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Preliminary Evaluation of Radiological Impact for Domestic On-road Transportation of Decommissioning Waste of Kori Unit 1

Ho-Seog Dho*, Myung-Hwan Seo, Rin-Ah Kim, Tae-Man Kim, and Chun-Hyung Cho

Korea Radioactive Waste Agency, 174, Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea

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Currently, radioactive waste for disposal has been restricted to low and intermediate level radioactive waste generated during operation of nuclear power plants, and these radioactive wastes were managed and disposed of the 200 L and 320 L of steel drums. However, it is expected that it will be difficult to manage a large amount of decommissioning waste of the Kori unit 1 with the existing drums and transportation containers. Accordingly, the KORAD is currently developing various and large-sized containers for packaging, transportation, and disposal of decommissioning waste. In this study, the radiation exposure doses of workers and the public were evaluated using RADTRAN computational analysis code in case of the domestic on-road transportation of new package and transportation containers under development. The results were compared with the domestic annual dose limit. In addition, the sensitivity of the expected exposure dose according to the change in the leakage rate of radionuclides in the waste packaging was evaluated. As a result of the evaluation, it was confirmed that the exposure dose under normal and accident condition was less than the domestic annual exposure dose limit. However, in the case of a number of loading and unloading operations, working systems should be prepared to reduce the exposure of workers.

Keywords: Decommissioning waste, Transportation container, RADTRAN, On-road transportation, Annual dose limit

*Corresponding Author.
Ho-Seog Dho, Korea Radioactive Waste Agency, E-mail: ehghtjr@korad.or.kr, Tel: +82-42-601-5356

ORCID

Ho-Seog Dho	http://orcid.org/0000-0001-9635-3932	Myung-Hwan Seo	http://orcid.org/0000-0002-0774-2029
Rin-Ah Kim	http://orcid.org/0000-0002-7873-5811	Tae-Man Kim	http://orcid.org/0000-0002-1566-8842
Chun-Hyung Cho	http://orcid.org/0000-0001-5258-6646		

1. Introduction

In accordance with the Korean government's decision to decommission the Kori unit 1 announced in June 2017 and energy conversion policy, the nuclear power plant decommissioning business is expected to start from 2026. Accordingly, the Korea Radioactive waste Agency (KORAD), a domestic radioactive waste disposal facility operating organization, plans to safely dispose of decommissioning radioactive waste in the currently operating the 1st phase underground disposal facility (silo type) and the 2nd phase surface disposal facility (reinforced concrete vault type) under constructing among the radioactive waste disposal facilities in Gyeongju.

The radioactive waste generated by the decommissioning of nuclear facilities is classified into intermediate, low, very low-level radioactive waste and exempt waste according to the level of radioactivity. It is very diverse in spent resin, spent filter, metal, concrete, dry waste, and so on. Among these, concrete, metals, and dry waste are generated in large quantities in a short period of time when facilities are dismantled and decontaminated. The management of decommissioning wastes with these characteristics with 200 L and 320 L steel drum is expected to result in difficulties in the operation of related facilities and the economic burden of power generation companies and waste disposal organization. Accordingly, the KORAD is developing new packaging, transportation, and disposal containers that have been diversified and enlarged in consideration of radiological characteristics, characteristics of disposal facilities, operational convenience and safety of disposal for the efficient and safe management of decommissioning waste.

In this study, the individual/collective exposure dose for the general public and radiation workers (loading/unloading and driving) considering normal conditions and accident conditions when transport decommissioning waste of the Kori unit 1 using the transport container under development were calculated using the RADTRAN code and the results were compared to domestic exposure dose limits. In addition, the change in the exposure dose to the public was analyzed according to the change in the release rate of radionuclides in the transport container during a transport accident. The RADTRAN code was developed by Sandia National Laboratories (SNL) in the United States as a program to calculate the radiation risk during the transport of radioactive materials. Initially, it was used as computer code to carry out radiation impact assessment when transporting radioactive materials in transport means including aircraft, but now it is used for radiation safety evaluation considering various transport models, routes, and transport scenarios through many improvements [1].

