A METHOD FOR STANDARDIZATION OF METHODOLOGIES FOR THE DETERMINATION OF THE CURIE CONTENT FOR LOW-LEVEL RADIOACTIVE WASTES PACKAGES

Changfuh Lan, Rodney D. Kinard, & Elizabeth G. Hough
Nuclear Production Department
Duke Power Company
Charlotte, NC 28242

ABSTRACT

This paper presents a simple, practical procedure as a standard method for converting exposure dose rate (mr/hr) into curie content for packaged radioactive waste. A right circular cylinder and a 4' x 4' x 6' rectangle models are used as the geometrical shapes simulating drum and box shipping container. A family of curves is utilized in the conversion of radwaste package exposure dose rate measurements to curie content. This method takes into account waste package and detector geometry, shielding and attenuation effects, the effective gamma energies of the emitted photons, and the number of photons per decay.

INTRODUCTION

Most of currently used methods to quantify the activities of individual radionuclides in low-level radioactive waste package have been based on conversion methods. These methods include the use of sophisticated computer codes, vendor-supplied curves of radiation exposure rate to curie conversion and rules of thumb and historical relationships. At a recent radwaste workshop the general opinion revealed by most of the participants was that estimates of both the total curie content and individual radionuclide quantities in waste packages are believed to be conservatively high by a factor of 2 to 100 (EP 82)[1].

Regulatory requirements related to the storage and disposal of solid radioactive waste are becoming increasingly restrictive and have added importance to accurate quantitative and qualitative determinations of the composition of solid radwaste. There is substantial agreement among those in the nuclear industry that we should be more accurate, and that standardization should be applied to the process of determining packaged radwaste curie content. The penalties for being grossly conservative will become more evident with the implementation of 10 CFR 61 and the waste classification scheme.

A large amount of present effort has been spent in developing a more accurate, reliable formula to calculate the total curie content of radioactive waste packages and standardizing its application for all our nuclear power stations. To develop such a formula for converting radwaste package exposure reading into curie content, we must take into account waste package and detector geometry, shielding and attenuation effects, the effective gamma energies of the emitted photons, and the number of photons per decay.

This paper presents a curie content determination method for 55 gal. drums and large shipping containers (wood or metal boxes), filled with plastic LSA material. A right circular cylinder and a 4' x 4' x 6' rectangle are used as the geometrical shapes simulating the 55 gal. drum and box containers. The LSA material consists of contaminated paper, plastic, and filters commonly utilized at a nuclear power plant. The radionuclides present and the effective gamma energy of the material was calculated from gamma spectra data of smears taken in numerous plant areas. The method accounts for container shielding effects and self-attenuation effects from the waste itself.

DEVELOPMENT OF CONVERSION FORMULA

This method is the result of a collection of formulas normally used in shielding calculation. A family of curves based upon a previously described model of a cylindrical source with self-absorption (Bo 65)[2] will be used in the development of exposure dose rate to curie conversion formula. Figure 1 shows a right circular cylinder model. Figure 2 shows a rectangular model considered as a cylindrical source with an effective radius of R.

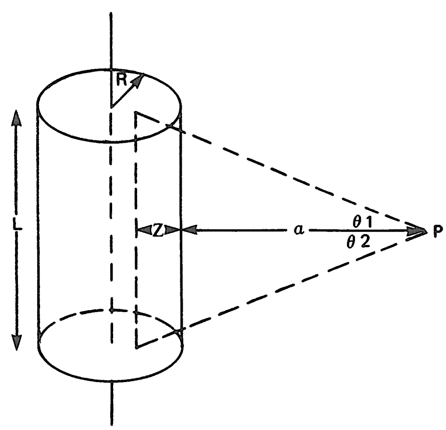

Fig. 1 Cylindrical model representing the 55 gal. drum *radioactive* waste container.

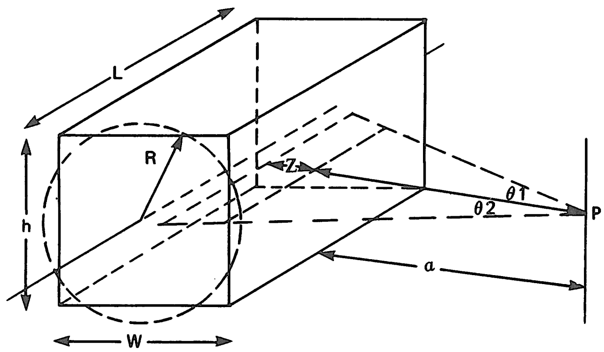

Fig. 2 Rectangular model representing the metal or wood box large radioactive waste container.

