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# Analysis of External Gamma Exposure

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## Abstract

The effect of average gamma energy on the external radiation dose has been analyzed. Cloud- and groundshine have been calculated according to the average gamma energy. Monte Carlo integration method was used for the calculation of cloudshine and Romberg quadrature method was adopted for groundshine. The analysis shows that the external gamma exposure is strongly dependent on the gamma energy and the distribution of radiation sources.

## I. Introduction

Estimation of gamma absorbed dose due to the release of radioactive materials is an essential requisite for radiation protection in emergency. The calculation of external gamma dose is the most difficult part of the dose evaluation because of the changing cloud deposition, the increasing plume size, and the long mean free paths of gamma rays in the air.[1] Several researchers have proposed simplified external dose calculation models based on the Gaussian type concentration distribution.[2-5] These model may not fit in a real environmental situation which often has a complex terrain surface and a non-uniform wind field. In order to develop a dose model which can be applied on a complex situation, the analysis gamma exposure is required.

The objective of this study is to analyze the effect of average gamma energy on the external gamma dose. For this purpose, cloud- and groundshine have been calculated according to the average gamma energy on several cases using Monte Carlo integration method[6,7] and Romberg quadrature method[8]. The sample-mean method has been used to calculate the gamma dose due to a rectangular which contains radioactive materials in Monte Carlo integration.

## II. External Gamma Exposure

For a point source of monoenergetic gamma emitting isotropically with activity of q Curie, the absorbed dose rate to a tissue at a distance r is given by[9]:

$$_{\gamma}\dot{D}_{(x,y,z,t)} = 0.0404 \frac{\mu_a \cdot q \cdot E_{\gamma} \cdot B(\mu, \mu_a, r) \cdot e^{-\mu r}}{r^2} \tag{1}$$

where r is the distance from the source to the receptor, $\mu_a$ is the energy absorption coefficient for air, $\mu$ is the total attenuation coefficient for air, B is the dose build-up factor and $E_{\gamma}$ is the average gamma energy emitted at each disintegration. The buildup factor used in this study was proposed by Gamertsfelder[9]:

$$B(\mu, \mu_a, r) = 1 + k \mu r , \tag{2}$$

where k is $(\mu - \mu_a)/\mu_a$ and Fig.1 shows $\mu$ and $\mu_a$.

The external dose rate absorbed by a receptor on the ground due to the radioactive materials distributed in the air is obtained by integrating the equation (1) over the entire hemisphere, that is:

$$_{\gamma}\dot{D}_{cl} = \int_0^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} {}_{\gamma}\dot{D}_{(x,y,z,t)} \, dx \, dy \, dz \tag{3}$$

The radioactive materials on the ground result in additional gamma dose to the public for a period of time even after the cloud has passed. The external dose rate due to the radioactive material deposited on the ground is given by[9]:

$$_{\gamma}\dot{D}_{gr} = 0.0404 \, \mu_a \cdot q \cdot E_{\gamma} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{(1 + k/2 \, \mu r) \cdot e^{-\mu r}}{r^2} \, dx \, dy \tag{4}$$

where k/2 is used in the build-up factor to account for the loss of the scattered radiation, $r = (b^2 + x^2 + y^2)^{1/2}$ and b is the shortest distance from the ground to the receptor.

## III. Analysis of Gamma Exposure

To analyze the effect of average gamma energy, cloudshine was calculated using Monte Carlo integration method for point source and volume sources. In this study, the sample-mean Monte Carlo method has been used for computing three-dimensional integrals. This method is based on the representation of the integral as a mean value.

$$I = \int_a^b g(x) \, dx , \tag{5}$$

is to represent it as an expected value of some random variable. Rewriting Eq(5) as

$$I = \int_a^b \frac{g(x)}{f_x(x)} f_x(x)\, dx \,, \tag{6}$$

assuming that $f_X(x)$ is any probability distribution function such that $f_X(x) > 0$ when $g(x) \neq 0$.

Then

$$I = E\left[\frac{g(x)}{f_x(x)}\right], \tag{7}$$

where the random variable X is distributed according to $f_X(x)$.

If the random variable is uniformly distributed

$$\text{If} \quad f_x(x) = \begin{cases} \frac{1}{b-a} & \text{for } a < x < b, \\ 0 & \text{otherwise;} \end{cases} \tag{8}$$

then

$$I = (b - a)\, E\,[g(X)]. \tag{9}$$

An unbiased estimator of I is its sample mean

$$\theta = (b-a)\frac{1}{N}\sum_{i=0}^{N} g(X_i). \tag{10}$$

Then the integral of Eq(3) can be carried out with Monte Carlo integration method using the following equation.

