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A Study on Scenario Selection for Evaluation of Fission Product Behavior during a Severe Accident at APR 1400 Nuclear Power Plants

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1. Introduction

As a part of an "Evaluation of the State-of-the-Art on the Fission Product Behavior and Improvement of the Iodine Evaluation Model" Project, we at KINS plan to investigate source term behavior during a severe accident by MELCOR [1] and to eventually compare it with results by RAIM [2] which is an add-on code to MELCOR including iodine behavior model developed by KINS. Since species and amount of fission products in the containment depend on a specific accident, it is necessary to select accident scenarios for the study, especially taking account of its relative importance of occurrence or resultant effects for a specific plant.

In this regard, we have reviewed U.S.NRC's State-of-the-Art Reactor Consequence Analyses (SOARCA) [3] and applied the SOARCA's method of scenario selection to Probabilistic Safety Assessment (PSA) [4] for Shin-Kori 3·4 nuclear power plants which are APR1400 type reactors. Furthermore, we have selected scenarios from the PSA results with a new criterion in the light of risk, which consists of probability and consequence of accidents of interest.

2. Scenario Selection in SOARCA

The objective of U.S.NRC's SOARCA is to evaluate plant improvements and changes not reflected in earlier NRC publications such as NUREG/CR-2239, NUREG-1150, and WASH-1400. The SOARCA team has performed plant-specific research for Peach Bottom [5] and Surry [6] nuclear power plants.

For the scenario selection, they used core damage frequency (CDF) for screening parameter and applied a screening guideline as follows:

CDF > 10^{-7} per reactor year *for bypass scenario like SGTR&ISLOCA,*
> 10^{-6} per reactor year *otherwise*

, where SGTR is steam generator tube rupture and ISLOCA is interfacing system loss of coolant accident. As shown the above criterion, it consists of a screening parameter and a screening value. In the SOARCA [3], they mentioned the reason for use of CDF is due to limitation of availability for Level 2 PSA and for use of the screening value appears to be based on their experiences using MELCOR and MAACS.

It is noteworthy that the screening criterion used a definite value. This value actually represents the status of safety technology for nuclear power plant at the time and the place where the criterion developed. Therefore, it should be changed as time goes on and can be affected by many external factors such as regulation policy, safety-related technology, improved PSA, and so on.

In practice, we have applied the SOARCA's criterion to CDFs from Shin-Kori 3·4 PSA, and interestingly all scenarios are screened out. This does not mean there is no scenario we need to study for safety. Considering we select scenarios for study according to the importance of accident in order, accumulated ratio of probability can be a better index to select rather than the definite value for the screening criterion. For example, the accumulated ratio was utilized for a scenario selection in RG. 1.216 by U.S.NRC [7].

3. Scenario Selection with Risk

We have selected scenarios from Shin-Kori 3·4 PSA [4] not using the SOARCA's method but introducing notion of risk, which is generally defined as probability (or frequency) times consequence. In particular, it has been widely recognized that the low probability accidents with high consequence also needs attention in analyzing possible accidents in nuclear power plants.

In contrast to SOARCA, Shin-Kori 3·4 PSA has conducted up to Level 3, which enables us to utilize source term category (STC) and its representing frequency (or release frequency) of Level 2 PSA as an accident frequency in the risk estimation. For investigating source term behavior, it is more reasonable to categorize accidents which releases comparable order of amount for source term species.

Furthermore, Shin-Kori 3·4 PSA provides information about release fraction of source terms estimated by MAAP, which is utilized as consequence values in risk estimation in practice. In the light of risk using release frequency of STC and release fraction for source term species of each STC as probability and consequences, respectively, we have selected the risk-dominant STCs for early release and late release cases. The selected representing scenarios of STCs are ISLOCA, SGTR, and Station Blackout (SBO).

Among the three scenarios, the SBO sequence is to be analyzed about the fission product behavior in the containment. It includes failure of the alternative AC power generator following a blackout event, successful operation of turbine-driven auxiliary feed water (AFW) pump, late recovery of off-site power before containment failure, in-vessel injection and successful actuation of cavity flooding system and spray system, and failure of hydrogen mitigation system. This sequence results in failure of reactor vessel and the containment.

