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Original Article

Radiological Safety Assessment of Transporting Radioactive Wastes to the Gyeongju Disposal Facility in Korea

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ABSTRACT

A radiological safety assessment study was performed for the transportation of low level radioactive wastes which are temporarily stored in Korea Atomic Energy Research Institute (KAERI), Daejeon, Korea. We considered two kinds of wastes: (1) operation wastes generated from the routine operation of facilities; and (2) decommissioning wastes generated from the decommissioning of a research reactor in KAERI. The important part of the radiological safety assessment is related to the exposure dose assessment for the incident-free (normal) transportation of wastes, i.e., the radiation exposure of transport personnel, radiation workers for loading and unloading of radioactive waste drums, and the general public. The effective doses were estimated based on the detailed information on the transportation plan and on the radiological characteristics of waste packages. We also estimated radiological risks and the effective doses for the general public resulting from accidents such as an impact and a fire caused by the impact during the transportation. According to the results, the effective doses for transport personnel, radiation workers, and the general public are far below the regulatory limits. Therefore, we can secure safety from the viewpoint of radiological safety for all situations during the transportation of radioactive wastes which have been stored temporarily in KAERI.

1. Introduction

The first-phase construction of a facility for the disposal of low and intermediate level radioactive waste was completed by the Korea Radioactive Waste Agency (KORAD) in 2014. The disposal facility consists of six concrete silos with the capacity of 100,000 drums of radioactive wastes. The permanent disposal of waste drums was started in 2015. Therefore, KORAD made an implementation plan for the management of low and intermediate level radioactive wastes [1] based on the basic plan for the management of low and intermediate level radioactive wastes [2] issued by the Ministry of Trade,

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Table 1 – A plan for the transportation of radioactive wastes in 2015.

Type	Capacity (L drum)	Amounts (drums)	Schedule	Transport mode
Decommissioning wastes	200	516	Nov–Dec 2015	Road transport
Operation wastes	200	284		

Industry, and Energy. According to the implementation plan, the waste generator is responsible for the transportation of wastes to the disposal facility, although KORAD can transport wastes based on the mutual agreement between the waste generator and KORAD. In addition, the wastes generated from nonreactor nuclear facilities such as research laboratories, medical facilities, research institutes such as Korea Atomic Energy Research Institute (KAERI), Daejeon, Korea, industrial facilities such as KEPCO Nuclear Fuel can be transported by road using a truck with a trailer. Before starting the transportation of wastes, a radiological safety assessment needs to be conducted for safe transportation through predetermined routes.

KAERI has ~20,000 drums of radioactive wastes based on 200-L drums which are stored temporarily in Daejeon and Seoul in Korea. Some of them are operation wastes generated from the routine operation of facilities in Daejeon (hereafter operation wastes) and the others are decommissioning wastes generated from the decommissioning of a research reactor in Seoul (hereafter decommissioning wastes). All operation wastes which were transported to the disposal facility in 2015 used high-efficiency particulate arrestance filters, but the decommissioning wastes comprises soils, concretes, metals, used filters, and noncombustible dry active wastes. According to the long-term plan of the transportation of radioactive wastes for the permanent disposal, 800 drums of radioactive wastes per year will be transported to the disposal facility of low and intermediate level radioactive wastes in Gyeongju city, Taiwan. A plan for the transportation of radioactive waste drums in 2015 [3] is summarized in Table 1. The mode of transport is road transport using a trailer that has a load capacity of 50 drums. The number of trailers for the transportation of wastes in 2015 was six for operation wastes and 11 for decommissioning wastes. According to the transportation plan, 284 drums of operation wastes in Daejeon and 516 drums of decommissioning wastes in Seoul were transported to the disposal facility from November 2015 to December in 2015.

