〈Technical Note〉

RADIATION SHIELDING EVALUATION OF IP-2 PACKAGES FOR LOW- AND INTERMEDIATE-LEVEL RADIOACTIVE WASTE

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Korea Hydro & Nuclear Power Co., Ltd. (KHNP) developed new IP-2 packages to transport low- and intermediate-level radioactive waste (LILW) steel drums from nuclear power plants to a disposal facility in accordance with IAEA and Korean transport regulations of radioactive material. Radiation shielding evaluation of the packages was carried out to demonstrate compliance with the regulatory requirements for IP-2 packages of radioactive material. Dose rate limits of LILW drums contained in the packages were determined.

KEYWORDS : IP-2 Package, Low- and Intermediate-Level Radioactive Waste, Disposal Facility, Shielding Evaluation, Dose Rate Limit

1. INTRODUCTION

Most low- and intermediate-level radioactive waste (LILW) generated from nuclear power plants, including dry active wastes, spent resin, spent filters, and concentrated wastes, are packed into DOT-17-type 200-liter and 320-liter steel drums, and temporarily stored on nuclear power plant sites. Korea Hydro & Nuclear Power Co., Ltd. (KHNP) developed two kinds of IP-2 packages to transport LILW drums from on-site temporary storage facilities of nuclear power plants to the disposal facility at Wolsong. The packages were designed to comply with IAEA and Korean transport regulations for Type IP-2 packages of radioactive material. Each package was designed exclusively for use with eight 200-liter or 320-liter waste drums, considering the weight limitation of packages containing waste drums not to exceed seven tons. The packages structures and external dimensions are identical; however, their inner dimensions are different due to the types of drums. This paper describes a radiation shielding evaluation using a computer code to demonstrate conformity with the regulatory requirements for IP-2 packages and to determine dose rate limits of LILW drums capable to be contained in the packages.

2. PACKAGE DESCRIPTION

Two kinds of IP-2 packages were designed to transport eight LILW steel drums of 200-liter or 320-liter size with the same external dimensions and to comply with IAEA Safety Standards Series No.TS-R-1 [1-2] and the Korea Atomic Energy Act [3-4] for IP-2 packages. Each package containing eight waste drums does not exceed seven tons of total weight due to the capacity of the gantry-type on-board crane of the purpose-built transport vessel. A fabricated

Fig. 1. Overview of IP-2 Package Model

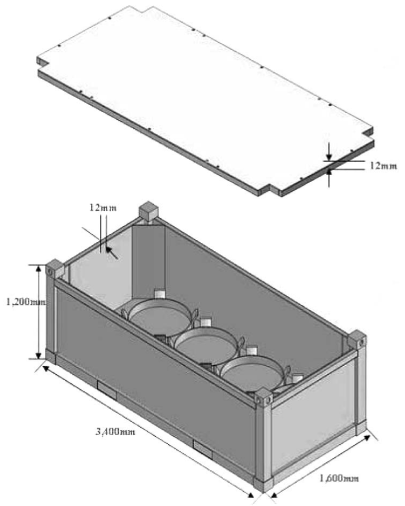


Fig. 2. Dimensions of the Package

package model is shown in Fig. 1. The dimensions of the package are 12 mm (T) × 1600 mm (W) × 3400 mm (L) × 1200 mm (H), as shown in Fig. 2. The body and lid of packages are made of carbon steel SS400, and the thickness of the body shielding wall and lid shielding plate of the packages was designed to be 12 mm. The lid is securely fastened down with lid bolts and waste drums are secured firmly by internal drum supports and absorbing rubbers to ensure that they do not move during transport. Waste types in the packages are classified as fourteen different kinds of LILW drums, as shown in Table 1. The packages were designed to ensure that the radiation level does not exceed 2 mSv/h at any point on the surface and 0.1 mSv/h at 2 m from the external surface of the packages [5-7].

3. RADIATION SHIELDING EVALUATION

Radioactive wastes consist of many radionuclides that emit gamma and beta rays. The energy spectra of LILW drums under 2 mSv/hr, which make up more than 80% of all waste drums, were used as the source terms. Source terms of LILW drums are tabulated in Table 2 [8]. Tc-99 and Fe-55 gamma rays were excluded in this shielding evaluation because of their small gamma emitting ratios, as compared with other nuclides. For the same reason, Ni-59 ß-ray was also excluded in this shielding evaluation. A beta ray is safer than gamma ray in terms of radiation hazard, but it generates bremsstrahlung and annihilation radiations. It was proved by preliminary simulations on a 320-liter drum containing wastes of a spent filter with beta rays that the dose rate at 2 m from the external surface of the package was as low as the radiation level of a 1E-06 fold in comparison with one from a gamma ray.

