Estimation of the Transportation Risks for the Spent Fuel in KOREA for Various Transportation Scenarios - 8317

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ABSTRACT

According to the long term management strategy for spent fuels in Korea, they will be transported from the spent fuel pools in each nuclear power plant to the central interim storage facility (CISF) which is to start operation in 2016. Therefore, we have to determine the safe and economical logistics for the transportation of these spent fuels by considering their transportation risks and costs. In this study, we developed four transportation scenarios by considering the type of transportation casks and transport means in order to suggest safe and economical transportation logistics for the spent fuels in Korea. Also, we estimated and compared the transportation risks for these four transportation scenarios. From the results of this study, we found that these four transportation scenarios for spent fuels have a very low radiological risk activity with a manageable safety and health consequences. The results of this study can be used as basic data for the development of safe and economical logistics for a transportation of the spent fuels in Korea by considering the transportation costs for the four scenarios which will be needed in the near future.

INTRODUCTION

At present, a total of 20 units of nuclear power plants (NPP) are in operation in Korea, sharing about 40 percent of the total production of electricity. These 20 units of NPPs are located at four different sites (Kori, Wolsong, Yonggwang, and Ulchin). In addition to these 20 units of NPPs, we have 4 more units that are currently under construction. Upon the completion of these units, the share of nuclear power generation will be increased to 46.1% by 2015. Such an active nuclear energy program, however, has inevitably resulted in producing significant quantities of low-and intermediate- level waste and spent nuclear fuel. The amount of spent nuclear fuel is also sharply increasing. The cumulative amount was about 7,960 ton in 2005, and we expect it to increase up to 19,000 ton by 2020. We expect the total amount of SF from the existing and planned NPPs during their life time to be about 36,000 tU.

The spent fuel is stored in temporary storage pools at plant sites. However, all the storage pools are expected to reach their full capacity in a couple of years. To resolve this insufficient storage capacity at each plant site, we have expanded the capacity by a re-racking and transshipment as a short-term solution. Ulchin units 1 and 2 have also expanded their storage capacity by adopting high-density storage racks, while Yonggwang unit 1 is also undertaking a transshipment of its spent fuel to its neighboring units 3 and 4. Also, we have a plan to construct and operate a Centralized Interim Storage Facility (CISF), which is to its start operation in 2016.

Before the operation of CISF starts, we have to prepare a suitable logistics system for the transportation of the spent fuel from each site to the CISF by considering the necessary safety and costs. The most important factor for the preparation of a suitable logistics system for the transportation of the spent fuel is a safety. Therefore, the objective of this study is to estimate and compare the safety level results resulting from accidents during the transportation of the spent fuel for various transport scenarios by considering the type of transportation casks and transport means in order to suggest a safe and economical transportation logistics system for spent fuels in Korea.