2. Characteristics of the Package and Transport Containers

Currently, the acquired and disposed of radioactive waste packages by the KORAD are limited to 200 L and 320 L of steel drums, which contain dry wastes during NPP operation. Operational dry wastes are generated in a relatively constant trend for each operating cycle or system (or stream) of a nuclear power plant, and the annual generation amount is around 100 drums per reactor unit. In contrast, decommissioning waste has various radiological characteristics such as intermediate, low, very low level, and the amount of generation is largely generated in a short period of time. In the case of a foreign nuclear power plant that has completed decommissioning, the amount of decommissioning waste is at the tens of thousands of drums per nuclear unit, which is much higher than the amount of dry waste during operation. In addition, it is confirmed that the fluctuations in the amount of generation and radioactivity are largely depending on the nuclear power plant operation characteristics, the applied decontamination method, and decommissioning technology [2].

There are various types of decommissioning waste such as metal, concrete, spent resin and spent filters, electric wires, and soil. In particular, in the case of metal waste, there

Table 1. The specifications of radioactive waste package and transportation containers

Type	Medium	Large	Soft Bag
Material	Structural Carbon Steel	Structural Carbon Steel	Polypropylene
Size W×L×H (meter)	1.6×3.4×1.2	2.4×6.0×1.3	1.1×1.4×1.0
Weight Empty (ton)	2.2	4.5	0.006
Max. Loading Weight (ton)	10	17	2
Contents	Metal, Concrete, Dry waste, etc.	Soft bag (8EA)	Concrete, Soil, etc.
Purpose	Package/Transport/Disposal	Transport/Disposal	package
Radioactive Waste Level	LLW	VLLW	VLLW

Table 2. The specifications of transportation vehicle

Tractor	Length (mm)	6,685
	Height (mm)	2,880
	Width (mm)	2,495
	Weight(ton)	8
Trailor	Length (m)	12.41
	Height (m)	1.41
	Width (m)	2.48
	Weight (ton)	6.7

are large metals, small metals, surface contaminated metals, and radioactive metals caused by neutron irradiation, and in the case of concrete waste, various shapes such as lumps and powders exist. For the safe disposal of decommissioning wastes having these characteristics, various new packages and transport containers were designed by considering the characteristics of each disposal facilities (the 1st phase silo disposal facility, the 2nd phase near-surface disposal facility, the 3rd phase landfill type disposal facility), radioactivity level, type and form, etc. In this study, the evaluation was performed on two types of designed transport containers, and the design specifications and characteristics of each transport container are shown in Table 1.

In order to transport the decommissioning waste, the specifications and characteristics of the transport vehicle and the maximum weight and size of the transport container are considered. According to the provisions of Chapter 3 ‘Restriction of Vehicle Operation’ of the Ministry of Land, Infrastructure and Transport’s Directive No. 1214, a transport vehicle which axial load exceeds 10 tons or the total weight including the vehicle exceeds 40 tons cannot pass on the national road and highway [3]. In consideration of this, it was assumed that two medium-sized transport containers (IP2 type) and one large container (HHISO type) were loaded per vehicle and transported from the Kori nuclear power plant to the storage building of the Gyeongju disposal facility. The number of annual transports was assumed to be 40 times for medium-sized containers and 30 times for large-sized containers in consideration of the amount of storage of the 2nd inspection building currently being designed by the KORAD. The specifications of the transport vehicle and the arrangement of containers are shown in Table 2 and Fig. 1.

The radioactive waste inside the medium-sized

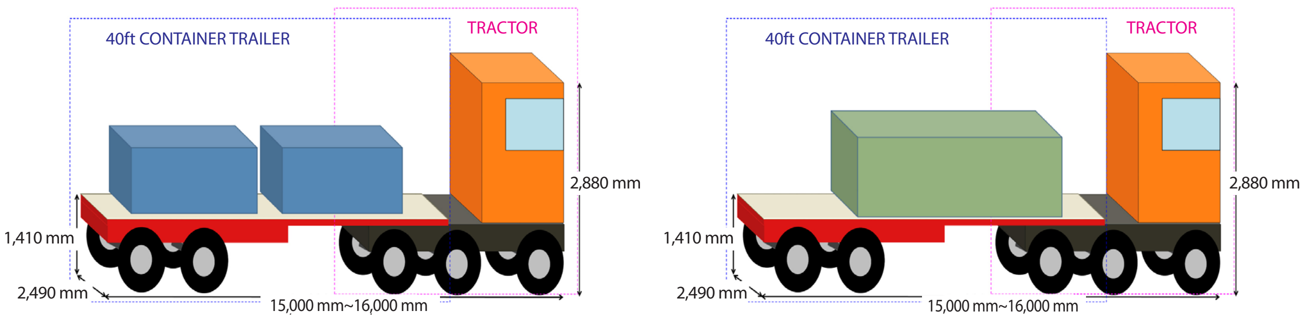

Fig. 1. The transportation truck and the arrangement of medium (top) & large (bottom) transportation containers.

