A CALCULATIONAL TECHNIQUE FOR ESTIMATING GAMMA RADIATION ABSORPTION IN LOW-LEVEL WASTE

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ABSTRACT

A calculational technique was developed for estimating gamma radiation absorption in low-level waste to predict combustible gas generation. The absorbed portions of gamma radiation energy were calculated with various energy levels, waste container geometries, and waste densities. The results were expressed as container specific equations with the functions of energy and waste density. This form of expression can be easily applied to generic low-level wastes.

Introduction

Combustible gas generation in low level waste is caused by radioanalysis resulting from radioactive decay of the nuclides contained in the waste. The majority of radiation sources are beta and gamma emitting nuclides. Beta radiation, including internal transition electron emission energy, is assumed to be totaly absorbed by the waste form. Therefore all beta emission energy contributes to the production of gases. A significant portion of the energy emitted by gamma decay is not absorbed by the waste, and does not contribute to gas production. Accurate calculation of combustible gas generation requires identification of the fraction of gamma radiation that is absorbed in the waste. A method developed to quantify the absorbed gamma fraction is described below.

Method

The technique developed is an application of a shielding calculation based on recent health physical data. A similar study has been done by EPRI* to estimate radionuclide concentrations in low level waste using external radiation measurements.[1] The computation is based on an equation for point-to-point relations of radiation attenuation and absorption. For a discrete gamma ray, the equation can be expressed as:

$$E_{abs}^{Point}(r) = I_o \cdot \mu_{am} \cdot \frac{\exp(-\mu_e r)}{4\pi r^2} \cdot B(\mu_e r) \qquad (1)$$

where

r = Distance from a source point, cm

$E_{abs}^{Point}(r)$ = Absorbed energy at a point, Mev/g/sec/cm^3

I_o = Source intencity, MeV/sec/cm^3

μ_{am} = Mass absorption coefficient, cm^2/g^2

μ_e = Liner attenuation coefficient, 1/cm

$B(\mu_e r)$ = Energy absorption buildup factor

To obtain total absorbed energy in the waste media, this equation is integrated over the source and irradiated volume as,

$$E_{abs}^{Total} = \rho \int_{V_R} \int_{V_S} E_{abs}^{Point} dV_R \, dV_s \qquad (2)$$

where

E_{abs}^{Total} = Total absorbed energy inside the waste media, MeV/sec

ρ = Density of waste, g/cm^3

V_R, V_S = Volume of irradiated or source media, cm^3

The integrations in Eq. (2) are replaced as simple sums of Eq. (1) and calculated by a point-kernal type shielding code QAD-FN[2], and by a desk top computer. The code, QAD-FN, is currently used at the Idaho National Engineering Laboratory and is a version of the QAD code originally written by R.E. Malenfant. The code was modified to calculate internal gamma energy deposition by placing the detection point network inside the modeled waste container and increasing the number of source and detection points. This allowed calculation of absorbed energy for larger container types. This technique was applied to four different waste configurations; 55 gal drum, 4 x 4 liner, 6 x 6 liner, and an intermediate sized liner (5 x 5). The source and detection point networks were carefully examined and modified for each configuration. The modeled configurations of these containers and the number of source and detection points are listed in the table below. The numerical error for these cases are in the order of 1%.

* The method examined below differs from the EPRI technique in placement of detection points.

Case No.	Radius/ Height [cm]	Source/Detection Points [-]	Note
1	30/90	67,500/48	55 gal drum
2	60/120	270,000/81	4 x 4 liner
3	70/140	350,000/100	5 x 5 liner
4	90/180	810,000/121	6 x 6 liner

Radiological Constants

There are three major constants which affect gamma energy absorption; absorption coefficients, attenuation coefficients and buildup factors. These are functions of material physical characteristics and gamma energy. Although various kinds of materials comprise low level waste, most are low atomic number elements, and are expected to show similar radiological behavior.

Water was selected in this study, as a reference substance, because of its upperbound absorption characteristics. Attenuation and absorption coefficients were taken from standard handbooks[3,4]. The energy absorption build-up factors were obtained from literature[5] and fitted to a third order polynominal over the range of 0 to 10 mean free paths to reduce the calculational error and approximate actual waste container conditions.

Results and Discussion

The calculation has been done for four containers with gravimetric density ranging from 0.6 to 2.0 g/cm^3. gamma energy spectrum is 0.4 to 2.0 MeV.

The results, expressed as absorbed percent of gamma radiation energy, are shown in Table I. Data has been interpolated by the least square fitting function described below. The choice of water as the limiting material yields a method appplicable to practically all low level waste forms.

$$E^{\gamma}_{abs}(x,y) = a_1xy + a_2x\sqrt{y} + a_3\sqrt{x}y + a_4x + a_5\sqrt{xy} + a_6y + a_7\sqrt{x} + a_8\sqrt{y} + a_9 \quad (3)$$

where

$E^{\gamma}_{abs}(x,y)$ = Absorbed portion of gamma radiation energy with density x, and energy, y

x = Density of waste media, g/cm^3

y = Gamma radiation energy, MeV

Constants a_1 to a_9 for different containers are summarized in Table II.

