Nuclear Energy Institute (NEI) 00-04 (as endorsed by RG 1.201) provides guidance pertaining to the decision regarding the categorization of components be presented to an expert panel, known as the Integrated Decision-making Panel (IDP). The IDP is composed of a group of experiences plant personnel representing diverse plant functions and responsibilities.

f. Response #1(f)

i. We have no additional feedback related to this topic.

g. Response #1(g)

i. Response to Question 1g states, "The PIE assumes fairly coarse failures in the SSCs: e.g. pump failure, rather than failure of specific components in the pump; generic fueling error (taken in the supporting safety analysis as the maximum physically permitted by the fueling mechanisms, rather than a realistic value)."

ii. The response to Question 1g does not fully address the issues of concern, i.e., it is unclear whether the assumptions made relevant to the frequency estimates, recovery, performance, etc., will be refined once more design/detailed specifications and information become available. If so, reevaluation of the first-of-a-kind SSCs and associated assumptions should be specified as a future step in the PIE methodology.

h. Response #1(h)

   i. Similar to some other responses, this response states what was done as opposed to what is required to be done by the methodology. We understand that simplified analyses are made during the design phase, but to provide an assessment of the methodology that will be used in the licensing phase, we need to understand the requirements of the methodology.

   ii. Response to Question 1h states, "The PIE analysis followed the same procedure used for all safety analysis in IMSR400: Safety Analysis Procedure IMSR400-30711-PRO-004. We also followed the relevant portions of the company QA [quality assurance] manual: IMSR400-30710-MAN-001."

   Was the QA manual IMSR400-30710-MAN-001 developed based on the principal elements of 10 CFR 50 Appendix B?

i. Response #2(a)

   i. We have no additional feedback related to this topic.

j. Response #2(b)

   i. We have no additional feedback related to this topic.

k. Response #3

   i. We have no additional feedback related to this topic.

l. Response #4

   i. Terrestrial's definition of "Power Operating States" is unclear to us and whether Terrestrial is committing to look at all Power Operating States or not. Terrestrial indicates that they will look at more than simply "At-Power", but it's not clear if they are committing to a thorough systematic approach. For example, Low Power, Shut Down (guaranteed), and Startup states/stages are not assessed in the report. Provide additional details regarding the methodology's approach for these states.

m. Response #5

   i. Response to Question 5 states "There was no screening done in the PIE." White paper, Page 7 states, "At this stage of the IMSR® design maturity, TEUSA has projected that most of the PIEs will have minimal or no consequences because of the fundamental nature of design and passive/inherent safety features of the IMSR400 facility. A more detailed radiological consequence assessment will be performed after the PSA is completed, which will occur prior to TEUSA submitting an SDA application."

   TEUSA should confirm whether any PIE will be screened based on the radiological consequences as part of the process. If so, describe the radiological consequence criteria to be used for PIE screening.

n. Response #6

   i. Terrestrial should explain how uncertainties are handled as part of the methodology even if the uncertainties themselves are unknown at this point.

   ii. Response to Question 6 states, “The PSA submitted for the License to Construct will address uncertainties in event frequency using sensitivity and uncertainty analysis.”

      The PSA uncertainty analysis examines the uncertainty spread in the results arising from the uncertainty in SSC failure probabilities and is not normally used to examine the uncertainty associated with the IE frequencies. TEUSA should explain in more detail how the PSA uncertainty analysis is intended to be applied.

o. Response #7

   i. Provide where and when design details for systems included in the PIE methodology will be provided along with identification of system dependencies, if any.

p. Response #8(a)

   i. Response to Question 8a states, “The plant is also computer- controlled, which reduces the chances of human error. A fueling error is a human induced event, probably the most significant, and is in the PIE. More details on human-initiated events will arise from the human factors review and the PSA as the design develops.”

      Human factors review is mentioned for the first time in the response to Question 8a. It is noted that the software and hardware failures are not in the PIE list.

q. Response #8(b)

   i. Response to Question 8b states, “Loss of DC power would be a subset of [PIE 3-8 (Loss of Offsite Power)].”
      Our current understanding is that the plant responses are different for these two initiators, but we also recognize that we do not have final plant details at this point. Therefore, additional clarification is needed. Otherwise, DC power should be treated separately.

   ii. Response to Question 8b states “Loss of HVAC will be included later as the HVAC safety functions are defined. We agree that some events need to be expanded in the next revision.”

      How does the safety function influence the PIE selection?

r. Response #8(c)

   i. Response to Question 8c states, “For a specific site, a more detailed list will be developed as part of the License to Construct.”

      TEUSA should clarify the design certification/standard design approval/combined license/operating license applicants’ responsibilities to confirm and complete the PIE list.

s. Response #8(d)

   i. The requested table appears to be incorporated into the wrong section. Please edit the document as necessary to put this table in the correct section.

t. Response #9

   i. Response to Question 9 states, "We agree. The events would be very site-specific – e.g., if there are already other reactors on site. Should a commitment be made for a multi-unit site, a multi-unit PIE (and /or PSA) would be performed. There are techniques being developed world-wide for the latter."

      TEUSA should include this response in its white paper.

