

Safety Analysis of Concrete Treatment Workers in Decommissioning of Nuclear Power Plant

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Nuclear power plant decommissioning generates significant concrete waste, which is slightly contaminated, and expected to be classified as clearance concrete waste. Clearance concrete waste is generally crushed into rubble at the site or a satellite treatment facility for practical disposal purposes. During the process, workers are exposed to radiation from the nuclides in concrete waste. The treatment processes consist of concrete cutting/crushing, transportation, and loading/unloading. Workers' radiation exposure during the process was systematically studied. A shielding package comprising a cylindrical and hexahedron structure was considered to reduce workers' radiation exposure, and improved the treatment process's efficiency. The shielding package's effect on workers' radiation exposure during the cutting and crushing process was also studied. The calculated annual radiation exposure of concrete treatment workers was below 1 mSv, which is the annual radiation exposure limit for members of the public. It was also found that workers involved in cutting and crushing were exposed the most.

Keywords: Radioactive waste, Concrete, Clearance, Radiation Exposure, Shielding

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1. Introduction

The decommissioning of a nuclear power plant (NPP) generates a large amount of industrial waste and radioactive waste [1-4]. Concrete waste, used in building and structural materials, accounts for more than 60% of the decommissioning waste [5]. It is expected that large amounts of concrete waste can be cleared according to the radioactive waste regulation. In accordance with nuclear safety and security commission (NSSC) Notice No. 2020-06, concrete waste, whose specific activity is found to be less than the permissible concentration or dose, can be cleared according to the radioactive waste regulation [6]. The cleared concrete waste, which is confirmed by safety analysis, is treated as common industrial waste and managed in a more flexible way.

Safety analysis for the process of clearance of decommissioning concrete waste usually includes radiation exposure from concrete waste treatment, transportation, and disposal. In this paper, safety analysis scenario development, evaluation of radiation exposure, and exposure reduction methods were systematically studied. For the evaluation of radiation exposure to crushing workers, cone and horizontal half cylinder shaped depositions were considered. The conventional transportation and loading/unloading condition was employed for the evaluation of radiation exposure to workers.

2. Methods

The external and internal exposure to concrete treatment workers was evaluated. A radiation exposure scenario was prepared according to treatment, transportation, and loading/unloading [7].

2.1 Evaluation Method

The external and internal radiation exposure was evaluated to perform the safety analysis of the decommissioning

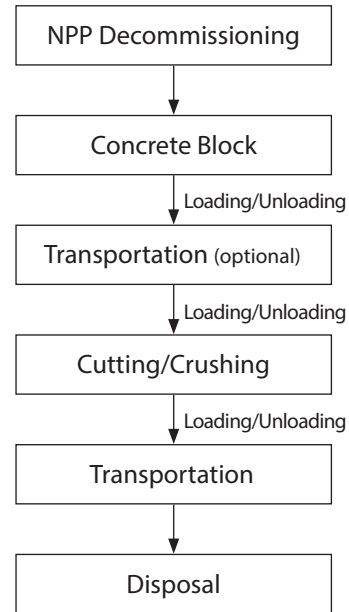


Fig. 1. Treatment of concrete waste from decommissioning for clearance.

concrete treatment worker. The effective dose was calculated using the MCNP 6 and dose conversion factor (DCF) from ICRP 74. The internal exposure was evaluated using the analytical model from NUREG-1640 and IAEA Safety Series-111-p-1.1 [8, 9]. The methods of safety analysis are summarized in Table 1.

2.2 Property of Concrete Waste

It is generally accepted that the primary nuclides that affect internal and external exposure in the concrete waste from decommissioning are ^{60}Co and ^{137}Cs . The maximum specific activity of nuclides from machine shop wall concrete waste from the Hanbit NPP was used in this study. The following conditions were used for the safety analysis of decommissioning concrete treatment workers.

