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THE RADIATION DOSE AROUND A RADIONUCLIDE DRAIN TANK IN A NUCLEAR MEDICINE FACILITY CALCULATED BY MONTE CARLO METHOD

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Abstract

A new method has been proposed for calculating the dose rate around a radioisotope reservoir tank using EGS4 (Electron Gamma Shower Version 4). Several improvements, such as uniform distribution of the radioactive substances in the reservoir tank and shielding effect by the tank wall, were made for more accurate determination of the activity-to-dose rate conversion coefficients. The Monte Carlo code EGS4 was employed in this report to calculate the cumulative dose around the reservoir tank. The results of calculations are useful for a design for radiation safety management in nuclear medicine facilities.

1. Introduction

In connection with recent spread of the PET (positron emission tomography) technique, it has been more important problem to estimate accurately the dose rate of radiation emitted from a tank for reservation of positron – emitting nuclides. The effective dose rate of an outside storage tank has conventionally been calculated assuming that the storage tank should be set underground and that all the radioactive materials should be located at the center of the surface1). This estimation method takes no account of the shield effect by water, which leads to overestimation. Recently, Yamamoto et al proposed a new approach to calculate the external effective dose rate from a radioisotope reservoir tank2). It was assumed that the radioactive nuclides were uniformly distributed in the storage tank of rectangular parallelepiped. They divided this tank equally into minute volumes, and calculated the effective dose rates with considering both the inverse-square law of the distance from the center of this volume element and the attenuation by water. They finally estimated the activity – to - effective dose rate conversion coefficient for 9 types of nuclides (^{51}Cr, ^{59}Fe, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I, ^{131}I and ^{201}Tl) regularly used for nuclear medicine diagnosis. The coefficients were also tabulated as a function of both the width of the parallelepipeds from 1 to 5m, and the distance from the surface of the storage tank at 0.1, 0.2, 0.5, 1, 2, 5 and 10 m. Such an excellent work me it easier to perform shield calculations at many nuclear medicine institutions.

However, there remain some problems in the previous work; for example, approximation of no attenuation by the wall material and neglect of scattering of photons. Thus, we have tried to improve the calculation technique by introducing a Monte Carlo simulation. It is the purpose of this report to determine more accurately the activity–to–effective dose rate conversion factors, and then to estimate the cumulative dose around the reservoir tank.

2. Materials and Method

The Monte Carlo code, EGS4 (Electron Gamma Shower Version 4) is widely used for radiation transport simulation with relatively high flexibility and is now applied to many fields including radiation safety management, health physics, medical physics and radiotherapy, and reactor design3).

2.1 Geometric conditions

For simplicity, it is assumed that the drain tank is a rectangular parallelepiped and filled with water containing radioactive substances uniformly. The size of the storage tank was varied for each calculation from 1 to 3 m. The thickness of the drain tank made of iron was set to 0 to 1 cm. The distance from the external surface of the storage tank to the point of interest was changed to 5m at 1m- step. The circumference of the tank is naturally in air at the temperature of 20-degree Centigrade and at one atmospheric pressure. The floor was assumed to be covered with the surface area of 100 square meters with the concrete whose thickness is 9m, and contribution of the scatter from a floor was investigated. Furthermore, the water level in a tank was changed and change of the rate of dose rate by the water level was observed.

2.2 Dose calculation

The personal dose equivalent, Hp (10) is called as 1cm dose equivalent in Japanese laws. There are several methods for evaluating the operational quantity. If both energy and angular distributions of photon fluencies are perfectly known, then Hp (10) can be calculated by using the conversion coefficients given by ICRP. In our case, however, it is difficult to apply this procedure because a time – consuming calculation is required for a sufficient statistical precision. The Hp (10) or the effective dose is approximated in this report by the absorbed dose averaged over the region with depths of 0.5 – 1.5 cm from the phantom surface.

A rectangular parallelepiped water slab with a surface area of 900 cm^2 and a thickness of 40 cm was used as phantom. Figure 1 shows the relative positions of the phantom to the tank. The average absorbed dose was calculated and the effective dose per decay for ^{18}F and ^{131}I, which is commonly used for PET and nuclear medicine, was obtained for each geometric parameter.

