Responses to CNSC/NRC Questions and Information Requests on IMSR® PIE

The CNSC/USNRC questions are shown in *italics* and the answers in normal typeface.

I. CNSC/NRC Information Requests on IMSR® PIE

1. Additional information regarding the approaches

Provide a summary that explains the findings of the different approaches used. Please include the following:

a) A summary (could be in a table form) of the output of different approaches used (e.g., bottom-up and top-down), and how the output of these approaches was compared and integrated in the list of PIE generated.

Response: The PIE document revision reviewed by the USNRC/CNSC used the top-down methodology only. The tables in the PIE report show the results. 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

TEI has committed to the CNSC that a fault-tree analysis and an FMEA will be part of the PSA for the Licence to Construct. Fault trees provide a similar perspective to a bottom-up analysis.

b) An identification of any limitations in the scope of the analysis and the level of detail used in each approach (e.g., scope of radioactive sources, processes such as fuel processing, etc.). Also describe how they might influence the results.

Response: The PIE list is first and foremost a design tool. Its purpose is 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. As such, the process is iterative: the PIE submitted to the CNSC/USNRC was the third iteration on IMSR400, and a fourth iteration will be prepared before the application for a Licence to Construct.

The level of detail in the PIE is determined by the level of detail in the design at the time. In principle, the scope includes 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. Fuel processing is not part of the reference design, and therefore was not included. Where design detail is still to be developed, the PIE used a bounding or representative event as a placeholder for a more detailed event initiator – e.g. core swap. Systems with lesser amounts of radioactive material (e.g. the secondary cooling salt) are added as the design details progress.

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. The safety analysis will choose bounding events for each PIE or group of PIEs to reduce the impact of design detail.

There is also a synergy between the PIE list and the PSA. While the PSA uses the PIE list as an input to its fault trees, the PSA may also generate events not in the PIE – that is a possible outcome of the fault trees and FMEA. The two methods will result in a consolidated list of PIEs by the time of application for a Licence to Construct.

c) A list of screened-out events and the rationale for screening them out, specifically those events screened out on the frequency basis, knowing that event frequencies quantification is not completed yet.

Response: 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 most cases, slow degradation of a barrier to unwanted movement of radioactivity was not considered a PIE. For example, unexpected and undetected degradation of fuel salt or coolant salt chemistry were not included specifically, as they are operational issues (long-term failure to monitor system health), not sudden events. However, "spontaneous" failure of a barrier was included, such as a sudden leak in the Reactor Vessel or a sudden break in the secondary or tertiary coolant systems. Such a failure could be caused by a number of factors, such as degradation in salt chemistry. 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. In any case, some such operational events are listed in the tables, and are dispositioned.

We did not generally include PIEs which described phenomenology rather than events. For example, "oxygen ingress into the fuel salt" is not a PIE but a description of the potential *consequence* of the PIE. The PIE itself (which might lead to oxygen ingress) is failure of the fuel salt boundary, which is included in the PIE document.

In the report, we did classify events as AOO, DBA, BDBA based on experience with other reactors, and engineering judgement where there were no good precedents, with the intent to confirm this classification in the PSA.

d) An explanation of the respective similarities and differences between Terrestrial's bottom-up and top-down approaches and how they are consistent with practices of Failure Modes and Effects Analysis (FMEA) and [ ].

Response: The top-down approach and the [ ] are similar. They start from the undesired event at the top (in our case, unwanted movement of radioactive material) and develop the chain downwards using the principle of immediate cause. The lowest level of resolution at the bottom is the PIEs.

FMEA is a different approach which was not used in the PIE list. We have committed to the CNSC that the PSA will include an FMEA, with emphasis on passive systems for which the failure modes may be subtle. Also as previously noted, a fault-tree analysis will be part of the PSA for the Licence to Construct. Fault trees provide a similar perspective to a bottom-up analysis.

e) A clarification of whether the top-down approach described by the methodology requires a single expert or a team (which includes multiple disciplines). If performed by a team, describe the attributes of the team and the qualification requirements for team members, if any.

Response: For the conceptual and early preliminary design, a single expert was enough for the PIE. We used a qualified and experienced safety analyst supervised by a senior safety manager.

As noted earlier, the PSA will potentially supplement the PIE with other events, using fault trees and FMEA. PSA team members come from a company (Risktec) with a broad experience in reactor technology including PSA. Risktec has its own internal review process which meets TE's QA requirements, and TEI will perform an independent review and acceptance of Risktec's work.

