Estimation of Dose Rate Distributions in a Low Level Radioactive-Waste Shipping Vessel by Applying the Monte Carlo Method

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INTRODUCTION

A low-level radioactive-waste shipping vessel in which as much as 3000 radwaste drums were loaded was supposed in the study, and the gamma-ray dose rate distributions in the shipping vessel were estimated by using the Monte Carlo coupling code system MORSE-CG/ RADWASTE-VESSEL. The calculated results from the MORSE-CG/ RADWASTE-VESSEL codé system were compared with other calculations by the point kernel codes, SPAN, QAD-CG, QAD-CG·GP, and QAD-CG with the attenuation cross sections. After comparison with each calculation, satisfactory agreement was obtained except a few dose points.

MONTE CARLO COUPLING CALCULATIONS

As illustrated in Fig.1, the supposed low-level radioactive-waste shipping vessel is to load as much as 3000 radwaste drums in the seven holds, and length of the ship is approximately 100m. Accordingly, it is very hard to obtain a reliable Monte Carlo result by usual one-through calculation. Hereupon, the Monte Carlo coupling technique was applied and the coupling code system MORSE-CG/ RADWASTE-VESSEL was produced, and right now the code system was used to calculate the gamma-ray dose rate distribution in the ship.

First Calculation Step

In the first calculation step of the code system, one of the seven holds loaded ~500 drums was modeled as a homogenized gamma-ray source region as shown in Fig.2. A pseudo detector point P was set at the top of the homogenized source region in the first calculation and the gamma-ray angular, energy, and total fluences were obtained from the first Monte Carlo calculation at the point P in Fig.2. The gamma-ray source energies from radioisotopes in the radioactive-waste are summarized in Table 1 and the composition of materials used in the calculations is indicated in Table 2.

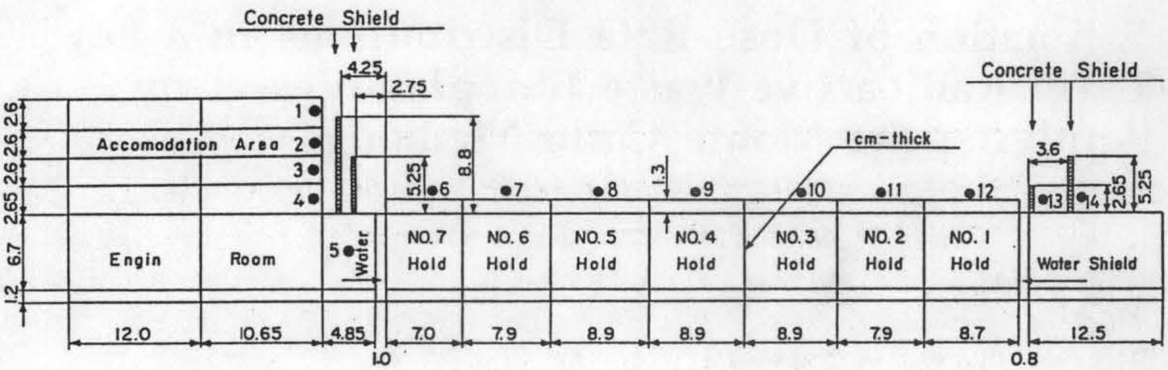

Fig. 1 A calculational model of a low-level radioactive-waste shipping vessel and dose points (1~14).