In order to evaluate the radiation shielding integrity of the packages and to determine the dose rate limits of LILW drums capable of being contained in the packages, radiation shielding analyses were carried out using the MCNP V5.0 code [9] with the MCNPLIB04 library. To decrease uncertainty regarding MCNP input, the number of particles transported was conducted up to 1E+08. To convert the flux at tally points with respective energy bands to actual dose rate, a flux-to-dose conversion factor of ANSI/ANS-6.1.1(1977)[10] was applied. Homogenized sources according to each kind of LILW were assumed to be uniformly distributed over the inside of the waste drum, only gamma-ray emitting nuclides were considered, and the dimensions of LILW drums in the packages were assumed to be identical. The packages with 200-liter and 320-liter drums were modeled by using a MCNP visual editor, and for a conservative analysis internal drum supports, corner fittings and side channels of the packages were excluded. Eight drums in the package were arranged as shown in Fig. 3. A shielded dry active waste drum and a spent filter drum were modeled as concrete inner shielded drums with shielding thicknesses of 6 cm and 18 cm, respectively. For a conservative analysis, the shielding thicknesses of the packages were assumed to be 11.5 mm due to manufacturing tolerance of 0.5 mm. The applied density of each radioactive waste was tabulated, as shown in Table 3 [11].

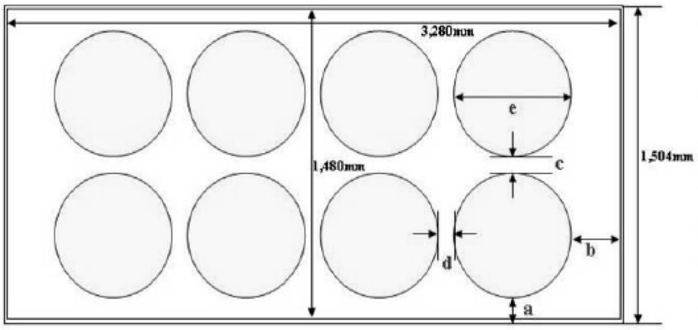
Table 1. Low- and Intermediate-Level Radioactive Waste Drum Classification

Dry active waste	Concentrated waste	Spent resin	Spent filter
General	Cement solidification	Cement solidification	Concrete
1) 200-liter drum	5) 200-liter drum	9) 200-liter drum	13) 200-liter drum
2)320-liter drum	6) 320-liter drum	10) 320-liter drum	14) 320-liter drum
Shielded	Paraffin solidification	Dried	
3) 200-liter drum	7) 200-liter drum	11) 200-liter drum	
Super compaction	8) 320-liter drum	12) 320-liter drum	
4) 320-liter drum			

Table 2. Radioactivity of Radionuclides for Waste Types

		Dry active waste						Spent filter	
	Nuclide	General (Bq/drum)	Fraction (%)	Shielded (Bq/drum)	Fraction (%)	Super compaction (Bq/drum)	Fraction (%)	Concrete lining (Bq/drum)	Fraction (%)
γ - emitter	Ce-144	5.22E+06	2.8E+0	2.41E+07	03E+00	2.10E+07	03E+00	3.89E+07	41E-02
	Co-58	3.38E+07	1.8E+1	1.57E+08	18E+00	1.36E+08	18E+00	5.18E+08	05E+00
	Co-60	3.82E+07	2.1E+1	1.77E+08	21E+00	1.53E+08	21E+00	1.31E+09	14E+00
	Cs-137	7.47E+06	4.0E+0	3.44E+07	04E+00	3.00E+07	04E+00	7.27E+08	08E+00
	I-129	4.68E+03	2.5E-3	2.16E+04	25E-04	1.61E+04	22E-04	1.32E+05	14E-04
	Nb-94	4.13E+05	2.2E-1	1.91E+06	22E-02	1.10E+06	15E-02	1.01E+05	11E-04
	Tc-99	5.24E+04	2.8E-2	2.42E+05	03E-02	2.03E+05	03E-02	2.04E+07	22E-02
	Fe-55	7.49E+07	4.0E+1	3.46E+08	40E+00	3.01E+08	40E+00	4.81E+09	51E+00
ß - emitter	C-14	5.16E+05	2.8E-1	2.38E+06	28E-02	2.07E+06	28E-02	4.86E+08	05E+00
	H-3	1.30E+07	7.0E+0	6.01E+07	07E+00	5.21E+07	07E+00	4.49E+06	05E-02
	Ni-59	1.91E+06	1.0E+0	8.83E+06	01E+00	7.66E+06	01E+00	1.79E+07	19E-02
	Ni-63	9.78E+06	5.3E+0	4.51E+07	05E+00	3.93E+07	05E+00	1.45E+09	15E+00
	Sr-90	7.42E+04	4.0E-2	3.42E+05	04E-02	2.98E+05	04E-02	5.37E+07	57E-02
α - emitter	Alpha	1.45E+04	7.8E-3	6.68E+04	78E-04	5.81E+04	78E-04	5.42E+04	06E-04
	Total	1.85E+08	100	8.57E+08	01E+02	7.44E+08	01E+02	9.44E+09	100