3. <u>Feedback/Questions on Responses to NRC-specific questions:</u>

a. Question #1

   i. The NRC staff agrees with the revised approach to approach this report as a white paper with staff feedback rather than approval as stated in the response. However, the NRC staff does wish to comment that the cover letter for the revised PIE White Paper is not in alignment with this response and indicates that TEUSA is still requesting staff approval. Based on the response to the question, the staff will proceed with a staff assessment.

b. Question #2

   i. The NRC staff can include an assessment of the PIE list within the context of white paper feedback. This feedback will likely rely heavily on audited information and it should be recognized that if TEUSA later wishes to obtain NRC staff approval in a future licensing action, some of this information might be necessary on the docket. It's also worth noting that the PIE list provided in the white paper did not fully follow the methodology provided in the initial white paper due to the incomplete design so the staff's feedback will be limited to the information provided along with identification of information we would need to see in the future. The NRC staff requests that TEUSA clarify the level of detail that the NRC staff should apply to the PIE list assessment.

   ii. The NRC staff recognizes the sensitivity to the phrase "essentially complete design". The staff's use of the phrase was not intended within the context of a Part 52 application but instead within the context of generically requesting NRC staff approval of a white paper. Perhaps a better explanation is that a fully developed methodology which is associated with a mature design will have far fewer limitations and conditions which will therefore increase the usefulness of the NRC's approval. However, since the response also indicates that we are to review this as a white paper now the NRC staff can simply point out areas that should be addressed at a later date. Does this approach align with TEUSA's request from the NRC staff?

   iii. The response states, "TEUSA would find it valuable if the staff can perform a detailed assessment of the PIE list information and document any potential concerns with the provided list (or conclude that the list appears to be reasonable given the maturity of the design and the information provided) in its assessment report."

The NRC staff cannot perform the preferred detailed assessment based on the limited information, but the NRC staff can provide a general assessment. Also, the NRC staff notes that the PIE list was not generated following the complete methodology and instead relied solely on engineering judgement at this stage. Therefore, the NRC staff cannot assess TEUSA's application of the methodology.

c. Question #3

i. Based on the response, the NRC staff would like to offer the following text taken directly from RG 1.233 in case there was ambiguity regarding basis for the staff's question:

> *C.1 Staff Position: NEI 18-04 provides an acceptable method for identifying and categorizing events, with the following clarifications:*
>
> *a. The staff emphasizes the cautions in NEI 18-04 that the F-C target figure does not depict acceptance criteria or actual regulatory limits. The anchor points used for the F-C target figure are expressed in different units, timescales, and distances than those used in NRC regulations to provide common measures for the evaluations included in the methodology.4. The F-C target provides a reasonable approach for use within a broader, integrated approach to determine risk significance, support SSC classification, and confirm the adequacy of DID.*
>
> *b. The F-C target and related discussions in NEI 18-04 include an upper bound event sequence frequency (i.e., 95th percentile) of 5×10-7/plant-year to define the lower range of BDBEs. Applicants should not consider this demarcation of lowest-event frequencies on the F-C target and category definitions a hard-and-fast cutoff but instead should consider it in the context of other parts of the methodology described in NEI 18-04. These other considerations include the role of the integrated decision-making panel described in Section 5 of NEI 18-04, DID assessments, accounting for uncertainties, and assessing for potential "cliff-edge effects," which involve a dramatic change in plant behavior caused by a small change in a plant parameter.*

ii. The NRC staff notes that the F-C target has been removed from the paper and therefore this question is no longer directly applicable. However, the revised wording still does not directly provide justification for the chosen cut-off points but instead simply states what they are. The NRC staff expects that future licensing action requests will include some level of justification.

4. <u>Feedback/Questions on revisions to PIE white paper:</u>

a. Section X of the revised report refers to DBDAs but then mentions that as of the revision there are 38 "beyond design basis events". We assume the acronym is supposed to be BDBAs and that there are 38 "beyond design basis accidents". Is this assumption correct?

b. Are Figures 1-7 supposed to be in Section IV instead of Section V?

5. <u>Additional Feedback:</u>

a. The white paper (Rev. 1) should consistently use the terms design basis event, beyond design basis event, design basis accident, and beyond design basis accident. It should be noted that DBAs are a subset of DBEs.

b. The white paper (Rev. 1) should consistently use the terms classification, classify, classes, categorization, and categories. For example:

- Page 4 states, "The main objective of this report is to identify all foreseeable PIEs, group them into categories, and classify the PIEs at this stage based on engineering judgement into AOOs, DBAs, and BDBAs."

- Page 4 states, "The PIEs are further grouped into categories, based on similarity of the initiating failures, key phenomena, or system and operator response."

- Page 6 states, "…the events are grouped into different categories i.e., AOO, DBA and BDBA."

c. A white paper sent to the NRC for review should use NRC terminology. For example, "PRA" as mentioned in 10 CFR 52.47(a)(27) and 10 CFR 52.79(a)(46), should be used instead of "PSA." Both are tools to quantify plant risk but they are performed based on different standards. Otherwise, include a description of PSA in the white paper and describe how it relates to "PRA".