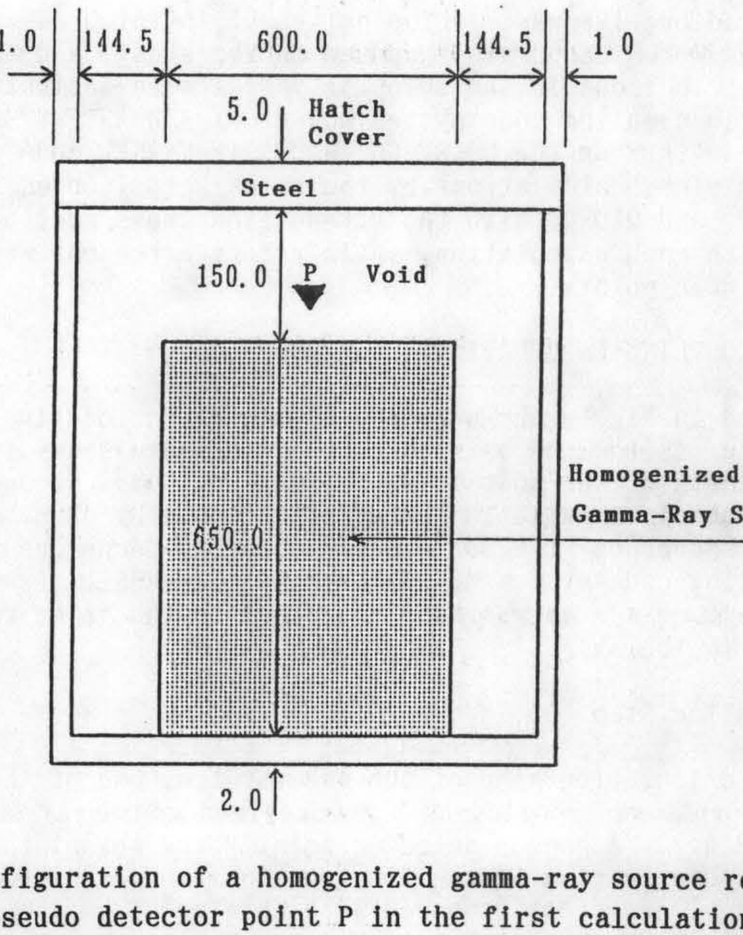

Fig. 2 Configuration of a homogenized gamma-ray source region and a pseudo detector point P in the first calculation step. The point P is center of the source region and 10cm-distance from the source surface. Dimensions are all in centimetres.

Table 1 Radioisotopes in Radwaste

Nuclide	Gamma-Ray Energy (MeV)	Composition(%)
^{54}Mn	0.835 [100%][a)]	9
^{60}Co	1.330 [100%] 1.170 [100%]	61
^{134}Cs	0.605 [100%] 0.796 [100%]	6
^{137}Cs	0.667 [100%]	24

a) The value in [ ] is a production rate of gamma rays per disintegration.

Table 2 Composition of Materials Used in the Calculation

Element	Composition (atoms/cm/b)				
	Concrete	Cement	Hold	Water	Steel
Hydrogen	5.47×10^{-3}	5.24×10^{-3}	1.60×10^{-3}	6.69×10^{-2}	
Carbon			3.85×10^{-6}		8.33×10^{-4}
Oxygen	4.20×10^{-2}	4.03×10^{-2}	1.23×10^{-2}	3.34×10^{-2}	
Magnesium	6.27×10^{-5}	6.01×10^{-5}	1.83×10^{-5}		
Aluminum	2.19×10^{-4}	2.10×10^{-4}	6.40×10^{-5}		
Silicon	1.82×10^{-2}	1.75×10^{-2}	5.32×10^{-3}		5.02×10^{-5}
Potassium			1.05×10^{-7}		2.28×10^{-5}
Calcium	2.27×10^{-3}	2.18×10^{-3}	6.63×10^{-4}		
Manganese			4.46×10^{-6}		9.65×10^{-4}
Iron	6.50×10^{-4}	6.23×10^{-3}	5.73×10^{-4}		8.29×10^{-2}

Energy Fluence at point P

The calculated energy fluence at the detector point P in Fig.2 is shown in Fig.3. To obtain the energy fluence in Fig.3, the random walks were carried out for 400,000 source gamma-rays, then fsd's (fractional standard deviation) of the total fluence was 0.034 and of the energy fluence was approximately 0.05 for the remarkable two peaks of ^{60}Co source by 30 min. running of the CRY-XMP computer. The remarkable two peaks around 1.2 MeV are due to the source gamma-rays of 1.17 and 1.33 MeV from ^{60}Co in the radioactive waste. More than 60 percent of source gamma-rays are generated from ^{60}Co in the waste. Accordingly, the remarkable peaks are to be observed at the detector point P in Fig.2 and lower energy part of the fluence is made up of the low energy source gamma-rays other than ^{60}Co and also the scattered gamma-rays in the radioactive waste. The energy fluence can be obtained from a transport calculation.