Safety is the first priority according to the implementation plan for the management of radioactive wastes, i.e., radioactive wastes have to be managed by the government in order to not impose undue risks to human health and environment because they are managed over long periods. Therefore, we have conducted a radiological safety assessment for the road transport of low level radioactive wastes using RADTRAN code developed by Sandia National Laboratories (Albuquerque, NM, USA) [4, 5]. It is an internationally accepted program and code for calculating the risks of transporting radioactive materials. RADTRAN code estimates consequences and risks associated with routine, incident-free transportation of radioactive materials, and with accidents that might occur during transportation.

The incident free (or normal) transportation is a transportation during which no accident, packaging, or handling abnormality or malevolent attack occurs. The transportation “accidents” are incidents in which there is a death, injury, or enough damage to an involved vehicle that it cannot move under its own power; other events that interfere with routine transportation are called “incidents.” In RADTRAN code, they use the term “accident” for both accidents and incidents. RADTRAN code is widely used for estimating radiological safety during the transportation of radioactive wastes and spent nuclear fuel in many countries [6–9].

We estimated exposure doses to transport personnel, radiation workers for loading and unloading of radioactive waste drums, and the general public for the case of normal transportation of wastes. Also, we estimated radiological risks and the effective doses for the general public resulting from accidents such as an impact and a fire caused by the impact accident during the transportation. We also checked the regulatory compliances by comparing the estimated exposure doses with the regulatory limits which are summarized in Table 2 [10].

2. Modelling and assumptions

We estimated exposure doses using RADTRAN code for normal transportation and accidents such as impact and fire. Exposure doses for normal transportation were calculated for groups of workers such as transport personnel and workers for loading and unloading of radioactive waste drums, and for members of the public including people sharing a transport link with the vehicle (on-link), people beside a transport link that the vehicle traverses (off-link), and people in the vicinity of the transporting vehicle while it is stopped (stop). Exposure doses for accidents were calculated for the general public who may be exposed to radioactive materials resulting from the breach of radioactive waste drums due to an impact or fire.

We obtained radionuclide characteristics data such as radionuclide inventory and external dose rate at one meter from the waste package surface using a relevant nuclide analyzer [11, 12]. The resulting radionuclide inventory data for

Table 2 – Regulatory limits for exposure dose in Korea.

	Radiation workers	Transport personnel	General public
Effective exposure dose rate	100 mSv for 5 yr & 50 mSv/yr	12 mSv/yr	1 mSv/yr

Table 3 – Radionuclide inventory in a waste drum.

Radionuclides	Half life (d)	Activity (Bq)	
		Operation wastes	Decommissioning wastes
H-3	4.51×10^{3}	4.86×10^{7}	4.62×10^{8}
C-14	2.09×10^{6}	1.75×10^{6}	2.50×10^{6}
Cr-51	2.77×10^{1}	6.00×10^{5}	–
Mn-54	3.13×10^{2}	3.20×10^{5}	–
Fe-55	9.86×10^{2}	1.49×10^{7}	1.02×10^{7}
Co-57	2.71×10^{2}	5.80×10^{4}	–
Co-58	7.08×10^{1}	8.19×10^{4}	–
Co-60	1.92×10^{3}	3.45×10^{6}	3.62×10^{7}
Ni-59	2.74×10^{7}	3.10×10^{6}	4.20×10^{6}
Ni-63	3.50×10^{4}	1.43×10^{7}	4.21×10^{7}
Sr-90	1.06×10^{4}	3.10×10^{6}	1.36×10^{6}
Nb-94	7.41×10^{6}	3.10×10^{6}	–
Nb-95	3.52×10^{1}	6.94×10^{5}	–
Tc-99	7.77×10^{7}	3.10×10^{6}	–
Ag-110m	2.53×10^{2}	1.02×10^{6}	–
I-129	5.73×10^{9}	2.78×10^{4}	–
Cs-134	7.52×10^{2}	5.84×10^{5}	7.34×10^{4}
Cs-137	1.10×10^{4}	5.26×10^{7}	6.85×10^{6}
Eu-152	4.87×10^{3}	–	7.15×10^{6}
Eu-154	3.21×10^{3}	–	3.07×10^{6}
U-235	2.57×10^{11}	9.44×10^{6}	–
Am-241	1.58×10^{5}	1.65×10^{7}	–
Total alpha (Pu-239)	8.78×10^{6}	1.08×10^{7}	3.21×10^{5}