At this point, we do not have plans for an additional multidisciplinary team for the next revision of the PIE. However, before the Licence to Construct, we will consider if such a team is needed.

f) A definition and examples of [ ] as stated in Section 2.2, Page 7 of IMSR400-30800-AR-001 (Rev.1) - Safety Analysis Postulated Initiating Events List. Also describe the spectrum of plant operating states (POS)/operational evolutions where this could occur.

Response: The top event of [ ] is derived as follows:

The overall objective of nuclear safety is to prevent or mitigate radioactive material releases into the environment. As a sufficient but not necessary condition, the integrity of the normal physical barriers which confine radioactive material must be preserved. Failure of any of these barriers is equivalent to [ ].

The major relevant physical barriers in IMSR400 are: the fuel salt itself, the Reactor Vessel, and the containment. The secondary coolant salt contains some activation products, so that the secondary salt piping is likewise a physical barrier. Other relevant barriers are the off-gas management and storage tanks, and the irradiated fuel transfer and storage equipment. The Reactor Auxiliary Building provides a partial barrier for some BDBAs. PIEs are therefore defined as events which could potentially threaten the integrity of one or more physical barriers. This is the basis of the top-down approach.

Some examples follow. The PIE is on the right-hand side of the chain below, and the barrier is on the left. The symbol >> means "can potentially cause". Note that this is the inverse of the order in the PIE report, which starts from a potential barrier challenge [ ] and develops the logic downwards to a specific cause. [

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For the PIE submitted to the CNSC/USNRC, the emphasis was on at-power operating states, as shutdown heat removal system(s) were still being developed. However, one shutdown PIE (fuel filling during startup – PIE 1-7) was included. We expect that at-power operating states will cover most but not all of the significant PIEs; however, the PSA will cover a wider range of initial states and supplement the current PIE list.

g) The assumptions made related to the first-of-a-kind SSCs and any limitations due to the lack of as-to-be-built and as-to-be-operated details that influence the PIE analysis.

Response: The PIE assumes fairly coarse failures in the SSCs: e.g. pump failure, rather than failure of specific components in the pump; generic fuelling error (taken in the supporting safety analysis as the maximum physically permitted by the fuelling mechanisms, rather than a realistic value). The coarseness of the assumptions insulates the PIE from design details and tends to lead to a conservative set of events. While further details may be incorporated in the PIE submitted for the Licence to Construct, reflecting design evolution, we do not expect such details to have a major effect on the current PIE. As noted earlier, the PSA will interact with PIE to refine/extend/remove events.

h) The quality assurance (QA) process used for this PIE analysis (if any). Also clarify whether the PIE identification methodology requires an independent assessment or peer review of the PIE list. If so, when would the results of this exercise be available for regulatory review?

Response: 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 manual: IMSR400-30710-MAN-001.

To date, review of the PIE has been in-house by supervision and by persons independent of the work. The IMSR400 QA process permits, but does not require, external review for this type of work.

2. Use of operating experience (OPEX) and other sources

a) Explain how OPEX from the Molten Salt Reactor Experiment is used and whether any PIE is added/removed with the rationale for doing so.

Response: We consulted the MSRE safety analysis report ("MSRE Design and Operations Report, Part V, Reactor Safety Analysis Report", ORNL report ORNL-TM-732, August 1964). The report has an excellent list of events which overlaps with the IMSR400 PIEs to a great extent, with due allowance for design differences. See Table below. Some of the events in the MSRE report are covered by other means in the IMSR400 PIE; some *phenomena* identified in MSRE as a PIE may occur as a *result* of specific PIEs in IMSR400. [

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Note that the MSRE Safety Report used a somewhat related method as IMSR400 to identify initiating events (Ref: "Historical Perspective - MSRE Safety Basis Authorization", by Dr. George Flanagan, Advanced Reactor Systems & Safety, Reactor & Nuclear Systems Division, Oak Ridge National Laboratory: MSR Workshop 2017.):

- "Each area of the MSRE that contained fuel or fission products was surrounded by at least 2 barriers
- Events were identified which could partially damage a single barrier - no release if second barrier remained undamaged
- Events that might damage two barriers were those that were considered to contribute to off-site consequences. Today these might be considered Beyond Design Basis Events
- Identified events were then analyzed as part of the safety analysis to provide detailed information on fuel/graphite and vessel temperature, power, and pressure"

