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Shielding Thickness Calculations for Line Gamma-ray Sources in Regular Geometrical Array

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—**ABSTRACT**—

A shielding calculation has been carried out for a storage vault of 5292(42 ×42×3) waste drums in which the mixed radioactive gamma-emitters are contained.

The required ordinary concrete shielding thickness seems to be approximately 50cm. The results in terms of dose rate for polyenergy gammas appear to be considerably higher than those of the averaged energy gamma.

1. Introduction

One of the important problems associated with the storage vault design, for the mixed form of various radioactive materials in regular geometrical array, is to calculate the shielding thickness. The solution to this problem involves many assumptions which simplify the calculations.[1] For instance, the geometrical complexity is simplified to a single-point, -spherical, -cylindrical, or -rectangular source, and polyenergy gammas to a single energy gamma(or averaged gamma). Although there is a merit in economy of the computing time, the simplification gives rise to a large error in the results.

In this study, we have therefore attempted to get the reliable shielding design parameter, i.e., concrete wall thickness, for the storage vault of radioactive waste drums by minimizing the approximation process.

2. Theoretical Background

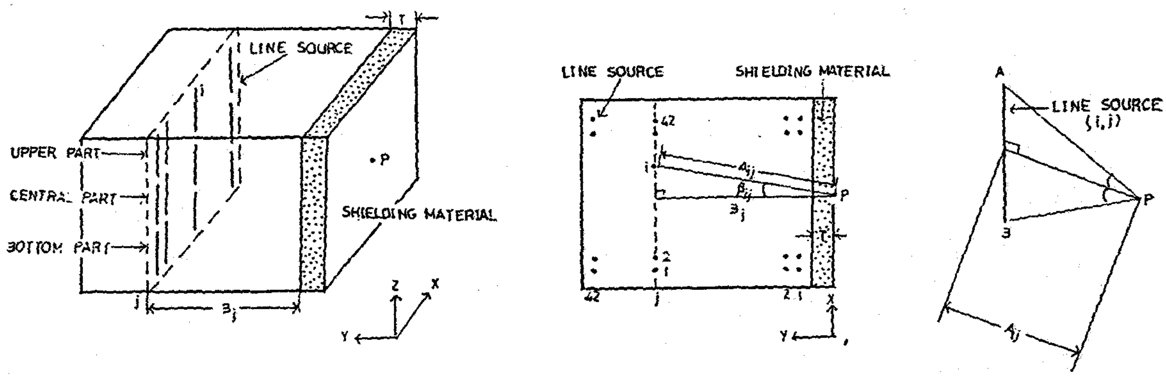
If the radioactive material is assumed to be uniformly distributed in the vertical hole of the waste drum, it can be approximated to be of line source. For the sake of simplicity in calculation, it is assumed that the edge-to-edge space between the drums is filled with the identical concrete while total concrete volume remains unchanged.

The gamma-ray flux(ϕ_r) at a detector, P, due to the uniformly arrayed line sources(Fig. 1) can be thus described by the expression,[2]

$$\phi_r=\phi_u+\phi_c+\phi_b \cdots\cdots (1)$$

with $\phi_u=\sum_{i=1}^{42}\sum_{j=1}^{42}\frac{S_L}{4\Pi a_{ij}}\sum_{l=1}^{2}A_l[F(\theta_{Bij},\ d_{ijl})-F(\theta_{Aij},\ d_{ijl})]$

$$\phi_c=\sum_{i=1}^{42}\sum_{j=1}^{42}\frac{S_L}{4\Pi a_{ij}}\sum_{l=1}^{2}A_l[F(\theta_{Aij},\ d_{ijl})-F(\theta_{Bij},\ d_{ijl})]$$



(A) (B) (C)

Fig. 1. Line Sources and Detector (P) : (A) Line Sources Array in X-Y-Z Coordinates, (B) Line Sources Array in X-Y Plane, (C) Source to Detector (P) Distance, A_{ij}