It is considered in Monte Carlo calculations that the result is not meaningful, questionable and reliable, if the values have a relative error of above 0.2, 0.1-0.2 and less than 0.1, respevtively[4)]. The number of positrons used in the simulation was 10^6. The relative error of the average absorbed dose varied from 0.01 to 0.11, which means results is therefore considered to be reliable.

2.3 Other conditions for calculation

The user codes were constructed based on the above assumptions, referring to "UCPHANTOM_REC1" (programmed by Dr. H. Hirayama (KEK) EGS4 USER CODE-- 26 JUL 2002/8030). Each positron with 633 keV was emitted uniformly in a rectangular tank, all radiation transports were pursued and the energy deposition in the slab phantom was finally summed up. The cut-off energies for the photons and the electrons were set to be 1keV and 5keV, respectively.

The effective dose was calculated for three months under the following conditions where 400MBq of ^{18}F is given to one patient, and 10 patients are subjected to PET examination per day, leading to the daily amount of ^{18}F of 4 GBq/day. A PET medical examination is performed at five days per week. In addition, about one hundredth of consumed amounts are assumed to flow into tank. The size of the drain tank currently installed at the nuclear medicine institution is 10 m^3 to 20 m^3.

Furthermore, the effective dose was calculated for three months under the following conditions where 3.7GBq of ^{131}I is given to one patient, and 13 patients are subjected to treatment per 3 months. And about one hundredth of consumed amounts are assumed to flow into tank.

3. Results

3.1 Dose from ^{18}F

Figure 1 shows the trajectory of 500 positrons emitted and all secondary radiation in the 27-m^3 tank. The right wall is iron of 1mm thick and the bottom of the tank assumed to be faces the floor of concrete. Some of radiation escape from sidewall should reach the water phantom. The average absorbed dose (Gy/decay) of the virtual water phantom is tabulated in Table 1 for each set of the tank size and the distance from the tank wall. The uncertainty of estimation is also indicated in parenthesis. The coefficients converting from the amount of decay into 1cm-dose equivalent were calculated and are summarized in Table 2. At the same decay number, the dose around the tank decreases with increasing the tank size. This tendency was prominent when the point of the interest was close to the tank. At a distance of 5m from the tank, the dose around the 1-m^3 tank was 6 times as large as that around the 27-m^3 tank. In addition, the 1 cm-dose equivalent was found to be about 3 times the average water absorbed dose. The fraction of transmitted radiation is also calculated as a function of iron wall thickness. As is represented in Table 3, the iron wall thinner than 3mm can hardly shield the radiation, and the dose rate is attenuated to be about 30-50% for 1-cm iron wall.

The maximum amount of radioactive nuclides, which flow into the tank per day, was estimated 4×10^7 [Bq] as stated in the previous section. Therefore, the amount of decay [A] of the radioactive nuclides in the tank for 3 months was calculated to 2.5×10^{13} [decay] as follows:

$$A = 13[W/3M] \times 5[day/W] \times \int_0^\infty 4 \times 10^7 [Bq/day] \times e^{-\lambda t} dt \cong 2.5 \times 10^{13} [\text{decay}] \qquad (1)$$

Table 4 summarizes the cumulative 1-cm dose equivalent for three months for each set of geometric parameters of the tank size and the distance from the tank wall and these data for the tank thickness of 3mm are also shown in Fig. 2. It is confirmed that the effective dose around the tank never exceeds 1.3 mSv/3months for any condition in Table 4 and a sufficient margin against the dose limit can be secured at 2m from the tank. Figure 3 shows the results for a thicker tank of 1-cm iron. When it was the tank with the thickness of 0.3cm iron sidewall and volume is 27 cubic meters, without taking scattering from the floor of concrete into consideration, it had estimated to 83% with S.D. was 4.3%. These data are useful for a check of security for radiation safety management. The technique for estimating the cumulative dose proposed in this report can also be applied to other facilities by substituting several parameters.

3.2 Dose from ^{131}F

The maximum amount of radioactive nuclides, which flow into the tank per 3 months, was estimated 4.8×10^8[Bq] as stated in the previous section. Therefore, the amount of decay [A] of the radioactive nuclides in the tank for 3 months was calculated to 1.6×10^{14} [decay].Figure 4 shows the results for a thicker tank of 1-cm iron. The dose rate around the tank with full and 1/10 are storing waste fluid for a 1-cubic meter rectangular parallelepiped is shown in Figure 5.