operation wastes and decommissioning wastes are summarized in Table 3. We assumed Pu^{239} as a representative radionuclide for total alpha to obtain conservative exposure doses. The measured range of external dose rates at 1 m from the waste package surface for operation wastes and decommissioning wastes are from 2.0×10^{-7} Sv/h to 1.3×10^{-6} Sv/h and from 2.7×10^{-7} Sv/h to 9.5×10^{-5} Sv/h, respectively. We used 1.3×10^{-6} Sv/h for operation wastes and 9.5×10^{-5} Sv/h for decommissioning wastes as external dose rates at 1 m from the waste package surface for conservatism.

The radioactive waste drums are transported by road using a truck. We selected transportation routes for both decommissioning wastes and operation wastes based on the condition such as low population density, low accident rate, exclusion of environmental protection area, and exclusion of a road limiting hazardous materials because Korea does not have any route selection standard. Because RADTRAN analyses are generally route specific, a route may be subdivided into segments (link) with independent, analyst-assigned values for population density and other route-specific parameters [13–15]. Many parameters can be segment specific, and individual stops may be analyzed separately. Therefore, we divided the transportation routes into 12 links, which are summarized in Table 4 with relevant parameter values. Decommissioning wastes were transported through entire links, but operation wastes were transported through DLINK_1 to DLINK_7.

The radioactive waste drums were transported by a truck with a container whose schematic diagram and properties are summarized in Fig. 1. According to a transportation plan of radioactive wastes in KAERI in 2015 [3], 284 drums of operation wastes and 516 drums of decommissioning wastes were transported. The maximum capacity of waste drums in a container are 50 drums, therefore, six containers for operation wastes and 11 containers for decommissioning wastes are necessary. A truck with a container is assumed to be operated by two transport personnel. No shielding is assumed for transport personnel.

We considered two kinds of handling of waste drums, i.e., loading and unloading of waste drums. The radiation workers for loading and unloading of waste drums were assumed to be four personnel and the average distance of handlers from the source was assumed to be 0.1 m and handling times were assumed to be 4 hours. Also, we assumed no shielding for handlers for conservatism.

The transport personnel were assumed to stop at an expressway rest area for refueling and rest for one time for the transportation of operation wastes and two times for the transportation of decommissioning wastes. To estimate exposure doses for people in the vicinity of the transporting vehicle while it is stopped, we assumed 30 minutes for a stop and 1 m and 70 m for minimum and maximum distance between the receptor and the radioactive cargo, respectively. For conservatism, we assumed no shielding for transport personnel and people in the vicinity of the transporting vehicle at the rest area.

3. Results and discussion

3.1. *Normal transportation*

The results of exposure doses for the normal transportation of operation wastes are summarized in Table 5. The exposure groups considered in this study were transport personnel,

Table 4 – Transportation route segments (link) and parameter values.

Link name	Length (km)	Population density[a] (persons/km^2)	Accident rate (accidents/veh-km)[b] Impact	Accident rate (accidents/veh-km)[b] Fire	Road type	Farm fraction[a] (%)
SLINK_1	16.6	22,654	$1.05\cdot010^{-9}$	$6.58\cdot510^{-14}$	Primary highway	13.0
SLINK_2	48.7	6,906	$1.50\ 0910^{-9}$	$9.39\cdot310^{-14}$	Primary highway	37.7
SLINK_3	30.9	328	$3.81\cdot810^{-9}$	$2.39\cdot310^{-13}$	Primary highway	29.1
SLINK_4	46.5	4,345	$3.67\cdot610^{-9}$	$2.30\cdot310^{-13}$	Primary highway	24.9
SLINK_5	22.9	4,345	$1.79\ 9310^{-9}$	$1.12\cdot110^{-13}$	Primary highway	24.9
DLINK_1	32.5	3,024	$6.90\cdot910^{-10}$	$4.32\cdot310^{-14}$	Primary highway	15.0
DLINK_2	35.7	100	$9.81\cdot810^{-10}$	$6.14\ 4810^{-14}$	Primary highway	11.4
DLINK_3	30.3	136	$8.43\cdot410^{-10}$	$5.28\cdot210^{-14}$	Primary highway	15.7
DLINK_4	32.4	686	$1.76\cdot710^{-9}$	$1.10\cdot110^{-13}$	Primary highway	19.4
DLINK_5	37.3	4,813	$1.26\cdot210^{-9}$	$7.89\cdot810^{-14}$	Primary highway	3.1
DLINK_6	45	614	$1.60\cdot610^{-9}$	$1.00\cdot010^{-13}$	Primary highway	24.2
DLINK_7	37	204	$4.84\cdot810^{-8}$	$3.03\cdot010^{-12}$	Secondary road	15.6