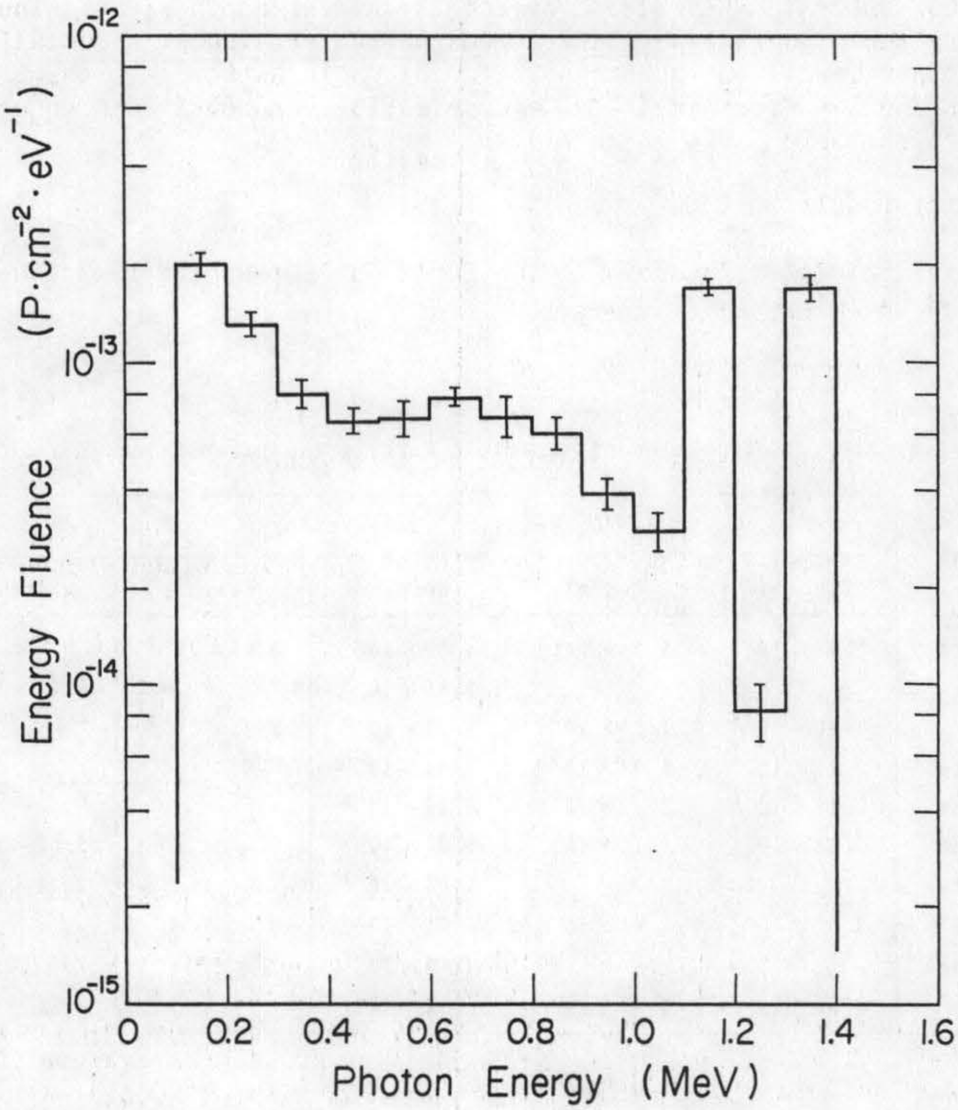

Fig. 3 Photon energy spectrum at location P in Fig. 2.