$\phi_B=\phi_u$

Here ϕ_u : the gamma-flux due to the upper part of the stacked drums

ϕ_c : the gamma-flux due to the central part of the stacked drums

ϕ_b : the gamma-flux due to the bottom part of the stacked drums

S_L : the line source strength, photon/cm-sec

$a_{ij}=(b_j+t)\ \sec\beta_{ij}$ (Ref. to Fig. 1)

t : the shielding thickness to be determined

$d_{ijl}=(1+\alpha_l)\mu\cdot a_{ij}$

μ : the linear attenuation coefficient, cm^{-1}

$A_2=1-A_1$

$\alpha_l,\ A_l(l=1,2)$: the coefficients in Taylor's formula for build-up factor[3]

$F(\theta, d)$: Sievert integral

$$=\int_0^{\theta}\exp(-d\sec\theta')d\theta'$$

If the gamma-ray flux is determined, subsequently the dose rate, D(mrem/hr), is calculated by

$$D=K\phi_r \quad\cdots\cdots(2)$$

where K is the flux-to-dose conversion factor.

3. Radiowaste Drum and Geometrical Array

As is shown in Fig. 2, the waste drum has a dimension of 60.72cm dia. and 90cm high, and is filled with ordinary concrete. A vertical hole of 7.62cm dia. and 80cm high is drilled in the ordinary concrte for which the radiowaste of the possible fission products can be inserted. The waste drums are stacked three high and arranged into a 42×42 planar array(cf. Fig. 3). The radiowaste consists of the mixed elements as can be seen in Table 1. Data on their nuclear properties were taken from Ref. 4.