We were not able to find actual operating events in MSRE which added to our PIE list. However, one event (inadvertent withdrawal of a control rod) has been reported informally by Syd Ball (presentation at the MSRE 50th Anniversary meeting at ORNL). The rod withdrawal caused a rise in power which was compensated by the inherent negative temperature feedback of the core. This was already identified in the IMSR400 PIE [ ] and the behaviour is qualitatively similar to what we would expect in IMSR400.

b) Explain if other sources are used, such as the information from the United Kingdom (UK) Office of Nuclear Regulation (ONR) workshop on licensing basis events identification (May 2019).

Response: We were not able to locate a UK report by this title. If what was meant was the "Molten Salt Reactor Initiating Event and Licensing Basis Event Workshop" held at Oak Ridge National Laboratory (ORNL) in May 2019, our safety manager attended that workshop. At that time, we did not find any major events that were not previously accounted for. As noted in an answer to a previous question, we did not generally include PIEs which described phenomenology rather than events; however, the generic USDOE/ONR report did, as it was not design-specific. For example, PIE009 in the USDOE/ONR report is "Vapor lock of heat exchanger"; in the IMSR400 PIE, this would be the *potential* consequence of an event such as loss of heat sink, not an event initiator.

We will however be reviewing the generic phenomena-based PIEs again for the next revision of the IMSRE400 PIE, to ensure they are covered (if applicable) by specific events.

3. Use of Phenomena Identification and Ranking Table (PIRT) Analyses

Was the generic PIRT analysis completed by U.S. Department of Energy/ONR analyses used to generate the PIE list? If so, explain how these analyses influenced the generated PIE list.

Response: We reviewed the generic USDOE/ONR PIRT after completing our own pre-PIRT on IMSR400. The focus was on comparing the lists of thermohydraulic phenomena and knowledge levels. We also reviewed the PIRT as part of the development of the IMSR400 PIE report but did not find additional events. This is partly because a PIRT is phenomena-based rather than event based, partly because a PIE is specific to a design, and partly because those events that were specifically listed in the USDOE/ONR report were, where applicable, already covered in the IMSR400 PIE.

4. Consideration of Plant Operating States (POS)

The white paper stated that "From the perspective of deterministic safety analysis, a comprehensive listing of PIEs should be prepared for all permissible plant operating modes: e.g., reactor startup, at-power and shutdown modes to ensure that the analysis of the behavior of the plant is complete." Please provide the listing of PIEs for the different POS. This should include the list of events during the shutdown state, such as module swap, and maintenance.

Response: Please see answer to Q 1(f) Part 2.

5. PIE screening based on dose calculations

Explain the rationale used to inform PIE screening based on dose calculations, considering the level of knowledge base for fission product release and transport.

Response: There was no screening done in the PIE. Events were allocated to AOOs, DBAs, and BDBAs based on expected frequency, and this is to be confirmed in the PSA. In the Canadian context, AOOs and DBAs have dose limits, but dose was not directly used as a screening criterion.

6. Consideration of uncertainties in PIE frequencies

Explain how the uncertainties in PIE frequencies will be used to inform the PIE classification, specifically for those events with a frequency on the border between two classes of events (borderline events).

Response: The preliminary assignment of PIEs to the category of AOO, DBA and BDBA was done using experience from other reactor types, and where that method was not practicable, using engineering judgement. The PSA submitted for the Licence to Construct will address uncertainties in event frequency using sensitivity and uncertainty analysis. Events on the borderline will generally be assigned to the higher-frequency category, or the sensitivity to reclassification will be determined.

7. Supporting information

Design details for systems included in the PIE methodology (e.g., instrument diagrams) need to be provided along with identification of system dependencies, if any. Examples include, but are not limited to, the irradiated fuel system, initial fuel system, make-up fuel system, off-gas removal system, and core swap system.

Response: These will be provided under separate cover.

8. Establishing Confidence in the Completeness of PIE list

a) Section 2.1, Page 7 of IMSR400-30800-AR-001 (Rev.1), indicates that considerations have also included human-induced initiating events. However, no human-induced initiating events are found in Figures 2-8 and Section 2.5. Clarification is needed.

