Asian Journal of Chemistry; Vol. 26, No. 13 (2014), 4049-4051

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.17710

Determination of Optimum Dimension for the High Radioactive Waste Storage Container†

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Published online: 23 June 2014; AJC-15405

To design the reasonable decommissioning scenario, an evaluation to determine the optimum thickness of radioactive waste storage containers (20 and 40 ton) was performed in terms of the radiological and economic aspects. The optimum thickness was regarded as the minimum thickness that is not allowed over the criterion surface dose rate (2 mSv/h). The surface dose rate was calculated using the MCNP code based on the concentration of Co-60. The optimum thickness of a 20 ton storage container was estimated to be from 34.3 to 19.2 cm. The optimum thickness of a 40 ton storage container was also evaluated the same as that of the 20 ton storage container. This result was considered due to the self-absorption of the radiation source in which the thickness was 30 cm or more. The internal volume of the 40 ton storage container was about 4 times larger than that of the 20 ton storage container.

Keywords: Decommissioning, Storage container, Radioactive waste, MCNP.

INTRODUCTION

The first commercial nuclear power plant (NPP) in Korea has been operating since 1978 and 23 nuclear power plants units are currently in operation. However, the design life of 12 units will end within 2030 and the design life of KORI-1 and WOLSONG-1 already ended in 2007 and 2012, respectively. KORI-1 was granted an extended life to 2018, but WOLSONG-1 remains undecided. Therefore, the development of a decommissioning technology and reasonable decommissioning scenario is required for the coming domestic commercial nuclear power plant decommissioning[1].

Meanwhile, the determination of dimensions and the number of segmented pieces is important for the setting of a reasonable decommissioning scenario is designed. Next, the determination of dimensions and the number of segmented pieces is determined by the dimension of a waste storage container. For this reason, a storage container is the main parameter to design the reasonable decommissioning scenario.

In this research, an evaluation to determine the optimum thickness of radioactive waste storage containers (20 and 40 ton) was performed in terms of the ease of transfer, storage and economic aspects such as a reduction of the cutting distance and time. Next, the decommissioning application was evaluated.

EXPERIMENTAL

In this research, the object considered as waste was the part that is relatively highly irradiated among the waste generated in a reactor pressure vessel (RPV) such as baffle, barrel, thermal shield and vessel (Fig. 1). It was assumed that the object waste has non decontamination or delay time after shutdown. A Co-60 nuclide was chosen as the main effective radionuclide because it is a relativity long-lived nuclide among the generated radionuclides during the decommissioning and contributes greatly to the exposure dose of the workers. The radioactivity inventories in each component are shown in Table-1.

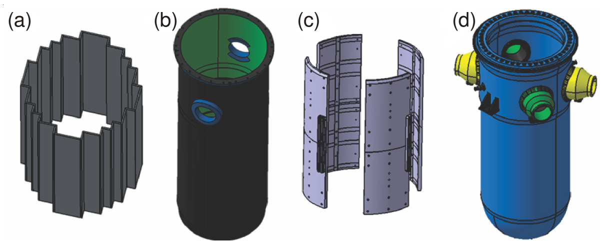

Fig. 1. Main components in reactor pressure vessel ((a) Baffle, (b) Barrel, (c) thermal shield, (d) vessel

The examined storage in this research is the 20 ton storage container (100 cm × 100 cm × 250 cm), considering the

†Presented at 5th International Symposium on Application of Chemical and Analytical Technologies in Nuclear Industries (Nu-ACT 2013), Daejeon, Korea

TABLE-1 RADIOACTIVITY INVENTORY OF EACH COMPONENT	
Object waste	Radioactivity inventory (Bq/ton)
Baffle	4.74×10^{15}
Core barrel	1.10×10^{15}
Thermal shield	2.51×10^{14}
Pressure vessel	9.58×10^{12}

easiness of the transport which is the loaded weight level of the general container cargo and the 40 ton storage container (200 cm × 100 cm × 250 cm) which extends the internal capacity to obtain economic feasibility of the cutting through reductions of the cutting time and total cutting length of the waste.

First, the optimum dimension in the 20 ton storage container was confirmed and second, the optimum dimension of the 40 ton storage container was confirmed using the results of first step.

