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Receipts Assay Monitor: Deadtime Correction Model and Efficiency Profile

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RECEIPTS ASSAY MONITOR: DEADTIME CORRECTION MODEL AND EFFICIENCY PROFILE

by

J. J. Weingardt and J. E. Stewart

ABSTRACT

Experiments were performed at Los Alamos National Laboratory to characterize the operating parameters and flatten the axial efficiency profile of a neutron coincidence counter called the Receipts Assay Monitor (RAM). Optimum electronic settings determined by conventional methods included operating voltage (1680 V) and gate width (64 μs). Also determined were electronic characteristics such as bias and deadtime. Neutronic characteristics determined using a ^{252}Cf neutron source included axial efficiency profiles and axial die-away time profiles.

The RAM electronics showed virtually no bias for coincidence count rate; it was measured as $-4.6 \cdot 10^{-5}$% with a standard deviation of $3.3 \cdot 10^{-4}$%. Electronic deadtime was measured by two methods. The first method expresses the coincidence-rate deadtime as a linear function of the measured totals rate, and the second method treats deadtime as a constant. Initially, axial coincidence efficiency profiles yielded normalized efficiencies at the bottom and top of a 17-in. mockup UF_6 sample of 68.9% and 40.4%, respectively, with an average relative efficiency across the sample of 86.1%. Because the nature of the measurements performed with the RAM favors a much flatter efficiency profile, 3-mil cadmium sheets were wrapped around the ^{3}He tubes in selected locations to flatten the efficiency profile. Use of the cadmium sheets resulted in relative coincidence efficiencies at the bottom and top of the sample of 82.3% and 57.4%, respectively, with an average relative efficiency of 93.5%.

I. INTRODUCTION

The Receipts Assay Monitor (RAM) is designed to perform nondestructive assay measurements of highly enriched uranium hexafluoride (UF_6) in Model 5A UF_6 cylinders using the self-interrogation method.[1] The self-interrogation, or self-source, method relies on a strong, random (α,n) reaction within the sample. Neutrons born in (α,n) reactions from ^{234}U alpha particles and fluorine cause fissions in the ^{235}U, which allows us to measure coincidence neutrons. Two measurements are performed on each UF_6 cylinder, one with a cadmium liner wrapped around the sample to prevent thermal neutrons from re-entering the sample and another with the cadmium liner removed. By applying the two measurements to the appropriate physics model, a facility can use the RAM to determine the mass of ^{235}U in the sample to within a few percent.[2] The total counting time required to reduce the error from counting statistics to 1% is less than 7 min. Thus, the RAM provides a facility with the ability to quickly and accurately verify that the mass of ^{235}U in the Model 5A UF_6 cylinders corresponds to the mass stated by the shipper's label.

II. THEORY

Coincidence deadtimes have been modeled as linearly increasing functions of the measured totals rate.[3] Determining coincidence deadtime requires one set of two measurements and can be calculated with the following formula:

$$\delta = \frac{\ln\left(\frac{R_{1m}}{R_{2m}}\right)}{T_{2m} - T_{1m}} \quad , \tag{1}$$

where R_m indicates measured coincidence count rate and T_m indicates measured totals count rate; subscript 1 refers to measurement with a ^{252}Cf source alone and subscript 2 refers to measurement with a californium source together with an americium-lithium (AmLi) source. Establishing the coefficients δ_0 and δ_1 of the coincidence-rate deadtime equation,

$$\delta = \delta_0 + \delta_1 \cdot T_m \quad , \tag{2}$$

requires that deadtimes be determined for several different measured totals rates. The results are then plotted as shown in Fig. 1. In plotting the results, the following question arises: At what value of T_m do we plot the measured value of deadtime (δ)? Recall that δ was calculated using two different measured totals rates (T_{1m} and T_{2m}). Should δ be plotted at T_{1m}, at T_{2m}, or at some value between them? None of the previous values is appropriate. The appropriate ordinate value at which to plot δ is the sum of T_{1m} and T_{2m}.