Table 3. Average radioactivity of the radioactive waste in medium size container

Isotopes	Specific Radioactivity ($Bq\cdot g^{-1}$)	Amount of Radioactivity (Bq)
^{3}H	8.59×10^{3}	8.59×10^{10}
^{14}C	1.36×10^{3}	1.36×10^{10}
^{55}Fe	3.63×10^{4}	3.63×10^{11}
^{58}Co	6.00×10^{3}	6.00×10^{10}
^{60}Co	7.67×10^{3}	7.67×10^{10}
^{59}Ni	1.87×10^{2}	1.87×10^{9}
^{63}Ni	2.41×10^{4}	2.41×10^{11}
^{90}Sr	1.63×10^{1}	1.63×10^{8}
^{94}Nb	6.61×10^{-1}	6.61×10^{6}
99Tc	2.83	2.83×10^{7}
^{137}Cs	6.59×10^{2}	6.59×10^{9}
^{144}Ce	3.65	3.65×10^{7}

Table 4. Radioactivity of the radioactive waste in soft bag package and large size container (VLLW Limit Activity)

Isotopes	Specific Radioactivity ($Bq\cdot g^{-1}$)	Amount of Radioactivity (Bq)	
		Soft bag	Large
^{3}H	1.0×10^{4}	2.00×10^{10}	1.6×10^{11}
^{14}C	1.0×10^{2}	2.00×10^{8}	1.6×10^{9}
^{54}Mn	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{55}Fe	1.0×10^{5}	2.00×10^{11}	1.6×10^{12}
^{60}Co	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{63}Ni	1.0×10^{4}	2.00×10^{10}	1.6×10^{11}
^{90}Sr	1.0×10^{2}	2.00×10^{8}	1.6×10^{9}
^{134}Cs	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{137}Cs	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{152}Eu	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{154}Eu	1.0×10^{1}	2.00×10^{7}	1.6×10^{8}
^{155}Eu	1.0×10^{2}	2.00×10^{8}	1.6×10^{9}

transport container was assumed to be low-level dry waste. As for the specific radioactivity of each nuclide, the maximum value of the nuclide analysis data of the dry waste accepted by the KORAD was applied. In addition, ^{60}Co, which is expected to have the most influence on the direct exposure of drivers or workers due to gamma rays, was applied by calculating the specific radioactivity that satisfies 0.1 $mSv\cdot h^{-1}$ at a location of 2 m on the surface of the transport container suggested by the domestic technical standard [4]. The radioactive waste inside the large transport container was assumed to be very-low level concrete radioactive waste. Concrete radioactive waste is packaged in soft bags and loaded into large transport containers. For the conservative evaluation, the specific radioactivity of each nuclide of concrete radioactive waste was applied to the upper limit of very low level radioactive waste, which is 100 times the radioactivity for regulatory clearance suggested in the domestic notice [5]. The amount of radioactiv-

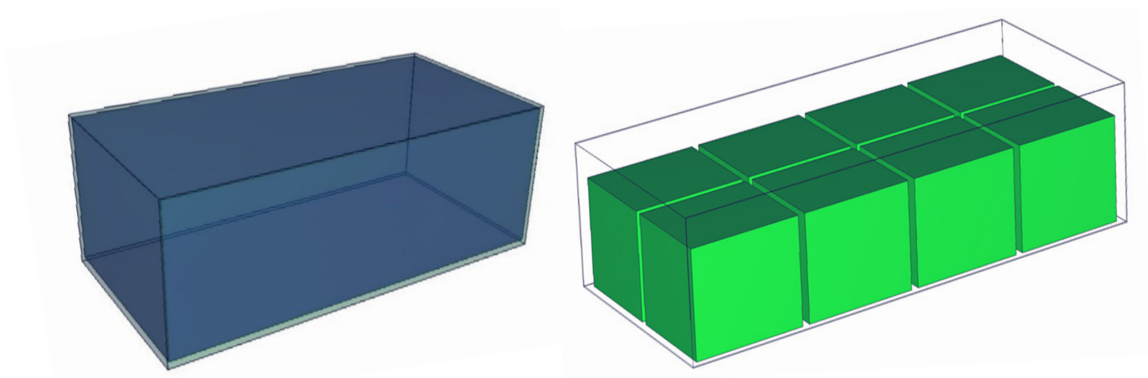

Fig. 2. MCNP modeling of medium size (Left) and large size (Right) transportation containers.