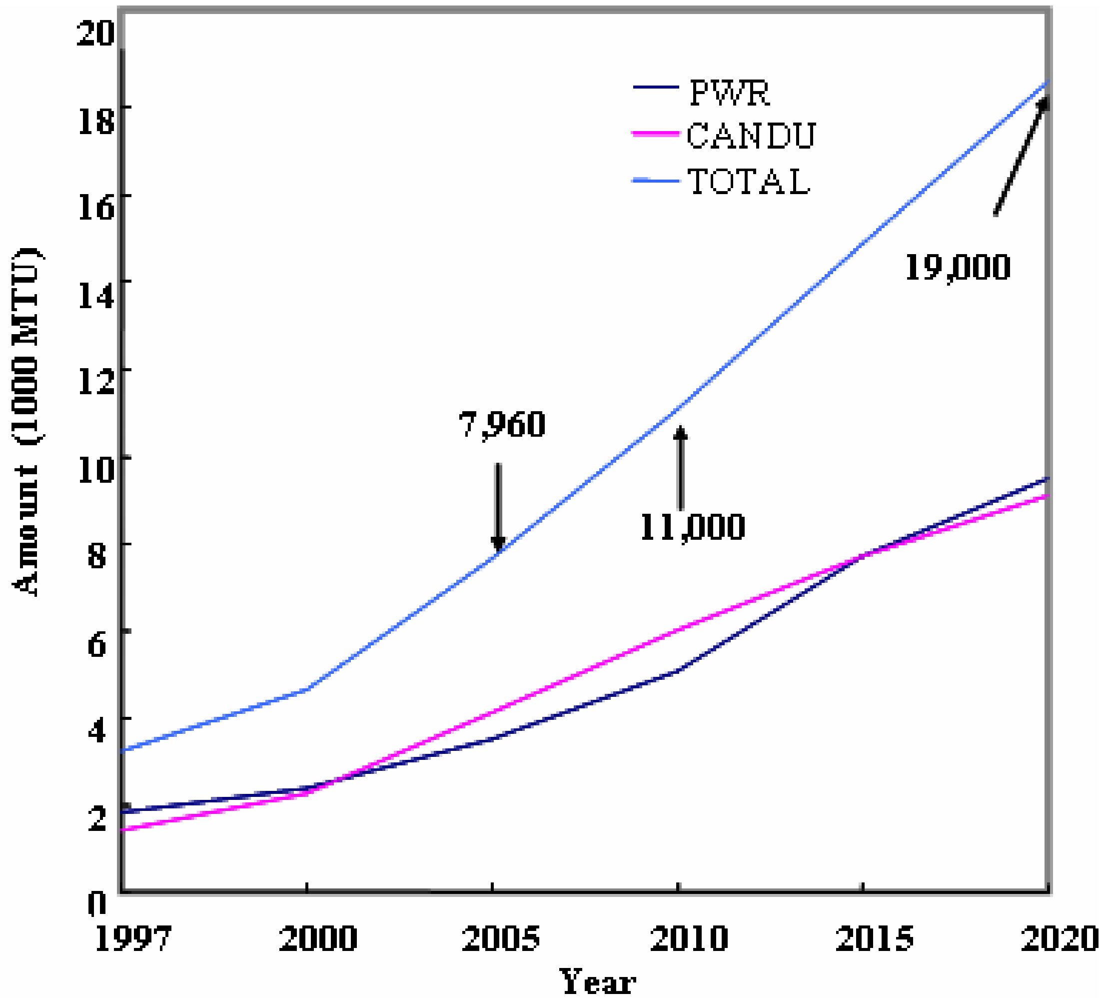

Fig. 1. The amount of spent fuel in Korea.

MODELING AND ASSUMPTIONS

Spent Fuel Quantities and Reference Fuel Assembly

Although there are different operation timeframes of the CISF site, we consider only the amount of the spent fuel assemblies stored at the Yonggwang nuclear power plant site. Total 17,000 spent fuel assemblies are expected to be transported from the Yonggwang nuclear power plant site to the CISF site by the year 2075 which are equivalent to 7,200 tU. During this study, we will consider 1 day to unload completely a cask at a final destination, and 1 day to prepare it for a return transport. The transit time by sea will be 24 hours.

Two types of fuel assemblies, i.e., Vantage 5H and Korea Standard Fuel Assembly (KSFA), are being operated at the Yonggwang nuclear power plants. However, we selected the Vantage 5H fuel assembly as a reference fuel assembly to be transported to the CISF site because most of the spent fuels stored at the spent fuel storage pool are Vantage 5H fuel assemblies. The radionuclide inventory of a reference fuel assembly was calculated by using the ORIGEN-ARP code[1]. During the calculation of the radionuclide inventory of a reference fuel assembly, we assumed that the initial enrichment of uranium was 4.5 wt.% and the discharge burnup was 45GWD/MTU. We used a nuclear reaction library obtained by using the SAS2 module[2] in the SCALE5 code package[3]. Also, we assumed that the cooling time was 7 years. The calculated radionuclide inventories based on these assumptions are summarized in Table I.