4. Preliminary analysis

In this study, a preliminary calculation has been carried out for a SBO sequence similar to the selected scenario suggested in Section 2, but with more severe and simple assumptions. For instance, AFW pump is unavailable from the beginning of the accident, and recovery of electricity has not been assumed, so that in-vessel injection, spray system and cavity flooding system do not work. We use MELCOR 1.8.6 with the models for the reactor coolant system (RCS) and the containment, as shown in Fig. 1 and Fig. 2, respectively.

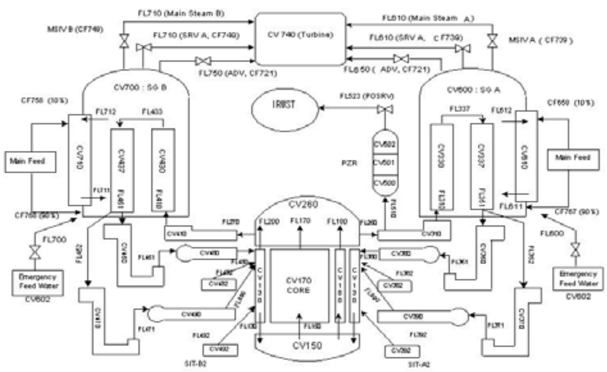

Fig. 1. Nodalization for reactor coolant system

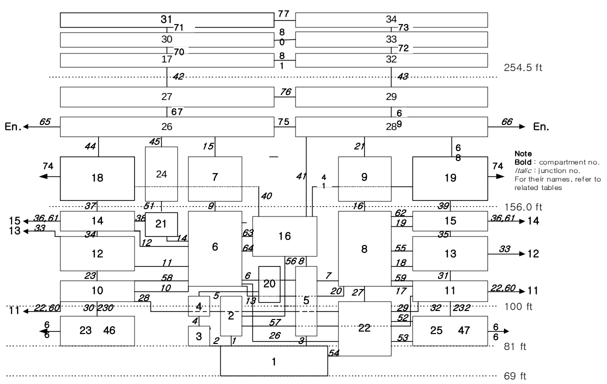

Fig. 2. Nodalization for containment system

Figs. 3 and Fig. 4 show the containment pressure and temperature, respectively. There is a rapid temperature increase due to dryout of water in the cavity. The following figures, Figs. 5-7, show the release fractions of volatile elements such as noble gas, cesium, and iodine in the form of CsI for the duration of about one day from the initiation of the accident. They release up to approximately 90% by 2.5 hrs. (9,000 s).