Table 5. The radiation dose rate of transportation containers

Type	Medium	Large
Surface dose rate [$mSv \cdot hr^{-1}$]	0.43	5.49×10^{-4}
1 m	0.18	2.13×10^{-4}
2 m	0.09	0.92×10^{-4}

ity for each major nuclide of radioactive waste per package is shown in Tables 3 and 4.

The surface dose rate of the transport container, which is an essential input value of the RADTRAN code used in this study, was calculated using the MCNP6 (ver1.0) computer code based on the radioactivity of the major gamma sources of radioactive waste inside the medium and large transport containers. The MCNP code developed by Los Alamos National Laboratory in the United States is a code widely used in shielding analysis for most particles such as neutrons and photons [6]. In order to convert the gamma flux into the dose, the flux-dose conversion factor of ICRP-74 was used [7]. In the case of low-level radioactive waste, ^{60}Co, which is existent in activation metal waste, was selected as the main gamma source of decommissioning radioactive waste. In the case of very low levels, ^{152}Eu and ^{154}Eu, which were generated due to activation concrete, were selected. The calculation result was less than 5% of the relative error suggested by the statistical check result of the MCNP and the reliability of the calculation result was confirmed. Fig. 2 and Table 5 show the MCNP modeling of the transport container and the results of the dose rate evaluation at the surface and the position of 1 m and 2 m.

3. Establishment of Domestic On-road Transport Route

The route to transport the decommissioning waste from the Kori nuclear power plant in Gijang-gun, Busan metropolitan to the storage building of the Gyeongju disposal facility consists of highways and national roads. In establishing the transport route, it was considered to minimize the possible exposure time and the probability of an accident by minimizing the transport time. In addition, the transport route was established by reviewing whether the transport route can pass through bridges and tunnels and other vehicle passage restrictions.

The transportation route is a distance of about 75 km from Jangan IC, which is the closest to the Kori nuclear power plant, to the Gyeongju storage building and is divided into 6 sections in consideration of the population density, traffic volume, road type and accident rate of the passing administrative district. For the population density in the transport route, the maximum value for each section

Table 6. Distances and population densities of the districts around the transport route

Section number	Starting and End Points of the Sections	Distance (km)	Adapted Population Density	Remarks
1	Kori NPP ~ Jangan IC	10.0	175 person/km^2 (Gijang-gun)	
2	Jangan IC ~ Chungryang IC	11.9	450 person/km^2 (Onyang-eup)	
3	Chungryang IC ~ Ulsan JC	9.5	323 person/km^2 (Chungryang-eup)	
4	Ulsan JC ~ Beomseo IC	8.3	925 person/km^2 (Beomseo-eup)	
5	Beomseo IC ~ DongGyeongju IC	27.5	170 person/km^2 (oedong-eup)	By way of oedong service Area
6	DongGyeongju IC ~ Disposal Facility	45.0	36 person/km^2 (Yangbuk-myeon)	

Table 7. Car accident rates on the transport route

Section Number	Daily Accident Occurrence	Daily Traffic	Car Accident Rate [Occurance/km·Car]	Type of the Road
1	8.22×10^{-2}	18,106	4.54×10^{-7}	National road
2	4.29×10^{-2}	48,906	7.38×10^{-8}	Highway
3	4.29×10^{-2}	31,169	1.45×10^{-7}	Highway
4	4.29×10^{-2}	23,144	2.23×10^{-7}	Highway
5	2.88×10^{-2}	20,919	5.00×10^{-8}	Highway
6	2.96×10-1	5,500	6.90×10^{-6}	National road

was applied in consideration of the exposed population in the event of an accident [8]. Data of Portal of National Statistical Office and Road Traffic Authority were applied to the average daily vehicle traffic per transport section [9]. The accident rate was calculated by the incidence of traffic accidents per vehicle on a unit length of the road, and the calculation formula is as follows [10].

$$[Accident\ Rate]_i = \frac{[Number\ of\ Accidents]_i}{[Number\ of\ Vehicles]_i \times [Length]_i} \quad (1)$$

where $[\text{Accident Rate}]_i$: Accident rate in section i [Number of accidents / vehicle·km]

$[\text{Number of Accidents}]_i$: Average number of accidents per day in section i [Number of accidents / day]

$[\text{Number of Vehicles}]_i$: Average daily vehicle traffic in section i [Vehicles / day]

$[\text{Length}]_i$: the length of section i [km].