For practical purposes, the dose point is measured at a distance from the midpoint of the cylinder such that $\Theta_1=\Theta_2=\Theta$. (Bo 65)[2] has presented the following general equation which applies to the geometrical shape chosen here.

$$I = \frac{S_L}{4\pi r} B[f(y+\mu_s Z,\Theta_1)+f(y+\mu_s Z,\Theta_2)] \qquad \text{Eq.(1)}$$

where: I = gamma ray intensity, MeV $cm^{-2}sec^{-1}$,

S_L = source strength, MeV cm^{-1} sec^{-1},

B = build up factor,

$r = a+Z$, cm,

a = distance from cylinder to the measuring dose point, cm,

Z = the effective center of the cylinder, self attenuation distance, cm,

$f(y+\mu_s Z,\Theta)$ = sievert function,

$y = \Sigma\mu_i X_i$,

X = thickness of container shield, cm,

μ_s = macroscopic cross-section of source material, cm^{-1},

Θ = angle formed by lines drawn from the dosage point to each end of the cylinder.

The relationship between gamma ray intensity and dose rate has been given previously (Bo 65)[1]:

$$D = S \cdot G \cdot A \cdot B \cdot (CF) \qquad \text{Eq.(2)}$$

where: D = dose rate at point P, mr/hr (1 mr = 10 micro S_v)

$S = S_L$

$G = \frac{1}{4\pi r}$, geometric attenuation

$A = 2[f(y+\mu_s Z,\Theta)]$ since $\Theta_1 = \Theta_2$

B = B, based on $y+\mu_s Z$

CF = conversion factor to convert MeV cm^{-2} sec^{-1} to mrem hr^{-1} (1 mrem = 10 micro S_v)

Prior to making any curie calculations from exposure dose rate measurement, it is necessary to make source strength calculations.

I. Source Strength Calculation

1. For Point Source:

$$S(\text{MeV Sec}^{-1}) = \text{Ci} \times \frac{3.7 \times 10^{10}\ \text{dps}}{\text{Ci}} \times \frac{\text{MeV}}{\text{disintegration}} \qquad \text{Eq.(3)}$$

where 3.7×10^{10} dps/Ci is a standard conversion factor.

1 curie = 3.7×10^{10} dis/sec = 3.7×10^{10} Bq

2. For Volume Source:

$$S_v\ (\text{MeV sec}^{-1}\ \text{cm}^{-3}) = \frac{\text{Ci} \times 3.7 \times 10^{10}\ \text{dps/Ci} \times \text{MeV/dis.}}{\text{V cm}^3} \qquad \text{Eq.(4)}$$

Where V cm^3 is volume of waste and equals to $\Pi R^2 L$

(1 Ci = 3.7×10^{10} dps = 3.7×10^{10} Bq)

3. Volume Source to Equivalent Cylinder Source Conversion:

A right circular cylindrical source with constant source strength S_v (MeV sec^{-1} cm^{-3}) can be approximated by a line source having a source strength S_L (MeV sec^{-1} cm^{-1}). Bowers (Bo 65)[1] presented the following equation:

$$S_L = (\Pi R^2) S_v \qquad \text{Eq.(5)}$$

Substituting "Eq.(4)" into "Eq.(5)", the total curie content of a cylinder is given by

$Q = L \cdot S_L / 3.7 \times 10^{10}\, E(\text{MeV})$ Eq.(6)

Where Q is activity in Ci

(Ci = 3.7×10^{10} Bq)

L is container's height or the longest dimension of the container

E is effective gamma energy

II. Dose Rate Curie Content Conversion Formula

Solving "Eq.(6)" by substituting "Eq.(2)" into "Eq.(6)" gives

$$Q = \frac{L \cdot D}{3.7 \times 10^{10} \cdot E \cdot G \cdot A \cdot B \cdot (CF)} \quad \text{Eq.(7)}$$

Equation (7) can be written in simplified form as

$$Q = KD \quad \text{Eq.(8)}$$

Where $K = L/3.7 \times 10^{10} \cdot E \cdot G \cdot A \cdot B \cdot (CF)$

The parameters in determining the conversion factor K can be calculated from the computation form and family of curves.