4. Discussion

The dose around the drain tank calculated under the above conditions was sufficiently low compared with the dose constraints of the Medical Service Law. The proposed method using Monte Carlo calculation, in general, gives a lower value of the dose equivalent compared with that reported earlier using conventional method. It is expected that a more practical design becomes possible by introducing the proposed method. Several types of radionuclides other than ^{18}F are used in actual PET examination. Since a difference in the positron energy hardly affects the energy of annihilation photons, the decay-dose conversion coefficient obtained in this study can be used for other PET nuclides. There remain a few improvements for more accurate evaluation. One of them is an estimation of a fraction of the positron emitting nuclides flowing into the tank. An actual amount of the nuclides may be smaller because the staying time of patients in a control area is short. In the second, a dynamic flow of radionuclides in drainage should be taken into account. It may be very difficult, but necessary to estimate the effect by discussing about 1) how to estimate the rate of mixing from the amount used in the drain tank; 2) how to estimate the amount of drain water; 3) comparison between the evaluated results and the actually measured values.

In general, drain tanks are installed in order to reduce the activity of radioactive nuclides by their decay. In the case of positron emitters they have a relatively short half-life. From a viewpoint of cost-benefit comparison, the expense of installation and maintenance of drain tanks and the possibility of increasing radiation exposure should be discussed carefully.

5. Conclusions

The Monte Carlo code EGS4 was employed to estimate the effective dose around a drain tank for positron emitting nuclides in PET facilities. In this estimation, two major improvements on the previous techniques were carried out, by taking account of the shield effect of both the water and the iron wall, and by supposing a uniform distribution of radioactive nuclides within the drain tank. Based on these assumptions, the dose per decay of radionuclide was calculated for several geometric parameters. The calculated dose was then converted into the dose equivalent for three months, and compared with the dose limits. It was confirmed that the calculated dose around the drain tank in the present condition was sufficiently lower than with the dose limits of the Japanese Medical Service Law.

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Acknowledgment

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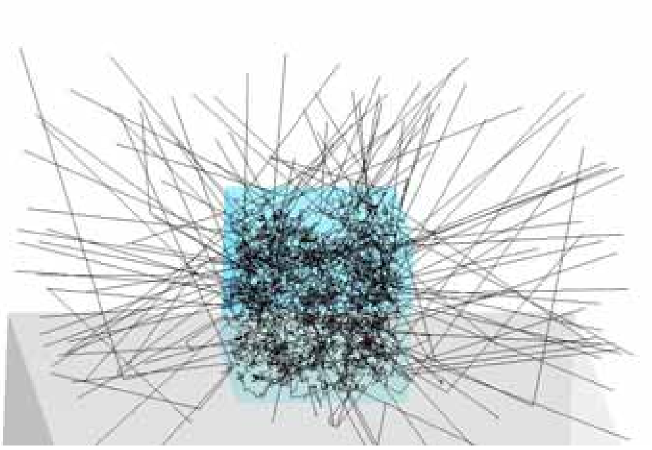

Figure 1 shows the trajectory of 500 positrons emitted and all secondary radiation in the 27-m^3 tank.

Table 1. Average water absorbed dose from ^{18}F per decay around a radionuclide reservoir tank with a 3-mm iron wall

Distance from tank wall	*Length of a side of the tank*		
	1 m	2 m	3 m
1 m	33±0.5, (1%)	11±0.3, (2%)	5.6±0.6, (11%)
2 m	12±0.3, (2%)	5.1±0.2, (4%)	2.5±0.1, (5%)
3 m	5.3±0.6, (11%)	2.5±0.1, (5%)	1. 5±0.1, (7%)
4 m	3.7±0.2, (4%)	1. 6±0.1, (6%)	1. 1±0.1, (8%)
5 m	2.4±0.1, (5%)	1±0.1, (8%)	0. 7±0.1, (10%)

Unit: 10^{-19} Gy/decay, mean ± standard deviation (relative error)

Table 2. Dose Equivalent (H (10)) from ^{18}F per decay around a radionuclide reservoir tank with a 3-mm iron wall