This approach has been derived analytically and proved experimentally. Let us examine the analytical proof. By definition of coincidence deadtime as a linear function of the measured totals rate, the following equations are assumed to be true:

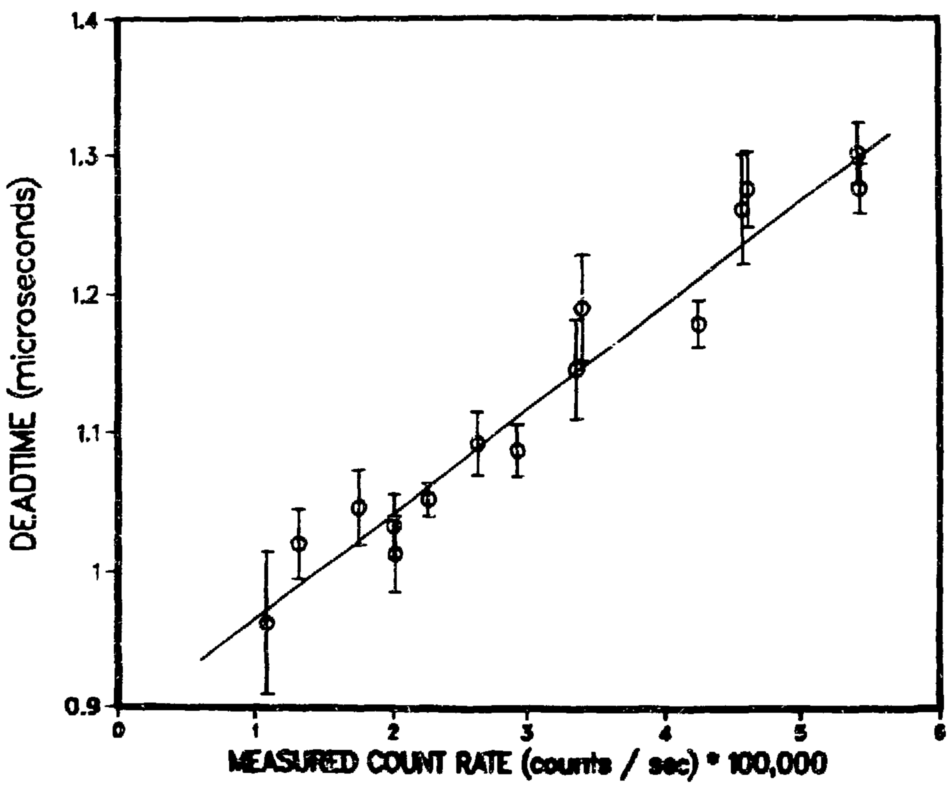


Fig. 1. Determination of coincidence-rate deadtime.

$$R_{1t} = R_{1m}\, e^{(\delta_0+\delta_1 T_{1m})T_{1m}} \quad . \tag{3}$$

$$R_{2t} = R_{2m}\, e^{(\delta_0+\delta_1 T_{2m})T_{2m}} \quad . \tag{4}$$

There is no difference between the two true coincidence count rates because the presence of a random AmLi neutron source does not influence the coincidence rate. Therefore, when Eq. (1) is used to calculate the deadtime, R_{1t} must equal R_{2t}. Thus,

$$R_{1m}\, e^{(\delta_0+\delta_1 T_{1m})T_{1m}} = R_{2m}\, e^{(\delta_0+\delta_1 T_{1m})T_{1m}} \quad , \tag{5}$$

and

$$\ln\left(\frac{R_{1m}}{R_{2m}}\right) = \delta_0(T_{2m} - T_{1m}) + \delta_1(T_{2m}{}^2 - T_{1m}{}^2) \quad . \tag{6}$$

Factoring $(T_{2m} - T_{1m})$ from the right-hand side of Eq. (6) yields

$$\frac{\ln\left(\frac{R_{1m}}{R_{2m}}\right)}{T_{2m} - T_{1m}} = \delta_0 + \delta_1(T_{2m} + T_{1m}) \quad . \tag{7}$$

Notice that the left-hand side of Eq. (7) is by definition δ (see Eq. 1). Thus,

$$\delta = \delta_0 + \delta_1(T_{2m} + T_{1m}) \quad , \tag{8}$$

and the coincidence-rate deadtime measured by the method discussed above corresponds to a totals rate of $T_{2m} + T_{1m}$ and should therefore be plotted at their sum.