APPLICATION

Figure 3 shows the computation form for curie content conversion calculation. A family of curves relating the conversion factor (K) with source self-absorption calculation and dose rate calculation is presented in Figs. 4 to 7. The use of computation form:

1. Information for individual nuclear power plants or other institutions and type of container to be used on the waste shipment.

2. A sketch of the container and detector geometry layout is made.

3. Input Data

   a) Effective gamma energy, $\bar{E}$, MeV; calculate E_γ from gamma spectra, based on smears of numerous plant areas or several packages.

   b) Container Shield Material; iron (55 gal. drum, metal box) or wood (wood box), etc.

   c) Thickness: container shield material thickness.

   d) Shield Material Absorption Coefficient ,μ, cm^{-1}; the μ value is determined for effective gamma energy, $\bar{E}_\gamma$, MeV.

4. Source Self-absorption Calculation

   a) Material; trash, evaporator concentrates or resins, etc.

   b) Self-absorption coefficient, μ_s, cm^{-1}; the μ_s value for waste material is determined for effective gamma energy, $\bar{E}_\gamma$, MeV.

   c) Using the values for "a" and "R" from the sketch on computation form, a/R and a+R values are calculated.

   d) a+R is multiplied by the valve of μ_s from 4(b) and the result entered in the μ_s(a+R) column.

   e) Using Fig. 4 and values of a/R and μ_s(a+R), value of "m" is determined.

   f) μ is multiplied by χ from 3(c) and the result entered in the $y = \mu\chi$ column.

   g) Using Fig. 5 and the values of a/R and y, value of $\mu_s Z/m$ is determined.

   h) Values of m and $\mu_s Z/m$ are multiplied together to obtain value of $\mu_s Z$.

   i) Value of $\mu_s Z$ is divided by the corresponding value of μ_s to obtain value of Z.

   j) The value of "a" plus the value of "Z" gives the value of "r" to calculate geometric attenuation, G.

5. Dose Rate Calculation: D = SGAB(CF)

   a) The geometric attenuation is calculated from $G = \frac{1}{4\pi r}$, where r = a+Z.

   b) After the values of y and $\mu_s Z$ are calculated from 4(f) and 4(h), the values of y and $\mu_s Z$ are then summed and entered in $y + \mu_s Z$ column.

   c) Using distances from the sketch on computation form for the opposite sides and the value of r = a+Z for the adjacent side, the value of Θ is calculated.

   d) Using Fig. 6 and values of $y + \mu_s Z$ and Θ, value for $f(y+\mu_s Z, \Theta)$ is obtained, and multiplied by 2 to give "A".

   e) B is obtained from the Radiological Health Handbook or the buildup curves for container shield material (iron, wood. etc) using a value of $y+\mu_s Z$.

   f) Using Fig. 7, value of CF is obtained for effective gamma energy, $\bar{E}$, MeV.

   g) Dose rate measurement, D, mr/hr (1 mr = 10 micro S_γ) is obtained at a distance of 3 feet from the midpoint of the container.

6. Curie Content Conversion Calculation: Q = KD

   a) Conversion factor K is calculated from previously determined or calculated data E,G,A,B and (CF), and L is the height or longest dimension of container obtained from the sketch.

   b) The dose rate curie content conversion formula for this type of container is then developed.

PLANT: ______________________

TYPE OF CONTAINER: ______________________

SKETCH OF SUBJECT GEOMETRY:

3. INPUT DATA

EFFECTIVE GAMMA ENERGY, E, MEV	CONTAINER SHIELD MATERIAL	THICKNESS x, cm	SHIELD MATERIAL ABSORPTION COEFFICIENT, μ, cm^{-1}

4. SOURCE SELF-ABSORPTION CALCULATION:

MATERIAL	SELF-ABSORPTION COEFF. μ_s cm^{-1}				a/R	a+R
μ_s (a+R)	m	$y = \mu x$	$\mu_s z/m$	$\mu_s z$	z, cm	r = a+z

5. DOSE RATE CALCULATION: D = SGAB (CF)

GEOMETRIC ATTENUATION, $g = ¼ \pi r$			SHIELD OPT. THICKNESS & SELF-ABSP. $y + \mu_s z$		
θ=ARCTAN L/2r	f $(y+\mu_s z, \theta)$	$A=2(f(y+\mu_s z, \theta))$	B	CF	D, mr/hr

6. CURIE CONTENT CONVERSION CALCULATION: Q = KD

$K = L / 3.7 \times 10^{10}$ E.G.A.B. (CF)	Q = KD

FIG. 3 COMPUTATION FORM FOR CURIE CONTENT CONVERSION CALCULATION

Fig. 3. Computation Form For Curie Content Conversion Calculation.

