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Radiation Shielding Simulation and Test Method for Sr-82/Rb-82 Generator Development

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1. Introduction

For the development of Sr-82/Rb-82 generators, the development of a shielding container with appropriate shielding ability should be accompanied. In general, the shielding ability test is entrusted to a company specializing in the shielding ability test. In order to evaluate the adequacy of the shielding ability test process, it is essential to compare the calculation results with the experimental results. In the results of several shielding tests performed previously, it was confirmed that the theoretical values and experimental values in the shielding test result report provided by the company generally agree well. On the other hand, these theoretical values and experimental values showed great differences from the calculation results using the MCNPX code.

In this paper, to understand the cause of this difference, the theoretical value by simple hand calculation, the calculated value using the simulation code, and the shielding ability test result obtained by participating in the experiment were compared with each other. Based on this result, a method for calculating a reference value and a method to improve the accuracy of the shielding ability test result that can be used in the design of the shielding body in the future are suggested.

2. Methods and Experiments

2.1 Simple calculations using formulas

For the evaluation of dose rate with shielding structures, the company were using simple equation as follows;

$$\dot{D} = \Gamma A/d^2 \times e^{-0.693\left(\frac{t_1}{hvl_1}+\frac{t_2}{hvl_2}\right)} \quad (1)$$

where, $\dot{D}$ is dose rate [mSv/hr], Γ is gamma constant [mSv·m^2/Ci-hr], A is source activity [Ci], d is the distance between source and detector [m], t_1 and t_2 are shielding layer thicknesses, and hvl_1 and hvl_2 are half value layer thicknesses of shielding materials.

While companies use the half-value layer thickness for easier calculation, the literature mainly suggests a method of calculating using a linear attenuation coefficient.

$$\dot{D} = \Gamma A/d^2 \times e^{-(\mu_1 t_1+\mu_2 t_2)} \quad (2)$$

where, μ_1 and μ_2 are linear attenuation coefficients of shielding materials [cm^{-1}].

2.2 Simulation Using MCNP Code

Simulation using MCNP code is a method known to obtain more accurate shielding capacity calculation results. In order to simulate the MCNP code, input for the structure of the shielding body and the source term is required first. Calculations were performed using the simplified shielding structure and detector positions are shown in Fig. 1 and Fig. 2.

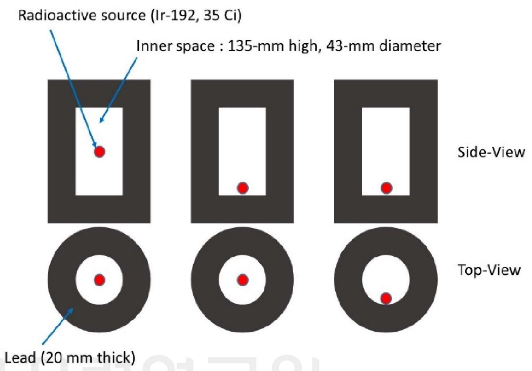

Fig. 1. Geometry of the Shielding Structure for the MCNP Code Simulation.

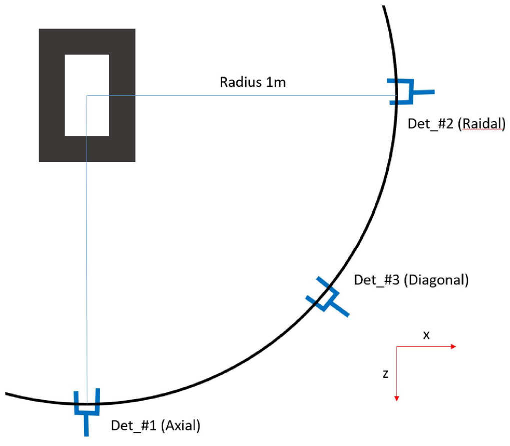

Fig. 2. Detector Position for the MCNP Code Simulation.

2.3 Experimental Set-Up

For the shielding ability test, 35.22-Ci Ir-192 radioactive source was used. For high radiation dose rate measurement, wide range gamma dose rate detector (Thermo Fisher Scientific, FHZ 612 Si-10) was used in combination with a telescope adapter, and the dose rate value was read using a survey meter (FH40G-L10). The measuring range of FHZ 612 Si-10 is 10 nSv/hr ~ 20 Sv/hr for 70 keV ~ 1.3 MeV gamma ray. The experimental setup is shown in Fig. 3.

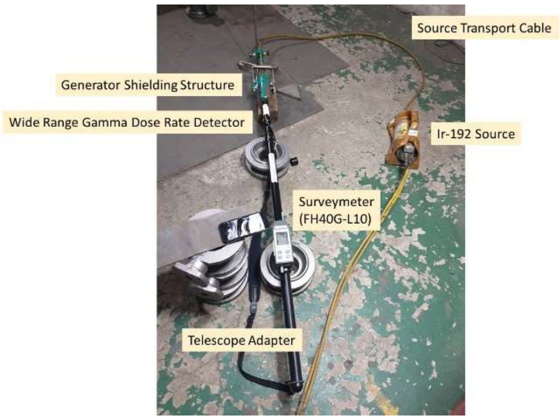

Fig. 3. Experimental Set-up for Shielding Performance Test.