		Dry active waste				Spent filter			
	Nuclide	Cement solid. (Bq/drum)	Fraction (%)	Paraffin solid. (Bq/drum)	Fraction (%)	Cement solid. (Bq/drum)	Fraction (%)	Dried (Bq/drum)	Fraction (%)
γ - emitter	Ce-144	3.04E+06	2.2E-1	7.16E+06	2.2E-1	6.86E+06	9.2E-2	3.49E+05	9.2E-2
	Co-58	2.26E+08	1.6E+1	5.31E+08	1.6E+1	2.79E+08	3.7E+0	1.41E+07	3.7E+0
	Co-60	7.20E+07	5.2E+0	1.70E+08	5.2E+0	9.11E+08	1.2E+1	4.62E+07	1.2E+1
	Cs-137	5.22E+07	3.8E+0	1.23E+08	3.7E+0	7.90E+08	1.1E+1	4.03E+07	1.1E+1
	I-129	3.27E+04	2.4E-3	7.71E+04	2.3E-3	1.21E+04	1.6E-4	6.16E+02	1.6E-4
	Nb-94	6.05E+04	4.4E-3	1.43E+05	4.3E-3	3.65E+04	4.9E-4	1.85E+03	4.9E-4
	Tc-99	1.45E+05	1.0E-2	3.41E+05	1.0E-2	6.26E+04	8.4E-4	3.20E+03	8.4E-4
	Fe-55	1.10E+08	7.9E+0	2.60E+08	7.9E+0	2.15E+09	2.9E+1	1.09E+08	2.9E+1
ß - emitter	C-14	2.60E+07	1.9E+0	6.13E+07	1.9E+0	2.11E+07	2.8E-1	1.08E+06	2.8E-1
	H-3	8.21E+08	5.9E+1	1.94E+09	5.9E+1	1.77E+06	2.4E-2	8.96E+04	2.4E-2
	Ni-59	3.44E+06	2.5E-1	8.14E+06	2.5E-1	3.84E+07	5.1E-1	1.95E+06	5.1E-1
	Ni-63	8.00E+07	5.8E+0	1.88E+08	5.7E+0	3.27E+09	4.4E+1	1.66E+08	4.4E+1
	Sr-90	9.54E+04	6.9E-3	2.25E+05	6.8E-3	3.05E+06	4.1E-2	1.56E+05	4.1E-2
α - emitter	Alpha	6.56E+03	4.7E-4	1.55E+04	4.7E-4	1.11E+04	1.5E-4	5.64E+02	1.5E-4
	Total	1.39E+09	100	3.29E+09	100	7.47E+09	100	3.79E+08	100



Symbol	Length (mm)	
	320L	200L
a	46	91
b	229.625	274.625
c	68	158
d	60.25	150.25
e	660	570

Fig. 3. Drum Arrangement and Dimensions of the Package

Table 3. Density of Radioactive Wastes

Radioactive wastes		Density(g/cm^3)
Dry active waste	General / shielded / super compaction	0.8
Concentrated waste	Cement solidification	2.3
	Paraffin solidification	1.2
Spent resin	Cement solidification	1.71
	Dried	1.1
Spent filter	Concrete shielded	2.3