Second Step Calculation

The random walk of the second calculational step in the MORSE-CG/ RADWASTE-VESSEL code system starts with the gamma-ray angular, energy, and total fluences obtained from the first calculation step at the point P. It was assumed that the all surfaces of the homogenized source region in Fig.2 have same flux density at the point P and also assumed that the surfaces of the source region in each hold have the same flux intensity at the point P. The complex as well as the large ship structures were taken into account in the second calculation step of the Monte Carlo coupling code system and the gamma-ray dose rates at the 14 dose points in Fig.1 were obtained from the second step calculations. In the second step, 100,000 source gamma-ray were generated from the coupling surfaces of the source region in each hold. That is the second step calculations were carried out for 700,000 source gamma-rays in all. The calculational sequence of the Monte Carlo coupling technique in the MORSE-CG/ RADWASTE-VESSEL code system is summarized in Fig.4. The coupling technique has provided a remarkable improvement especially to three-dimensional neutron streaming problems in both the calculated results and the fractional standard deviations as compared with usual one-through Monte Carlo calculations.

The final result of interest

The final result of interest in the Monte Carlo coupling technique is obtained as follows.

$$\lambda(\bar{r}') = So \cdot N \cdot \Phi f(\bar{r}) \cdot Ac \cdot N \cdot Ds(\bar{r}')$$

where

λ = final result of interest at a dose point $\bar{r}'$ in the second step (mrem/h)

So = gamma-ray source intensity in the homogenized source region ($\gamma \cdot s^{-1} \cdot hold^{-1}$) : source region = 2.028×10^{8} cm^3 for No.1 hold
3.354×10^{8} cm^3 for No.2~No.7 hold

N = number of hold included in the second calculational step

$\Phi f(\bar{r})$ = total gamma-ray flux per source gamma-ray at a point $\bar{r}$ on the homogenized source region, calculated by the first calculational step ($\gamma \cdot s^{-1} \cdot cm^{-2} \cdot$ source gamma $ray^{-1} \cdot hold^{-1}$) : $\Phi f = 1.32\times10^{-7}$ at P in Fig.2

Ac = surface area of the homogenized source region in a hold :
Ac = 1.040×10^{6} cm^2 for No.1 hold
1.465×10^{6} cm^2 for No.2~7 hold

$Ds(\bar{r}')$ = gamma-ray dose rate per source gamma ray at a detector point $\bar{r}'$, obtained from the second step

$$Ds(\bar{r}') = \sum_g \Phi_s^g(\bar{r}') \cdot P_s^g(\bar{r}')$$

$\Phi_s^g(\bar{r}')$ = energy gamma-ray flux for the g'th group per source gamma ray at a detecter point $\bar{r}'$($\gamma \cdot s^{-1} \cdot cm^{-2}$ · source gamma ray)

$P_s^g(\bar{r}')$ = dose conversion factor for the g'th group per unit flux ($/mrem \cdot h^{-1} \cdot \gamma^{-1} \cdot cm^2 \cdot s$)

The more detail informations and the applying techniques on the coupling calculation are available from Three-Dimensional Neutron Streaming Calculations Using Monte Carlo Coupling Technique, Ueki K. Nucl. Sci. Eng., 79, 253 (1981). The applying instance to calculate the neutron dose rate distributions in a spent fuel shipping vessel is described in Measurement of Dose Rates and Monte Carlo Analysis of Neutrons in a Spent-Fuel Shipping Vessel, Ueki K., Namito Y., and Fuse T. Nucl. Technol. 74, 164 (1986).

COMPARISON WITH OTHER CODES

Comparison of the calculated gamma-ray dose rates at the 14 dose points by the Monte Carlo code system with other codes of the SPAN, QAD-CG, QAD-CG·GP, and QAD-CG with attenuation cross section is summarized in Table 3. In Table 3, the calculated dose rates on the hatch covers of the vessel (i.e., dose points 6~12 agree fairly well in each codes. However, there are large discrepancies in each calculated values in the accommodation areas (i.e., dose points 1~3 and also at the bow (i.e., dose points 14 and 15). The differences or the discrepancies may be due to the calculational method or the modeling of the vessel. However, we have no experimental or measured data for the radioactive waste shipping vessel. Therefore, we can not decide whichever code is better or suitable to the calculation.
As a conclusion, we observed some differences or discrepancies in each calculated dose rate at a point, however, the codes employed in this study can be employed to calculate the dose rate distributions in the radioactive waste shipping vessel and the results may be reasonable.

REFERENCES

Ueki K. Three-Dimensional Neutron Streaming Calculations Using Monte Carlo Coupling Technique, Nucl. Sci. Eng., 79, 253 (1981).

