MCNP and VISIPLAN codes based comparative assessment on worker's dose to the treatment of waste mixture from Wolsong nuclear power plant

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1. Introduction

There have been cases where intermediate-level beta-^{14}C was present in the spent resin treatment plant storage tank, which is a mixed waste product generated from Wolsong nuclear power plant [1]. Therefore, beta-nuclide removal technology is required for radioactive mixed waste treatment in the storage tank. The radioactive mixed waste has different radioactivity levels and physical and chemical properties, so it must be separated and then processed. To operate the beta radionuclide removal treatment system developed to treat mixed waste, the mixed waste must be injected into the injection tank. This process requires the worker to open the lid of the injection tank and directly inject the mixed waste sample from a crane at the same height as the injection tank. Therefore, a dose assessment is necessary to ensure the radiation safety of the workers. Accordingly, it was necessary to evaluate the impact of the mixed waste on the workers when injecting the sample, and the VISIPLAN 4.0 and MCNP codes were utilized. This study aims to evaluate the external radiation exposure dose of workers using each code and the internal radiation exposure dose considering the worker's breathing and the shielding ability of the APF10 mask worn, and to suggest radiation work time according to sample injection work [2].

2. Materials and Method

2.1 Radioactivity Concentrations

The radioactive mixed waste considered for zeolite, spent activated carbon, and spent resin. The corresponding radioactivity concentrations are presented in Table 1, which shows the radioactivity concentrations of each radionuclide considered for dose assessment. The radioactive mixed waste sample loaded into the injection tank consists of zeolite, activated carbon, and spent resin in a weight ratio of 1:1:8, with a capacity of 2 kg.

Table I: Radioactivity concentration by nuclide in radioactive mixed waste

			(Bq/g)
	Zeolite	Spent activated carbon	Spent resin
^{57}Co	0.00E+00	0.00E+00	2.91E+01
^{60}Co	9.37E+01	1.85E+02	4.94E+02
^{51}Cr	0.00E+00	0.00E+00	2.58E+02
^{134}Cs	6.60E+01	2.47E+00	1.57E+01
^{137}Cs	9.11E+04	2.45E+03	1.72E+04
^{54}Mn	0.00E+00	0.00E+00	2.67E+01
^{95}Nb	8.68E-01	7.31E+00	4.39E+01
^{125}Sn	0.00E+00	1.55E+01	4.25E+02
^{95}Zr	0.00E+00	0.00E+00	2.75E+01
^{152}Eu	0.00E+00	0.00E+00	5.12E+02
^{154}Eu	0.00E+00	0.00E+00	4.33E+01
^{3}H	8.55E+03	1.56E+04	3.30E+04
^{14}C	1.98E+02	2.22E+03	1.54E+05

2.2 Modeling

The MCNP code is a probabilistic code that requires descriptions of all isotopes and weight fractions, including density, and requires material input data to be as specific as possible. VISIPLAN is a deterministic calculation code with its own material composition and density [3]. To ensure the validity of dose assessments for radiation workers, the results from the two codes were compared. Figure 1 shows the injection tank and dose assessment locations modeled by the VISIPLAN and MCNP codes.

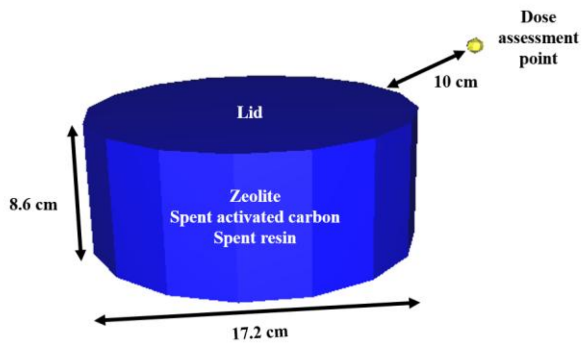

Fig. 1. Injection tank modeling and dose assessment point

The injection process for radioactive mixed waste samples involves placing them in dedicated sealed transport tank, having workers transport them to the loading injection tank location, placing them inside the processing unit, and closing the lids. The dose assessment was performed at a location 10 cm horizontally above the equipment, which is assumed to be directly in front of the chest for an adult male. And figure 2 presents the process of radioactive mixed waste injection.