Tables 6 and 7 show the details of the administrative district through the transport route, the length of each section, the representative population density, and the accident rate, respectively.

Table 8. Results of the direct dose rate of transportation scenario

	Collective Dose Rate [man·mSv]		Individual Dose Rate (mSv)		Annual Individual Dose Rate ($mSv·y^{-1}$)		Annual Limit ($mSv·yr^{-1}$)
	Medium	Large	Medium	Large	Medium	Large	
Drivers	$1.12×10^{-1}$	$7.21×10^{-4}$	$5.6×10^{-2}$	$3.61×10^{-4}$	2.24	0.11	12
Public	$1.75×10^{-2}$	$1.49×10^{-3}$	$1.57×10^{-5}$	$7.36×10^{-8}$	-	-	1
Loading/Unloading Workers	4.85	$5.86×10^{-3}$	$8.08×10^{-1}$	$9.57×10^{-4}$	32.3	0.003	20

4. Transportation Scenario

In this study, normal and accident scenarios were derived according to transport conditions, and assumptions for each scenario applied to the radiation impact assessment are as follows.

4.1 Normal Condition

Under normal transport conditions, the transportation containers were not damaged. In addition, only external exposure by gamma rays was considered as the condition for radioactive exposure. The number of personnel in the transport vehicle is set to two (driver and assistant). The separate shielding devices in the vehicle for occupants are not considered. The speed of the transport vehicle was set at 60 $km·hr^{-1}$ on the highway and 30 $km·hr^{-1}$ on the national road. The exposure targets on the transport route were set to the general public and the transportation workers within a radius of 800 m from the transport vehicle. Among the subjects of exposure, the general public is residents near the transport route and the persons in vehicles who approach the transport vehicle while driving. The residents were calculated through the maximum population density in the administrative district of the transport route section. The number of persons in the vehicle was calculated according to the average daily vehicle traffic per section and two persons per vehicle. When loading and unloading the drum, 6 workers per vehicle perform work for 0.5 hours at a distance of 0.1 m from the container. During the transport of decommissioning waste, the vehicle stops once for 30 minutes at the rest area of the high way for the driver's rest. When stopping, the minimum distance between the transport container and the exposed public was set to 1m and it was assumed that no shielding device was installed.

4.2 Accident Condition

The accident condition scenario assumed that damage to the transport container or the inner package occurs due to a physical impact on the transport vehicle when transporting the decommissioning waste. Transport accidents occur with 100% probability in each section, and the amount of radionuclide leakage due to damage to transport containers and packages was assumed to 0.1%, which is the air release rate of radionuclides in the package in case of a drop accident suggested in NUREG/CR-4370 [11]. Except for gaseous nuclides (^3H, ^{14}C), all nuclides are leaked in the form of aerosols [12], and the deposition rate was set to the RADTRAN default value of 0.1 $m·s^{-1}$. The targets of exposure were set to the transport worker and the general public around the route. Radiation exposure considered internal exposure by respiration of radioactive materials emitted in the form of aerosols and external exposure by radiation emitted from radioactive materials in the form of resuspended, clouded, and deposited on the ground. After a transport accident, the evacuation time of the general public was set to 24 hours. Weather conditions

Table 9. Result of dose rate of medium size transportation container considering the normal condition of the route

(Unit : person-mSv (Collective) / mSv (Individual))