[a] Derived from 2013 urban statistical data in Korea.
[b] Derived from 2015 traffic accident data in Korea.

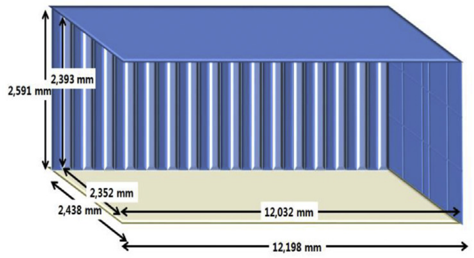
radiation workers for loading and unloading of radioactive waste drums, and for members of the public including people sharing a transport link with the vehicle (on-link), people beside a transport link that the vehicle traverses (off-link), and people in the vicinity of the transporting vehicle while it is stopped (stop). The number of transport personnel for the transportation of operation wastes is 12 because six trucks are used and two persons are assumed to be assigned for each truck. The number of radiation workers for loading and unloading of waste drums is 48 because four persons for loading and four persons for unloading for each truck are assumed to be assigned.

The individual exposure doses for transport personnel and radiation workers are 1.23×10^{-2} mSv/y and 8.96×10^{-2} mSv/y, respectively. These values are 0.10% and 0.18% of regulatory limits which are listed in Table 2. The effective doses for members of the public, people sharing a transport link, people beside a transport link, and people in the vicinity of the transporting vehicle while it is stopped are 1.68×10^{-6} mSv/y, 8.10×10^{-9} mSv/y, and 1.52×10^{-4} mSv/y, respectively. All these values are far below the regulatory limit of 1 mSv/y. Therefore, normal transportation of operation wastes by truck will impose negligible radiological impact on transport personnel, radiation workers, and general public.

The results of exposure doses for normal transportation of decommissioning wastes are summarized in Table 6. The number of transport personnel for the transportation of decommissioning wastes is 22 because 11 trucks are used and two persons are assumed to be assigned for each truck. The number of radiation workers for loading and unloading of waste drums is 88 because four persons for loading and four persons for unloading for each truck are assumed to be assigned.

The individual exposure doses for transport personnel and radiation workers are $1.55 \times 10^{+0}$ mSv/y and $6.26\times10^{+0}$ mSv/y, respectively. These values are 12.9% and 12.5% of regulatory limits which are listed in Table 2. The effective doses for members of the public, people sharing a transport link, people beside a transport link, and people in the vicinity of the transporting vehicle while it is stopped are 2.37×10^{-4} mSv/y, 2.68×10^{-6} mSv/y, and 2.20×10^{-2} mSv/y, respectively. All these values are far below the regulatory limit of 1 mSv/y. Compared with the results of exposure doses for normal transportation of operation wastes, exposure dose values for

Schematic diagram of a container



Properties of a container	
Type	Back door open
Materials	Carbon steel
Dimension	12 × 2.4 × 2.5 m
Dead weight	4 ton
Maximum load	21 ton
ISO test item	ISO 1496–1

Fig. 1 – Schematic diagram of a container and its properties. ISO, International Organization for Standardization.

