# A DOSE TO CURIE CONVERSION METHODOLOGY

P. A. Stowe
Arizona Nuclear Power Project
Palo Verde Nuclear Generating Station
Phoenix, Arizona 85036

## ABSTRACT

Development of the computer code RadCAT (Radioactive waste Classification And Tracking) has led to the development of a simple dose rate to curie content conversion methodology for containers with internally distributed radioactive material.

It was determined early on that, if possible, the computerized dose rate to curie evaluation model employed in RadCAT should yield the same results as the hand method utilized and specified in plant procedures.

A review of current industry practices indicated two distinct types of computational methodologies are presently in use. The most common methods are computer based calculations utilizing complex mathematical models specifically established for various container geometries. This type of evaluation is tedious, however, and does not lend itself to repetition by hand. The second method of evaluation, therefore, is simplified expressions that sacrifice accuracy for ease of computation, and generally over estimate container curie content.

To meet the aforementioned criterion current computer based models were deemed unacceptably complex and hand computational methods to be too inaccurate for serious consideration. The contact dose rate/curie content analysis methodology presented herein provides an equation that is easy to use in hand calculations yet provides accuracy equivalent to other computer based computations.

## BACKGROUND

In any volume source the dose rate measured at a point on the surface is due to the contribution of the gamma rays emitted by isotopes distributed within the source that pass thru the surface plane at that point. Further, it can be seen that as the gamma ray emitter recedes away from the surface point within the source medium, contribution of the emitter to the total dose rate is reduced due to distance and attenuation in the waste media. The relative orientation of the emitter is not important as long as the ray path is the same. Therefore, if the emitter is embedded far enough away, the gamma ray becomes fully attenuated and has no affect on the dose measurement. This self shielding distance is a function of gamma energy and media density. For large radioactive waste containers, the self shielding distance is less than its physical dimensions. This means that is a mid-plane dose rate measurement is taken, all of its contribution is from a hemispherical region surrounding the measurement point with all other regions self shielded. The contact dose rate is, therefore, relatively insensitive to container geometries. Geometry differences that do exist can be minimized allowing the use of infinite medium specific isotope constants for contact dose rate.

The factor designed E in the following equations (Equilibrium Absorbed Dose Constant (1) is this constant and has units of (mR/hr)(uCi/gm). This term accounts for all photons emissions by an isotope and therefore a lower energy cutoff of fifty KEV was used for RadCAT evaluations.

Containers of small physical dimensions or very low densities will incur inaccuracy due to the self shielding distance exceeding the container physical dimensions. The minimum container size and density for which this method has been validated is a 55 gallon drum at .3 gm/cc (18.7 lb/ft 3).

## COMPUTATIONAL PROCEDURE

This section describes the steps necessary to evaluate the curie content of any waste container using methodology presented herein.

Given a waste container with a known isotopic distribution, perform the following to determine curie content,

using: $D_i = C_i E(1-3^{-uR})/2P$ (1)

where $C_i$ = percent abundance of isotope 1

$u$ = linear mass attentuation coefficient

$R$ = effective radius of a hemisphere of equivalent volume (minimizes geometry errors)

$P$ = waste density in gm/cc

A) Using the percent abundance compute each isotope's surface dose rate $D_i$

B) Sum the dose rates $D_i$ to get $D_t$, the total projected surface dose rate.

C) Since Step A assumes the percent abundance is in units of uCi/cc divide the measured contact dose rate by the total projected dose rate to obtain scaling factor S.

D) Multiply $C_i$ by volume V (in cc's) and scaling factor S to obtain the microcuries of isotope i.

Once this procedure is completed, the surface dose rate may be computed for any future date by simply decay correcting the scaled isotopic and calculating $D_t$ for this date.

If each isotope emits gammas, the Mother/Daughter relationships should be established before performing the dose to *curie* evaluation, otherwise significant errors in the curie content analysis may be introduced by not accounting for the gamma emission of the omitted isotope.

Listed below in Table I is E (equilibrium absorbed dose factor) for the twenty seven (27) isotopes found in the RadCAT library and are in units of (mR/hr)/(uCi/gm).