- Mass of treated concrete waste: 40 t/d
- Radioactive concentration of ^{60}Co : $1.39 \times 10^{-2} \text{ Bq}\cdot\text{g}^{-1}$
- Radioactive concentration of ^{137}Cs : $1.42 \times 10^{-2} \text{ Bq}\cdot\text{g}^{-1}$
- Annual working hours: 2,000 h

Table 1. Safety analysis method for concrete treatment worker

External exposure	Method	NUREG-1640
	Code	MCNP 6
	Flux to Dose conversion factor	ICRP 74
Internal exposure	Method	IAEA Safety Series 111-p-1.1 NUREG-1640
	Dose conversion factor	IAEA Safety Series 115

Table 2. Radiation exposure of workers for various processes

Scenario	Scenario	Exposure path	
		External	Internal
SC1	Cutting/Crushing	EE1	IH1
SC2	Transportation	EE2	-
SC3	Loading/Unloading	EE3	IH3



(a)



(b)

Fig. 2. Photos of decommissioning concrete treatment facility: (a) concrete crusher and (b) conveyer for crushed concrete.

2.3 Exposure Scenario for Safety Analysis

Most of the concrete waste generated from the decommissioning of buildings in the NPP is expected to be classified as clearance level waste [5]. Concrete waste, which is cleared according to the NSSC Notice, can be managed as generic industrial waste. It will be processed in an on-site facility or satellite facility for convenient waste management. After treatment, the concrete waste is transported to a municipal disposal or landfill facility.

The treatment of decommissioning concrete waste consists of various processes: crushing, screening, separation,

etc. The general procedure for the treatment and disposal of concrete waste from NPP decommissioning is shown in Fig. 1. During the treatment process, the iron reinforcement bars in the concrete are removed using a magnetic separator in the facility. The crushing process is repeated to obtain the desired particle size, and the resulting concrete is deposited on the ground of the facility at the end of the process. A photo of a treatment facility is shown in Fig. 2.

A safety analysis scenario for worker radiation exposure is shown in Table 2. The scenario consists of transportation, loading/unloading, and crushing, similar to NUREG-1640 [8].

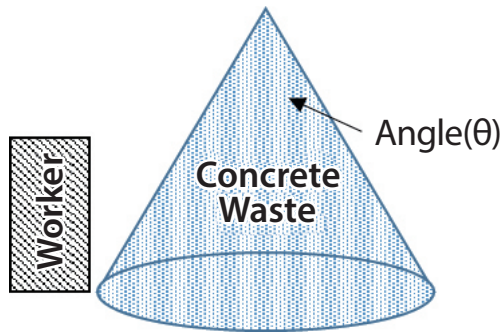


Fig. 3. Schematic of external exposure with cone shape.

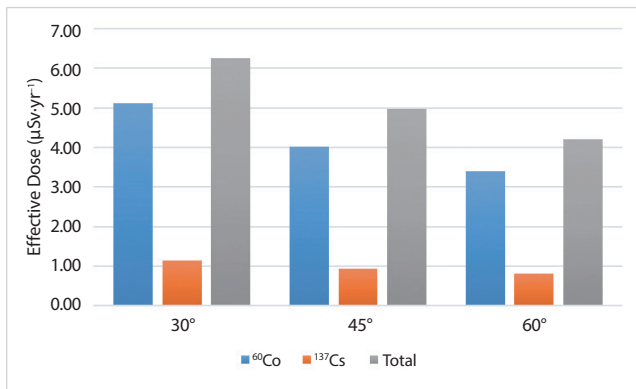


Fig. 4. Effective dose evaluation of worker with cone model.

3. Results and Discussions

3.1 External Exposure

The treated concrete is piled up on the ground of the treatment facility. Their shapes are a cone or horizontal half cylinder. Both are considered for the safety analysis [8].

3.1.1 Concrete Cutting and Crushing Worker

The cutting and crushing worker is exposed to direct external exposure during treatment near a pile of crushed concrete. It is supposed that the shape of the crushed concrete is a cone or horizontal half cylinder.

