Radiation Physics Note 78

ACTIVITY CONTENT APPROXIMATION IN RADIOACTIVE WASTE DRUMS

Kathy Graden

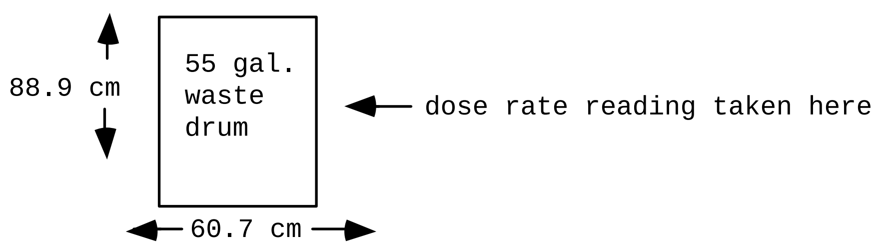
Revised, May 1990

The purpose of this R.P. Note is to characterize the activity content of radioactive waste in a 55 gal. waste drum from a dose rate reading at the surface of the barrel.

The major types of materials that are generated as waste are steel, aluminum copper and plastic. Mn-54, Na-22, Zn-65 and Co-60 are the major activation products of these materials that are of concern.

The assumptions made in determining a formula for activity content within a waste drum are as follows:

1. Uniform distribution of material in drum
2. Cylindrical source (not point source)
3. Average energy of activation products to be 1 MeV
4. Dose rate measurement taken on the surface of drum at the midpoint:



5. Equation for cylindrical source defined as follows (Eq. 1):

$$\dot{D} = \frac{K(E) E S_v R_o^2}{4}\left[\frac{A_1}{a+Z_1} e^{-b_{21}}\left(K(\theta_{11}, b_{21}) + K(\theta_{21}, b_{21})\right) + \frac{A_2}{a+Z_2} e^{-b_{22}}\left(K(\theta_{12}, b_{22}) + K(\theta_{22}, b_{22})\right)\right]^*$$

Where:

S_v = source strength of cylindrical volume isotropic source (disintegrations $cm^{-3} sec^{-1}$).

$\dot{D}$ = total dose rate (R/hr).

K(E) = energy flux to dose rate conversion factor (R/hr per MeV/cm^2 sec).

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* This formula and the tables referred to in the following discussion are from the Photon Shielding Manual, Anthony Foderaro, 2nd ed.

E = energy of source (MeV).

R_o = radius of cylinder (cm).

a = distance from point of measurement to drum on contact, so a=0.

Z_1,Z_2 = self attenuation distance of cylinder (cm). Z_i(i=1,2) are given in Table Z4.

A_1,A_2,α_1,α_2 = buildup factor coefficients, with $A_2 = 1-A_1$.

K (θ_{1i},b_{2i}), K (θ_{2i},b_{2i})= Sievert secant integral given in Table F2.

$b_2 = b_1 + \mu_s Z$, where b_1 = shield thickness, which is 0 in this case.

$b_{2i} = (1+\alpha_i)b_2 = (1+\alpha_i)\ \mu_{si} Z_i$.

μ_s = linear attenuation coefficient (cm^{-1}).

$\mu_{si} = (1+\alpha_i)\mu_s$ (i=1,2).

Because there are various types, combinations and amounts of waste material in each waste drum, general assumptions must be made to characterize the linear attenuation coefficient based on differing densities and mass attenuation coefficients of waste materials. Finally, the value chosen for the equation should provide most conservative estimate of activity in the drum.

The last column in the following table shows the range of linear attenuation coefficient values for typical waste materials.

Isotope/ material	Atomic Number (Z)	Energy (MeV)	ρ (gm/cm^3)	μ_m (cm^2/gm)	μ_s (cm^{-1})
Mn-54	25	0.835	7.2	~0.0600	0.432
Co-60	27	1.25	8.9	~0.0600	0.534
Fe-55	26	0.23	7.86	0.0599	0.470
Na-22	11	1.28	0.971	0.0609	0.059
Copper	29	--	8.94	0.0589	0.527
Aluminum	13	--	2.7	0.0613	0.165
Polyethylene	--	--	0.935	0.0727	0.068
Glass	--	--	4.5	0.0633	0.285

Values taken from the Health Physics and Radiological Health Handbook, 1984, Nucleon Lectern Associates, Inc.