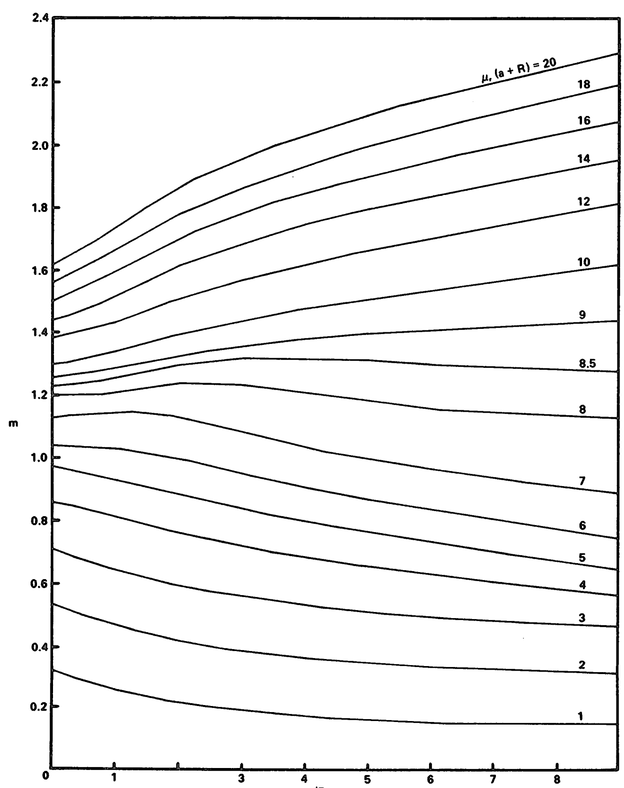

FIG. 4 CYLINDER SELF ABSORPTION PARAMETER, m, a/R<10

FROM: BLIZARD, E. P. AND ABBOT, L. S. (ed.). REACTOR HANDBOOK, 2ND EDITION, VOL. III, PART B. SHIELDING, INTERSCIENCE PUBLISHERS, INC. (1962)

Fig. 4. Cylinder Self Absorption Parameter, m, a/R<10.

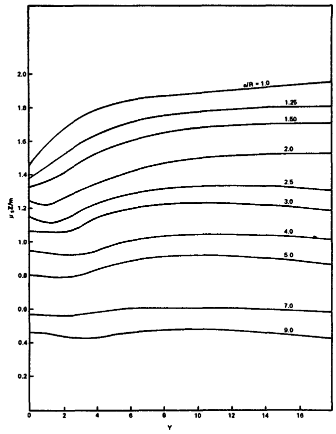

FIG. 5 CYLINDER SELF ABSORPTION, a/R<10 FROM: BLIZARD, E. P. AND ABBOT, L. S. (ed.) REACTOR HANDBOOK, 2ND EDITION, VOL. III, PART B. SHIELDING, INTERSCIENCE PUBLISHERS, INC. (1962)

Fig. 5. Cylinder Self Absorption, a/R<10.

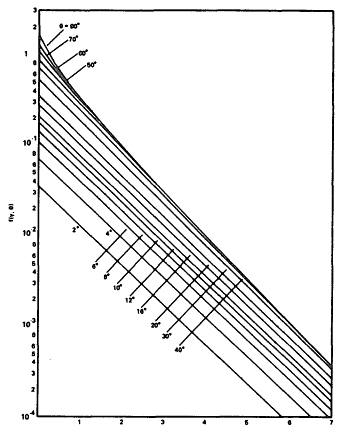

FIG. 6 ATTENUATION FUNCTION FOR A SEMI-INFINITE LINE SOURCE BASED ON DATA FROM "ISOTOPIC GAMMA SOURCES," BIBERGAL, A. V., ET. AL., (1960)

Fig. 6. Attenuation Function for a Semi-Infinite Line Source.