TABLE I

Equilibrium Absorbed Dose Constants

| | |
|---|---|
| Na-24 | 8770 |
| Cr-51 | 66 |
| Mn-54 | 1784 |
| Co-58 | 1754 |
| Fe-59 | 2520 |
| Co-60 | 5340 |
| Zn-65 | 1216 |
| Zr-95 | 1574 |
| Nb-95 | 2106 |
| Mo-99 | 318 |
| Tc-99m | 294 |
| Ru-103 | 1000 |
| Ru-106 | 418 |
| Ag-110m | 5930 |
| Ag-110 | 64 |
| Sn-113 | 10 |
| In-113m | 704 |
| Sb-122 | 1034 |
| Sb-124 | 3928 |
| I-131 | 810 |
| I-133 | 1294 |
| Cs-134 | 3568 |
| Cs-137 | 1276 |
| Ba-140 | 308 |
| La-140 | 4840 |
| Ce-144 | 50 |
| Pr-144 | 144 |

COMPARISON

Illustrated in Fig. 1 is a side by side comparison of results obtained by EPRI's DOSCON (2) and RadCAT for a 55 gallon drum and a 195 cubic foot liner containing the following isotopic distribution:

| | |
|---|---|
| 15% | Cr-51 |
| 5% | Mn-54 |
| 8% | Fe-59 |
| 25% | Co-58 |
| 20% | Co-60 |
| 2% | Zn-65 |
| 5% | Zr-95 |
| 12% | Nb-95 |
| 3% | Cs-134 |
| 5% | Cs-137 |

Density was varied from .3 gm/cc to 2.3 gm/cc to cover the total range of common waste densities. Since DOSCON evaluates dose rate to curies based on a 3 foot dose rate reading, a calculated 3 foot reading equating 1000 mR/hr contact was utilized for the DOSCON evaluations.

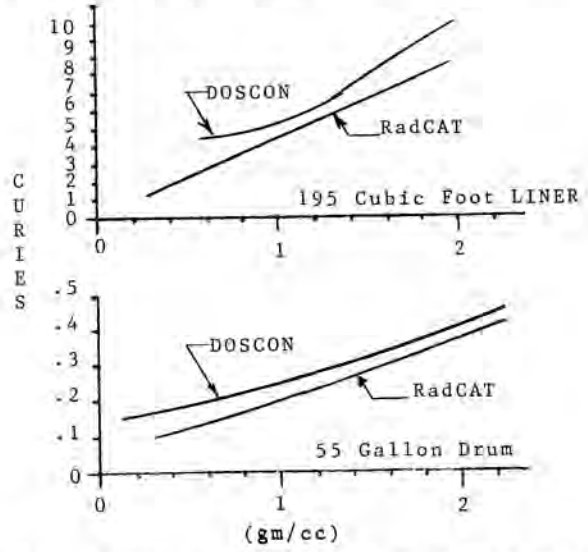


Fig. 1. Curies vs. Density for DOSCON and RadCAT.

DERIVATION OF THE MATH MODEL

Equation 1 is a converted for of the finite sphere formula found on page 23 of Ref. 3. For situations where the self shielding distance is exceeded, buildup (scatter gammas) maximizes at the value equal to buildup at one mean free path. This coupled with unit conversions permits the computation of E for any given isotope. If E cannot be found in Ref. 1 for a given isotope, it may be evaluated using E-BAR and attenuation data for the most prominent gamma.

Since contact dose rate is equated to a hemispherical source region, the base equation must be divided by two.

OPTIONAL FUNCTIONS

The base methodology may be modified to handle such cases as off-contact dose rate measurements or small objects such as radioactive filters.

To evaluate off-contact dose rate Eq. (1) needs only to be modified as follows:

$$D_i = C_i EA(1 - e^{-uR})/2P \qquad (2)$$

where $A = [r/(r+d)]^2$

d = distance from the container

r = container radius

The term A needs to be determined once for a container at a given distance.

The A term represents the ratio of the surface areas enclosing the source area and a similar shaped area enclosing the source at the measurement distance. Use of Eq. (2) is the same as Eq. (1) and the same evaluation process should be followed. However, no shielding must exist between the container and measurement point.

Individual filters may be evaluated by modifying Eq. (1) as follows:

$$D_i = (.36)C_i E(1 - e^{-uR})/2P \qquad (3)$$

The factor (.36) accounts for both geometric and Buildup variations.

Off-contact dose rate calculations for individual filters may be accomplished by combining the modifications made in Eq. (2) with Eq. (3).

REFERENCE

1. "Nuclear Decay Data for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities", ORNL/NUREG/TM-102, August, 1977.

2. FODERARO, A., "The Photon Shielding Manual", Second Edition, Pennsylvania State University.

3. "Determination of Waste Container Curie Content from Dose Rate Measurements", NWT Corp., July, 1983.