A cone with vertex angles of 30, 45, and 60 degrees is considered. The distance between the worker (black box with hatched lines) and surface of the cone (dotted cone

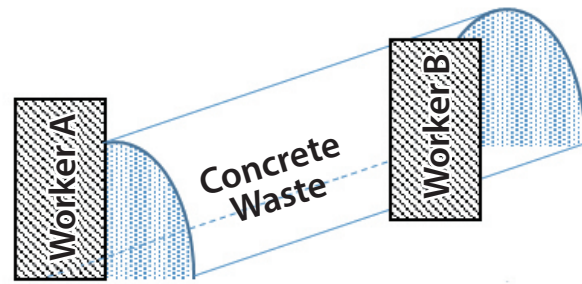


Fig. 5. Schematic of external exposure with horizontal half cylinder.

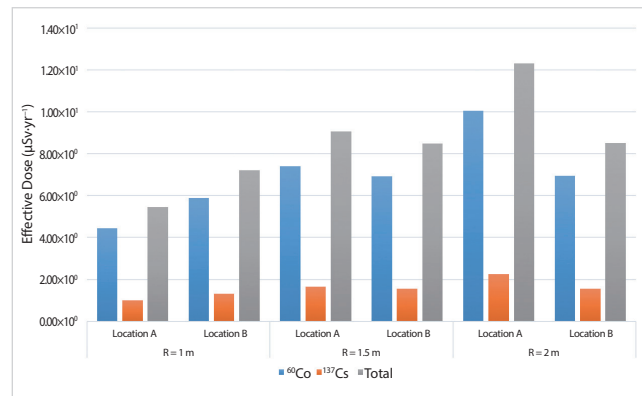


Fig. 6. Effective dose evaluation of worker with horizontal half cylinder.

shape) is 10 cm in this evaluation, as shown in Fig. 3.

The effective dose of the worker from external exposure in the cone scenario, with vertex angles of 30, 45, and 60 degrees, is shown in Fig. 4. It was found that the maximum exposure to the worker is an effective dose of $6.26 \mu\text{Sv}\cdot\text{yr}^{-1}$ ($3.13 \times 10^{-3} \mu\text{Sv}\cdot\text{h}^{-1}$), a cone scenario with vertex angle of 30 degrees. It was also found that as the vertex angle increases, the radiation exposure decreases. It seems that the increased distance from the enlarged vertex angle decreases the radiation exposure.

A horizontal half cylinder with radii of 1, 1.5, and 2 m was considered, as shown in Fig. 5. Two independent working locations were considered in this evaluation. The distance between worker A and the top surface is 10 cm. The distance between worker B and the side region is 10 cm.

The effective dose of the worker from external exposure in the horizontal half cylinder scenario with radii of 1, 1.5, and 2 m is shown in Fig. 6. It was found that the

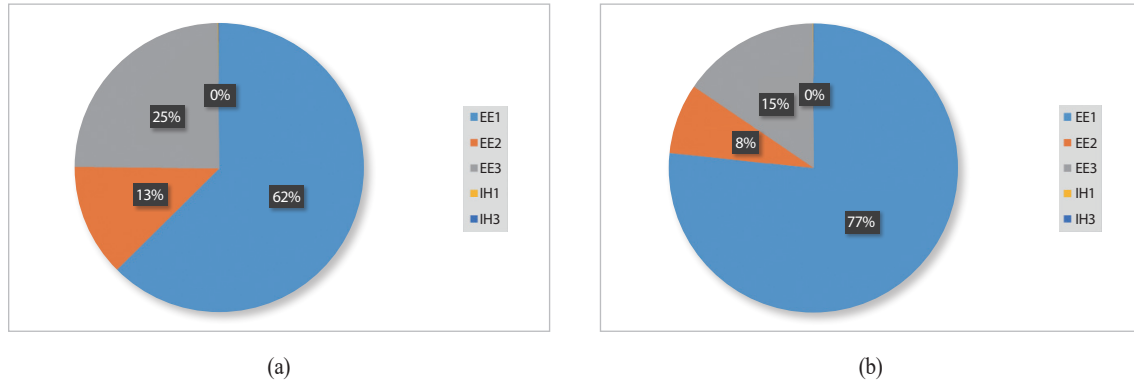


Fig. 7. Effective dose evaluation of worker with (a) cone and (b) horizontal half cylinder scenario.

