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A comparative study on the source term management in PWR and SFR severe accidents

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1. Introduction

The review guidance of PWR severe accident source term is under development. The current draft has been completed and the final draft will be announced in December 2017. And this guidance provides a total of 15 assessment criteria.

Currently, there is no directive guidance for the SFR severe accident source term and will be required in the future for licensing. The above review guidance of PWR severe accident source term will give a good insight in preparing the licenses for the SFR severe accident source term. In this paper, it is discussed about countermeasures for licensing SFR severe accident source term according to the review guidance of PWR severe accident source term.

2. Regulation for Source Term

2.1 Regulation for source term

2.1.1 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.

2.1.2 NUREG 1465

After about thirty years from the publication of TID-14844, the NRC presented a revised source term in NUREG-1465 [2]. 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 [3]. 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.

2.1.3 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 [4] 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.* "

2.2 The review guidance of PWR severe accident source term

The review guidance for an accident impact assessment has been developed with 15 items for source term assessment bases. As a general aspect, the assessment has to be performed with consideration for each plant characteristics and required to perform for whole period after an accident. Also it is required to perform the uncertainty analysis. It is distinguished to four phases for the fission product release: gap, early in vessel, ex-vessel, late in-vessel release same as NUREG-1465.

The main contents of the source term assessment criteria for this assessment are below:

1. Event sequence selection and uncertainty analysis
2. Fuel inventory
3. Specific activity within the RCS
4. Gap release
5. Early in-vessel release
6. Fission product retention within RCS
7. Release from RCS after the vessel failure
8. Ex-vessel release
9. Long-term release
10. Chemical form of fission products
11. Non-radiative aerosol
12. Characteristics of aerosol
13. Numerical code
14. Fission product removal mechanism
15. Containment leakage rate

Each content will be described in more detail as follows. The selection of event sequences should cover 90% in order of the degree of contribution of core damage frequency as a result of Level 1 PSA, and a deterministic best-estimated analysis should be carried out for each event. And the uncertainty variable should be selected and a representative source term of statistically significant level should be derived. The calculation of fuel inventory should be performed taking into account conservative operating variables through internationally accepted numerical computer codes. Specific activity within RCS may be subject to the operating limits specified in the Operating Technical Specifications, excluding iodine spikes.

Regarding fission product releases and chemical forms, Reg. Guide 1.183 should be applied. And the gap release ratio of each specific plant type should be presented. For fission product retentions in the RCS, consideration should be given to the residual of fission products in the reactor coolant system pipes and the phenomenon of the release reduction to the containment. The amount and characteristic of non-radioactive aerosols generated at each release phase should be assessed. And all the numerical codes used in the assessment of the source terms are only validated by the international virtues and have been verified experimentally. In order to remove fission products, the amount and characteristics of non-radioactive aerosols generated at each release phase should be evaluated. Finally, the leakage rate of the containment should be considered in terms of the effect of the pressure change inside the containment

2.3 Review of the plan for reaction according to the PWR source term assessment guidance

The review of the plan for reaction according to the assessment guidance missioned above is performed. Table 1 shows the results from the review.

Table 1. The plan for reaction according to assessment guidance

No.	*Assessment guidance*	*Plan for reaction*
1	Event sequence selection and uncertainty analysis	• Select the event sequence using existing PSA Level 1 • Require to perform the PIRT for the event sequence selection and the uncertainty analysis
2	Fuel inventory	• Perform the fuel inventory analysis using ORIGEN code
3	Specific activity within the RCS	• Using the operating limits of technical specification
4	Gap release	• Require to prepare SFR fission products release phase responded to NUREG-1465 • Arrange criteria and basis of the release phases • Arrange basis of chemical form about fission products • Require to verify the phenomena of a bubble transport and a radionuclide vaporization from the pool to the cover gas • Require the experimental data of phenomena occurred in the pool as a condensation, deposition etc.
5	Early in-vessel release	
6	Fission product retention within RCS	
7	Release from RCS after the vessel failure	• Assume the leakage from seals around reactor head penetrations respond to the vessel failure • Require uncertainty analysis regarding the design of the reactor head and the magnitude of leakage from the cover gas region into the containment
8	Ex-vessel release	
9	Long-term release	• Consider the radionuclide vaporization from the pool as the long-term release
10	Chemical form of fission products	• Arrange basis of chemical form about fission products responded to NUREG-1465
11	Non-radiative aerosol	• Require to analysis the characteristics of aerosols
12	Characteristics of aerosol	
13	Numerical code	• Using numerical code for

		the severe accident (ex, MELCOR) verified internationally • Except for that, require the experimental data for verifying
14	Fission product removal mechanism	• Require to identify the removal mechanism within the sodium pool, cover gas and containment and the experimental data of each phenomena
15	Containment leakage rate	• Consider the effect of change the internal pressure in the containment for containment analysis • Be able to consider the conservative hole size instead of this effect

3. Conclusions

The review guidance of PWR severe accident source term is under development. Currently, there is no directive guidance for the SFR severe accident source term and will be required in the future for licensing. The above review guidance of PWR severe accident source term will give a good insight in preparing the licenses for the SFR severe accident source term. In this paper, it is discussed about countermeasures for licensing SFR severe accident source term according to the review guidance of PWR severe accident source term.

The review of the plan for reaction according to the assessment guidance is performed. As a result, it is founded that there are gaps in many parts of the comparison between the guidance for the PWR severe accident source term and current Research Status of SFR source term. In particular, it is necessary to define the release fraction in SFR source term corresponding to NUREG-1465 and to confirm the phenomenon experienced by the radionuclide occurring within the pool.

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