Ueki K., Namito Y., and Fuse T. Measurement of Dose Rates and Monte Carlo Analysis of Neutrons in a Spent-Fuel Shipping Vessel, Nucl. Technol. 74, 164 (1986).

First MORSE Calculation

- ○ Start the random walk from the homogenized source.
- ○ The initial statistical weight of each source photon is set as 1.0.
- ○ Provide the pseudo-detector on the surface of the homogenized source.
- ○ Calculate spatial distributions of angular, energy, and the total fluence at the pseudo-detector.

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Preparation of Boundary Source Conditions

- ○ Establish the provability density functions (pdf's) of the angular, energy, and total fluence in the detector.
- ○ Provide the subroutine SOURCE so as to be able to use the pdf's as boundary source conditions in the second MORSE calculation.
- ○ Also provide the subroutine SDATA in order to treat the boundary source conditions consistently.

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Second MORSE Calculation

- ○ Start the sequence random walk with the boundary source conditions from the SOURCE subroutine.
- ○ The initial statistical weight of each source photon is also set as 1.0.
- ○ Calculate the fluence at real dose points in the vessel.
- ○ Multiply the total fluence, λ', obtained from the first MORSE calculation, by the output of interest, λ^*, of the second MORSE calculation.
- ○ Obtain the final result of interest, λ, as

$$\lambda = \lambda' \cdot \lambda^*$$

Fig.4 Calculational sequences of the Monte Carlo coupling technique (MORSE-CG/ RADWASTE-VESSEL code system)

Table 3　Comparison of calculated gamma-ray dose rates in a low-level radioactive-waste shipping vessel. The calculated results are normalized as mrem/h per source photon with a given energy spectrum per second from a unit volume (cm^3). Futhermore the total source volume of 2.215×10^{9} cm^3 in the vessel is multiplied to the calculated values.

(mrem/h)

code / dose point	SPAN	QAD-CG	QAD-CG·GP	QAD-CG with Attenuation Cross Section	MORSE-CG/ RADWASTE-VESSELE
①	6.68×10^{-5}	2.36×10^{-6}	7.04×10^{-5}	6.41×10^{-5}	1.50×10^{-4}
②	1.29×10^{-6}	1.63×10^{-6}	1.11×10^{-6}	7.00×10^{-6}	5.44×10^{-7}
③	7.30×10^{-6}	3.06×10^{-6}	6.40×10^{-6}	2.98×10^{-5}	7.10×10^{-7}
④	1.64×10^{-5}	3.18×10^{-6}	1.26×10^{-5}	5.94×10^{-5}	2.45×10^{-6}
⑤	2.51×10^{-5}	2.92×10^{-5}	3.05×10^{-5}	1.41×10^{-3}	1.29×10^{-4}
⑥	3.83×10^{-3}	4.73×10^{-3}	4.16×10^{-3}	3.32×10^{-3}	5.20×10^{-3}
⑦	3.86×10^{-3}	4.76×10^{-3}	4.20×10^{-3}	3.36×10^{-3}	7.45×10^{-3}
⑧	3.86×10^{-3}	4.75×10^{-3}	4.20×10^{-3}	3.36×10^{-3}	7.21×10^{-3}
⑨	2.25×10^{-2}	2.47×10^{-2}	2.25×10^{-2}	2.58×10^{-2}	4.39×10^{-2}
⑩	2.26×10^{-2}	2.48×10^{-2}	2.25×10^{-2}	2.58×10^{-2}	3.95×10^{-2}
⑪	2.24×10^{-2}	2.46×10^{-2}	2.23×10^{-2}	2.55×10^{-2}	3.94×10^{-2}
⑫	1.91×10^{-2}	2.12×10^{-2}	1.90×10^{-2}	2.29×10^{-2}	2.00×10^{-2}
⑬	5.12×10^{-5}	4.04×10^{-5}	4.35×10^{-5}	2.05×10^{-4}	2.20×10^{-4}
⑭	3.77×10^{-7}	3.87×10^{-6}	2.51×10^{-7}	8.73×10^{-6}	1.75×10^{-6}