Distance from tank wall	*Length of a side of the tank*		
	1 m	2 m	3 m
1 m	94±3.8	30±2.1	14±1.4
2 m	29±2.1	13±1.5	5±0.9
3 m	16±1.5	7±1.2	4±0.7
4 m	8±1.2	4±0.9	3±0.7
5 m	6±0.1	2±0.4	2±0.5

Unit: 10^{-19} Sv/decay, mean ± standard deviation

Table 3. Transmission of radiation from ^{18}F through an iron wall

Distance from tank wall	*Rate of transmission of the iron tank wall for radiation Mean (S.D.)*		
	tank wall = 1 mm	tank wall = 3 mm	tank wall = 10 mm
1 m	100% (37%)	101% (15%)	27% (7%)
2 m	102% (21%)	101% (21%)	28% (10%)
3 m	100% (22%)	100% (22%)	32% (12%)
4 m	100% (26%)	101% (26%)	51% (17%)
5 m	100% (31%)	102% (31%)	47% (21%)

Note: The Reservoir Tank is of a rectangular parallelepiped shape, and the volume is 27 m^3.

Table 4. Dose Equivalent (H (10)) from ^{18}F per 3 months around a Reservoir Tank

Distance from tank wall	*Length of a side of the Radionuclide Reservoir Tank*		
	1 m	2 m	3 m
1 m	240±9.5	74±5.4	34±3.6
2 m	73±5.2	32±3.6	14±2.4
3 m	41±3.9	19±2.9	8.9±1.8
4 m	21±2.9	11±2.1	7.6±1.8
5 m	14±2.5	4.2±1.1	4.1±1.2

Note: This simulation was calculated with the assumption that the total dosage of ^{18}F is 4GBq at the prescribed time per 3 months. Unit: μSv/3months, Dose Equivalents are indicated as mean ± standard deviation

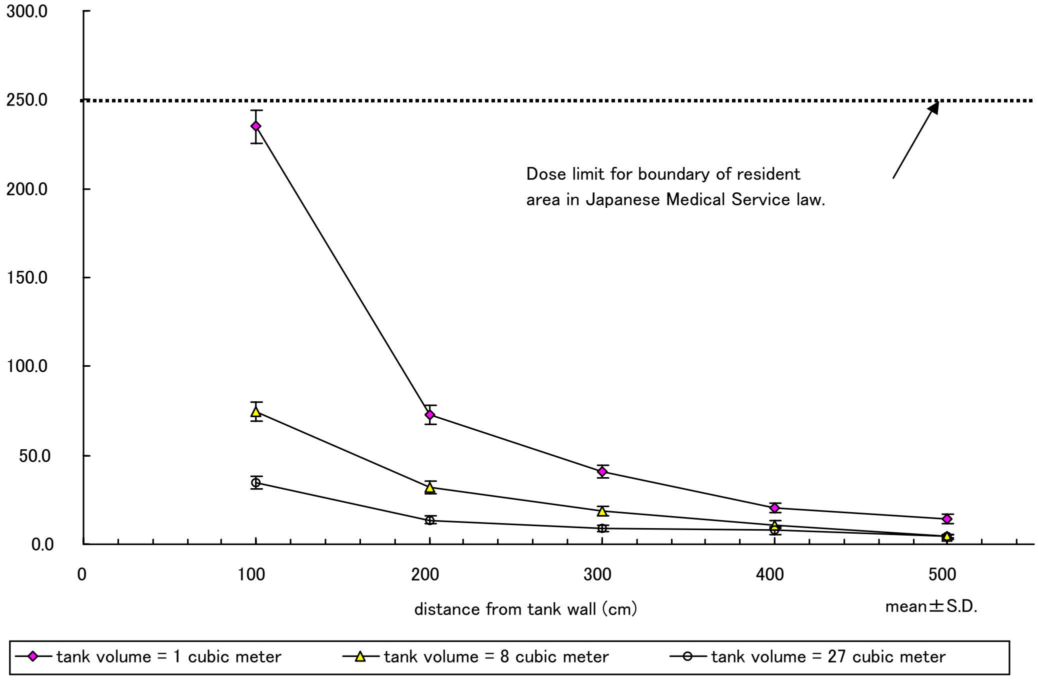

Fig. 2 Cumulative dose from ^{18}F around tanks with a 3-mm iron wall for 5 × 10^{14}decaiy over 3 months

