Uncertainty of Leak Path Fraction in Source Term Assessment of Fuel Examination Facility

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1. Introduction

To evaluate the integrity of spent fuel storage, Post Irradiation Examination Facility (PIEF) has been operating in the Korea Atomic Energy Research Institute (KAERI) site. Various tests of spent fuel can be carried out in the areas of pool and a hot cell in PIEF. Radionuclides could be discharging from fuel failure in a hypothetical accident. Gas and aerosol types of the fission products could be released into the outside environment through PIEF. The previous study shows the accident analysis of PIEF using the conservative assumptions and a MELCOR code for the emergency preparedness [1]. Because of relatively low decay heat of spent fuel, the behavior of the fission products in the atmosphere composed mostly of air in PIEF could be quite different from source term assessment of a general nuclear power plant under a severe accident. Uncertainty analysis should be evaluated to decide the adequate boundary values in source term assessment of PIEF. It is necessary to study further the following topics. (1) Failure scenario of spent fuel in pool and a hot cell, (2) Initial inventory of radionuclides within the failed spent fuel, (3) Release fraction of the fission products from cladding failure, (4) Leak path fractions of aerosol and vapor releasing into the outside environment through rooms within PIEF, (5) source term considering scenario, inventory, release and leak path fraction introduced above. Firstly, this study estimates the uncertainty of leak path fraction introduced from the previous study [1].

2. Methods and Results

Method of source term assessment has been developing from the experts' opinions in the past to the calculation of an accident analysis code that can simulate the complex physical phenomena. A MELCOR code that is one of the most actively used codes for severe accident analysis can evaluate the aerosol transport and deposition. From the assumption of accident scenario and MELCOR modeling, we induce the key variable that influences the behavior of the fission products.

2.1. Accident Scenario

It assumed that spent fuel was failed by falling in a storage pool, and the fission products then were released into a pool. Here, we did not consider a drainage scenario that can expose fuel in air. Fuel failure induced by cladding oxidation will not occur for the spent fuel cooled for more than 17 months, because of the low decay heat. Krypton (Kr), cesium (Cs), and tellurium (Te) were chosen as the main radionuclides in source term assessment of PIEF, as shown in Table I [1]. Their inventory depends on burnup and cooling period.

Table I: Release fraction

Key nuclide	Type	Accident scenario		
		Hot-gap	Cold-gap	Fire
Kr-85	Gas	0.4	0.4	1
Cs-134	Aerosol	0.03	0.003	0.3
Cs-137		0.03	0.003	0.3
Te-127		0.001	0.0001	0.006
Te-127m		0.001	0.0001	0.006
Te-129		0.001	0.0001	0.006

Release fractions of key radionuclides were set, as shown in Table I, because it is impossible to simulate a falling accident using a MELCOR code. The release fraction of aerosol is lower than that of noble gases, it can be determined by the accident scenario grouped by hot-gap, cold-gap, and fire. Here, a cold-gap presents mechanical failure of spent fuel in a storage pool. The release fraction of a cold-gap is one tenth of that of a hot-gap that indicates an accident of spent fuel cladding failed by exothermic oxidation. It was assumed that 90% of aerosol could be removed by pool scrubbing.

2.2. MELCOR Modeling

Figure 1 shows that the shortest leak path from a pool (CV901) to the outside environment (CV600) was modeled by control volume (CV) and flow path (FL) in a MELCOR code. The initial inventory of the key radionuclides discharging from fuel failure was set to mass source in the atmosphere above a pool (CV458).

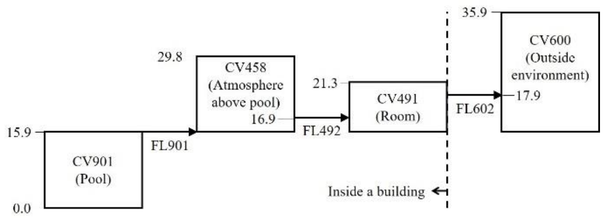

Fig. 1. Nodalization of the shortest leak path of PIEF.

Aerosol and gas leak can be occurred by the pressure difference caused by wind blowing on the exterior wall of PIEF. The pressure difference was assumed to be 5.25 Pa at wind speed of 5 m/ as shown in Fig. 2. A gap in a building was modeled as a leak path (FL602) having 0.00635 m in diameter.

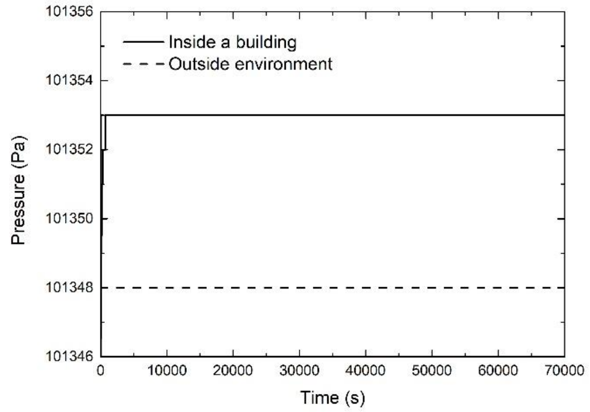

Fig. 2. Pressures of inside PIEF and outside environment.