Response: The inherent and passive characteristics of IMSR400 reduce the possibility of human errors leading to a significant event. For example, it is not easily possible to disable or turn off inherent reactivity compensation or a passive heat removal system. The plant is also computer-controlled, which reduces the chances of human error. A fuelling 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.

b) Section 2.1 of IMSR400-30800-AR-001 (Rev.1), specifies that the PIE analysis also includes internal common-cause (CC) events; however, some internal CC initiating events are not found in the report (e.g., loss of direct current power, loss of Heating, Ventilation and Air Conditioning). Clarification is needed.

Response: These are implied in the PIE list. As noted earlier, the PIEs are a high-level grouping of events, and can be made more precise as the detailed design develops. Loss of DC power would be a subset of [ ]. 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.

c) Some external hazards (e.g., hurricane, seiche, volcanic, avalanche, landslide, pipeline accident, biological events) are not shown in Figure 3 "Top-Down Flowchart" of IMSR400-30800-AR-001 (Rev.1). Clarification is needed.

Response: The events listed are typically considered for a generic site. We would rule out sites where avalanches, volcanoes, landslides, large piping explosions etc. are possible. Hurricanes are bounded by strong winds / tornadoes. Flooding includes seiche. The events of most practical significance in "generic" design are earthquakes, fires, tornadoes and flooding – we assume values which bound most sites (e.g., maximum Design Basis Earthquake acceleration of 0.3g). For a specific site, a more detailed list will be developed as part of the Licence to Construct. One of the sites under review has a nearby railway line, which imposes specific protection requirements.

d) Figures 2 through 8, "PIEs Identification Top-Down Flowchart," of IMSR400-30800-AR-001 (Rev.1) should be replicated in the TEUSA white paper to support NRC staff review.

Response: The figures have been incorporated into the updated TEUSA white paper.

9. Multi-reactor/unit plant

Based on the provided plant description, the IMSR® 400 PIE analysis was performed on plants with only one reactor. How would the results of the safety analyses be impacted for a multiple unit facility? For example, it is necessary to understand how initiating events that impact specific combinations of multiple reactors and sources of radioactive material in shared facilities are identified.

Response: 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.

II. U.S. NRC Comments on the TEUSA White Paper, Postulated Initiating Events for the IMSR®, that require further discussion:

TEUSA is requested to provide responses to the following observations which will inform:

- *U.S. NRC's strategy for responding to the White Paper and*
- *Future collaborative activities with CNSC to inform a Joint Report containing feedback on the subject of the vendor's processes and methodologies for identification and selection of PIE*
- *Future MOC questions and outcomes to address the above*

1) *In TEUSA Letter #L201022, dated October 22, 2020 (found in the U.S. NRC's Agencywide Documents Access and Management System (ADAMS) Accession No. ML20318A178), TEUSA transmits white paper "Postulated Initiating Events for the IMSR®" and requests the U.S. NRC to review the white paper. Additionally, the letter requests that the U.S. NRC approve five specific items based on the information provided. In approval request #2, TEUSA requests the U.S. NRC to approve the methodology used to develop the list of PIE.*

   The U.S. NRC staff notes that the document "A Regulatory Review Roadmap for Non-Light Water Reactors" (ADAMS Accession No. ML17312B567) provides a description of various preapplication options available to applicants for communicating plans and soliciting feedback from the U.S. NRC staff. It states that white papers can be used "to request general feedback, to obtain preliminary regulatory responses (e.g., a template could be submitted to propose a reasonable format and content for a submittal), or a more formal regulatory decision (e.g., applicability of a regulatory requirement to the design)." Per this guidance, an applicant can direct the staff to provide a more rigorous assessment of the white paper or provide high level feedback. However, the vehicle for obtaining approvals is a topical report, which receives a stand-alone safety evaluation report, management review, and Advisory Committee on Reactor Safeguards review.

   If TEUSA wishes to obtain approval for the PIE methodology, TEUSA must submit the methodology as a topical report. The topical report should contain a sufficient level of detail for the staff to make a finding that it meets applicable regulatory requirements. Alternatively, TEUSA can direct the staff to perform a thorough assessment of the white paper per the options described above. The staff can review the white paper to identify missing information, request clarification, and capture the staff's conclusions in an assessment report.

Response: TEUSA was hopeful that NRC would consider a transformative change to its long-established practice of issuing only safety evaluations for topical reports. Given the NRC views expressed in the comment above, TEUSA will modify its approach in its subsequent submittal of revised PIE information to request a staff assessment of the modified white paper to identify missing information, request clarification, and capture the staff's conclusions in an assessment report.