Table I. Radionuclide Inventory for a Reference Spent Fuel Assembly

Radionuclide	Inventory	Radionuclide	Inventory
H-3	2.65E+02	Ba-137m	4.99E+04
Mn-54	3.43E-03	Ce-141	1.45E-18
Fe-55	7.24E-01	Ce-144	1.06E+03
Co-58	1.80E-01	Pr-144	1.06E+03
Co-60	2.59E+01	Pr-144m	1.49E+01
Kr-85	3.18E+03	Pm-147	1.28E+04
Sr-89	2.10E-10	Pm-148m	2.98E-15
Sr-90	3.66E+04	Sm-151	2.15E+02
Y-90	3.66E+04	Eu-154	2.40E+03
Y-91	3.30E-08	Eu-155	5.97E+02
Zr-95	6.47E-07	U-232	1.62E-02
Nb-95	1.43E-06	U-233	1.70E-05
Ru-103	1.79E-14	U-234	5.20E-01
Rh-103m	1.79E-14	U-235	7.48E-03
Rh-106	2.44E+03	U-236	1.51E-01
Rh-106m	0.00E+00	U-238	1.33E-01
Ru-106	2.44E+03	Pu-238	2.07E+03
Sn-123	3.03E-04	Pu-239	1.61E+02
Sb-125	7.28E+02	Pu-240	2.60E+02
Te-125m	1.78E+02	Pu-241	5.34E+04
Te-127	5.80E-04	Am-241	7.91E+02
Te-129	2.18E-19	Am-242m	5.39E+00
Te-129m	3.41E-19	Cm-242	5.02E+00
I-129	1.84E-02	Am-243	1.72E+01
Cs-134	5.29E+04	Cm-244	1.98E+03
Cs-137	5.29E+04		

Transport Casks and Vehicles

We considered two types of transport casks. One is based on a existing TN international concept, the TN24-XLH, capable of carrying 24 spent fuel assemblies, and the other is the KN-12 cask being used in Korea. Detailed specifications of the casks are given in Table II.

Table II. Specifications of Transport Casks

Cask	TN24-XLH	KN-12
Loaded weight (tons)	125.6 (transport) 116.4 (handling) 119 (storage)	83
Dimensions (m)	Diameter: 2.935 Length: 7.013	Diameter: 1.942 Length: 4.809
Capacity	24 spent fuel assemblies	12 spent fuel assemblies
Status	Licensed and operated (in France) – IAEA 1996	Licensed and operated (in Korea)

We considered two types of ships, the INF2 and INF3 ships[4]. The INF2 ships are certified to carry irradiated nuclear fuel or high-level radioactive wastes with an aggregate activity of less than $2x10^6$ TBq and they are also certified to carry plutonium with an aggregate activity less than $2x10^5$ TBq. The number of transported casks per INF2 ship will depend on the casks activities. INF3 ships are certified to carry irradiated nuclear fuel of high-level radioactive wastes, and certified to carry plutonium with no restriction on the aggregate activity of the materials.

Transportation Scenarios

We assumed that the CISF site is located near the Wolsong nuclear power plant site. Both the Yonggwang and Wolsong nuclear power plant sites are located near the coastline. Therefore, we only considered a maritime transportation, and the distance between these two sites is approximately 650 km. If we assume that the first phase of the transport between the Yoggwang site and CISF will start in 2016, and it will last 25 years, 472 fuel assemblies will transported per year. The four transportation scenarios by considering the capacity of the casks and the ships are summarized in Table III. The transportation risks resulting from the accidents based on these four scenarios will be estimated and compared by using the RADTRAN5 code[5].

Table III. Transportation Scenarios

Scenario	Transportation cask	Ship	No. of fuel Transportation cask	Number of maritime journeys
1	TN24-XLH	INF2	5	4
2	TN24-XLH	INF3	20	1
3	KN-12	INF2	10	4
4	KN-12	INF3	40	1

Estimation of Transportation Risks

We estimated the transportation risks by using the RADTRAN5 code[5]. It is a computer code for an analysis of the consequences and risks of a radioactive material transportation. It can be used for the estimation of risks associated with an incident-free transportation of a radioactive material and with accidents that might occur during transportation. According to the definition of US Department of Transportation), incident-free (or normal) transportation is the transportation during which no accident, packaging, or handling abnormality or malevolent attack occurs. The accidents considered during the transportation risks assessment are an impact, fire, foundering, foundering and sinking accident, etc. All major modes of commercial transport may be analyzed with RADTRAN5: highway, rail, barge, ship, cargo air, and passenger air. The RADTRAN5 component models and their interrelationships are shown in Fig. 2.