III. RESULTS

The fundamental operating parameters of a neutron coincidence counter include operating voltage, gate width, and bias towards coincidence counts. The optimum operating voltage for the RAM (1680 V) was determined by establishing a voltage plateau (see Fig. 2). After the voltage was permanently set, measurements were performed to establish the gate width that yields the smallest relative error [$\sigma(R)$] in the coincidence count rate (R) from a ^{252}Cf source (that is, to minimize % $\sigma(R)/R$). Figure 3 shows the relative error in R as a function of gate width for the cadmium liner inserted and removed. In both cases, a 64-μs gate resulted in the lowest relative error. The next step in characterizing the detector was to check for a bias towards coincidence counts. After 57,000 s of measurements using a random neutron source (AmLi), the detector was found to have virtually no bias or at most a very small negative bias of $4.6 \cdot 10^{-5}$% with a standard deviation of $3.3 \cdot 10^{-4}$%.

After establishing the operating voltage and an efficient gate width and demonstrating that the RAM has almost no counting bias from a random source, we determined the deadtime using the equations described in Sec. II. The first attempt to establish detector deadtime as a function of the measured totals count rate yielded the data shown by the open circles and the dashed

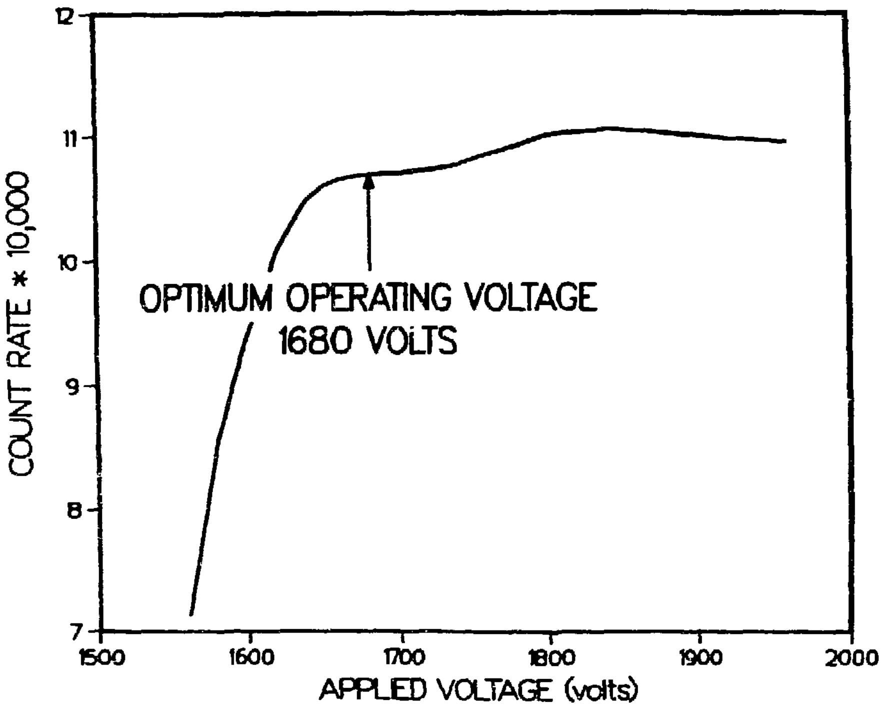


Fig. 2. Voltage plateau.