Various tally positions to evaluate dose rate on and at 2 m from the external surface of the top and side of the packages are shown in Fig. 4. To determine the positions exhibiting the maximum dose rate, a multiple dose assessment was conducted. It was found that the estimation of dose rate at 2 m from the external surface of the package was more dominant than that on the surface, and the dose rate over the top of the package was higher than the dose rate from the side of the same distance. For example, the distribution of dose rates on and at 2 m from the top surface of the package with spent resin drums is shown in Fig. 5. Therefore, dose rates at 2 m from the external surface of the top and the side of each package were calculated. On the basis of the calculated dose rates at 2 m from the external surface of the top and the side of the packages, dose rate limits of each LILW drum to be contained in the packages were tabulated, as shown in Table 4.

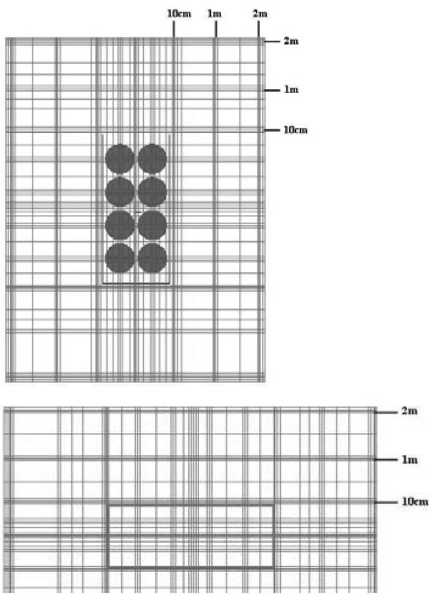
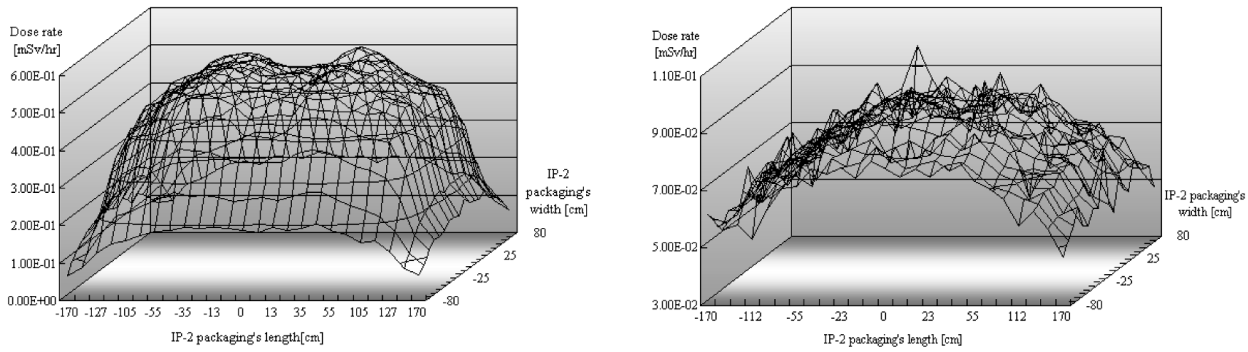


Fig. 4. Positions used to Access Dose Rates for a Given Package

In practice, at nuclear power plants and disposal facilities, two IP-2 packages will be loaded and transported on a vehicle at a time by the transport mode shown in Fig. 6. Hence, a radiation shielding evaluation for two serial packages was carried out, as shown in Fig. 7, which represents tally positions to evaluate the dose rate on and at 2 m from the external surface of the top and side of the two serial package mode. For example, distribution of dose rates on and at 2 m from the top surface of two serial packages with spent resin drums is shown in Fig. 8. To model the two serial packages, a space of 22 cm between two packages on the vehicle was assumed. The method of radiation shielding evaluation for two serial packages was identical to the single package. Dose rate limits of waste drums for two serial packages are tabulated in Table 5.