3. Results and Discussion

2.1. Calculation Results Using Formula

For the calculation of dose rate, some important constants have to be defined. The gamma constant of Ir-192 is 4.8 mSv·m^3/hr·Ci, half value thickness of lead is 4.8 mm. The linear attenuation coefficients are shown in Table 1 for various materials. The mass attenuation coefficients of air and lead are also shown in Fig. 4. The calculation value is 9.42 mSv/hr with 1 m distance.

Table 1: Linear Attenuation Coefficients, [cm^{-1}] [1]

		Quantum energy, MeV												
	ρ, g/cm^3	0.1	0.15	0.2	0.3	0.5	0.8	1.0	1.5	2	3	5	8	10
C	2.25	0.335	0.301	0.274	0.238	0.196	0.159	0.143	0.117	0.100	0.080	0.061	0.048	0.044
Al	2.7	0.435	0.362	0.324	0.278	0.227	0.185	0.166	0.135	0.117	0.096	0.076	0.065	0.062
Fe	7.9	2.72	1.445	1.090	0.838	0.655	0.525	0.470	0.383	0.335	0.285	0.247	0.233	0.232
Cu	8.9	3.80	1.830	1.309	0.960	0.730	0.581	0.520	0.424	0.372	0.318	0.281	0.270	0.271
Pb	11.3	59.7	20.8	10.15	4.02	1.64	0.945	0.771	0.579	0.516	0.476	0.482	0.518	0.552
Air	1.29×10^{-3}	1.95×10^{-4}	1.73×10^{-4}	1.59×10^{-4}	1.37×10^{-4}	1.12×10^{-4}	9.12×10^{-5}	8.45×10^{-5}	6.67×10^{-5}	5.75×10^{-5}	4.6×10^{-5}	3.54×10^{-5}	2.84×10^{-5}	2.61×10^{-5}
H_2O	1	0.167	0.149	0.136	0.118	0.097	0.079	0.071	0.056	0.049	0.040	0.030	0.024	0.022
Concrete*	2.35	0.397	0.326	0.291	0.251	0.204	0.166	0.149	0.122	0.105	0.085	0.067	0.057	0.054

*Ordinary concrete of the following composition: 0.56%H, 49.56%O, 31.35%Si, 4.56%Al, 8.26%Ca, 1.22%Fe, 0.24%Mg, 1.71%Na, 1.92%K, 0.12%S.
Source: From National Bureau of Standards Report No. 1003, 1952.

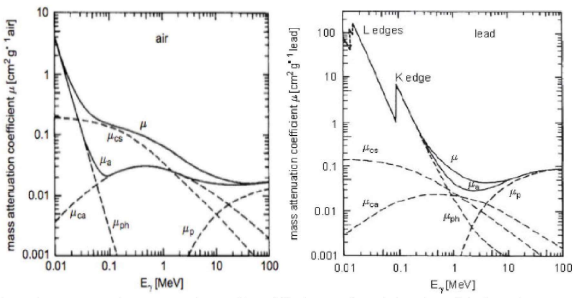

Fig. 4. Mass Attenuation Coefficient for (a) air, (b) lead.

2.2 Simulation Results

Table 2 shows the calculation results using the MCNP code simulation. It can be seen that different calculation results are shown depending on the location of the Ir-192 source. Comparing the case where the source is placed in the center of the bottom of the shield and the case where the source is located at an intermediate height, it can be seen that the difference in dose rate values in the axial and radial directions is different. This result may be attributed to the scattering effect of gamma rays within the shield.

Table 2: MCNP Code Simulation Results

	Det#1 (Axial)	Det#2 (Radial)	Det#3 (Diagonal)
H*(10) @ Inner Wall [mSv/hr]	5.36	3.61	1.45
H*(10) @ *Center* [mSv/hr]	3.81	3.94	1.51

2.3 Experiment Data

For the experiment results are shown in Table 3.

Table 3: Experiment Results

	Det#1 (Axial)	Det#2 (Radial)	Det#3 (Diagonal)
H*(10) @ Inner Wall [mSv/hr]	6.3~6.67	3.07~3.28	2.50~2.67

3. Conclusions

Comparing the code simulation result with the experimental result, the difference in dose rate according to the measurement direction is confirmed and the tendency is consistent. The reason why the difference in values in the diagonal direction appears larger is presumed to be because the angles given in the two cases are different. The simple calculation result using the formula shows a larger difference than the code calculation result, so it can be concluded that it is necessary to use the code calculation result when designing the shield. In order to obtain more accurate test results, it is necessary to participate in the shielding test rather than entrust it entirely to a company.

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