		Exposure by Inhalation	Exposure by Resuspension	Exposure by Cloudshine	Exposure by Groundshine	Total
1	Collective	1.73×10^{-8}	1.45×10^{-10}	5.40×10^{-10}	6.03×10^{-9}	2.41×10^{-8}
	Individual	1.18×10^{-11}	9.9×10^{-14}	3.69×10^{-13}	4.12×10^{-12}	7.76×10^{-12}
2	Collective	2.51×10^{-8}	2.09×10^{-10}	7.81×10^{-10}	8.72×10^{-9}	3.48×10^{-8}
	Individual	5.60×10^{-12}	4.66×10^{-14}	1.74×10^{-13}	1.94×10^{-12}	7.76×10^{-12}
3	Collective	2.82×10^{-8}	2.36×10^{-10}	8.79×10^{-10}	9.82×10^{-9}	3.92×10^{-8}
	Individual	1.10×10^{-11}	9.18×10^{-14}	3.42×10^{-10}	3.82×10^{-12}	1.53×10^{-11}
4	Collective	1.09×10^{-7}	9.07×10^{-10}	3.38×10^{-9}	3.78×10^{-8}	1.51×10^{-7}
	Individual	1.69×10^{-11}	1.41×10^{-13}	5.24×10^{-13}	5.86×10^{-12}	2.34×10^{-11}
5	Collective	5.10×10^{-9}	4.26×10^{-11}	1.59×10^{-10}	1.78×10^{-9}	7.08×10^{-9}
	Individual	1.30×10^{-12}	1.09×10^{-14}	4.06×10^{-14}	4.55×10^{-13}	1.81×10^{-12}
6	Collective	2.44×10^{-7}	2.04×10^{-9}	7.60×10^{-9}	8.49×10^{-8}	3.39×10^{-7}
	Individual	1.80×10^{-10}	1.51×10^{-12}	5.61×10^{-12}	6.27×10^{-11}	2.50×10^{-10}

Table 10. Result of dose rate of large size transportation container considering the normal condition of the route

(Unit : person-mSv (Collective) / mSv (Individual))

		Exposure by Inhalation	Exposure by Resuspension	Exposure by Cloudshine	Exposure by Groundshine	Total
1	Collective	2.39×10^{-7}	2.00×10^{-9}	1.12×10^{-11}	1.28×10^{-10}	2.41×10^{-7}
	Individual	1.63×10-^{10}	1.37×10^{-12}	7.65×10^{-15}	8.74×10^{-14}	1.65×10^{-10}
2	Collective	3.45×10^{-7}	2.88×10^{-9}	1.61×10^{-11}	1.85×10^{-10}	3.49×10^{-7}
	Individual	7.69×10^{-11}	6.42×10^{-13}	3.59×10^{-15}	4.12×10^{-7}	7.78×10^{-11}
3	Collective	3.89×10^{-7}	3.25×10^{-9}	1.82×10^{-11}	2.09×10^{-10}	3.92×10^{-7}
	Individual	1.51×10^{-10}	1.26×10^{-12}	7.08×10^{-15}	8.13×10^{-14}	1.53×10^{-10}
4	Collective	1.50×10^{-6}	1.25×10^{-8}	6.99×10^{-11}	8.03×10^{-10}	1.51×10^{-6}
	Individual	2.33×10^{-10}	1.94×10^{-12}	1.08×10^{-14}	1.24×10^{-13}	2.34×10^{-10}
5	Collective	7.03×10^{-8}	5.87×10^{-10}	3.28×10^{-12}	3.77×10^{-11}	7.09×10^{-8}
	Individual	1.80×10^{-11}	1.50×10^{-13}	8.38×10^{-16}	9.63×10^{-15}	1.81×10^{-11}
6	Collective	3.36×10^{-6}	2.81×10^{-8}	1.57×10^{-10}	1.80×10^{-9}	3.39×10^{-6}
	Individual	2.48×10^{-9}	2.07×10^{-11}	1.16×10^{-13}	1.33×10^{-12}	2.50×10^{-9}

Table 11. Result of dose rate of medium size transportation container considering the accident condition of the route

(Unit : person-mSv (Collective) / mSv (Individual))

		Exposure by Inhalation	Exposure by Resuspension	Exposure by Cloudshine	Exposure by Groundshine	Total
1	Collective	3.82×10^{-2}	3.19×10^{-4}	1.19×10^{-3}	1.33×10^{-2}	5.30×10^{-2}
	Individual	3.12×10^{-7}	2.60×10^{-9}	9.71×10^{-9}	1.09×10^{-7}	4.33×10^{-7}
2	Collective	3.40×10^{-1}	2.84×10^{-3}	1.06×10^{-2}	1.18×10^{-1}	4.71×10^{-1}
	Individual	1.08×10^{-6}	9.02×10^{-9}	3.37×10^{-8}	3.75×10^{-7}	1.50×10^{-6}
3	Collective	1.95×10^{-1}	1.63×10^{-3}	6.06×10^{-3}	6.77×10^{-2}	2.70×10^{-1}
	Individual	8.63×10^{-7}	7.21×10^{-9}	2.68×10^{-8}	3.00×10^{-7}	1.19×10^{-6}
4	Collective	4.87×10^{-1}	4.07×10^{-3}	1.52×10^{-2}	1.69×10^{-1}	6.76×10^{-1}
	Individual	7.49×10^{-7}	6.26×10^{-9}	2.34×10^{-8}	2.60×10^{-7}	1.04×10^{-6}
5	Collective	1.02×10^{-1}	8.52×10^{-4}	3.18×10^{-3}	3.55×10^{-2}	1.42×10^{-1}
	Individual	8.57×10^{-7}	7.16×10^{-9}	2.67×10^{-8}	2.98×10^{-7}	1.19×10^{-6}
6	Collective	3.54×10^{-2}	2.95×10^{-4}	1.10×10^{-3}	1.23×10^{-2}	4.91×10^{-2}
	Individual	1.40×10^{-6}	1.17×10^{-8}	4.37×10^{-8}	4.88×10^{-7}	1.95×10^{-6}

