Review of the Regulation Status of Source Term for Sodium-Cooled Fast Reactor in US

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1. Introduction

To get a license of a commercial nuclear power plant, it is essential to ensure the safety of the public and environment by providing protections against the release of radionuclides. As a part of the process to assess the safety of a nuclear power plant design, the source term expected to occur during normal reactor operation and accident sequences is analyzed, where a source term is considered to be the types and amounts of radionuclides that could be released to the environment.

Nearly all the currently operating light water reactors in Korea have been designed and licensed using the so-called "TID-14844 Source Term [1]". This description of the accident source term was developed about 50 years ago based on experiments involving furnace heating of irradiated reactor fuel chips. Unfortunately this TID-14844 source term is unsuitable for Sodium-cooled Fast Reactors (SFRs), as the phenomena associated with the base accidents are not comparable to SFR accidents.

The Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) has adopted the metal-fuel and pool-type for its inherent safety. In this study we expect that the same source term for Power Reactor Innovative Small Module (PRISM) which designed by General Electric (GE) and adopted the same metal-fuel and pool-type. However, currently nothing is determined for the source term analysis in the PGSFR. Early in licensing efforts, GE indicated interest in development of a mechanical source term (MST) appropriate for metal-fuel and pool-type SFRs. The US Nuclear Regulatory Commission (NRC) has repeatedly indicated an expectation that future advanced reactor license applications should include a mechanistic assessment of potential radionuclide release [2-4]. Also the Commission indicated that sufficient fuel qualification data should be available and fuel performance should be sufficiently well understood for normal and off-normal conditions. Due in part to the absence of metal-fuel data and the lack of credible fuel damage scenarios, in the PRISM PSID, conservative bounding assumptions regarding releases were utilized until additional MST research and development could be conducted [5].

In the early 1990s, the NRC began formally addressing the use of MSTs in advanced reactor licensing with the issuance of SECY-93-092 [2] following a request from the Commission for a review of the state-of-the-art of source term analyses. The staff addressed the source term issue for the PRISM, the MHTGR, the PIUS, and the Canadian Deuterium-Uranium (CANDU) 3 reactor designs and recommended to the Commission that mechanistic source terms should be allowed.

In 2003, Commission issued SECY-03-0047 [3] to provide for Commission consideration options and recommended positions for resolving the seven policy issues associated with the design. The source term is one of the policy issues. And the staff recommends that for the purpose of siting and containment/confinement decisions, and conservative source terms for AOOs and DBEs are used. For emergency planning purposes a best estimate source term would be acceptable.

In SECY-05-006 [4], dated January 7, 2005, Commission updates the issues in SECY-03-0047. The Commission approved the use of scenario-specific source terms provided that the staff understands the fission product behavior, plant conditions and performance.

This paper reviews the regulation status and history of the source term for the metal-fuel and pool-type SFR in US.

2. Revision of Regulatory Source Terms

Initial source term parameters for LWRs have been developed using knowledge available at the time. Therefore, progress in the state-of-the-art has led to revise regulatory source terms. The various iterations of the regulatory requirements for source terms have been discussed.

2.1 TID-14844

In 1962, the US Atomic Energy Commission (AEC) issued the Technical Information Document (TID) titled "Calculation of Distance Factors for Power and Test Reactor Sites" [1], also known as TID-14844. TID-14844 included guidance regarding the assumed fractional release to containment, atmospheric transport and dispersion behavior, and calculation of offsite consequences. The source term was based on deterministic assumptions for a maximum credible accident in an LWR, which was loosely defined in the TID as a substantial core melt resulting from a loss of coolant accident (LOCA). In general, this TID-14844 source term is unsuitable for SFRs, as the phenomena

associated with the base accident (LOCA) are not comparable to SFR accidents.

2.2 NUREG 1465

After about thirty years from the publication of TID-14844, the NRC presented a revised source term in NUREG-1465 [6]. This NUREG-1465 attempted to address the weakness that resulted from the conservative, simplistic assumptions of TID-14844. NUREG-1465 presents unique boiling water reactor (BWR) and pressurized water reactor (PWR) source terms that are based on a range of accident scenarios derived from NUREG-1150 analyses [7]. NUREG-1465 explicitly addresses fuel failure phenomena, quantitatively considers uncertainties, and provides guidance on in-containment retention mechanisms. And according to uncertainty analyses, NUREG-1465 includes timed-releases with credit for engineered safety features. As with TID-14844, the release fractions of NUREG-1465 are considered unsuitable for SFRs.

2.3 Mechanistic Source Term (MST)

In the early 1990s, the NRC began formally addressing the use of MSTs in advanced reactor licensing with the issuance of SECY-93-092 [2] following a request from the NRC for a review of the state-of-the-art of source term analyses. This SECY reviewed the vendor-proposed source terms for advanced reactors currently in the pre-application stage. The NRC recommended that;

"*…source terms should be based upon a mechanistic analysis and will be based on the staff's assurance that the provisions of the following three items are met:*

- *The performance of the reactor and fuel under normal and off-normal conditions is sufficiently well understood to permit a mechanistic analysis. Sufficient data should exist on the reactor and fuel performance through the research, development, and testing programs to provide adequate confidence in the mechanistic approach.*
- *The transport of fission products can be adequately modeled for all barriers and pathways to the environs, including specific consideration of containment design. The calculations should be as realistic as possible so that the values and limitations of any mechanisms or barrier are not obscured.*
- *The events considered in the analyses to develop the set of source terms for each design are selected to bound severe accidents and design-dependent uncertainties.* "

3. The History of Source Term for SFR

In this paper, the history of source term is divided into two sections based on a time that "actinide recycling project" started. In August 1994 Congress terminated the reactor program and shut down the IFR operation. But the Clinton administration agreed to fund the fuel reprocessing program – renamed the "actinide recycling project" – while closing down the venerable EBR-II and other supporting facilities.