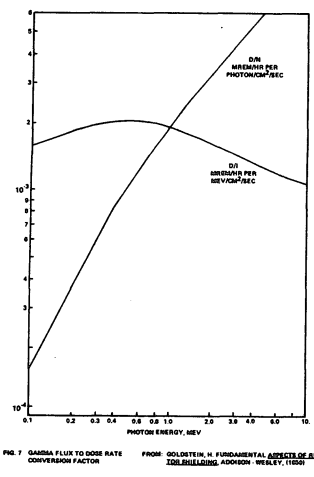

FIG. 7 GAMMA FLUX TO DOSE RATE CONVERSION FACTOR FROM: GOLDSTEIN, H. FUNDAMENTAL ASPECTS OF REACTOR SHIELDING, ADDISON - WESLEY, ([illegible])

Fig. 7. Gamma Flux to Dose Rate Conversion Factor.

EXAMPLE AND RESULT

Given a typical 55 gal. drum of 0.12 cm in wall thickness, having a height of 85 cm and a diameter of 56 cm, filled with compactable trash. Assume that the waste contents density is 1.0 g/cm^3 and a effective gamma energy of 0.59 MeV. From the computation form (Fig. 3) and the sketch (Fig. 1):

3. Input Data

   a) Effective Gamma Energy, $\bar{E}$, MeV: 0.59 MeV

   b) Container Shield Material: iron

   c) Thickness; χ, cm: 0.12 cm

   d) Shield Material Absorption Coefficient, μ, cm^{-1}: 0.6 cm^{-1} (RHH70)[3]

4. Source Self-Absorption Calculation

   a) Material: trash (same density as H_2O)

   b) Self-absorption coefficient, μ_s, cm^{-1}: 0.09 (RHH70)[3]

   c) a/R = 3.27

   d) a+R = 47" or 119.38 cm

   e) $\mu_s(a+R) = 10.7$

   f) m = 1.5

   g) y = 0.072

   h) $\mu_s Z/m = 1.03$

   i) $\mu_s Z = 1.545$

   j) Z = 17.2 cm

   k) r = 108.6 cm

5. Dose Rate Calculation

   a) $G = 7.33 \times 10^{-4}$ cm^{-1}

   b) $y+\mu_s Z = 1.617$

   c) $\Theta = \text{arc tan } \frac{42.5}{108.6} = 21.4°$

   d) $f(y + \mu_s Z,\Theta) = 6.8 \times 10^{-2}$

   e) $A = 2\,(f(y + \mu_s Z,\Theta)) = 1.36 \times 10^{-1}$

   f) B = 4.0 (RHH70)

   g) $CF = 2.05 \times 10^{-3}$ mrem/hr per meV/cm^2/sec[1]

   h) D (mr/hr) = dose rate reading from 3 feet. (1 mr = 10 micro S_v)

6. Curie Content Conversion Calculation

   a) $K = L/3.7 \times 10^{10} \cdot E \cdot G \cdot A \cdot B \cdot (CF)$

   $= 85/(3.7 \times 10^{10})\,(0.59)\,(7.33 \times 10^{-4})\,(1.36 \times 10^{-1})\,(4.0)\,(2.05 \times 10^{-3})$

   $= 4.76 \times 10^{-3}$

   b) $Q\,(Ci) = (4.76 \times 10^{-3})D(mr/hr)$

If the drum dose rate measurement reads 50 mr/hr (50 centi S_v/hr) at 3 feet from the center, the curie (or Becquerel) content is then given by,

$Q = (4.76 \times 10^{-3})\,(50) = 238 \times 10^{-3}$ Ci
or = 238 mCi

$= 8.806 \times 10^9$ Bq

REFERENCES

1. Ep 82 — EPRI NP-2403-LD, Research Project 1568, Workshop Proceedings: Radwaste Radionuclide Measurements and Regulatory Requirements. (Prepared by NWT Corporation, San Jose, CA.)

2. Bo 65 — Bowers, R. R., Geller Leonard, Cagnetta, J. P., Stoller, S. M., Nuclear Power Station Shielding Manual, 1965. Niagara Mohawk Power Corporation, Buffalo, N.Y.

3. RHH 70 — Radiological Health Handbook, 1970. Edited by Bureau of Radiological Health, Rockville, Maryland.