2.3. Uncertainty of Aerosol Density

A MELCOR code was developed to assess the behavior of the fission products in the containment atmosphere filled with steam under a severe accident. Unlike the previous source term assessment using a MELCOR code, the uncertainty of aerosol transport in air should be considered in the accident analysis of PIEF. The previous study set the density of aerosol to 11460 kg/m^3 that is much bigger than the default density of aerosol (1000 kg/m^3) in a MELCOR code [1]. The bulk densities of cesium and tellurium are 1930 kg/m^3 and 6240 kg/m^3, respectively. However, the effective density of micro-scale aerosol particles will be much smaller than the bulk density. Aerosol particles will be suspended in the atmosphere filled with steam that will be generated considerably in a severe accident of a general nuclear power plant. This is why the default density of aerosol is set to 1000 kg/m^3 like steam in a MELCOR code. The leak path fraction of aerosol having the density of 11460 kg/m^3 was compared with that of 1000 kg/m^3, as shown in Fig. 3. Leak path fraction nearly tripled at 70000 s, when the aerosol density was reduced by about 90%.

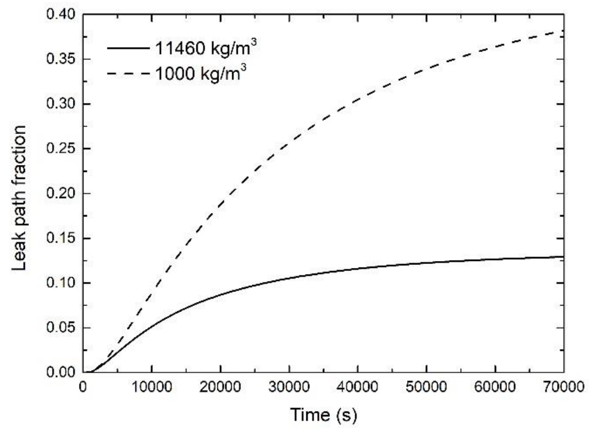

Fig. 3. Leak fraction with different aerosol densities.

Aerosol particles suspended in air can be agglomerated each other, and the larger particles can then be deposited on the wall. A MELCOR code calculates agglomeration and deposition of aerosol particles. Most of the aerosol particles were deposited on the wall of the control volume (CV458) located above a pool. The deposition fraction of aerosol having the density of 11460 kg/m^3 was higher than that of 1000 kg/m^3, as shown in Fig. 4. Higher deposition fraction causes lower leak path fraction, as shown in Fig. 3. Aerosol deposition can be occurred by gravitational settling, Brownian diffusion, thermophoresis, diffusiophoresis, and turbulent flow. The effect of gravitational settling determined by the particle density will be dominated to particle deposition in a large scaled control volume like a PIEF building.

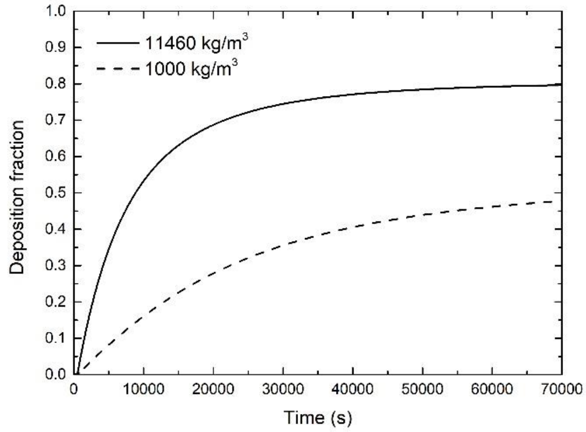

Fig. 4. Aerosol deposited on the wall of CV458.

3. Conclusion

This study evaluated a leak path fraction of the fission product discharging from a hypothetical accident scenario of Post Irradiation Examination Facility (PIEF) using a MELCOR computer code of version 2.2.11932. The leak path fraction can strongly depend on the aerosol density that is one of the key uncertainty factors. It is important to decide the effective density of aerosol particles suspended in air, because gravitational settling determined by the particle density will be dominated to particle deposition in a large scaled building. This result can contribute to the bounding analysis for source term assessment of spent fuel having low decay heat.

ACKNOWLEDGMENTS

This work was supported by KAERI Research & Development Program, funded by the Korean government, Ministry of Science and ICT.

REFERENCES

[1] Goanyup Lee, B. S. Kim, H. C. Lee, J. S. Kim, P. K. Choi, M. J. Khang, and D. S. Kim, Accident analysis of Post Irradiation Examination Facility (PIEF) for the emergency preparedness, Report, TR-6394, Korea Atomic Energy Research Institute, 2016.