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17-KEV X-RAY OUTPUT OF PLUTONIUM

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This Document consists of
7 Pages No. 10
12 Series Series

17-KEV X-RAY OUTPUT OF PLUTONIUM

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Classification Controlled and Changed To

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By Authority of SE Gydesen
12-16-93 CG-DAR-1

By JE Savely 1-4-94
Verified By DK Hansen, 1-14-94

Radiological Physics Operation
Physics and Instruments Research and Development Operation
HANFORD LABORATORIES OPERATION

November 5, 1958

HANFORD ATOMIC PRODUCTS OPERATION
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17-KEV X-RAY OUTPUT OF PLUTONIUM

In the production of plutonium in a reactor, plutonium-238, 240, and 241 are formed as well as Pu²³⁹ (1). It is well known that the specific alpha activity of the plutonium varies as the percentages of these isotopes are changed. Kinderman, et al (1) have worked out the relationship between isotopic content and MWD/ton exposure. In some cases, the plutonium is measured by counting the uranium L x rays emitted rather than alpha rays. These x rays are of several energies, but appear as a 17-Kev peak with a scintillation spectrometer. This is a particularly important technique for in vivo measurements of plutonium in wounds (2). In general, the yield of 17-Kev x rays from the unknown is compared with the yield from a standard source which has been standardized by alpha counting. An error is introduced if the number of 17-Kev x rays per alpha particle for the standard source is different from that of the unknown source. Much of the data needed to accurately calculate the x-ray output per alpha ray is unknown; however, some simplifying assumptions can be made with sufficient accuracy for most purposes.

In the discussion below, we will use the following constants:

Pu ²³⁸	$T_{1/2} = 90 \text{ years}$	24% of disintegrations go to 45-Kev excited state.
Pu ²³⁹	$T_{1/2} = 2.44 \times 10^4 \text{ years}$	11% of disintegrations go to 51-Kev excited state.
Pu ²⁴⁰	$T_{1/2} = 6580 \text{ years}$	24% of disintegrations go to 44-Kev excited state.
Pu ²⁴¹	$T_{1/2} = 13.3 \text{ years}$	Alpha emission occurs in 10 ⁻³ % Approximately no x rays produced

Let X_n be the fraction by weight of Puⁿ present. The total alpha activity for a pure isotope is given by $kN/T_{1/2}$ where k is a constant and N is the number of atoms of the isotope present. For the purposes of our approximation, the difference in

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atomic weight of the plutonium isotopes is negligible and N is proportional to the total weight of the isotope present. Let

A = total alpha activity of a mixture of plutonium isotopes

then

$$A = KM \left(\frac{X_{238}}{90} + \frac{X_{239}}{2.44 \times 10^4} + \frac{X_{240}}{6.58 \times 10^3} + \frac{10^{-5} X_{241}}{13.3} \right). \quad \text{Eq. (1)}$$

Where

M = weight of plutonium present

$$X_{239} = 1 - X_{238} - X_{240} - X_{241}. \quad \text{Eq. (2)}$$

Inserting Eq. (2) in Eq. (1) and simplifying, we have

$$A = KM \left(1.11 \times 10^{-2} X_{238} + 4.1 \times 10^{-5} + 1.11 \times 10^{-4} X_{240} - 4.03 \times 10^{-5} X_{241} \right). \quad \text{Eq. (3)}$$

In order to calculate the 17-Kev x-ray output, we must make some assumptions. First, the internal conversion coefficients must be assumed equal for plutonium-238, 239, and 240. This is permissible since internal conversion occurs in approximately 100% of all cases. Second, the fluorescent yield must be assumed equal for plutonium-238, 239, and 240. This should also be a good approximation. We will also assume that the plutonium is new so that the Am^{241} content is zero since this is easily corrected for experimentally. U^{237} is present in equilibrium after about two weeks but is negligible as a source of 17-Kev x rays. Let

Y = x-ray activity.

For a pure isotope, Y is proportional to the product of the activity and the fraction of the disintegrations going to the excited state. Then

$$Y = CKM \left(\frac{0.24 Y_{238}}{90} + \frac{0.11 X_{239}}{2.44 \times 10^4} + \frac{0.24 X_{240}}{6.58 \times 10^3} \right). \quad \text{Eq. (4)}$$

Inserting Eq. (2) in Eq. (4), we have

$$Y = CKM \left(0.266 \times 10^{-2} X_{238} + 0.452 \times 10^{-5} + 0.32 \times 10^{-4} X_{240} - 0.452 \times 10^{-5} X_{241} \right). \quad \text{Eq. (5)}$$

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Number of x rays per alpha ray = Y/A.

$$Y/A = C \frac{(26.6 X_{238} + 0.0452 + 0.32 X_{240} - .0452 X_{241})}{(110.6 X_{238} + 0.41 + 1.11 X_{240} - 4.03 \times 10^{-5} X_{241})}. \quad \text{Eq. (6)}$$

The constant C in Eq. (6) can be evaluated from the fact that $(4 \pm 1)\%$ of the alpha decays from pure Pu^{239} are accompanied by 17-Kev x rays (3).

$$Y/A = \frac{0.363 (26.6 X_{238} + 0.0452 + 0.32 X_{240} - 0.0452 X_{241})}{(110.6 X_{238} + 0.41 + 1.11 X_{240} - 4.03 \times 10^{-5} X_{241})} \quad \text{Eq. (7)}$$

Using the measured values and empirical relations given by Kinderman, et al (1), we have plotted Y/A as a function of MWD per ton irradiation (Fig. 1). The absolute accuracy of this curve is about $\pm 25\%$ since it depends on the $(4 \pm 1)\%$ yield of x rays given by West (3). For relative values, however, the accuracy should be much better. We estimate the relative accuracy between points on the curve is about $\pm 5\%$.

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1. HW-26584, E. W. Kinderman, et al
2. Geneva Paper 756, W. C. Roesch and J. W. Baum.
3. West, D. And J. K, Dawson, Proc. Phys. Soc., London 64A, 586 (1951).

Figure 1

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