Table 5 – Exposure doses for normal transportation of operation wastes.

		Population dose (man-mSv/yr)	Individual exposure dose (mSv/yr)	Regulatory limit (mSv/yr)	Percentage of regulatory limit (%)
Transport personnel		1.47×10^{-1}	1.23×10^{-2}[a]	12	0.10
General public	On–link	1.40×10^{-1}	1.68×10^{-6}[b]	1	0.00017
	Off–link	4.28×10^{-3}	8.10×10^{-9}[b]	1	0.0000008
	Stop	5.91×10^{-2}	1.52×10^{-4}[b]	1	0.024
Radiation worker		$4.30 \times 10^{+0}$	8.96×10^{-2}[c]	50	0.18

[a] Derived from dividing population dose by total number of transport personnel (12).
[b] Derived from dividing population dose by number of people for each exposure group.
[c] Derived from dividing population dose by total number of radiation workers (48).

normal transportation of decommissioning wastes are about two orders of magnitude higher than those for operation wastes. This is due to the fact that the external dose rate at 1 m from the waste package of decommissioning wastes are much higher than that of operation wastes, large amount of waste drums to be transported, and longer transport distance. However, all the exposure dose values are far below the regulatory limits. Therefore, we can transport decommissioning wastes without imposing undue radiological impacts on workers and general public.

3.2. *Accidents*

We estimated population risks and exposure doses of accidents for the general public. Among many incidents and accidents, we consider only an impact and a fire caused by the impact accident. The accident rate derived from the statistical data of traffic accidents in Korea for each route segment is summarized in Table 4. We divided all the radionuclides into two physical/chemical groups such as gases and solid materials. Only H-3 and C-14 are gases and all the other nuclides are assumed to be solid materials.

The most important parameter for estimation of risks and exposure doses of accidents is the release fraction for each radionuclide. A release fraction is the fraction of each radionuclide in the cargo that could be released in an accident, depends on the physical and chemical properties of the radionuclides and on the severity of the accident. The severity of the accident is divided into several categories depending on factors such as impact speed and geometry, type of impacted objects, crush, puncture, fire, and immersion. However, we assigned only one category of accident severity for each accident such as an impact and a fire accident. Then, we assigned a single release fraction of 0.1% for an impact and a fire accident for conservatism [16, 17]. The release fraction of 0.1% is a value recommended as an upper bound release factor for use in screening assessment [17].

The other important parameters for estimation of risks and exposure doses of the accident situation are aerosol fraction and respirable fraction. The aerosol fraction is the fraction of each release faction that would be aerosolized in an accident, depends on physical behavior of the radionuclides and on the severity of the accident. The respirable fraction is the fraction of each aerosol fraction that consists of particles or droplets most of which are small enough to enter the lung alveoli (usually considered to be $< 10\ \mu$ in diameter), depends on the physical and chemical behavior of the radionuclides and on the severity of the accident. We assumed that all the radionuclides released to the atmosphere due to an accident are aerosolized for conservatism. Therefore, we assigned an aerosol fraction of 1.0 for all physical/chemical groups. Although the respirable fraction value is often between 0.05 and 0.1, we assigned 1.0 for respirable fraction value for conservatism.

A deposition velocity is necessary for the estimation of exposure doses for each pathway. A deposition velocity depends on the size, density, and shape of the radionuclides that are released into the environment as a result of the accident. We assigned a deposition velocity of 0.0 m/s for a gas group because gases do not deposit. We assigned a deposition velocity of 0.01 m/s for a solid material group, which is often used as being generally representative of aerosol particles [4, 5].

Table 6 – Exposure doses for normal transportation of decommissioning wastes.

