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Development of Accident Scenario for Interim Spent Fuel Storage Facility Based on Fukushima Accident

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1. Introduction

700 MTU of spent nuclear fuel is discharged from nuclear fleet every year and spent fuel storage is currently 70.9% full. The on-site wet type spent fuel storage pool of each NPP(nuclear power plants) in Korea will shortly exceed its storage limit. Kori nuclear power plant is predicted to exceed its storage capacity in 2016, Hanbit in 2019, Hanul in 2021 and Wolsung in 2018. Although the storage capacity can be expanded by transferring the spent fuel between NPPs and installing high density storage rack, there are still some limits to increase the ultimate capacity of storage. Against this backdrop, the Korean government has rolled out a plan to construct an interim spent fuel storage facility by 2024. However, the type of interim spent fuel storage facility has not been decided yet in detail.

The Fukushima accident has resulted in more stringent requirements for nuclear facilities in case of beyond design basis accidents. Therefore, there has been growing demand for developing scenario on interim storage facility to prepare for beyond design basis accidents and conducting dose assessment based on the scenario to verify the safety of each type of storage.

2. The influence of spent fuel storage facilities in Fukushima accident

2.1 The influence on Each Type of Fukushima NPP Storage Facility

The cause of Fukushima nuclear power plant damage can be divided into two groups: the earthquake of 9.0 magnitude and massive tsunami. Especially, the second 15-meter-high tsunami out of a series of seven tsunamis caused the gravest damage to NPPs.

The floating debris from tsunami destroyed all intake structures, leading to a loss of ultimate heat sink. Also, the seawater flow into the building destroyed the electricity supply system and cooling system. Consequently, SBO (Station Blackout) occurred in Fukushima NPP units 1 to 4 while only one EDG (emergency diesel generator) could be used to cool the reactor and spent fuel pool in the NPP units 5 and 6.

The earthquake and tsunami which triggered Fukushima accident were beyond design basis accidents. Therefore, the structural integrity and cooling function of spent fuel pool, all of which were aimed at preparing for beyond design basis accident, emerged as a big issue in global nuclear power industry in the wake of Fukushima accident. Fukushima NPP has 3 types of spent fuel storage: spent fuel pool inside reactor building, spent fuel pool for common use, and on-site dry type spent fuel storage facility. Namely, we can compare and analyze the safety of each type of spent fuel storage based on Fukushima accident.

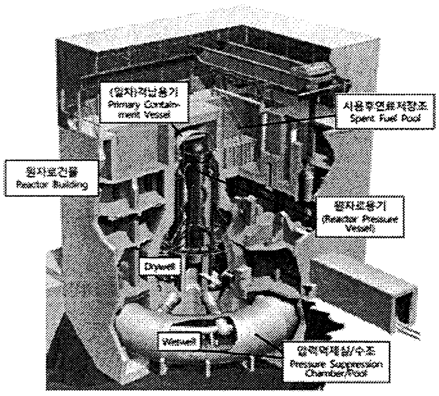

Fig. 1. Spent fuel storage pool inside reactor building of Fukushima NPP

Spent fuel pool inside containment of Fukushima NPP lost its cooling function since it was greatly affected by the tsunami and earthquake. As the spent fuel pool inside reactor building was located on the upper side of building, people raised the possibility of the massive release of cooling water through the cracks of spent fuel pool structure. Some also concerned about another possibility of lowering level of cooling water since loss of cooling function might lead to evaporation of cooling water containing radioactive materials. As a number of fuel rods might be exposed in both cases, safety of spent fuel pool inside reactor drew urgent attention.

The spent fuel pool for common use contained 60% (6,375 assemblies) of total spent fuel assemblies and about 80% of storage capacity was filled with spent fuel. Nonetheless, there has not been much concern for the spent fuel pool for common use because the decay heat of spent fuel in the pool was very low and the pool was barely affected by earthquakes. In addition, although 9 on-site dry type spent fuel storage facilities contained 408 spent fuel assemblies, they reportedly maintained their structural integrity better than two other types of storages even in the middle of rubbles.

This is mainly because the cask for dry type storage facility was designed to assure its safety by carrying out simulation tests such as drop test, bursting test, flooding test, and fire test to an extreme level. The global trend in designing dry type storage facility after 9.11 terrorist attack in the U.S. is to design a storage facility which even can withstand Aircraft Engine Crash. Likewise, the designing process of storage facility underscores the importance of safety as well.