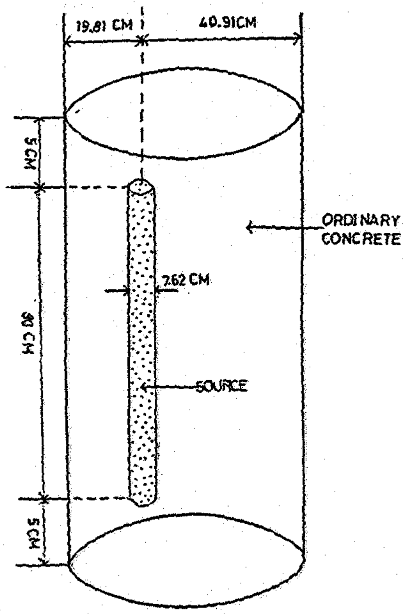


Fig. 2. Radiowaste Drum with Hole

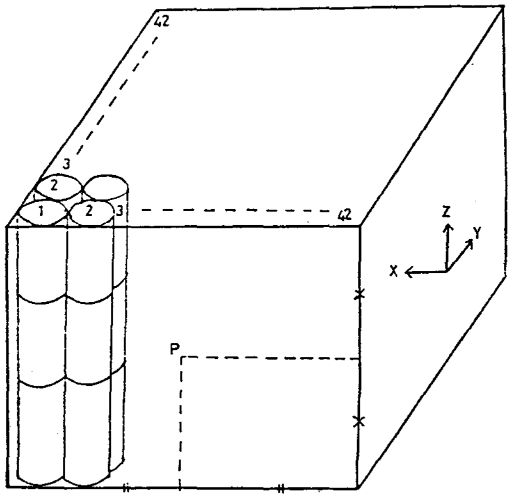


Fig. 3. Geometrical Array of 5292 Radiowaste Drums

Table 1. Radioactive Elements Under investigation with Their Nuclear Properties

Element	Half life	Average gamma energy (MeV)	μCi/cc
Mn- 54	303d	0.835	3.700×10^{-3}
Fe- 59	45.6d	0.963	5.400×10^{-4}
Co- 58	71.3d	0.746	4.700×10^{-3}
Co- 60	5.2y	1.252	2.800×10^{-3}
Sr- 89	52.7d	0.011	7.400×10^{-8}
Y- 91	59d	0.013	6.000×10^{-6}
Zr- 65	65.5d	0.755	1.862×10^{-4}
Nb- 95	35d	0.765	2.800×10^{-4}
I-131	8.05d	0.376	5.684×10^{-3}
Cs-134	52.0d	0.704	1.514×10^{0}
Cs-136	13.5d	0.683	9.123×10^{-3}
Cs-137	30d	0.662	3.995×10^{0}
Ce-144	284d	0.131	2.470×10^{-5}
	Overall average	0.673MeV	5.541μCi/cc

4. Calculation

Eq. (1) was numerically calculated with the aid of an electronic computer, CYBER-70. Sievert integral was obtained from Ref. 2. Originally it is given as a graphical form, and for the calculational convenience was therefore transformed into an analytical form by employing a least-squares method.

The results got for the mixed radioactive elements were compared with the computed value for the single energy gamma source (or the overall average energy gamma source).

A numerical calculation of Eq. 2 was made by the computer as mentioned above. In the conservative point of view, the dose calculation was based on the flux-to-dose conversion factor of the uncollided photon.

5. Results and Discussion

In Table 2 are summarized the calculated results for ordinary concrete. As can be seen in Table 2, it is clear that there is a significant difference between results based on the overall average energy gamma and polyenergy gamma, say gamma-rays from mixed radioactive elements. For comparison, the computing time was presented in the last row.

According to the calculated results for the polyenergy gammas, the shielding thickness required seems to be about 50cm or so. It should be added, however, that an overestimation of the dose may be made because the dose calculation was performed on the basis of

Table 2. Comparison of Dose Rate as a Function of Ordinary Concrete Shielding Thickness

Shielding thicknes (cm)	Dose rate (mR/hr)	
	Overall average energy	Polygamma energy
0	4.2818×10^{2}	4.5932×10^{3}
30	6.9094×10^{0}	7.9366×10^{1}
35	2.9930×10^{0}	3.5162×10^{1}
40	1.2202×10^{0}	1.4640×10^{1}
45	5.1462×10^{-1}	6.3063×10^{0}
50	2.2876×10^{-1}	2.8033×10^{0}
Computing time	70 sec	400 sec

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virgin gamma-ray energy spectrum, being independent of scattering in material. Nevertheless, this result is acceptable in the standpoint of radiation protection.

Summing up the above, it is concluded that a shielding calculation should be based on the polyenergy gammas rather than the averaged energy gamma when the mixed radioactive elements present.

References

1) R. G. Jaeger and E. P. Blizard (Ed.), "Engineering Compendium on Radiation Shielding," pp. 363-367, Spring-Verlag, Berlin (1968).
2) T. Rockwell Ⅲ (ed.), "Reactor Shielding Design Manual," pp. 345-425, D. Van Nostrand Co., Inc., New York (1956).
3) H. Goldstein and J. E. Wilkins, Jr., "Calculations of the Penetration of Gamma-rays," NYO-3075 (1954).
4) C. M. Leaderer, J. M. Hollander and I. Perlman, "Table of Isotopes," 6th Ed., John Wiley and Sons, Inc., New York (1967).

—抄　　錄—

감마선을 放出하는 放射性廢棄物드럼 5292개 (42×42×3) 貯藏施設의 適正 콘크리트 遮蔽體 두께를 算出하였다. 廢棄物이 여러가지 種類의 放射性元素로 構成되어 있다고 할때 平均한 감마선 에너지와 個個 감마선 에너지에 대하여 計算한 結果를 서로 比較하였다.

그 結果 適正遮蔽體의 두께는 50cm 程度로 判明되었다. 그런데 平均 감마선 에너지에 根據하여 計算한 線量値는 個個 감마선 에너지에 대한 값보다 同一두께의 遮蔽體에 대해서 훨씬 적었다.