maximum exposure to a worker is a scenario with a horizontal cylinder with a radius of 2 m and effective dose of $12.3 \mu\text{Sv}\cdot\text{yr}^{-1}$ ($6.15 \times 10^{-3} \mu\text{Sv}\cdot\text{h}^{-1}$). It was also found that as the radius increases, the radiation exposure to the worker increases. As the radius of deposited concrete waste increases, the facing area for worker A increases. It seems that the increased facing area enables the densification of radiation in the piled concrete and results in the increased radiation exposure. In the case of worker B, the facing area decreases as the radius of deposited concrete waste increases. The enlarged depth, which has a self-shielding effect, and decreased facing area for worker B, allows the gradual increase in radiation exposure as the radius of the piled concrete increases.

3.1.2 Concrete Transportation Truck Driver

Generally, concrete waste is transported to a satellite treatment facility and municipal landfill facility using an exclusive transportation truck [7]. The radiation exposure of the truck driver is usually included in safety analysis. The generic physical specifications of a transportation truck are 2.6 m (W) \times 14.6 m (L) \times 2.9 m (H) with maximum loading of 25 tons, as found in NUREG-1640. In this safety analysis, 80% loading of concrete waste was considered for the radiation exposure of truck driver. A schematic diagram of this analysis is shown in Fig. 7. The distance between the driver and the radioactive waste is

1.1 m. The calculated effective dose of the driver is $1.26 \mu\text{Sv}\cdot\text{yr}^{-1}$ ($0.63 \times 10^{-3} \mu\text{Sv}\cdot\text{h}^{-1}$).

3.1.3 Crushed Concrete Loading/Unloading worker

A concrete waste loading and unloading worker was also included. The distance between concrete waste and worker is 1 m in this analysis. The calculated effective dose of loading and unloading is $2.46 \mu\text{Sv}\cdot\text{yr}^{-1}$ ($1.23 \times 10^{-3} \mu\text{Sv}\cdot\text{h}^{-1}$).

3.2 Internal Exposure

The concrete waste crushing worker and loading/unloading worker receive internal exposure during the process. The nuclides and their specific activity are the same as the external exposure safety analysis case. The DCF in the IAEA Safety Series 115 is used to evaluate the effective dose rate.

3.2.1 Concrete Cutting and Crushing Worker

It is assumed that the concrete crushing worker inhales radioactive nuclides during the process. An analytical model, as shown in eq. 1, was used for the evaluation of internal exposure for a crushing worker. The DCF in the IAEA Safety Series 115 was adopted for the internal exposure evaluation [10]. The inhalation rate and exposure duration are $1.2 \text{ m}^3\cdot\text{h}^{-1}$ and $2,000 \text{ h}\cdot\text{yr}^{-1}$, respectively. The airborne

