11.1 Analysis of Radionuclide Behavior in a BWR Mark-II Containment under Severe Accident Management Condition in Low Pressure Sequence

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ABSTRACT

In the Level 2 PSA program at INS/NUPEC, MELCOR1.8.3 is extensively applied to analyze radionuclide behavior of dominant sequences. In addition, the revised source terms provided in the NUREG-1465 report have been also discussed to examine the potential of the radionuclides release to the environment in the conventional siting criteria.

In the present study, characteristics of source terms to the environment were examined comparing with results by the Hypothetical Accident (LOCA), NUREG-1465 and MELCOR1.8.3 calculation for a typical BWR with a Mark-II containment in order to assure conservatives of the Hypothetical Accident in Japan.

Release fractions of iodine to the environment for the Hypothetical Accident and NUREG-1465, which used engineering models for predicting radionuclide behaviors, were about 10^{-4} and 10^{-6} of core inventory, respectively, while the best estimate MELCOR1.8.3 code predicted 10^{-9} of iodine to the environment. The present study showed that the engineering models in the Hypothetical Accident or NUREG-1465 have large conservatives to estimate source term of iodine to the environment.

Key Words: BWR, Severe Accident, Hypothetical Accident, NUREG-1465, Source Terms

1. Introduction

Institute of Nuclear Safety in Nuclear Power Engineering Corporation (INS/NUPEC) is carrying out a program for developing methodology of Level 2 PSA and severe accident analysis(1). In the program, MELCOR1.8.3(2), (3) is extensively applied to analyze radionuclide behavior of dominant sequences. In addition, the revised source terms provided in the NUREG-1465 report(4) have been also discussed at INS/NUPEC to examine the influence to the release of radionuclides to the environment in the conventional citing criteria(5).

In the present study, characteristics of source terms to the environment were examined comparing with results by the Hypothetical Accident (LOCA), NUREG-1465 and MELCOR1.8.3 for a typical BWR with a Mark-II containment in order to make sure conservatives of the Hypothetical Accident in Japan. The MELCOR1.8.3 code with improved models was applied to the analysis of radionuclide behavior. A large break LOCA, which is a typical low-pressure accident sequence, was selected in the present study.

The calculated results showed that source term of iodine to the environment by the Hypothetical Accident and NUREG-1465, which used engineering models for predicting radionuclide behaviors were about 10^{-4} and 10^{-6} of core inventory, respectively, while MELCOR1.8.3 predicted 10^{-9} of iodine to the environment. The results of the present study indicated that the engineering models in the Hypothetical Accident or NUREG-1465 have large conservatives to estimate source term of iodine to the environment.

2. Models in Hypothetical Accident, NUREG-1465 and MELCOR

(1) Source Terms to Containment in Hypothetical Accident and NUREG-1465

In the Hypothetical Accident(5), radionuclides are categorized into three groups, which are noble gases, iodine and particulate. Source terms of noble gas and iodine for the Hypothetical Accident are 100% and 50% of core inventory, respectively. In addition, 90% of iodine released to the containment is assumed to be gas of I_2

form, and instantaneous releases noble gas and iodine at the accident initiation are assumed. As for particulate, release to the environment is not taken into account because release of particulate is assumed to be negligible small comparing with those of noble gas and iodine.

In NUREG-1465(4), radionuclides are categorized into 8 groups, which are noble gases, iodine, Cs, Te, Ba, Ru, Ce and La. In addition, dominant form of Iodine is assumed to be aerosol of CsI. The source term of iodine to the containment for a BWR is 30% of core inventory. Releases of radionuclides to the containment are dependent on time from accident initiation.

(2) Deposition and Removal of Radionuclides in Containment

In the Hypothetical Accident, instantaneous natural deposition for iodine is assumed, and spray removal of iodine is calculated by the engineering model that the concentration of iodine in the containment is reached to the equilibrium condition between spray liquid and gas. Partition coefficient of iodine between spray liquid and gas is assumed to be 100 at the equilibrium condition.