Studying the influence of Fukushima accident on spent fuel facilities, we realized that the radionuclides leakage of on-site spent fuel pool has drawn grave concern. In this regard, this research developed accident scenario for performing the radionuclides leakage assessment in follow-up study in case of the wet-type spent fuel storage facility of spent nuclear fuel

3. Development of Accident Scenario for Interim Spent Fuel Storage Facility

3.1 Assumption of Accident Scenario based on Fukushima Accident

This study assumes that the type of interim storage facility is wet storage and its cooling system is out of order because of the beyond design base accident (Beyond DBA). The research also assumes that the vapor containing radionuclides is spread out during the period when the cooling system is out of order. In reality, the wet storage cooling and cooling water supplementation systems in Fukushima reactors did not work properly because of the loss of alternating current power source. It took 20 to even 150 days to restore the cooling system depending on the damage of each storage facility. Particularly, in unit 4, all the fuel rods in the core had been transferred to on-site wet storage for the overhaul of the reactor. Therefore, there were many spent fuel assembly in on-site wet storage in unit 4 compared to other on-site spent fuel wet storage, the spent fuels leaded to a relatively heavy heat load.

Table I: Storage status of spent fuel in Fukushima NPP

Unit			1	2	3	4	5	6
The number of assembly	Core		400	548	548	0	548	764
	On-site wet storage	Spent Fuel	292	587	514	1331	946	876
		New Fuel	100	28	52	204	48	64
The amount of Cooling water(m3)			1020	1425	1425	1425	1425	1500

Therefore, the scenario assumes that the radioactive cooling water evaporated and diffused for 140 days during which the Fukushima NPP unit 4 was in recovery.

Table II: Recovery period for cooling systems in on-site storage facilities in Fukushima NPP site

Unit	Recovery completion date	Recovery period (day)
1	2011.8.10	150
2	2011.3.11	20
3	2011.6.30	110
4	2011.7.31	140

According to the report released by Tokyo Electric Power, the radionuclide analysis of a water sample taken from the unit 4 spent fuel pool on April 28, 2011 detected levels of Cs-137 of 55Bq/cm^3, indicating that spent fuel rods were damaged because of Fukushima accident. This figure could be a base data in assuming the spent fuel damage rate for developing accident scenario after beyond design basis accident took place. In this study, it is assumed that the spent fuel damage rate determined based on the inventory of spent fuel documented in Yucca Mountain Safety Evaluation Report[2] and the amount of Cs-137 detected in the water sample. The main described above are presented in Table 3 as follows.

Table III: Main Assumption of Accident Scenario

	Assumption	Basis Data
Method and Type	Wet-type interim storage facility	-
Accident Consequence	Loss of Cooling System	-
Inventory	PWR spent fuel inventory	Yucca Mountain repository SAR
Diffusion Period	140 days	Recovery Period of Unit 4 of Fukushima NPP
Damage Rate	5.6E-6 %	Leakage Rate of Unit 4 of Fukushima NPP

3.2 Development of Accident Scenario

The cooling system in interim storage facility of spent nuclear fuel is assumed to have lost its cooling function because of beyond design base accident. Consequently, the facility could not remove the decay heat of spent nuclear fuel. In addition, the structural integrity of spent nuclear fuel is partially damaged in some rate due to the effect of accident or decay heat of spent nuclear fuel. Radionuclide in spent fuel leaks out to the cooling water as much as the damage rate of spent fuel and the whole nuclides would be mixed with the cooling water. Because of heat load of spent fuel, the temperature of the cooling water in wet interim storage rises up to boiling point. Therefore, radionuclide-containing cooling water evaporates from liquid to gaseous form. It takes 140 days to recover the cooling system. The circumjacent residents of the interim storage facility are internally exposed by inhaling the radioactive nuclide and externally exposed to radioactive materials of plume.

4. Summary

This paper could develop accident scenario for wet-type interim spent fuel storage facility by studying the influence of Fukushima accident on spent fuel facilities. Focusing on Fukushima accident was an appropriate case study to develop the accident scenario because the accident was beyond design-basis accident and three different types of spent nuclear fuel storage facilities existed at Fukushima site.

First and foremost, we need objective data to accurately measure the radionuclide distribution in beyond design base accident (Beyond DBA) scenario. Especially, exposure dose rate varies according to PWR spent fuel inventory and damage rate of spent fuel. If we obtain the accurate information mentioned above, we need to reassess the radionuclide leak based on the information. We are going to develop computing module on the scenario and carry out evaluation on the effect of exposure dose in follow-up research. We also need to develop additional scenario assuming another radionuclide leak caused by the cracks in the wet storage facility. Likewise, we ought to comprehensively assess radionuclide leakage by taking various cases into account. The development of another scenario and radionuclide leakage assessment will be performed in series of follow-up study.

Since the method of spent fuel interim storage has not been decided yet, we should develop additional scenario to assess another kinds of radionuclide leakage. For example, we need to develop scenarios on radionuclide leakage resulting from block of air inflow tract aimed at cooling the canister and damage of the integrity of dry storage facility caused by the long period of the storage.

REFERENCES

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[2] Yucca Mountain Repository Safety Assessment Report, DOE Rev.0, 2008

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