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Application of COG-09-9030 and REGDOC-2.4.1 for i-SMR Deterministic Safety Analysis

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1. Introduction

The innovative Small Modular Reactor (i-SMR) has been developed to enhance safety and economic feasibility while maintaining operational flexibility. Korea Hydro & Nuclear Power Co., Ltd. (KHNP) is reviewing international regulatory requirements, including the deterministic safety analysis (DSA) standards established by the Canadian Nuclear Safety Commission (CNSC), and evaluating their potential applicability for future deployment [1].

REGDOC-2.4.1, "Deterministic Safety Analysis," defines methodologies for safety assessment of nuclear reactors, categorizing accident scenarios into Anticipated Operational Occurrences (AOO), Design Basis Accidents (DBA), and Beyond Design Basis Accidents (BDBA) [2]. Additionally, COG-09-9030, "Principle & Guidelines for Deterministic Safety Analysis," provides a systematic framework for conducting safety evaluations for CANDU and SMR technologies [3].

This study examines how COG-09-9030 and REGDOC-2.4.1 can be applied to i-SMR's deterministic safety analysis to ensure compliance with international safety standards. The focus is on adapting existing safety analysis methodologies to the unique design characteristics of i-SMR, particularly its passive safety features and modular construction.

2. Overview of REGDOC-2.4.1 and COG-09-9030

2.1 REGDOC-2.4.1 Deterministic Safety Analysis (DSA) Requirements

The REGDOC-2.4.1 establishes comprehensive requirements for deterministic safety analysis, focusing on:

- Application in VDR Phase III:
  - REGDOC-2.4.1 serves as a key evaluation criterion in the Phase III of VDR, where the technical feasibility of reactor design and compliance with regulatory requirements are comprehensively reviewed
- Classification of Accident Categories [2].
  - AOO (Anticipated Operational Occurrences)
  - DBA (Design Basis Accidents)
  - BDBA (Beyond Design Basis Accidents)
- Implementation of Defense-in-Depth (DiD): A structured five-level DiD framework to mitigate potential accidents.
  - (Level 1) Prevention of Abnormal Operation and Failures – Quality control, strict operational procedures, and reliable system design
  - (Level 2) Control of Abnormal Operation and Detection of Failures – Early detection and automated protection systems
  - (Level 3) Control of Design Basis Accidents (DBA) – Emergency Core Cooling System (ECCS) and multiple safety mechanisms
  - (Level 4) Control of Beyond Design Basis Accidents (BDBA) & Mitigation of Severe Accidents – Additional safety measures to minimize radiological release
  - (Level 5) Mitigation of Radiological Consequences & Emergency Response – Emergency procedures to minimize public and environmental impact
- Acceptance Criteria for Radiation Exposure.
  - AOO: 0.5 mSv
  - DBA: 20 mSv
  - BDBA: No deterministic limits, but ALARA (As Low As Reasonably Achievable) principles apply

These concepts are crucial for evaluating i-SMR's passive safety systems and natural circulation cooling features under regulatory standards.

2.2 COG-09-9030 Guidelines for Deterministic Safety Analysis

The CANDU Owners Group (COG) developed COG-09-9030, which provides a structured methodology for performing deterministic safety analyses while ensuring compliance with CNSC requirements. The key principles include [3]:

- Application of Best Estimate plus Uncertainty (BEAU) Methods.
- Integration of Probabilistic and Deterministic Safety Analysis (PSA & DSA).
- Single Failure Criterion (SFC) Implementation in Safety Systems.

For i-SMR, these principles must be carefully considered due to its passive safety mechanisms and modular design, which necessitate tailored safety analysis approaches.

3. Application of COG-09-9030 and REGDOC-2.4.1 to i-SMR

3.1 i-SMR's Unique Design Considerations

The i-SMR differs significantly from traditional large-scale reactors in its power output, cooling system, and safety design. Unlike conventional CANDU reactors, which utilize active safety systems and heavy water cooling, i-SMR adopts passive safety mechanisms and natural circulation cooling, reducing the reliance on external power and active components.

Understanding these fundamental design differences is critical for developing an appropriate deterministic safety analysis (DSA) approach. Table 1 provides a comparative analysis of the i-SMR and traditional CANDU reactors, emphasizing the transition from active to passive safety systems and its implications for deterministic safety analysis.

Table 1. Comparison of i-SMR and Traditional CANDU Reactors

Aspect	Traditional CANDU	i-SMR
Reactor Power	700–900 MWe	170 MWe
Safety System	Active Safety Features	Passive Cooling & Automatic Shutdown
Containment Design	Large reinforced concrete containment	High-integrity Integrated Containment Vessel (ICV)

3.2 Key Challenges in Applying REGDOC-2.4.1 to i-SMR

While i-SMR offers enhanced safety features, its compliance with REGDOC-2.4.1 requires rigorous assessment in the following areas:

- Passive Safety System Performance: Unlike active safety systems in traditional reactors, i-SMR relies on natural circulation for cooling. It must be demonstrated that passive safety features can meet the regulatory criteria for DBA and BDBA scenarios [2].
- Defense-in-Depth (DiD) Framework: i-SMR's Level 4 and 5 DiD strategies must be validated to ensure containment integrity and emergency preparedness [2].
- Uncertainty Quantification in BEAU Methods: Since i-SMR introduces novel design features, uncertainty in deterministic analysis models should be carefully assessed using computational simulations [3].

4. Recommendations for i-SMR's Compliance with REGDOC-2.4.1

To facilitate regulatory approval, i-SMR must address technical and procedural requirements set by CNSC and international bodies. Key considerations include:

- Alignment with REGDOC-2.4.1: Ensuring that DSA methodologies fully incorporate passive safety system performance metrics [2].
- Standardization with COG-09-9030: Integrating PSA-DSA hybrid approaches to provide comprehensive safety assessments.
- Advanced Computational Validation: Utilizing CFD (Computational Fluid Dynamics) and multi-physics simulations to reinforce safety case evaluations. Specific applications may include LOCA (Loss-of-Coolant Accident) response modeling, passive cooling performance verification, and containment pressure behavior assessment under BDBA conditions.

By adopting these measures, i-SMR can demonstrate regulatory compliance while ensuring safety and reliability in deployment.

5. Conclusions

This study analyzed the application of COG-09-9030 and REGDOC-2.4.1 to i-SMR's deterministic safety analysis. Key findings include:

- REGDOC-2.4.1 mandates expanded DBA/BDBA analysis for i-SMR's passive safety features [2].
- COG-09-9030 provides a structured DSA framework that must be adapted for SMR applications [3].
- Hybrid PSA-DSA methodologies can enhance i-SMR's regulatory compliance strategy [3].

Further study should focus on developing advanced multi-physics simulations and experimental validation techniques to further substantiate i-SMR's deterministic safety analysis compliance.

REFERENCES

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