3.1 Past Activities

According to NUREG-0968[8], Safety Evaluation Report on the application for a construction permit for the Clinch River Breeder Reactor Plant, prepared by the NRC and summarized the results to date the staff's safety review in 1968. Severe accidents were not considered in this report, and for the source term design-base releases are based on operation with 1% failed fuel; estimates of releases are based on operation with 0.1% failed fuel. NRC published NUREG-1226[9] in 1988 and provided severe accident and source term policies, that will use the improved information from extensive research on radioactive material releases (i.e., source terms) under severe accident conditions. And an advanced reactor could be proposed that would meet these preventative requirements with such sufficiency that relief could be justified in the type of source terms and severe accident mitigate features from that traditionally employed on LWRs.

In 1989, DOE has proposed the use of mechanistic siting source terms in lieu of the TID-14844, no conventional containment building, and no requirements for preplanned offsite emergency evacuation or drills [10]. NRC staff listed eight PRISM design features that deviated significantly from current LWR regulatory requirements [2]. For these issues, either existing regulations do not apply to the design or the pre-applicant has proposed criteria that differ significantly from the current regulations. And one of these issues is about the calculation of source term. And NRC staff considered that in order to evaluate the safety characteristics of advanced reactor designs that are significantly different from LWRs, a different method needs to-be developed for calculating postulated radionuclide releases (source terms). In a June 26, 1990, Staff requirements memorandum (SRM) related to SECY-90-016, the Commission asked the staff to submit a paper-describing the status of efforts to develop an updated source term that takes into account "best" "available estimates" and current knowledge on the subject. In response to this request, the staff is developing a revision to the TID-14844 source term. The staff proposal to base the source terms on mechanistic analyses appears reasonable, although it is clear that the present data base will need to be expanded.

3.2 Present Activities

After the introducing 10 CFR 50.67 for operating reactors, the discussion on source terms continued but with focus on non-LWR use. SECY-02-0139 presents the difference between operating LWR and future plants as following:

"Current LWRs use site-specific parameters (e.g., exclusion area boundary) and a predetermined source term into containment to analyze the effectiveness of the containment and site suitability for licensing purposes. These source terms are described in documents TID-14844 and NUREG-1465 and are based upon enveloping the fission product releases that would be predicted to occur given a core melt accident. On the other hand, future plants, particularly non-LWRs, propose not to use a predetermined source term for assessing the effectiveness of plant mitigation features or site suitability, but rather to use plant-specific accident source terms corresponding to each of the AOOs and DBEs defined for the plant. Such an approach puts a burden on the applicant and staff to understand the fission product release characteristics and uncertainties associated with a variety of accident scenarios"

NRC SECY-03-0047 is published to provide for Commission consideration options and recommended positions for resolving the seven policy issues associated with the design and licensing of future non-light-water reactor designs discussed in SECY-02-0139. The issue about source term involved in this SECY is what condition should be used for licensing decisions. Commission recommended that the use of scenario-specific source terms provided there is sufficient understanding and assurance of plant and fuel performance and deterministic engineering judgement is used to bound uncertainties. This approach is also dependent upon understanding fuel and fission product behavior under a wide range of scenarios and on ensuring fuel and plant performance is maintained over the life of the plant. This approach is also very dependent on the event selection process. For the purpose of siting and containment/confinement decisions, the staff recommends that conservative source terms for AOOs and DBEs be used. For emergency planning purposes a best estimate source term would be acceptable.

In 2005, SECY-05-0006 is issued to propose a framework for the "Use of Scenario-Specific Source Terms for Licensing Decisions" and licensing approach for new plant licensing, in support of SRM-SECY-03-0047. The Commission approved the use of scenario-specific source terms provided that the staff understands the fission product behavior and plant conditions and performance. Among other topics within SECY-05-0006, it specifically addressed how the staff proposed to integrate scenario-specific source terms into the proposed regulatory structure for new plant licensing. The staff proposed using a flexible, performance-based approach to establish scenario specific licensing source terms. The key features of the staff's approach were as follows:

- Scenarios are to be selected from a design-specific probabilistic risk assessment.
- Source term calculations are based on verified analytical tools.
- Source terms for compliance should be 95 percent confidence level values based on best estimate calculations.
- Source terms for emergency preparedness should be mean values based on best estimate calculations.

Source terms for licensing decisions should reflect scenario-specific timing, form, and magnitude of the release. This approach puts the burden on the applicant to develop the technical basis. An applicant could, however, propose to use a conservative source term.

4. Conclusions

Nearly all the currently operating light water reactors in KOREA have been designed and licensed using the so-called "TID-14844 Source Term". Unfortunately this TID-14844 source term is unsuitable for SFRs, as the phenomena associated with the base accidents are not comparable to SFR accidents. In this study, we expect that the same source term that was used in PRISM would be applied into the source term analysis for the PGSFR. However, currently nothing is determined for the source term analysis in the PGSFR. In the early 1990s, the NRC began formally addressing the use of MSTs in advanced reactor licensing with the issuance of SECY-93-092 following a request from the Commission for a review of the state-of-the-art of source term analyses. And this regulatory source terms has been revised via progress in the state of the art. The US NRC stated an expectation for advanced reactor vendors to present MST in their license applications.

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