$${}_{\gamma}\dot{D} = (\Delta x \Delta y \Delta z)\frac{1}{N_t}\sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{k=1}^{n} {}_{\gamma}\dot{D}_r(X_i, Y_j, Z_k) \tag{11}$$

where, $N_t = l \times m \times n$

$\Delta x = x_{i+1} - x_i$

$\Delta y = y_{i+1} - y_i$

$\Delta z = z_{i+1} - z_i$

The results obtained with the Monte Carlo method are presented in Figs. 2 and 3. Fig.2 shows the effect of the size of the regular hexahedrons of gamma source on the receptor apart 1 m from the source. It also shows that the minimum exposure dose rate is represented around 0.07 MeV when the size of a hexahedrons is small. But gamma dose rate increases monotonically when the size is large with $V = 50^3$ $m^3$. This phenomenon can be explained qualitatively with Fig.3. It shows the effect of the source-receptor distance on the gamma dose rate due to the volume source of V = 1 $m^3$. Comparing four lines obtained with four different source-receptor distance, it is known that the contribution of sources with low average gamma energy below 0.07 MeV is negligible when source apart far distance more than 50 m. It is due to the effect of attenuation and absorption of photon in the air represented in Fig.1. And this phenomenon makes the monotonic increase of gamma dose rate given from a large volume source. Fig.4 shows the gamma dose rates at height of 1 m above the ground contaminated with unit radiation source as a function of the radius of the circle. In case of groundshine, the minimum values are obtained around 0.07 MeV regardless of the size of area source.

### IV. Conclusions

The characteristics of external gamma exposure has been analyzed. Cloud- and groundshine have been calculated for different size of gamma sources and different source receptor distances. From this assessment, it is founded that the gamma exposure rate is strongly dependent on the configuration of radiation source in the air. The obtained results can be used as a basis for the development of a real-time radiological dose assessment model.

## References


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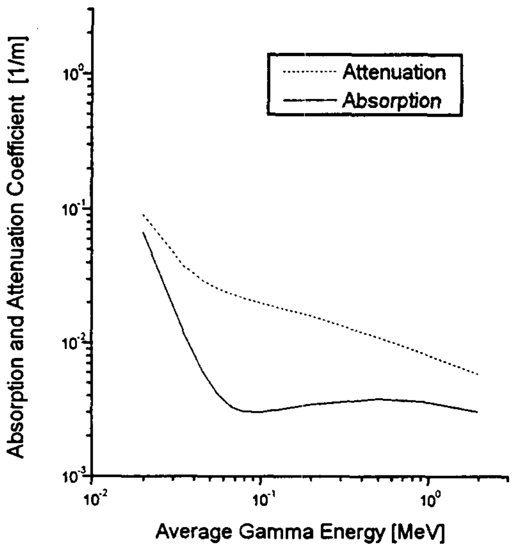


Fig.1 Attenuation and Absorption Coefficients.

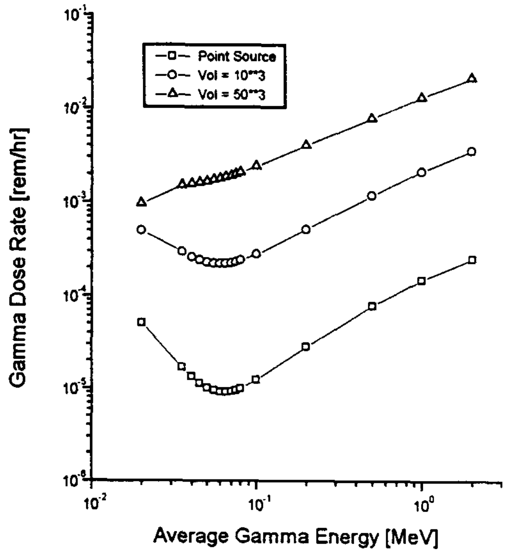


Fig.2 Effects of Volume on Cloudshine.

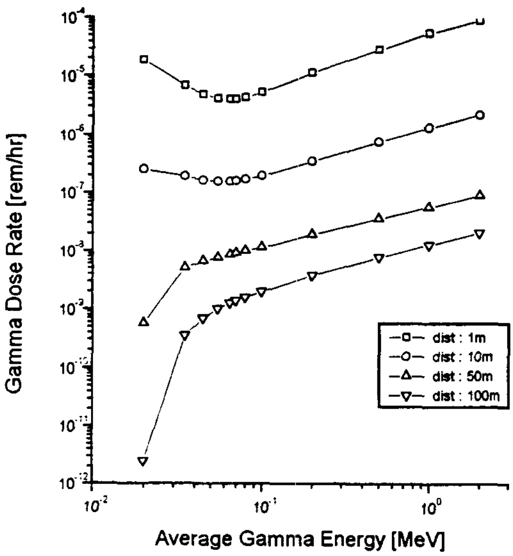


Fig.3 Effects of Distance on Cloudshine.

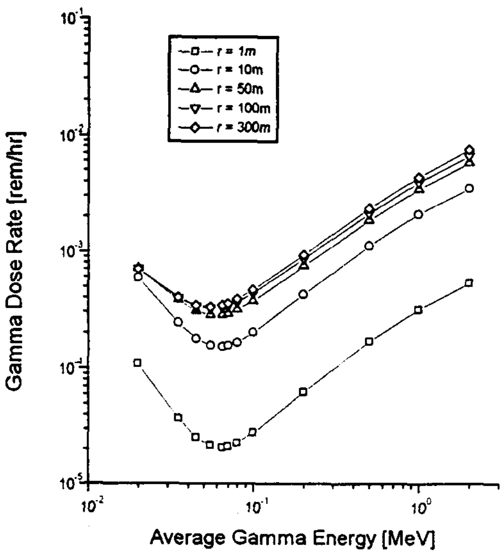


Fig.4 Effects of Area on Groundshine.