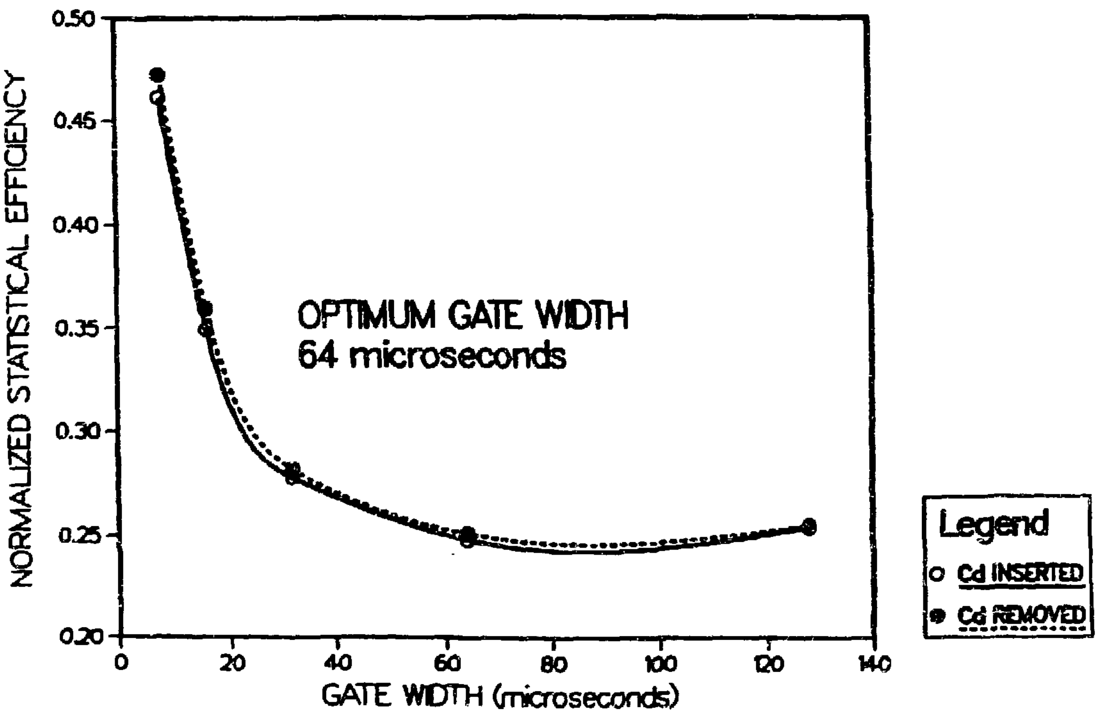


Fig. 3. Relative statistical error in coincidence counting rate (cadmium liner inserted and removed).

line in Fig. 4. The calculated value of δ was plotted at the larger value of the two measured totals rates. A least-squares fit to the data is given by

$$\delta = 8.56 + (8.45 \cdot 10^{-7})T_m \quad , \tag{9}$$

where T_m is measured in counts per second and δ has the units of microseconds. The second attempt in which the calculated value of δ was plotted at the sum of the two totals rates yielded the data shown by the solid circles and the solid line in Fig. 4. The least-squares fit is given by

$$\delta = 0.949 + (3.62 \cdot 10^{-7})T_m \quad . \tag{10}$$

In both of the previous cases, the totals-rate deadtime was determined to be the coincidence-rate deadtime divided by 3.85. Finally, in a new approach to deadtime measurements,[4] both the coincidence-rate deadtime and the totals-rate deadtime are treated as constants whose values are 0.252 µs and 0.976 µs, respectively. The method incorporates a totals-rate deadtime equation taken from Knoll.[5] The deadtime-corrected counting rates are given by the following equations:

$$R_t = R_m e^{\delta T_t} \quad . \tag{11}$$

$$T_t = T_m e^{\Delta T_m e^{\Delta T_m e^{\Delta T_m e^{\Delta T_m e^{\Delta T_m \cdots}}}}} \tag{12}$$