According the nuclear safety and security commission (NSSC), the surface dose rate to the conveyance vessel was not allowed over the criterion surface dose rate (2 mSv/h)[2]. Because of this, the criterion surface dose rate was applied as the standard value to determine the optimum dimension of the storage container. The method to determine the optimum dimension of the storage container, which is not allowed to go over the standard value (2 mSv/h) is as follow: Fix the total dimension of the storage. Change the thickness of the storage container and detect the surface dose rate. Obtain the maximum dimension of the storage container, which is not allowed to go over the standard value.

The materials of the waste and storage container are steel (7.86 g/cm^3) and it is assumed that the waste volume was the same as the internal volume of the storage container. The surface dose rate was calculated using MCNP5, which is a general-purpose Monte Carlo N-Particle code and was developed at Los Alamos National Laboratory.

RESULTS AND DISCUSSION

In the case of a 20 ton storage container, the optimum dimensions of each main component in reactor pressure vessel are as follows: 34-35 cm at the baffle, 30-31 cm at the barrel, 27-28 cm at the thermal shield and 19-20 cm at the vessel. To obtain the precise optimum dimension, the surface dose rate was recalculated in 0.1 cm intervals in the previously obtained dimension range and the recalculated results of the optimum dimensions of each main component in reactor pressure vessel shown in Table-2. The baffle showed the surface dose rate of 1.996 mSv/h for a 34.3 cm thickness and the barrel showed 1.959 mSv/h in 30.9 cm the thermal shield showed 1.966 mSv/h in 27.3 cm and the vessel, which has a relatively low radioactivity inventory, showed 1.971 mSv/h in 19.2 cm. As the maximum capacity of the waste volume of each component, the baffle is 178,853 cm^3, the barrel is 274,629 cm^3, the thermal shield is 398,801 cm^3 and the vessel is 802,929 cm^3. The changes in the surface dose rate according to the thickness of the main components are shown in Fig. 2.

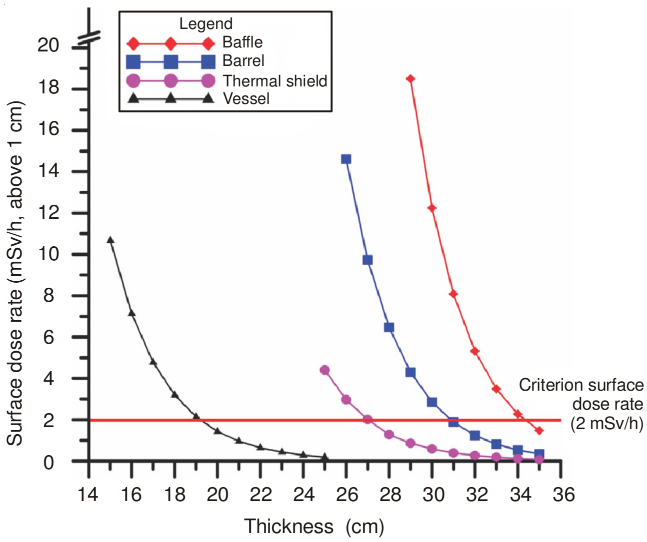

Fig. 2. Surface dose rate according to the thickness of main components

It was determined in consideration of the convenience of the product and the change of the container weight according to the change of thickness that it is advantageous for the thickness to be thin in terms of the economic and transport aspects. Therefore, the optimum thickness of the 20 ton storage container satisfying as the standard value (2 mSv/h) is 34.5 cm at the baffle, 31 cm at the barrel, 28 cm at the thermal shield and 20 cm at the vessel.

Although the length is increased 2 fold, the internal volume is also increased 4.2 fold, the optimum thickness and the surface dose rate of the 40 ton storage container were evaluated to be same as those of the 20 ton storage container (Table-3).