In NUREG-1465, natural deposition rate and spray removal rate are given by time dependent parameters from accident initiation.

(3) Models in MELCOR1.8.3

In MELCOR1.8.3(3), radionuclides are classified into 12 groups by their chemical characteristics. Release rates of radionuclides to the containment are calculated by the CORSOR-M model considering the core temperature inside MELCOR1.8.3.

For natural deposition of radionuclides, MELCOR1.8.3 can treat adsorption, condensation, evaporation, diffusion, gravitational settling, thermophoresis and diffusiophoresis. For spray removal of radionuclides, MELCOR1.8.3 takes into account diffusion, impaction, inertia and interception for aerosol, and calculates gas diffusion at the spray droplet surface considering dissolution of gaseous radionuclides. In addition, radionuclide removals by pool scrubbings are calculated using the detailed and semi empirical models.

In MELCOR1.8.3, mechanistic models are used for analyzing radionuclide behavior compared with engineering models that are used in the Hypothetical Accident and NUREG-1465.

3. Source Term Analysis

3.1 Analytical Conditions

A large break LOCA for a BWR-5 (3,293MWt) with Mark-II containment was selected in the present study. The accident sequence, which is a typical low-pressure accident sequence, is the specified event of the Hypothetical Accident in Japan, while the frequency would be quite small. An instantaneous pipe break in the recirculation loop of the reactor coolant system was assumed.

(1) Release Pathway of Radionuclides

Figure 1 shows the release pathways of radionuclide in the present study. Radionuclides released from the core are transported to the drywell through the pipe break location. Some of radionuclides in the drywell move to the suppression pool through vent pipes. In addition, some of radionuclides in the drywell are released to the reactor building by leakage from the containment. Radionuclides in the reactor building are released to the environment through the filter system in the Standby Gas Treatment System (SGTS) in the reactor building. During transportation of radionuclides in the pathways, some of radionuclides are removed by natural deposition, containment spray, pool scrubbing and filter systems.

(2) Analysis Cases

Table 1 shows analysis cases in the present study to examine conservative merging of engineering models in the Hypothetical Accident and NUREG-1465 comparing with the MELCOR1.8.3 prediction. As for the cases 1 and 2 in Table 1, engineering models were used to calculate deposition and spray removal of radionuclides. In the case-3, MELCOR1.8.3 was used with best estimate models mentioned in Chapter 2(3).

In Case-3, a recovery of the water injection to the reactor coolant system by LPCI was assumed at 0.5 hour after the accident initiation. The release fraction of iodine to the containment was estimated to be about 30% of the core inventory. This release fraction is as same as that of NUREG-1465 assumption.

Table 1 Analytical Cases

Type	Case	Release to PCV	Natural deposition	Spray removal	Pool scrubbing
Engineering	Hypothetical Accident (Case-1)	Instantaneous release (50% of core inventory for iodine) Dominant form of iodine is I_2.	Instantaneous deposition for 1/2 of I_2 released to PCV	Equilibrium between spray liquid and gas with partition coefficient 100	Not considered
	NUREG-1465 (Case-2)	Time dependent release rates for each radionuclide (30% of core inventory for iodine) Dominant form of iodine is CsI.	Constant deposition rates for each radionuclide in the present study (30% of core inventory for iodine)	Constant removal rates for each radionuclide in the present study	Not considered in the present study
Best estimate	MELCOR1.8.3 (Case-3)	Code calculation (Release to PCV is continuing to the core cooling by water injection from LPCI at 0.5 hour after the accident initiation.) Dominant form of iodine is CsI.	Code calculation (adsorption, condensation, evaporation, diffusion, gravitational settling, thermophoresis, diffusiophoresis and aerosol growth by agglomeration and condensation)	Code calculation (dissolution, impaction, interception, inertia)	Code calculation (dissolution, diffusion, gravitational settling, diffusiophoresis, inertia)

PCV : Containment. The calculations were performed by 30 days from accident initiation.