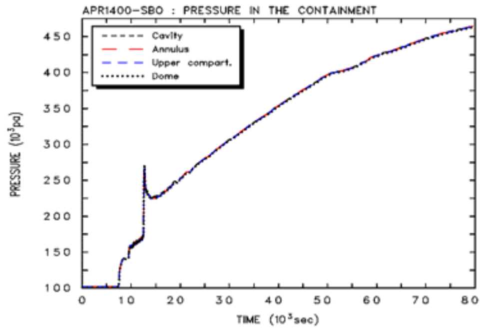

Fig. 3. Containment pressure

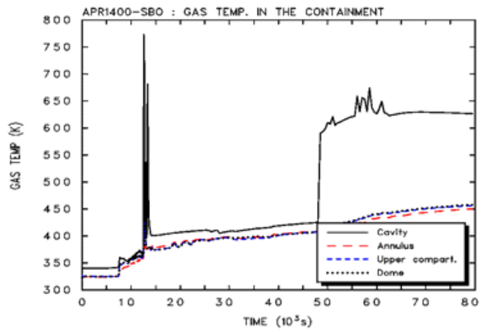

Fig. 4. Containment temperature

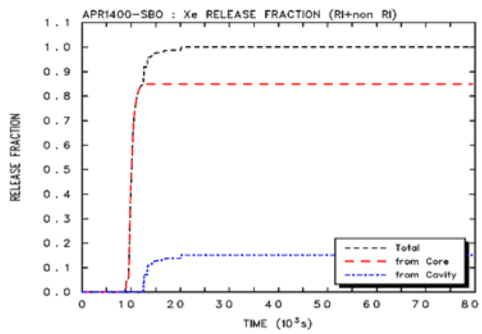

Fig. 5. Release fraction of the core inventory: Xenon

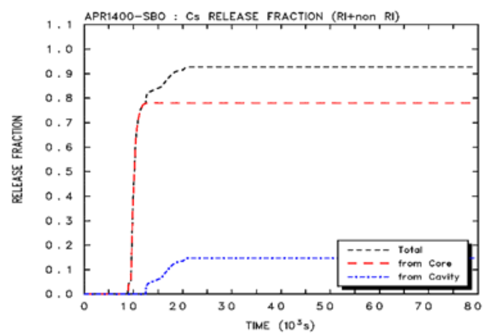

Fig. 6. Release fraction of the core inventory: Cesium

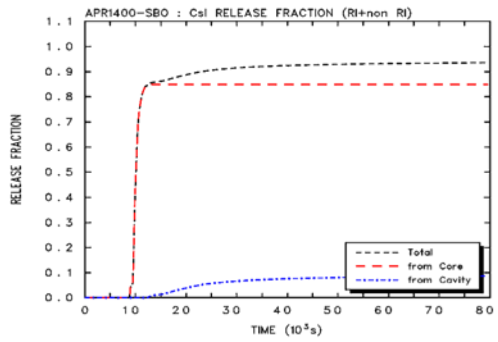

Fig. 7. Release fraction of the core inventory: CsI

5. Summary

In this study, we have selected scenarios for evaluation of fission product behavior during a severe accident. Applying the U.S.NRC's SOARCA method to Shin-Kori 3·4 PSA revealed that it is practically useful to set a relative criterion for scenario studies since making a definite criterion as in SOARCA requires to consider many spatiotemporal factors such as regulation policies and safety technologies. With this in mind, the relative criterion of the scenario selection has been created using release frequency and release fraction of source term in the respect of risk from APR 1400 type Shin-Kori 3·4 Level 2 PSA. The selected representing scenarios are ISLOCA, SGTR, and SBO. A preliminary analysis has been tried for a SBO sequence with more severe and simple assumptions using MELCOR. The results show early release of volatile elements in the containment.

ACKNOWLEDGMENT

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REFERENCES

[1] Gauntt, R. O. et al., MELCOR Computer Code Manuals, NUREG/CR-6119, Vol. 1 and Vol. 2, Rev. 2, SAND2000-2417, 2000.
[2] Jae Yong Oh et al., Development of Assessment Methodology of Chemical Behavior of Volatile Iodide under Severe Accident Conditions Using EPICUR Experiments, Korea Nuclear Society Spring Meeting, 2011.
[3] Richard Chang, Jason Schaperow, Tina Ghosh, Jonathan Barr, Charles Tinkler, Martin Stutzke, "State-of-the-Art Reactor Consequence Analyses (SOARCA) Report", U.S.NRC NUREG-1935, Nov. 2012.
[4] Korea Hydro & Nuclear Power Co., Ltd, Shin-Kori 3·4 PSA Report, addendum of operation license documents for Shin-Kori 3·4 submitted to KINS.
[5] Sandia National Laboratories, "State-of-the-Art Reactor Consequence Analysis Project: Uncertainty Analysis of the Unmitigated Long-Term Station Blackout of the Peach Bottom Atomic Power Station", U.S.NRC, NUREG/CR-7155, Draft Report, 2012.
[6] Sandia National Laboratories, "State-of-the-Art Reactor Consequence Analyses Project: Volume 2: Surry Integrated Analysis", U.S.NRC, NUREG/CR-7110, Vol. 2, Jan. 2012
[7] U.S. Nuclear Regulatory Commission, "Containment Structural Integrity Evaluation for Internal Pressure Loadings above Design-basis Pressure", U.S. NRC, Regulatory Guide 1. 216 Rev. 0, Aug. 2010.