Figure 1 shows typical example of the methods application. The volume of hydrogen generated after sealing is plotted as a ratio of container void space. The waste media chosen is dewatered resin with ^{60}Co loaded to the regulatory limit[6], 10 Ci/ft^3. This figure illustrates four plots of gamma radiation absorption, 100% absorption, 6 x 6 liner, 4 x 4 liner, and 55 gal drum, and the absorbed percent of gamma energy for each container is listed in the parentheses. This calculation includes any applicable decay energy of ^{60}Co.

The significance of evaluating the percent of gamma energy absorbed by the waste can be seen clearly. Compared to the 55 gal drum case, the total absorption case (normally used by industry) will over predict gas production by a factor of two. This will cause a waste generator to take actions to prevent combustible mixtures (vent) twice as often and double manrem and dollar expenditures.

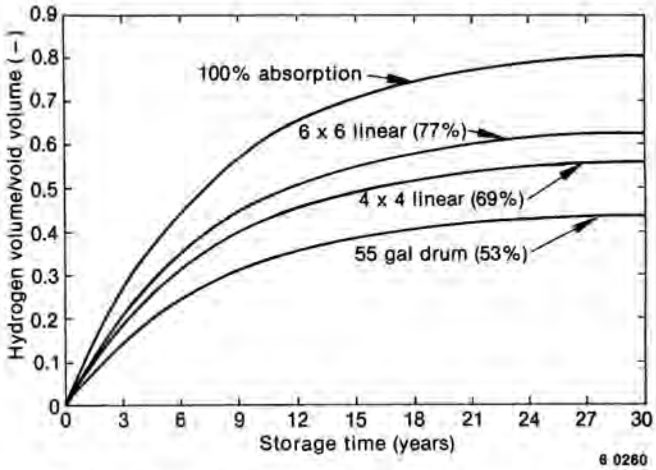

Fig. 1. Hydrogen Generation in Dewatered Resin (Density: 1.0g/cm^3, G-H_2: 0.12 molecule /100 eV, Void Volume: 60% of Bulk Volume of Resin).

TABLE I

Gamma Energy Absorption Percentage

Container[a]	Density[c]	Energy[b] 0.4	1.0	2.0	Note
30/90	6.0000E-01	45.6894	40.0910	34.3298	55 gal drum
	8.0000E-01	54.5134	48.3317	42.0109	
	1.0000E+00	60.9414	54.6901	48.2414	
	1.5000E+00	70.6475	65.0612	59.2058	
	2.0000E+00	75.5871	70.8238	65.9195	
60/120	6.0000E-01	63.9283	57.6887	51.1064	4 x 4 liner
	8.0000E-01	71.0530	65.3157	59.1550	
	1.0000E+00	75.5488	70.3911	64.8325	
	1.5000E+00	81.4383	77.4160	73.3375	
	2.0000E+00	83.9640	80.6775	77.6518	
70/140	6.0000E-01	68.1213	62.0894	55.6456	5 x 5 liner
	8.0000E-01	74.5277	69.1646	63.3853	
	1.0000E+00	78.4773	73.7308	68.6713	
	1.5000E+00	83.9372	79.8475	76.2470	
	2.0000E+00	85.5449	82.2778	79.9512	
90/180	6.0000E-01	74.1570	68.6829	62.7335	6 x 6 liner
	8.0000E-01	79.3225	74.6983	69.6728	
	1.0000E+00	82.5386	78.4174	74.1956	
	1.5000E+00	86.3314	83.2331	80.2763	
	2.0000E+00	87.6969	85.1385	83.1447	

a. Radius/Height, cm.
b. Million electron volt.
c. gram/cm^3.

TABLE II

Fitted Constants for Gamma Radiation Absorption

Fitting Constant	Container Radius/Height [cm] 30/90	60/120	70/140	90/180
a_1	0.388	-0.0430	-0.0977	-0.321
a_2	-0.579	0.106	0.197	0.591
a_3	-0.871	0.112	0.276	0.748
a_4	-0.245	-0.518	-0.543	-0.634
a_5	1.354	-0.134	-0.423	-1.252
a_6	0.485	-0.0547	-0.158	-0.402
a_7	0.954	1.371	1.428	1.549
a_8	-0.937	-0.137	0.0557	0.502
a_9	3.302×10^{-6}	-9.973×10^{-7}	-1.554×10^{-6}	-2.947×10^{-6}

REFEPENCES

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