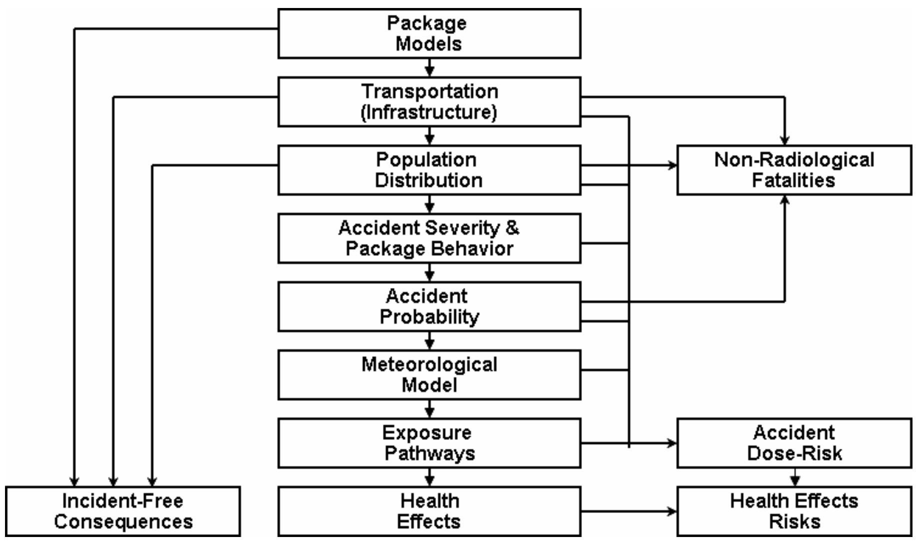

Fig. 2. RADTRAN5 component models and their interrelationship.

We considered three accidents, that is, a collision, a fire, and a foundering and sinking. The accident probabilities were derived from results of IAEA Coordinated Research Project[6]. They gathered and examined accident data in order to develop accident frequencies for ship accidents. Fifteen years of ship accident data covering the years 1979 to 1993 were gathered and examined. In order to obtain the ship accident frequencies, we used the ship accident frequencies suggested by them and the actual distance between the Yonggwand NPP and the CISF sites, which is approximately 650 km. Then we obtained the accident frequencies, which are 6.22×10^{-7} accidents/km for a collision, 6.59×10^{-8} accidents/km for a fire, and 4.78×10^{-7} accidents/km for a foundering and sinking accident.

We classified the radionuclides into five groups, i.e., inert gas, iodine, cesium, ruthenium, and particulates. The release fractions for these five radionuclide groups were derived from the results of the Modal Study cask regions[7]. The NRC Modal Study designated several discrete cask response regions and assigned release fractions for each radionuclide group for these five radionuclide groups. We selected the highest value of the release fractions in order to obtain conservative results. Other parameters that enter the calculational process, such as shielding factors, deposition velocity, aerosol fraction, and a respirable fraction were derived from the DOE Handbook on a Transportation Risk Assessment[8].

RESULTS AND DISCUSSION

Risks for the spent fuel transportation arise from both conventional vehicular accidents and exposures to a ionizing radiation under both normal and accident conditions. Transportation risk includes health and safety risks that arise from the exposures of workers and members of the public to radiation from shipments of wastes[9]. The health effect risks arise from exposures to people who travel, work, or live near transportation routes and transportation workers themselves to radiation from radioactive waste packages.