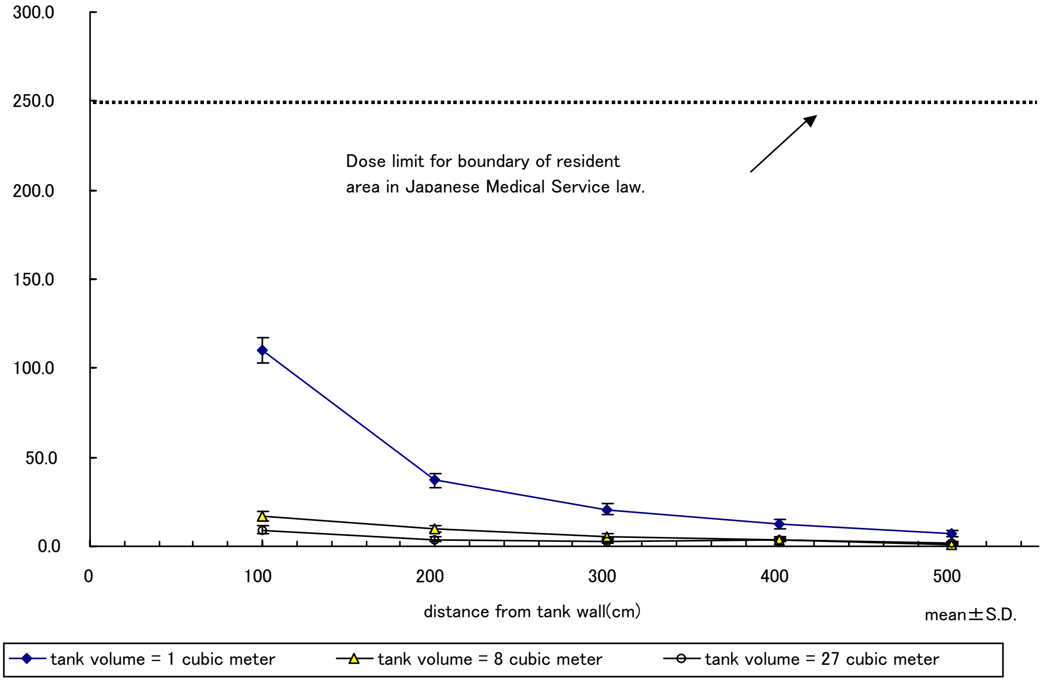

Fig. 3 Cumulative dose from ^{18}F around the tanks with a 1-cm iron wall for 5 x 10^{14}decay over 3 months.