Buildup factor coefficients have been averaged for an energy of 1 MeV for aluminum, iron, ordinary concrete and water (plastic). The following values were taken from Table B2.

Isotope/Material	A_1	α_1	α_2
Aluminum	28.782	-.0682	-.0297
Iron	24.957	-.0609	-.0246
Ordinary Concrete	25.507	-.0723	-.0184
Water (plastic)	19.601	-.0904	-.0252
AVERAGES	24.712	-.0730	-.0245

To illustrate how the conversion factor to convert dose rate to activity content was determined, a dose rate of 1 mR/hr is used.

The variables in the dose rate conversion equation taken from the Photon Shielding Manual are defined as follows:

$\dot{D}$ = 0.001 R/hr
K(E) = 1.84 x 10^{-6} R/hr per MeV/cm^2 sec (Table C1)
E = 1 MeV
R_o = 30.35 cm
a = 0
μ_s = 0.318 cm^{-1}

From Table Z4, $\frac{\mu_{si} Z_i}{m_i}$ = 2.35 (because a=0,b_1,=0)

$\mu_{s1} = (1+\alpha_1)\mu_s$ = (1-0.073) (0.318) = 0.295
$\mu_{s2} = (1+\alpha_2)\mu_s$ = (1-0.0245) (0.318) = 0.310

μ_{s1} x (R_o+a) = (0.295) (30.35+0) = 8.95
μ_{s2} x (R_o+a) = (0.310) (30.35+0) = 9.41

Again, From Table Z4, m_1 = 1.26, m_2 = 1.28

Therefore, $Z_1 = \frac{(2.35)(1.26)}{0.295} = 10.04$

$Z_2 = \frac{(2.35)(1.28)}{0.310} = 9.7$

From the average values of buildup coefficients given above, A_1 = 24.71 and A_2 = 1-A_1=-23.71.

And, b_{21} = (1-0.073)b_2 = 0.927 $\mu_{s1}Z_1$ = 2.746

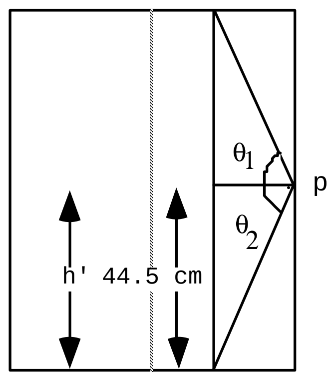
b_{22} = (1-0.0245)b_2 = 0.976 $\mu_{s2}Z_2$ = 2.935

Since the dose rate measurement is made at the midpoint of the drum (point P), $\theta_1 = \theta_2$ (see Figure below). From this, $\theta_{11} = \theta_{12}$ and $\theta_{21} = \theta_{22}$.

From the Figure, $\tan\theta = \frac{h'}{Z}$ so $\theta = \tan^{-1}\left(\frac{h'}{Z}\right)$, where h' is one half the height of the drum.

Then $\theta_{11} = \theta_{12} = \tan^{-1}\left(\frac{44.45}{10.04}\right) = 77.3^{o}$.

And $\theta_{21} = \theta_{22} = \tan^{-1}\left(\frac{44.45}{9.70}\right) = 77.7^{o}$.



With these values and by use of Table F2, the term in brackets [ ] in equation 1 is 0.0412.

And, $\dot{D} = 1.745 \times 10^{-5} \times S_v$.

For a dose rate $\dot{D}$ of 1×10^{-3} R/hr,

$S_v = 57.3$ disintegrations - sec^{-1}-cm^{-3},

or $S_v = 1.548 \times 10^{-6}$ mCi-cm^{-3}.

Total activity content of the drum can be obtained by multiplying by the volume, $V=\pi r^2 h = 2.573 \times 10^5$ cm^3.

Therefore, the activity per mR/hr measured at the surface of the drum at its midpoint is:

$$\text{Activity} = 1.548 \times 10^{-6} \times 2.573 \times 10^{5} = 0.398 \text{ mCi}.$$

Based on the assumptions discussed above, a dose rate of 1 mR/hr measured at the midpoint of the drum is approximately equal to 0.4 mCi of activity.

To be conservative, a factor of 2 overestimate will be used to approximate the activity of the waste drum. Thus, a measured dose rate of 1 mR/hr represents an activity of 0.8 mCi, or rounding, an activity of 1 mCi. In conclusion, the approximate activity in millicuries is equal to the dose rate in mR/hr measured at the surface of midpoint of the drum.