		Population dose (man-mSv/yr)	Individual exposure dose (mSv/yr)	Regulatory limit(mSv/yr)	Regulatory limit (%)
Transport personnel		$3.40 \times 10^{+1}$	$1.55 \times 10^{+0}$[a]	12	12.9
General public	On-link	$2.60 \times 10^{+1}$	2.37×10^{-4}[b]	1	0.024
	Off-link	$5.64 \times 10^{+0}$	2.68×10^{-6}[b]	1	0.00027
	Stop	$1.73 \times 10^{+1}$	2.20×10^{-2}[b]	1	2.20
Radiation worker		$5.51 \times 10^{+2}$	$6.26 \times 10^{+0}$[c]	50	12.5

[a] Derived from dividing population dose by total number of transport personnel (22).
[b] Derived from dividing population dose by number of people for each exposure group.
[c] Derived from dividing population dose by total number of radiation workers (88).

The population risks and individual exposure doses for an impact and a fire accident during the transportation of operation wastes are summarized in Table 7 for each route segment. The individual exposure doses are obtained by dividing the population risk by accident rate and total number of population. According to the results, the population risks are very small and the individual exposure doses are negligible compared with the regulatory limit value of 1.0 mSv/y. The population risk values for an impact and a fire accident are different because the accident rates are different. However, the individual exposure doses have the same values for each route segment because we assigned the same release fraction value for each accident.

The population risks and individual exposure doses for an impact and a fire accident during the transportation of decommissioning wastes are summarized in Table 8 for each route segment. Also the population risks are very small and the individual exposure doses are negligible compared with the regulatory limit value of 1.0 mSv/y. Similar to the case of operation wastes, the individual exposure doses have the same values for each route segment because we assigned the same release fraction value for each accident although the population risk values for an impact and a fire accident are different due to different accident rates for each route segment.

The accurate values of release fraction, aerosol fraction, and respirable fraction for each accident severity category considering several factors such as impact speed and fire duration are necessary in order to estimate population risks and individual exposure doses for accidents more accurately. However, we assigned the conservative values derived from references for these parameters because we do not have parameter values based on experiments and/or tests. Therefore, we performed a sensitivity analyses for these parameters, and the results are plotted in Figs. 2 and 3. The X-axis of Figs. 2 and 3 is individual exposure doses for the general public who may be exposed to radionuclides which may be released to the atmosphere due to an impact or a fire. The exposure doses for accident situations are proportional to the activity level of radionuclides released to the atmosphere, aerosol fraction, and respirable fraction.

The maximum exposure doses for accidents for the transportation of operation wastes and decommissioning wastes are 2.94×10^{-4} mSv/y and 1.30×10^{-5} mSv/y for the route segment of DLINK_5, respectively. As shown in Figs. 2 and 3, if we assume that all the radionuclides are released to the atmosphere, i.e., if we assign 1.0 for the release fraction value with the value of 1.0 for the aerosol fraction and respirable fraction, the exposure doses for accidents during the transportation of operation wastes and decommissioning wastes are 2.94×10^{-1} mSv/y and 1.30×10^{-2} mSv/y for the route segment of DLINK_5, respectively. These values of exposure doses are maximum and are far below the regulatory limits of 1 mSv/y. Also, as shown in Figs. 2 and 3, the exposure doses will decrease if the values of aerosol fraction and respirable fraction decrease because we have already assigned the maximum values of aerosol fraction and respirable fraction. Therefore, we can secure safety from the viewpoint of radiological safety for every situation during the transportation of radioactive wastes which are stored temporarily in KAERI.

Table 7 – Risks and exposure doses for accidents during transportation of operation wastes.

Link	Population risk (man-mSv/yr)		Individual exposure dose (mSv/yr)
	Impact	Fire	
DLINK_1	$7.51\cdot 510^{-7}$	$5.26\cdot 210^{-11}$	$2.57\cdot 510^{-4}$
DLINK_2	$1.33\cdot 310^{-8}$	$9.35\cdot 10^{-13}$	$9.68\cdot 610^{-5}$
DLINK_3	$1.32\cdot 310^{-8}$	$9.28\cdot 210^{-13}$	$8.22\cdot 210^{-5}$
DLINK_4	$1.49\cdot 410^{-7}$	$1.04\cdot 010^{-11}$	$8.81\cdot 810^{-5}$
DLINK_5	$2.50\cdot 510^{-6}$	$1.76\cdot 710^{-10}$	$2.94\cdot 910^{-4}$
DLINK_6	$1.68\cdot 610^{-7}$	$1.18\cdot 110^{-11}$	$1.22\cdot 210^{-4}$
DLINK_7	$1.39\cdot 310^{-6}$	$9.76\cdot 710^{-11}$	$1.01\cdot 010^{-4}$

Table 8 – Risks and exposure doses for accidents during transportation of decommissioning wastes.