(a) On Surface (b) At 2 m from Surface

Fig. 5. Distribution of Dose Rate of the Top of a Package (e.g., Spent Resin)

Table 4. Dose Rate Limits of Waste Drums a Given Package

Low- and intermediate-level radioactive waste	200-liter drum(mSv/h)		320-liter drum(mSv/h)	
	Top	side	Top	side
Spent resin, cement	1.120	0.991	1.132	0.982
Spent resin, dried	1.035	0.962	0.909	0.803
Concentrated waste, cement	1.236	1.045	1.055	0.863
Concentrated waste, paraffin	1.087	1.002	0.953	0.835
Spent filter	0.896	1.378	0.975	1.115
Dry active waste, general	0.942	0.721	0.837	0.774
Dry active waste, shielded	0.900	1.011	-	-
Dry active waste, super compacted	-	-	0.644	0.643

Table 5. Dose Rate Limits of Waste Drums for Two Serial Packages

Low- and intermediate-level radioactive waste	200-liter drum(mSv/h)		320-liter drum(mSv/h)	
	Top	side	top	side
Spent resin, cement	0.854	0.757	0.784	0.657
Spent resin, dried	0.787	0.732	0.858	0.758
Concentrated waste, cement	0.939	0.794	0.846	0.692
Concentrated waste, paraffin	0.829	0.765	0.768	0.673
Spent filter	0.932	1.433	0.913	1.038
Dry active waste, general	0.713	0.696	0.649	0.600
Dry active waste, shielded	0.832	0.829	-	-
Dry active waste, super compacted	-	-	0.503	0.502

4. CONCLUSIONS

Two kinds of IP-2 packages were developed to transport LILW drums by a purpose-built vessel from the on-site temporary storage facilities of nuclear power plants to a disposal facility and to comply with the requirements of the IAEA's safe transport regulations and the Korea Atomic Energy Act. Radiation shielding evaluation to determine dose rate limits of LILW drums to be contained in the packages was carried out by using a computer code. In consideration of the distribution of dose rates of LILW drums stored in the temporary on-site storage facility of

Fig. 6. Vehicle Transport Mode with Two Serial Packages

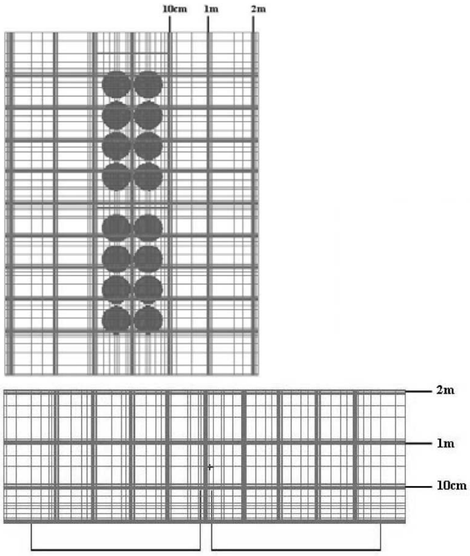
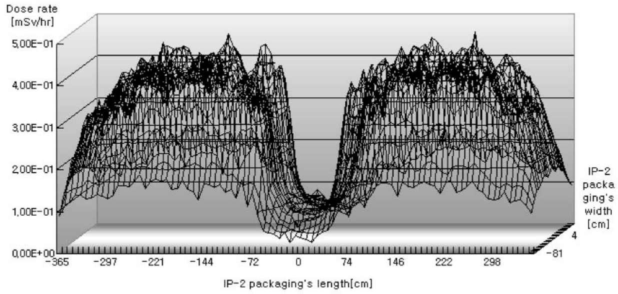
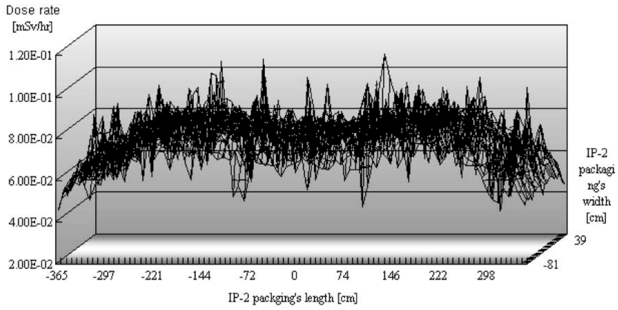


Fig. 7. Positions to Access Dose Rate for Two Serial Packages



(b) At 2 m from Surface



(a) On Surface

Fig. 8 Distribution of Dose Rate of the Top of Two Serial Packages (e.g., Spent Resin)

nuclear power plants, new packages, aimed at LILW over 2mSv/hr, with walls thicker than 12 mm need to be developed to transport all LILW drums stored in the temporary storage facilities of nuclear power plants. KHNP intends to design new packages for the remaining waste drums.

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