Canada's Nuclear Regulator

November 2017

Phase 1 Executive Summary
Pre-Project Design Review of Terrestrial Energy Inc. Integral Molten Salt Reactor -400

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

Executive Summary

A pre-licensing review of a new nuclear power plant (NPP), also referred to as a vendor design review (VDR), provides an opportunity for CNSC staff to assess a design prior to any licensing activities that would use that design, enabling the vendor to identify potential issues that would require resolution. Phase 1 of a VDR determines whether the vendor is demonstrating intent to be compliant with CNSC requirements in its design processes and outcomes.

The CNSC has completed a Phase 1 VDR of the Terrestrial Energy Inc. (TEI) 400-thermal-megawatt integral molten salt reactor (IMSR400). Based on the documentation submitted, CNSC staff have concluded that:

- TEI has demonstrated an understanding of CNSC requirements applicable to the design and safety analysis of the IMSR400
- TEI has demonstrated its intent to comply with CNSC regulatory requirements and expectations for NPPs. TEI has demonstrated that it intends to adequately justify the use of alternative approaches in meeting design requirements, as articulated in section 11 of REGDOC-2.5.2, *Design of Reactor Facilities: Nuclear Power Plants,* where:
    - the alternative approach would result in an equivalent or superior level of safety; or
    - the application of the requirements in REGDOC-2.5.2 would not serve the underlying purpose, or is not necessary to achieve the underlying purpose
- TEI is integrating Fukushima lessons learned into IMSR design provisions; and
- Additional work is required by TEI to address the findings raised as part of this review, including the need to establish robust quality-assured processes for design and safety analysis activities.

Background

Introduction

The Canadian Nuclear Safety Commission (CNSC) is Canada's sole nuclear regulatory agency and operates under the *Nuclear Safety and Control Act* (NSCA). The CNSC regulates the use of nuclear energy and materials to protect health, safety, security and the environment, and to implement Canada's international commitments on the peaceful use of nuclear energy.

A pre-licensing review of a vendor's reactor design, also referred to as a vendor design review (VDR), is a high-level assessment of a proposed reactor technology. It is an optional service provided by the CNSC when requested by a vendor. This service does not involve the issuance of a licence under the NSCA and is not part of the licensing process. The conclusions of such reviews will not bind or otherwise influence decisions made by the Commission.

The review is intended to provide early feedback to the vendor as it addresses Canadian regulatory requirements and expectations in its design. The CNSC will require a more detailed review of the design and safety case for a specific application for a licence to construct a nuclear power plant (NPP) at a specific site. The VDR process provides benefits to Canadians by enabling CNSC staff to:

- understand the implications of new technological approaches
- identify challenges associated with the interpretation of requirements
- develop regulatory positions as needed

Terrestrial Energy Inc. (TEI) is designing a 400-thermal-megawatt integral molten salt reactor (IMSR400), with a net electrical output of approximately 200 megawatts. The IMSR400 design draws upon past operational experience from research and development efforts such as the molten salt reactor experiment that operated in Oak Ridge as part of Oak Ridge National Laboratory's Molten Salt Reactor Program.

In February 2016 a service agreement was signed between the CNSC and TEI for the conduct of a Phase 1 VDR of the IMSR400. The Phase 1 review report outlines the review process followed, and the assessment findings and conclusions of that review.

Overview of vendor design review process

CNSC guidance document GD-385, *Pre-licensing Review of a Vendor's Reactor Design* describes the VDR process provided by the CNSC for assessing a vendor's design for a new NPP or small reactor. The review considers the areas of design that relate to reactor safety, security and safeguards.

A VDR provides an early opportunity to identify potential regulatory or technical issues in the design process, particularly those that could result in significant changes to the design or safety analysis. The review assesses whether the design meets the intent of requirements for design and safety analysis as articulated in CNSC regulatory document REGDOC-2.5.2, *Design of Reactor*

Facilities: Nuclear Power Plants, or RD-367, *Design of Small Reactor Facilities*, and other applicable regulatory documents and standards.

The VDR is divided into three phases, each requiring increasingly more detailed technical information:

- **Phase 1: Compliance with regulatory requirements.** The conceptual design is expected to be completed and described. For a discrete set of focus areas, CNSC staff assess how the vendor's design processes demonstrate intent to meet CNSC requirements.

- **Phase 2: Identification of potential fundamental barriers to licensing.** Subsequent to Phase 1, this phase goes into further detail, with a focus on identifying whether there are any potential fundamental barriers to licensing.

- **Phase 3: A follow-up to Phase 2.** This phase focuses on a more detailed review of selected focus areas identified by the vendor that pertain to a licence to construct.