Link	Population risk (man-mSv)		Individual exposure dose (mSv/yr)
	Impact	Fire	
SLINK_1	$1.92\cdot 910^{-7}$	$1.25\cdot 210^{-11}$	$5.77\cdot 710^{-6}$
SLINK_2	$8.45\cdot 410^{-8}$	$5.50\cdot 510^{-12}$	$5.83\cdot 810^{-6}$
SLINK_3	$6.47\cdot 410^{-9}$	$4.22\cdot 210^{-13}$	$3.70\cdot 710^{-6}$
SLINK_4	$1.24\cdot 210^{-7}$	$8.10\cdot 110^{-12}$	$5.55\cdot 510^{-6}$
SLINK_5	$2.98\cdot 910^{-8}$	$1.94\cdot 910^{-12}$	$2.74\cdot 710^{-6}$
DLINK_1	$3.30\cdot 310^{-8}$	$2.15\cdot 110^{-12}$	$1.13\cdot 110^{-5}$
DLINK_2	$5.87\cdot 810^{-10}$	$3.82\cdot 810^{-14}$	$4.27\cdot 210^{-6}$
DLINK_3	$5.82\cdot 810^{-10}$	$3.79\cdot 710^{-14}$	$3.63\cdot 610^{-6}$
DLINK_4	$6.55\cdot 510^{-9}$	$4.26\cdot 210^{-13}$	$3.88\cdot 810^{-6}$
DLINK_5	$1.10\cdot 110^{-7}$	$7.17\cdot 110^{-12}$	$1.30\cdot 310^{-5}$
DLINK_6	$7.41\cdot 410^{-9}$	$4.81\cdot 10^{-13}$	$5.39\cdot 310^{-6}$
DLINK_7	$6.12\cdot 110^{-8}$	$3.98\cdot 910^{-12}$	$4.43\cdot 410^{-6}$

4. Summary and conclusions

The permanent disposal of low and intermediate level radioactive wastes was started by KORAD in 2015. Therefore, KAERI can transport low level radioactive wastes generated from the routine operation of facilities and the decommissioning of a research reactor for permanent disposal. However, we have to make radiological safety assessments before starting the transportation in order to secure radiological safety during normal transportation and accidents. Therefore, we estimated exposure doses to transport personnel, radiation workers for loading and unloading of radioactive waste drums, and the general public for cases of normal transportation of wastes using RADTRAN code. Also, we estimated radiological risks and effective doses for the general public resulting from the accidents such as an impact and a fire after an impact during the transportation. Finally we checked the regulatory compliances by comparing the estimated exposure doses with the regulatory limits.

According to the results, all exposure doses for the normal transportation of operation wastes and decommissioning wastes are far below the regulatory limits. The exposure doses