in the event of a transport accident were set to Pasquill Category D section.

5. Results

In the event of normal transport and transport accidents, the collective exposure dose to the public and radiation workers was calculated using the RADTRAN computer program. Also, based on the calculated collective exposure dose and the number of people around the route, the individual exposure dose was calculated and compared with the national standard. Table 8 shows the results of exposure dose evaluation for each exposed target during normal transportation and loading/unloading of the decommissioning waste of Kori-1 NPP. When transporting the decommissioning waste, the individual exposure dose of the driver of the transport vehicle is 5.6×10^{-2} mSv for medium-sized containers and 3.61×10^{-4} mSv for large containers. The individual exposure dose to the public of vehicles approaching the route is 1.57×10^{-5} mSv for medium-sized containers and 7.36×10^{-8} mSv for large containers. The individual exposure dose of the loading and unloading workers is 8.08×10^{-1} mSv for medium-sized containers and 9.57×10^{-4} mSv for large containers.

In this study, exposure doses were calculated according to the behavior of radioactive materials leaked from medium/large transport containers during transport accidents. Table 9 and 10 show the exposure dose for each section considering the accident rate. This result takes into account the leakage of radioactive materials due to accidents during normal transportation. The individual exposure dose for each section considering the number of population is 7.76×10^{-12} mSv ~ 2.50×10^{-10} mSv when transporting medium-sized containers, and 7.78×10^{-11} mSv ~ 2.50×10^{-9} mSv when transporting large containers. The evaluation result is very low compared to the annual dose limit (1 mSv) of the general public.

Table 12. Result of dose rate of large size transportation container considering the accident condition of the route

(Unit : person-mSv (Collective) / mSv (Individual))

		Exposure by Inhalation	Exposure by Resuspension	Exposure by Cloudshine	Exposure by Groundshine	Total
1	Collective	5.26×10^{-1}	4.40×10^{-3}	2.46×10^{-5}	2.82×10^{-4}	5.31×10^{-1}
	Individual	4.29×10^{-6}	3.59×10^{-8}	2.01×10^{-10}	2.30×10^{-9}	4.33×10^{-6}
2	Collective	4.68	3.91×10^{-2}	2.19×10^{-4}	2.51×10^{-3}	4.72
	Individual	1.49×10^{-5}	1.24×10^{-7}	6.95×10^{-10}	7.97×10^{-9}	1.50×10^{-5}
3	Collective	2.68	2.24×10^{-2}	1.25×10^{-4}	1.44×10^{-3}	2.71
	Individual	1.19×10^{-5}	9.91×10^{-8}	5.53×10^{-10}	6.37×10^{-9}	1.20×10^{-5}
4	Collective	6.71	5.60×10^{-2}	3.13×10^{-4}	3.60×10^{-3}	6.77
	Individual	5.48×10^{-5}	4.57×10^{-7}	2.56×10^{-9}	2.94×10^{-8}	5.53×10^{-5}
5	Collective	1.41	1.17×10^{-2}	6.57×10^{-5}	7.54×10^{-4}	1.42
	Individual	2.17×10^{-6}	1.80×10^{-8}	1.01×10^{-10}	1.16×10^{-9}	2.18×10^{-6}
6	Collective	4.87×10^{-1}	4.07×10^{-3}	2.27×10^{-5}	2.61×10^{-4}	4.92×10^{-1}
	Individual	4.09×10^{-6}	3.42×10^{-8}	1.91×10^{-10}	2.19×10^{-9}	4.13×10^{-6}