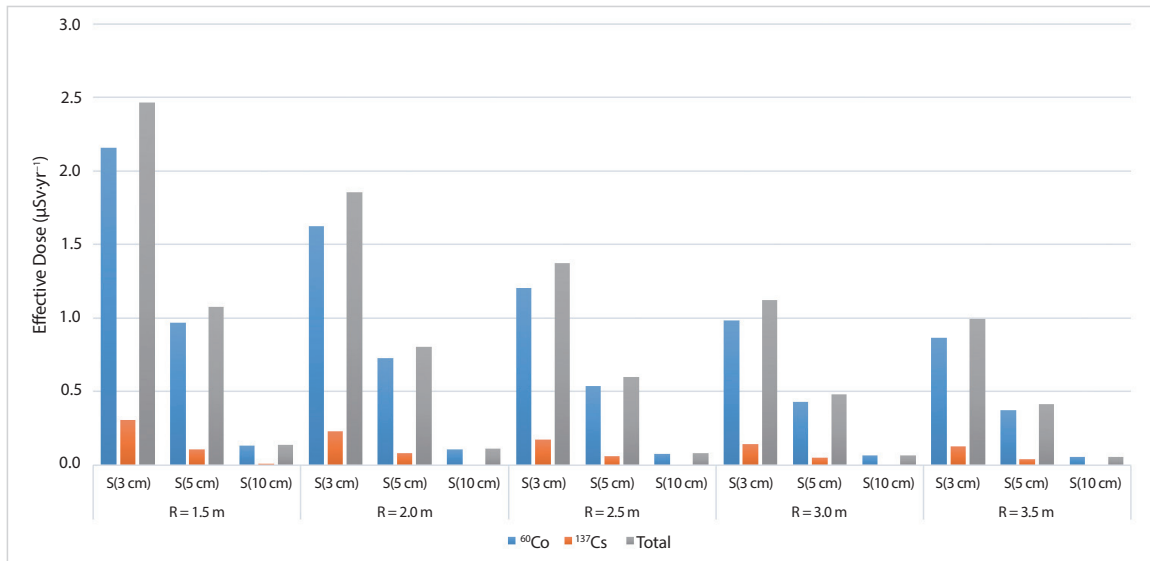


Fig. 8. Effective dose evaluation of standing hollow cylinder with respect to outer radius and thickness.

concentration of dust is $10 \text{ mg}\cdot\text{m}^{-3}$ in accordance with Ministry of Employment and Labor notice no. 2020-48. The evaluated internal exposure for a crushing worker is $1.20 \times 10^{-2} \text{ }\mu\text{Sv}\cdot\text{yr}^{-1}$.

$$D_{IH} = C_{ij} F_{ih} R_h T_{iy} X_d e^{-\lambda t} \quad (1)$$

D_{IH} : Effective dose of nuclide inhalation of radionuclides ($\text{Sv}\cdot\text{yr}^{-1}$)

C_{ij} : Specific activity of nuclides in the radioactive waste ($\text{Bq}\cdot\text{g}^{-1}$)

F_{ih} : Dose conversion factor for inhalation of nuclides ($\text{Sv}\cdot\text{Bq}^{-1}$)

R_h : Inhalation rate ($\text{m}^3\cdot\text{h}^{-1}$)

T_{iy} : Duration of internal exposure ($\text{h}\cdot\text{yr}^{-1}$)

X_d : Airborne concentration of dust ($\text{g}\cdot\text{cm}^{-3}$)

3.2.2 Crushed Concrete Loading/Unloading Worker

It is assumed that the worker loading and unloading concrete inhales radioactive nuclides during the process. The same analytical model, DCF, and coefficients were

used. The evaluation of internal exposure for the worker loading and unloading concrete is $1.20 \times 10^{-2} \text{ }\mu\text{Sv}\cdot\text{yr}^{-1}$.

3.2.3 Shielding Effect Analysis of External Exposure Analysis

Fig. 7 shows the radiation exposure distribution of internal and external exposure. It was found that the concrete cutting and crushing process worker receives more than 62% and 77% of the total radiation exposure in the cone and horizontal half cylinder scenarios, respectively.

