Review of Mechanistic Source Term (MST) Application to KHNP's i-SMR

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1. Introduction

The source term defines the types and amounts of radionuclides released into the environment under various accident conditions. Traditionally, source term models such as TID-14844 and NUREG-1465 have been used for Light Water Reactors (LWRs), applying conservative assumptions to estimate potential releases [1,2].

However, these models do not fully reflect the characteristics of Small Modular Reactors (SMRs) like KHNP's i-SMR, which incorporate advanced passive safety features, compact designs, and modular construction [3].

To address these limitations, the Mechanistic Source Term (MST) approach has been introduced, providing a realistic assessment of fission product behavior based on reactor-specific conditions [4]. MST has been extensively studied in advanced reactors such as Sodium-Cooled Fast Reactors (SFRs), where unique fission product retention mechanisms exist [3,5]. These findings can provide valuable insights into the application of MST to i-SMR.

Recent studies have also compared source term management strategies in Pressurized Water Reactors (PWRs) and SFRs, highlighting key differences in accident progression and fission product retention mechanisms [6]. These insights reinforce the necessity of MST for reactors like i-SMR, where conventional source term models may not be directly applicable.

This study explores how MST can be applied to KHNP's i-SMR, considering its design features and regulatory implications.

2. Overview of Source Term Models

2.1 Traditional Source Term Models and Their Limitations

Early source term models relied on conservative assumptions:

- TID-14844 (1962): Developed for LWRs, assuming a large break LOCA scenario with maximum fission product release [1].
- NUREG-1465 (1995): Introduced accident-specific source terms, differentiating between PWRs and BWRs [2].

While effective for LWR licensing, these models do not account for the passive safety features of i-SMR, leading to overestimation of source term and emergency planning requirements [3].

2.2 Introduction of MST for SMRs

The U.S. NRC and international regulatory bodies have acknowledged the need for MST in advanced reactors:

- SECY-93-092 (1993): Proposed MST for non-LWRs, emphasizing reactor-specific fission product transport mechanisms [4].
- SECY-03-0047 (2003) & SECY-05-0006 (2005): Allowed for scenario-specific evaluations based on plant performance [4].

Comparative studies between PWRs and SFRs indicate that fission product behavior, containment efficiency, and accident management strategies significantly influence source term estimation [6]. These findings further emphasize the importance of adopting reactor-specific MST approaches for i-SMR.

MST provides a more accurate safety assessment, potentially allowing reduced Emergency Planning Zones (EPZs) and flexible siting options for i-SMR [7].

3. Application of MST to i-SMR

3.1 i-SMR Design Features Affecting MST

The KHNP's i-SMR is designed with enhanced passive safety and modular architecture, which influence radionuclide release behavior. Table 1 compares key aspects of i-SMR with traditional LWRs.

The i-SMR's integral reactor design and natural circulation cooling lead to different fission product transport mechanisms, requiring MST-based analysis rather than conventional models [3].

3.2 MST Analysis for i-SMR

Key considerations for MST application to i-SMR include [8]:

- Passive containment cooling: Unlike traditional LWRs, i-SMR relies on natural convection for decay heat removal, affecting fission product retention [5].

- Limited core inventory: The smaller reactor core reduces the total radionuclide inventory, lowering potential source term release.
- Aerosol transport modeling: MST must account for fission product behavior in a compact containment, differing from large-scale PWRs [3].

Studies comparing PWR and SFR source term retention highlight the importance of reactor-specific MST methodologies, particularly for advanced reactor designs like i-SMR [6]. These factors suggest that MST could justify smaller exclusion zone distances and emergency planning areas for i-SMR [8].

Table 1. Comparative Analysis of Source Term Characteristics in LWRs and i-SMR

Aspect	Conventional LWR	i-SMR
Reactor Type	Large PWR/BWR	Integral PWR
Safety System	Active ECCS	Passive cooling & automatic shutdown
Primary Containment	Large dry containment	Compact, High-Integrity Integrated Containment Vessel (ICV)
Fission Product Transport	Water-borne pathways	Gas-phase and passive retention

4 Regulatory Implications of MST for i-SMR

4.1 MST and Licensing Flexibility

Existing regulations (10 CFR 50.34, 10 CFR 100.11) do not prescribe a single source term model for SMRs [7]. MST offers:

- A performance-based alternative to TID-14844 and AST (Alternative Source Term).
- Potential for risk-informed EPZ adjustments, enhancing i-SMR's deployment flexibility [3].

Comparative analysis of source term management in PWR and SFR accidents suggests that existing regulatory frameworks may need adaptation to accommodate MST methodologies for i-SMR [6]. The insights gained from PWR source term management can help refine regulatory expectations for MST application in i-SMR, particularly regarding source term mitigation strategies.

These findings emphasize the need for further discussions with regulatory authorities to define MST implementation criteria specific to SMRs, ensuring alignment with international safety standards.

4.2 MST's Role in i-SMR Commercialization

The Regulatory acceptance of MST could benefit i-SMR by:

- Reducing siting constraints, allowing deployment closer to demand centers.
- Lowering emergency response requirements, optimizing operational costs.
- Enhancing safety justification, supporting global licensing efforts [5].

To establish MST-based licensing frameworks for i-SMR, further collaboration with regulatory authorities such as KINS is essential, particularly in developing performance-based source term methodologies aligned with international safety standards.

5. Conclusions

The adoption of Mechanistic Source Term (MST) for KHNP's i-SMR represents a major shift from traditional TID-14844 and AST models. MST better reflects the passive safety features and fission product behavior of i-SMR, enabling:

- A more realistic source term evaluation.
- Potentially reduced EPZ and flexible siting regulations.
- Improved regulatory pathways for international deployment [3].

Further study should focus on validating MST methodologies for i-SMR through experimental and computational modeling [5,6].

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