Table 13. Expected dose rate considering release rate of radioactive waste

Release rate (%)	Individual Dose Rate (mSv)		Note
	Medium	Large	
10	1.95×10^{-4}	5.53×10^{-3}	
20	3.90×10^{-4}	1.10×10^{-2}	
50	9.75×10^{-4}	2.76×10^{-2}	
80	1.56×10^{-3}	4.42×10^{-2}	
100	1.95×10^{-3}	5.53×10^{-2}	

On the other hand, the exposure dose for each section considering the 100% accident incidence rate is shown in Table 11 and 12, respectively. The individual exposure dose for each section considering the number of population is 4.33×10^{-7} mSv to 1.04×10^{-6} mSv when transporting medium-sized containers, and 4.33×10^{-6} mSv to 1.20×10^{-5} mSv when transporting large containers.

Apart from the exposure dose evaluation for each transport condition, the trend of the exposure dose rate of the public according to the change in the release rate of radionuclides under accident conditions was analyzed. In the event of an accident, the radioactive waste leakage rate was assumed to be 100%. The individual dose rate for each container and the maximum exposure sections were evaluated as 1.95×10^{-3} mSv in the 6th section for medium containers, and 5.53×10^{-2} mSv in the 4th section for large containers. The evaluation result is very low compared to the annual dose limit (1 mSv) of the general public.

6. Conclusion

In this study, the effects of radiation on road transport routes (highways and national highways) of decommissioning wastes of the Kori unit 1 were evaluated. The radiation source term of the decommissioning waste was derived by considering the characteristics of the transport container, the maximum transportable weight and the type of radioactive waste inside the package. For the source term of the very low level waste, the maximum value suggested in the domestic notice was applied for conservative evaluation. When radioactive waste from the decommissioning of the Kori nuclear power plant is transported through a set of transport route using a medium or large transport container, the annual individual exposure dose of the transport vehicle driver is 2.24 mSv for medium-sized containers and 0.11 mSv for large containers. The annual individual exposure dose of the loading and unloading workers was estimated to be 32.2 mSv for medium-sized containers and 0.03×10^{-1} mSv for large containers.

In the case of the normal transportation of medium-sized and large-sized vehicles, the exposure dose to the driver was evaluated at 18% and 0.9% of the national standard, and it was confirmed that the exposure dose of the general public was below the national standard. In the case of the exposure dose of workers, it was confirmed that the exposure dose of workers when loading and unloading a large container was less than the national standard, but it was confirmed that the exposure dose of workers when loading and unloading a medium-sized container exceeded the national standard. In addition, the maximum value of the radiation impact evaluation results considering the accident rate during normal transportation was 2.50×10^{-10} mSv when transporting a medium-sized container, and 2.50×10^{-9} mSv when transporting a large container. Among the results of the radiation impact assessment considering the 100% accident rate, the maximum value was 1.04×10^{-6} mSv when transporting medium-sized containers, and 1.20×10^{-5} mSv when transporting large containers. The exposure dose according to the radioactive material leakage rate applied in the transport accident evaluation was calculated as 1.95×10^{-3} mSv for medium-sized containers and 5.53×10^{-2} mSv for large containers when the leakage rate was 100%. The results of individual exposure dose evaluation for each scenario performed in this study were compared with the annual dose limit of 1 mSv to the general public, and the results were evaluated as insignificant radiation effects.

We found that the effect of radiation on the public and workers when transporting radioactive waste from the Kori nuclear power plant on land was lower than that of the domestic national standard. However, the exposure dose of workers during the loading and unloading of medium-sized containers exceeded the national standard. This excessive exposure may occur due to the increase in loading and unloading operations according to the number of transports. Therefore, it is necessary to prepare a working system such as shift work, remote handling equipment operation, enhanced exposure dose management using individual dosimeter. In addition, the new transportation containers under developing needs a simplified design of the vehicle binding part of the container and the container lid binding device in order to prevent the occurrence of cumulative radiation dose due to a number of operations for the loading and unloading workers of nuclear power plants and radioactive waste disposal facilities. Currently, in Korea, it is stipulated in Article 71 of the Nuclear Safety Act and Article 108 of the Enforcement Decree of the Nuclear Safety Act that the transport of radioactive materials by nuclear business operators must be reported to the Nuclear Safety Committee. The results of this study are expected to be used as a basis for explaining the degree of radiation impact on workers involved in the on-road transport of decommissioning waste and the general residents near the transport route to stakeholders including the Nuclear Safety and Security Commission, and so on.

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