This result was considered to be due to the self-absorption of the radiation source in which the thickness was 30 cm or more. The mass absorption coefficient of Co-60 (1.332 MeV), which is the object nuclide in this research, was 5.26 × 10^2 cm^2/g when the shield is iron and the linear attenuation coefficient (μ) is 0.414 cm^{-1} considering the density of the shield (7.8 g/cm^3). Through the value of the linear attenuation coefficient, half-value layer (HVL) which is thickness of the material at which the intensity of radiation entering it is reduced by one half[3] and tenth-value layer (TVL) were calculated using the following equations;

$$\text{HVL}: \frac{1}{2} = e^{(-\mu x_H)} \quad (1)$$

$$\text{TVL}: \frac{1}{10} = e^{(-\mu x_T)} \quad (2)$$

TABLE-2 OPTIMUM THICKNESS OF A 20 TON STORAGE CONTAINER

Type	Dimension (L × W × H) (cm)	Internal dimension (L × W × H) (cm)	Thickness (cm)	Weight (ton)	Capacity (cm^3)	Main object
A	100 × 100 × 250	31 × 31 × 181	34.5	18.1	173,941	Baffle
B		38 × 38 × 188	31.0	17.4	271, 472	Barrel, thermal shield
C		60 × 60 × 210	20.0	13.6	756,000	Vessel

TABLE-3
OPTIMUM THICKNESS OF 40 TON STORAGE CONTAINER

Type	Dimension (L × W × H) (cm)	Internal dimension (L × W × H) (cm)	Thickness (cm)	Weight (ton)	Capacity (cm^3)	Main object
A-1		131 × 31 × 181	34.5	33.3	735,041	Baffle
B-1	200 × 100 × 250	138 × 38 × 188	31	31.3	985,872	Barrel, thermal shield
C-1		160 × 60 × 210	20	23.3	2,016,000	Vessel

where Linear attenuation coefficient (cm^{-1}), half-value layer (cm), tenth-value layer (cm).

Next, the half-value layer was 1.67 cm and tenth-value layer was 5.56 cm. Moreover, if the thickness is over 15 cm, the radioactivity concentration above the surface was reduced 1/500 times that of the internal concentration and the radioactivity concentration at the waste internal part was nearly effective on the surface dose rate. That is, the effect of the self-absorption is large in the internal radioactive waste, if the thickness of the radioactive waste is over 30 cm. In the case of a thickness of 20 cm, which is the thinnest thickness in this research, the radioactive concentration at the surface was 1/5,000 times lower than the internal radioactive concentration (Fig. 3). Therefore, an increase in the volume of the waste and the radioactive concentration were not effective at a surface dose rate of above 1 cm (Table-4).

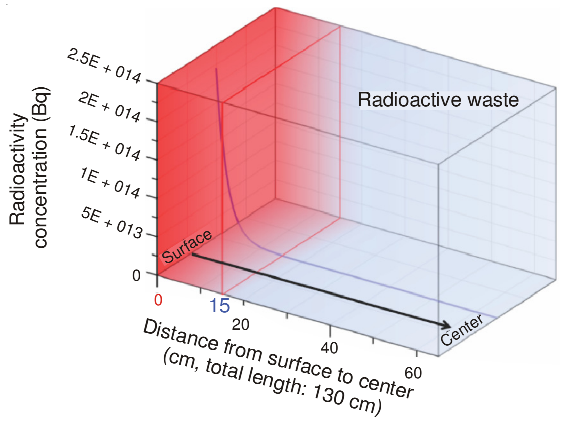

Fig. 3. Radioactivity concentration of radioactive waste by the distance

TABLE-4
MAXIMUM RADIOACTIVE CONCENTRATION OF EACH COMPONENT

Components	Maximum radioactive concentration (Bq)	
	20 ton storage container	40 ton storage container
Baffle	6.61×10^{15}	2.76×10^{16}
Barrel	2.36×10^{15}	8.53×10^{15}
Thermal shield	7.81×10^{14}	2.53×10^{15}
Pressure vessel	6.00×10^{13}	1.57×10^{14}

Conclusion

In this research, the optimum dimension of a high radioactive waste storage container which is the main parameter to design a reasonable decommissioning scenario was determined and an application feasibility study was performed for real decommissioning work. The optimum thickness of a 20 tonnes storage container was estimated to be from 34.3 to 19.2 cm. The optimum thickness of a 40 tonnes storage container was also evaluated to be the same as that of the 20 tonnes storage container. This result was considered to be due to the self-absorption of the radiation source. As a result, the 40 tonnes storage container was evaluated to have advantages in applying real decommissioning work from the radiological and economic aspects. Additional investigations into such aspects as the waste disposal cost and the transportation cost of the storage containers will be carried out in the future.

ACKNOWLEDGEMENTS

This research was supported by the Nuclear R&D Program through the Ministry of Science, ICT & Future Planning.

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