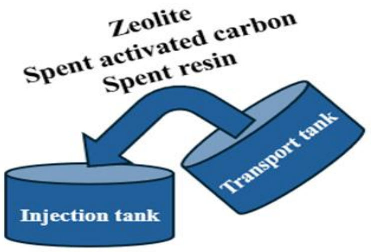

Fig. 2. Mixed waste injection scenario at wolsong nuclear power plant

During this process, the lids of the injection and transport tank are open, the worker is directly exposed to radiation while handling the radioactive mixed waste sample, and the associated dose is assessed. And the internal dose assessment was performed using the activity (Bq) of each radionuclide based on their weight ratios, the dose conversion factors (mSv/Bq) provided in ICRP Publication 119, the beta radionuclide removal treatment system facility volume of 624 m^3, a worker's breathing rate of 1.2 m^3/h, and the application of an APF 10 mask.

3. Results and Discussion

This study evaluated the radiation dose rate received by workers during radioactive mixed waste sample injection operation. The results of the external and internal dose assessments using VISIPLAN and MCNP codes are shown in Table II. It was found that ^{137}Cs accounted for approximately 90% of the total external dose rate and about 85% of the internal dose rate, which appears to be attributable to its highest radioactive concentration.

Table II: External dose assessment(VISIPLAN and MCNP) and internal dose assessment results

			(mSv/h)
	External dose rate		Internal dose rate
	VISIPLAN	MCNP	
^{57}Co	4.30E-05	1.07E-05	8.42E-06
^{60}Co	1.00E-02	1.57E-02	2.77E-03
^{51}Cr	1.40E-04	7.71E-05	2.86E-06
^{134}Cs	4.10E-04	1.69E-04	7.17E-05
^{137}Cs	1.90E-01	1.88E-01	5.96E-02
^{54}Mn	2.10E-04	2.67E-04	9.86E-06
^{95}Nb	3.40E-04	4.06E-04	2.21E-05
^{125}Sn	1.10E-03	2.50E-03	4.34E-04
^{95}Zr	2.20E-04	2.40E-04	2.12E-05
^{152}Eu	5.90E-03	4.28E-03	6.14E-03
^{154}Eu	4.60E-04	3.54E-04	6.66E-04
^{3}H	N/A	N/A	4.54E-04
^{14}C	N/A	N/A	3.09E-04
VISIPLAN total	2.79E-01		
MCNP total	2.83E-01		

The total dose, which is the sum of the internal and external dose assessment results, is 2.79E-01 mSv/h for the VISIPLAN code and 2.83E-01 mSv/h for the MCNP code. Considering the annual effective dose limit of 20 mSv for workers, the VISIPLAN code estimated the allowable working time to be 72 hours, while the MCNP code estimated it to be 71 hours. The VISIPLAN code evaluates external dose based on its own material composition and density, while the MCNP code evaluates it based on directly entered material input data describing all isotopes, densities, and other factors. Therefore, it is difficult to determine which code is more accurate. However, the relative error of the total external dose results for all radionuclides, 1.41%, suggests that both codes' results can be considered good agreement.

4. Conclusions

This study evaluated the external and internal dose rate to workers when directly injecting radioactive mixed waste samples into the injection tank of beta radio nuclide removal treatment system. The VISIPLAN code estimated an allowable working time of 72 hours, while the MCNP code estimated 71 hours. Conservatively as the injection process is completed within one minute, it is concluded that the radiological safety of workers can be ensured within the allowable time frame.

REFERENCES

[1] Yoon, J. Y., Hwang, S., & Kim, H. R. (2025). Radiological safety of workers for the beta-nuclide removal treatment of the mixed waste from Wolsong nuclear power plant. Nuclear Engineering and Technology. Advance online publication. https://doi.org/10.1016/j.net.2025.103802

[2] Occupational Safety and Health Administration. (2019). Assigned protection factors for the revised respiratory protection standard. Maroon Ebooks.

[3] Bednár, D., Lištjak, M., Slimák, A., & Nečas, V. (2019). Comparison of MCNP and VISIPLAN dose-field calculations for multilayer shielding. Radiation Protection Dosimetry, 186(1), 82–91. https://doi.org/10.1093/rpd/ncz224

[4] International Atomic Energy Agency. (2011). Radiation protection and safety of radiation sources: International basic safety standards (Interim ed.). IAEA.