Shielding structures for concrete cutting and crushing process workers were considered. The suggested structures for the shielding are a standing hollow cylinder and hexahedron, which are made of stainless steel. It is expected that they will enable the effective management, including handling, transportation, etc., of the crushed concrete and reduce the radiation exposure to workers. Outer radii of 1.5, 2, 2.5, 3, and 3.5 m and thicknesses of 3, 5, 10 cm of the cylindrical structure were considered. Fig. 8 indicates that the effective dose decreases as the outer radius and thickness increases. The evaluated

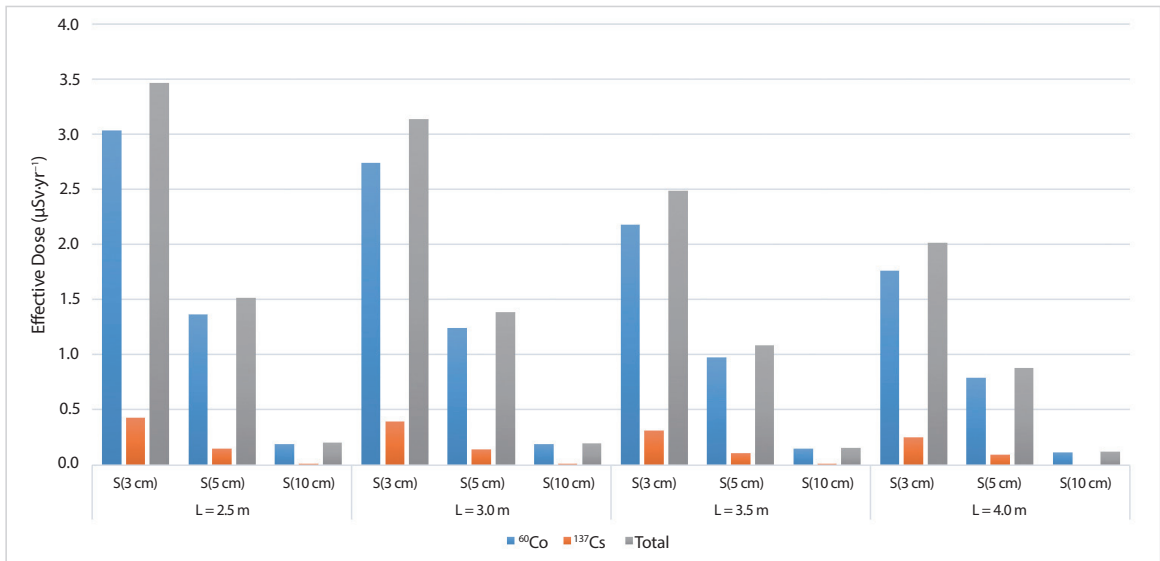


Fig. 9. Effective dose evaluation of hexahedron with respect to length and thickness.

total effective dose for a cutting and crushing worker is $9.92 \times 10^{-1} \mu\text{Sv}\cdot\text{yr}^{-1}$ with an outer radius of 3.5 m and thickness of 3 cm in a standing hollow cylindrical structure. A hexahedron structure with lengths of 2.5, 3, 3.5, and 4 m and thicknesses of 3, 5, and 10 cm were also considered. Fig. 9 indicates that the effective dose decreases as the length and thickness increases. The evaluated total effective dose for a cutting and crushing worker in a hexahedron structure is $2.02 \mu\text{Sv}\cdot\text{yr}^{-1}$ with a length of 4 m and thickness of 3 cm.

4. Conclusion

The radiation exposure for the treatment of concrete waste from the decommissioning of an NPP was evaluated. Safety analysis scenarios, including internal and external exposure, were developed based on NUREG-1640 and IAEA reports. The results indicate that the cutting and crushing worker receives most of the exposure. Since the radiation exposure of the worker evaluation data is usually employed in waste clearance safety analysis, the reduction

of radiation exposure to a worker has the advantage of an effective waste clearance process. A standing hollow cylinder and hexahedron structures were suggested as shielding structures. It was found the radiation exposure for the cutting and crushing worker decreases as the radius of the cylindrical structure, length of the hexahedron structure, and thickness increases. The calculated annual radiation exposure of concrete treatment workers is lower than 1 mSv, annual radiation exposure limit for public. According to the calculated data, it is reasonable to conclude that the radiological effect from the treatment is very low.

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