The VDR process includes 19 standard focus areas as follows:

Focus area	Description
1	General plant description, defence in depth, safety goals and objectives, and dose acceptance criteria
2	Classification of structures, systems and components (SSCs)
3	Reactor core nuclear design
4	Fuel design and qualification
5	Control system and facilities
6	Means of reactor shutdown
7	Emergency core cooling and emergency heat removal systems
8	Containment/confinement and safety-important civil structures
9	Mitigation of design extension conditions
10	Safety analysis (deterministic safety analysis, probabilistic safety analysis) and internal and external hazards
11	Pressure boundary design
12	Fire protection
13	Radiation protection
14	Out-of-core criticality
15	Robustness, safeguards and security
16	Vendor research and development program
17	Management system of design process and quality assurance in design and safety analysis
18	Human factors
19	Incorporation of decommissioning in design considerations

Application of REGDOC-2.5.2 to a molten salt reactor technology

Although regulatory document REGDOC-2.5.2, *Design of Reactor Facilities: Nuclear Power Plants* was written to be technology-neutral to the extent practicable, it contains requirements and guidance that incorporate extensive operating experience from water-cooled reactors. It is recognized that specific technologies may use alternative approaches. When a design other than a water-cooled reactor is considered in Canada, the design is subject to the safety objectives, high-level safety concepts and safety management principles associated with REGDOC-2.5.2. CNSC staff acknowledges that in some cases, existing requirements or guidance are not appropriate or fully applicable to non-water-cooled reactors. Professional judgement and transparent processes are used to ensure that the application of, or departure from, REGDOC-2.5.2 requirements is treated fairly and consistently, to achieve the required level of safety.

Phase 1 design review results

Based on the documentation submitted, CNSC staff concluded that:

- TEI has demonstrated an understanding of CNSC requirements applicable to the design and safety analysis of the IMSR400
- TEI has demonstrated its intent to comply with the CNSC regulatory requirements and expectations for NPPs. TEI has demonstrated that it intends to adequately justify the use of alternative approaches in meeting design requirements, as articulated in section 11 of REGDOC-2.5.2, where:
    - the alternative approach would result in an equivalent or superior level of safety; or
    - the application of the requirements in REGDOC-2.5.2 would not serve the underlying purpose, or is not necessary to achieve the underlying purpose
- TEI is integrating Fukushima lessons learned into IMSR design provisions; and
- Additional work is required by TEI to address the findings raised as part of this review, including the need to establish robust quality-assured processes for design and safety analysis activities.

TEI recognizes that research and development activities will play a significant role in justifying the use of alternative approaches in addition to any relevant operating experience.

Noteworthy findings that will require additional follow-up with TEI in a future review are briefly summarized below:

1. There is a need for additional evidence to indicate that TEI has a documented systematic process in place to support its design activities. While TEI is working towards establishing quality-assured processes for design and safety analysis activities, many overarching design process documents, such as safety design guides and safety specification documents, are under development. TEI is expected to demonstrate in Phase 2 that it has established sufficient systematic processes in its management system to support its ongoing development activities.

2. Overall, several features are currently at the conceptual level of design and will require additional technical information, based on research and development and design activities, to demonstrate:
    - that predictions of system performance and reliability are commensurate with a safety function
    - that design specifications for SSCs important to safety are adequate
    - the role of a first-of-a-kind plant in the research and development program, to develop the necessary data to further support safety margins and operating performance under various plant states
3. In part due to the novel design of the IMSR400, there are features of the design that require further consideration:
    - TEI recognizes that further work is necessary to predict core behaviour in the presence of damaged core internal components. CNSC staff also acknowledge that the definition of core damage as defined in REGDOC-2.5.2, and its associated safety goals, may not be applicable to the IMSR design. CNSC staff are reviewing whether changes to REGDOC 2.5.2 are required.
    - TEI has proposed that failure of the core vessel would constitute a severe accident. While CNSC staff agree that this may be an acceptable position, TEI is expected to complete its analysis work to describe what constitutes core damage for the IMSR. Confirmatory work in safety analysis may lead to a better understanding of severe accidents.
    - Power control of the reactor is performed indirectly through heat removal by the heat sinks on the primary and secondary side, relying on the negative power reactivity feedback of the core. In Phase 2, TEI is expected to indicate how it intends to validate predictions of reactor dynamics and heat sinks' performance when dealing with aging mechanisms such as mechanical, chemical and irradiation effects on materials. This is necessary to confirm predicted control scheme performance and ensure adequate core stability over the life of the reactor.
4. In Phase 2, TEI will need to demonstrate that human factors in design has been appropriately addressed in its operability and maintainability programs which are currently under development.

Notwithstanding the above, these finding are resolvable and will be followed up in future VDRs.