3.2 Calculated Results

Figure 2 shows a comparison of iodine release fractions to the environment predicted by the Hypothetical Accident (Case-1), NUREG-1465 (Case-2) and MELCOR1.8.3 (Case-3).

In the Hypothetical Accident and NUREG-1465, which used engineering models for predicting radionuclide behaviors, release fractions of iodine to the environment were about 10^{-4} and 10^{-6} of the core inventory, respectively. However, MELCOR1.8.3 with best estimate models predicted 10^{-9} for iodine to the environment. The difference of iodine release fractions between the Hypothetical Accident and NUREG-1465 was dominated by the release fractions to the containment. In addition, difference between NUREG-1465 and MELCOR1.8.3 was dominated by spray removal. The calculated results of iodine by MELCOR1.8.3 indicated that iodine removal by spray become significant.

3.3 Effects of Spray Removal on Radionuclide Behavior

Figure 3 shows the trends of CsI mass fraction in the drywell predicted by MELCOR. The radionuclide releases to the containment were started at about 12 minutes after accident initiation due to core damage in the MELCOR1.8.3 calculation. With increase of CsI mass in the containment atmosphere, depositions of CsI in the drywell also became significant by gravitational settling that was enhanced by aerosol growth by agglomeration.

After the spray operation, CsI in the drywell was dramatically reduced by the spray removal as well as diffusiophoresis due to the steam condensation to the containment wall. During this period, CsI in the drywell reaches to the quasi steady state as shown in Figure 3. This is because that removal rate of CsI was balanced to the transportation rate of CsI from wetwell through the vacuum breaker between the drywell and the wetwell. However, CsI in the containment atmosphere was continuously decreased due to the spray removal and natural deposition by 30 days.

3.4 Release Fraction of Particulate to the Environment

In the Hypothetical Accident, release of particulate to the environment is not considered because the release of particulate would be quite small comparing with those of noble gas and iodine. In the calculation using MELCOR1.8.3, release fractions of particulate to the environment were examined.

Figure 4 shows the radionuclide release fractions to the environment calculated by MELCOR1.8.3. The release fraction of xenon group to the environment by 30 days was about 10^{-3} of the core inventory, and the release fractions of Cs and CsI groups were about 10^{-10} respectively, and the release fraction of Te was about 10^{-11}. Releases of Mo, La and Cd were negligible. In addition, the release fraction of Ce was quite small based on the calculated result by MELCOR1.8.3.

4. Conclusion

In conclusion, the calculated results of the Hypothetical Accident, NUREG-1465 and MELCOR1.8.3 at INS/NUPEC showed that

(1) release fractions of iodine to the environment for the Hypothetical Accident and NUREG-1465, which used engineering models for predicting radionuclide behaviors, were about 10^{-4} and 10^{-6} of the core inventory, respectively. MELCOR1.8.3 with best estimate models predicted 10^{-9} for CsI to the environment,
(2) the calculated results indicated that the dominant mechanisms of aerosol removal were gravitational settling enhanced by agglomeration and diffusiophoresis due to steam condensation at the wall as well as spray removal,
(3) release fractions of particulate such as Ce to the environment was quite small comparing with those of noble gas and iodine,
(4) the present study showed that the engineering models in the Hypothetical Accident or NUREG-1465 have large conservatives to estimate source term of iodine to the environment in the Large Break LOCA sequence.

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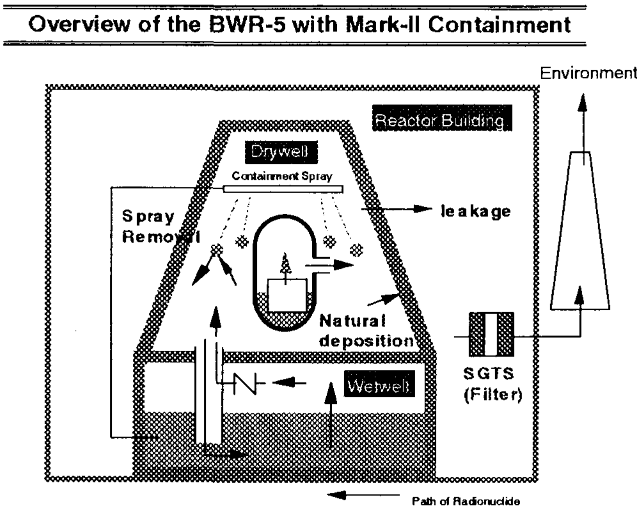