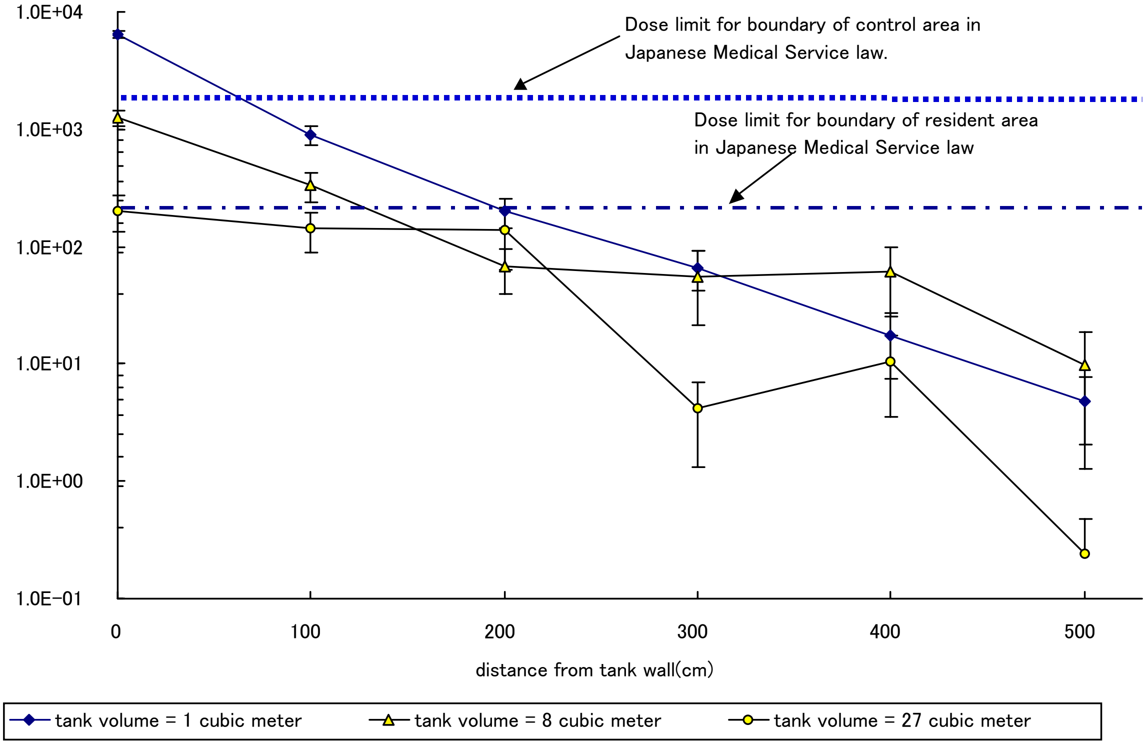

Fig. 4 Cumulative dose from ^{131}I around the tanks with a 3-mm iron wall for 1.6 x 10^{14}decay over 3 months.

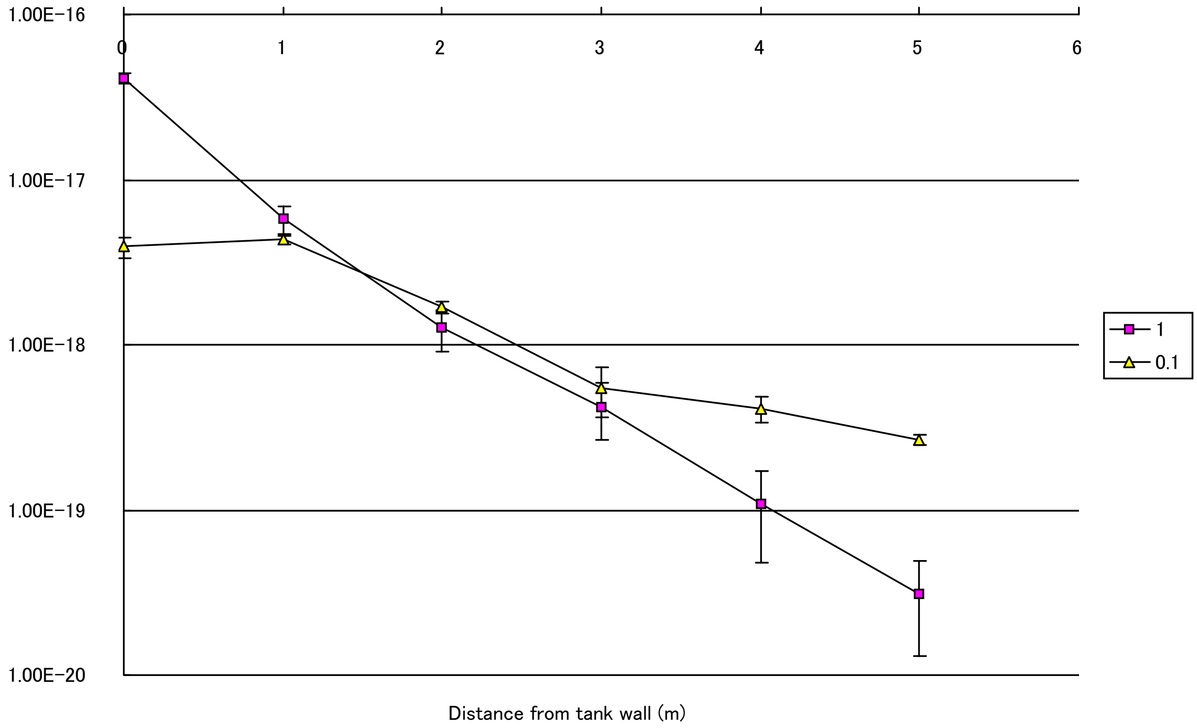

Figure 5 shows the dose rate around the tank with full (1) and 1/10(0.1) are storing waste fluid for a 1-cubic meter rectangular parallelepiped contained with ^{131}I.