2) *In approval request #1, TEUSA requests the U.S. NRC to approve the list of postulated initiating events included within the white paper. In approval request #5, TEUSA requests that the U.S. NRC approve the list of postulated initiating events in future licensing actions.*

   The staff notes that while the methodology is included within the white paper, it is not a previously approved methodology and since it is not submitted as a topical report, the U.S. NRC staff is unable to approve the white paper. Additionally, a completed IMSR® design has not been submitted to the U.S. NRC yet, so the staff cannot determine if all appropriate design considerations were considered when developing the potential initiating event list. Based on the information provided, the staff can perform a detailed assessment of the PIE list information provided and document any potential concerns with the provided list (or conclude that the list appears to be reasonable based on the information provided) in an assessment report.

   If TEUSA wishes to obtain staff approval of requests 1 and 5 from Letter #L201022, then the methodology and analysis will need to be submitted as a topical report and the analysis must be based on an essentially complete design. Any design changes between the essentially complete design included in the topical report and the final design, will result in additional review during licensing application reviews.

Response: As stated in response to Comment #1, in its subsequent submittal of a revised PIE methodology white paper, TEUSA will modify its approach to request a staff assessment of the modified white paper to identify missing information, request clarification, and capture the staff's conclusions in an assessment report. 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.

TEUSA notes that the staff has introduced the philosophy that the analysis must be based on "an essentially complete design." That phrasing has very specific meaning in applications for design certification within Part 52. Such a general position for topical reports would limit the number of topical reports that TEUSA would like to submit on a variety of subjects because the overall design has not progressed to an essentially complete design. TEUSA requests the staff to reconsider this view and continue the practice of incorporating conditions or limits within safety evaluations that reflect areas where details are still under development or where additional technical justification would be needed if referenced in a subsequent license application.

3) *In approval requests #3 and #4 in TEUSA Letter #201022, TEUSA requests the U.S. NRC to approve the threshold used to establish Anticipated Operational Occurrences and Design Basis Events, respectively.*

   Similar to the staff's comments regarding "approval" of white papers noted in feedback item (1), the staff can only assess the information provided in the white paper and provide feedback in relation to the information. This does not imply approval; however, it can be used to illustrate information that will be reviewed in a future licensing action.

   Additionally, requests #3 and #4 from Letter #L201022 use Regulatory Guide (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" as a basis for the values chosen. Section VII of *the white paper identifies the threshold for PIE classification for IMSR® but does not provide justification other than to compare it with RG 1.233. The staff notes that RG 1.233 endorses Nuclear Energy Institute (NEI) 18-04, which initially introduced the Failure-Consequence Curve concept along with the associated event classification cut-off values. However, RG 1.233 also states that NEI 18-04, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" is an integrated methodology. Since it is the NRC's understanding that TEUSA is not following the licensing modernization project process in its entirety, additional information should be provided to justify the chosen cut-off points for the IMSR® design.*

Response: TEUSA disagrees with the staff statement that the threshold limits used in RG 1.233 are only applicable to the integrated methodology of NEI 18-04. TEUSA suggests that the NRC basis for not accepting the proposed event classification threshold limits within its comment, conflates two very distinct decision criteria. The first is the selection of a threshold cutoff limit for accident classification categories and the second is the selection of radiological consequence criteria to be used to assess the risk posed by any accident in that specific accident category. The two criteria are mutually exclusive and independent of the process used to identify and categorize postulated initiating events.

TEUSA notes that the use of a frequency consequence curve was the staff vehicle used to establish the radiological consequence values that would be used to determine if the risk from the established accident category would be acceptable and therefore, no additional plant systems or plant operations would be needed. TEUSA also notes that the threshold limits used by TEI in event classification are not new, they are more expansive in the design basis event category than used in RG 1.233, and that NRC has used these or similar threshold limits for event classification for a substantial period dating back to the seminal documents for the Next Generation Nuclear Plant (NUREG 1860, December 2007). Our views are further supported by the current staff intent (based on its published draft Part 53 rule language) to use the same or similar threshold limits as appropriate threshold limits for event classification for applications that would not be required to implement the integrated methodology specifically approved by RG 1.233.

Nonetheless, TEUSA will provide additional justification for its use of the proposed threshold limits for event classification in its next submittal on PIE.