Figure 1. Release pathways of radionuclide

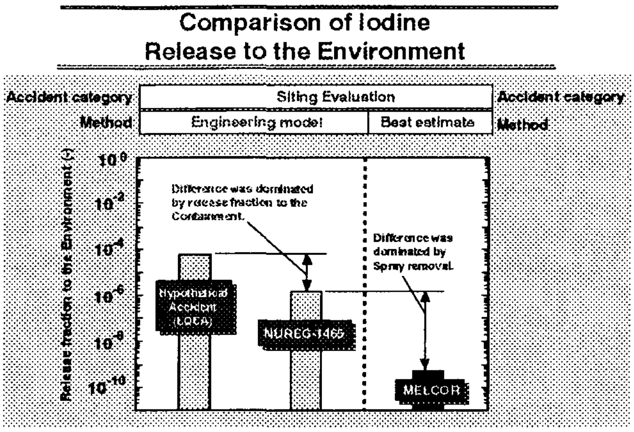

Figure 2. Comparison of iodine release fractions to the environment predicted by the Hypothetical Accident, NUREG-1465 and MELCOR

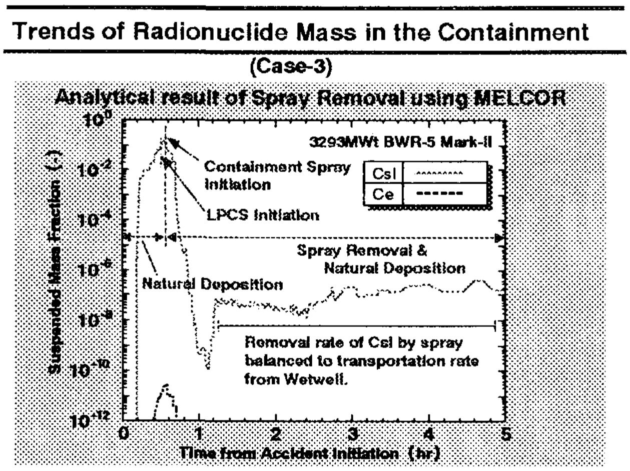

Figure 3. Trends of CsI mass fraction in the drywell predicted by MELCOR

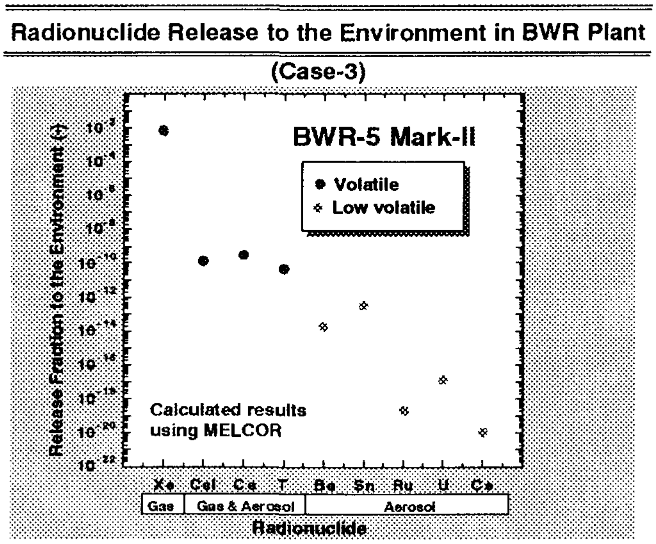

Figure 4. Radionuclide release fractions to the environment calculated by MELCOR1.8.3