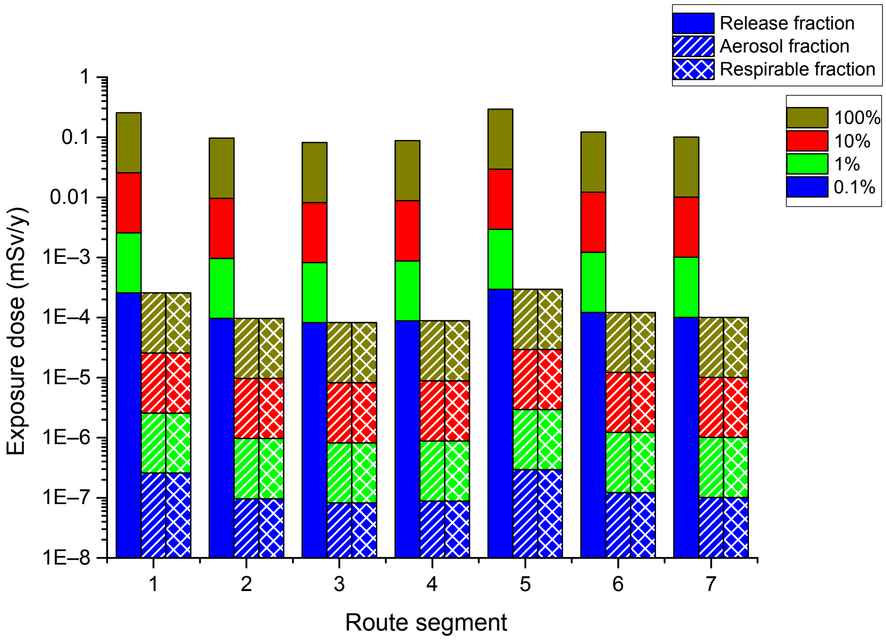


Fig. 2 – Sensitivity analysis results for operation wastes.

for normal transportation of decommissioning wastes are about two orders of magnitude higher than those for operation wastes due to high surface external dose rate, large amount of waste drums to be transported, and longer transport distance. The exposure doses for the accidents during the transportation of both operation wastes and decommissioning wastes for the general public are negligible compared with the regulatory limit of 1 mSv/y. Also, we performed sensitivity analyses for important parameters such as release fraction, aerosol fraction, and respirable fraction in order to overcome the conservative estimation of exposure doses. According to the sensitivity results, the maximum exposure doses for accidents are far below the regulatory limits, even if all the radionuclides are released to the atmosphere. Therefore, we can secure radiological safety for both normal transportation and accidents such as an impact and a fire from the viewpoint of radiological safety during the transportation of radioactive wastes which are stored temporarily in KAERI.

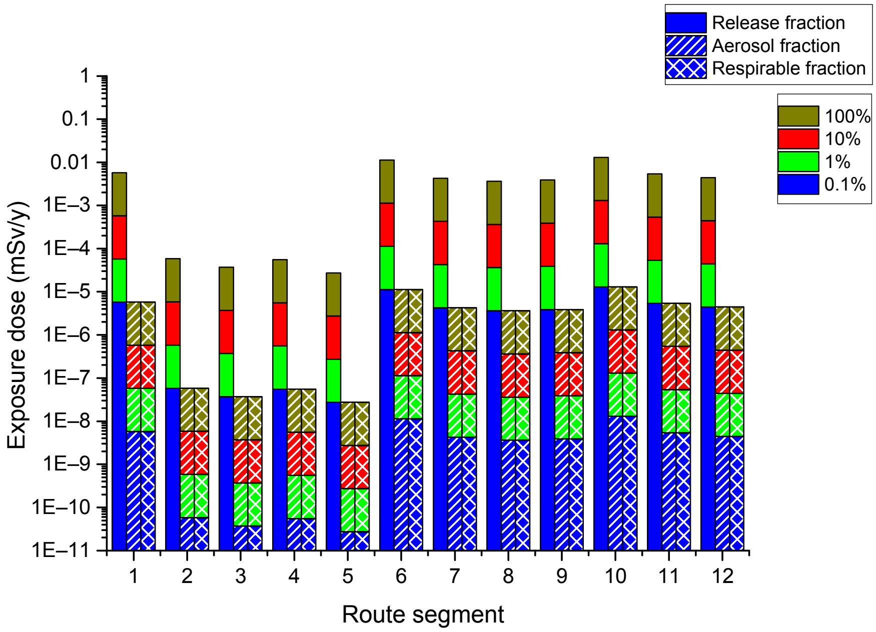


Fig. 3 – Sensitivity analysis results for decommissioning wastes.

Conflicts of interest

All authors have no conflicts of interest to declare.

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