The incident-free results for the in-transit population exposure in person-Sv are in the range of 1.69×10^{-5} and 4.23×10^{-6} for all the accidents considered in this study. According to the results summarized in Table 4, the expected values for the population risk in person-Sv for the maritime transportation are in the range of 1.74×10^{-8} and 2.20×10^{-8} for a collision accident, 1.85×10^{-9} and 2.35×10^{-9} for a fire accident, 1.34×10^{-8} and 1.70×10^{-8} for a foundering and sinking accident. All these values for the population risks in person-Sv are low radiological risk activities with manageable safety and health consequences.

Although the amount of transportation casks per year is the same for the four scenarios, the population risk for the case of using the INF-2 ship shows a higher value than that for the case of using the INF-3 ship. This may be attributed to the fact that the INF-3 ship can carry more transportation casks per journey than the INF-2 ship because the INF-3 ships are certified to carry plutonium with no restriction on the aggregate activity of the materials. Therefore, we have to reduce the number of journeys per year in order to reduce the population risks resulting from the accidents during the maritime transportation of spent fuels. And the results expressed as a population risk show the same value if we use the same transportation ship with the same amount of transportation casks. Among the three accidents considered in this study during the maritime transportation, the population risk for the fire accident shows the minimum value of the population risk because the occurrence probability of the fire accident is the lowest and we use the same value for the release fraction.

Table IV. Expected Values of Population Risk (Person-Sv)

Accident / Scenario	Collision	Fire	Foundering and Sinking
1	2.20E-08	2.34E-09	1.69E-08
2	1.74E-08	1.85E-09	1.34E-08
3	2.19E-08	2.35E-09	1.70E-08
4	1.75E-08	1.85E-09	1.34E-08

CONCLUSIONS

We developed four transportation scenarios by considering the type of transportation casks and transport means in order to suggest a safe and economical transportation logistics system for spent fuels in Korea. For these four transportation scenarios, we estimated and compared the transportation risks resulting from accidents during a transportation from a nuclear power plant site to a centralized interim storage facility by using the RADTRAN5 program. We considered three accidents, that is, a collision, a fire, and a foundering and sinking accident. The expected values for the population risk in person-Sv are low radiological risk activities with manageable safety and health consequences. Among the four scenarios, the scenario using the KN-12 cask and the INF2 ship revealed the largest value for the population risk in person-Sv due to a small capacity of the cask and many maritime journeys. The results of this study can be used as basic data for the development of a safe and economical logistics system for a transportation of the spent fuels in Korea by considering the transportation costs for the four scenarios which will be needed in the near future.

ACKNOWLOGMENTS

This project has been carried out under the Nuclear R&D Program by Ministry of Science and Technology.

REFERENCES

1. I. C. Gauld, et al., "ORIGEN-ARP: Automatic Rapid Processing for Spent Fuel Depletion, Decay, and Source Term Analysis," ORNL/TM-2005/39, Version 5, Vol. I, Book 2, Sect. D1, Oak Ridge National Laboratory, (2005).
2. I.C. Gauld, and O.W. Hermann, "SAS2: A Coupled One-dimensional Depletion and Shielding Analysis Module," ORNL/TM-2005/39, Version 5, Vol. I, Book 3, Sect. S2, Oak Ridge National Laboratory, (2005).
3. "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation," ORNL/TM-2005/39, Version 5, Vols. I, II, and III, Oak Ridge National Laboratory, (2005).
4. WNTI, World Nuclear Transport Institute, Fact Sheet, No. 5, The INF Ship.
5. K. S. Neuhauser, F. L. Kanipe, and R. F. Weiner, "RADTRAN5 Technical Manual," SAND2000-1256, Sandia National Laboratory, (2000).
6. J. Sprung and D. Ammerman, "Methods for the Assessment of Risk in the Sea Transport of Radioactive Material," IAEA-CN-101/60, (2003).
7. Fischer, L. E., et al., "Shipping Container Response to Severe Highway and Railway Accident Conditions," NUREG/CR-4829, UCID-20733, (1987).
8. S. Y. Chen, et al., "A Resource Handbook on DOE Transportation Risk Assessment," DOE/EM/NTP/HB-01, (2001).
9. "Going the Distance?: The Safe Transport of Spent Fuel and High-Level Radioactive Wastes in the United States," National Academic Press, (2006).