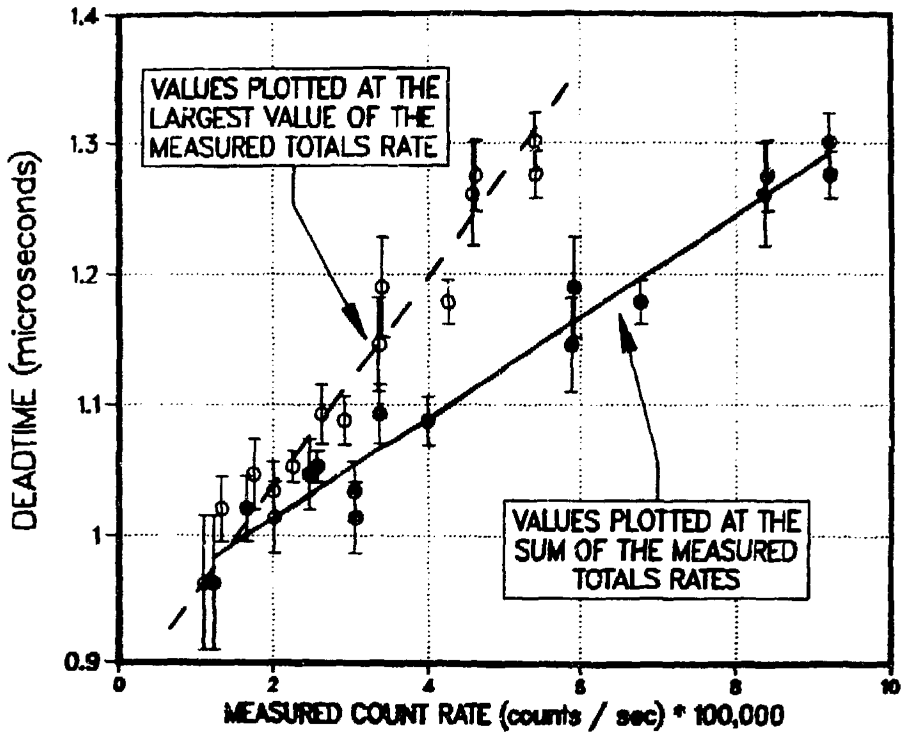
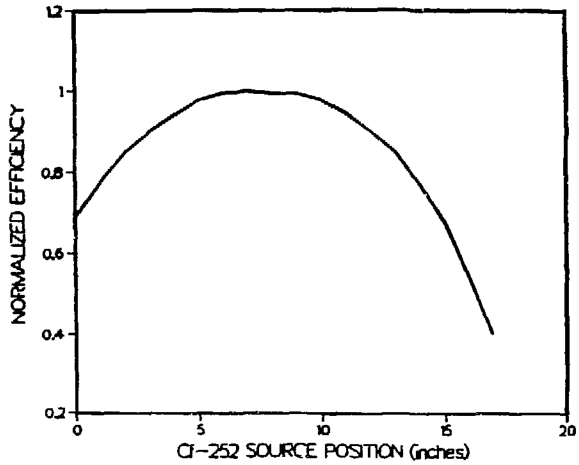


Fig. 4. Determination of deadtime using two sets of experimental data.

where Δ is the totals-rate deadtime in microseconds, and the subscripts t and m refer to true rates and measured rates, respectively.

After applying an appropriate deadtime correction to the experimental data, we measured and subsequently flattened the axial detection efficiency profile. First, to simulate operating conditions, a mock-up Model 5A UF_6 cylinder was constructed and filled with equal volumes of sand and lead shot to simulate the neutron scattering that occurs during normal operation. Figure 5 shows the axial efficiency profile before any attempt was made to flatten the profile. We flattened the profile to various degrees by wrapping 3-mil cadmium sheets around the ^{3}He tubes in different locations. The flattest profile was achieved by using the repeating configuration shown in Fig. 6. The final profile, shown in Fig. 7, resulted in an absolute average efficiency of 19.8% as compared with 25.4% for the original detector configuration. Thus, by flattening the axial efficiency profile with thin cadmium sheets we reduced the absolute efficiency by 22%.

Fig. 5. Initial axial efficiency profile.



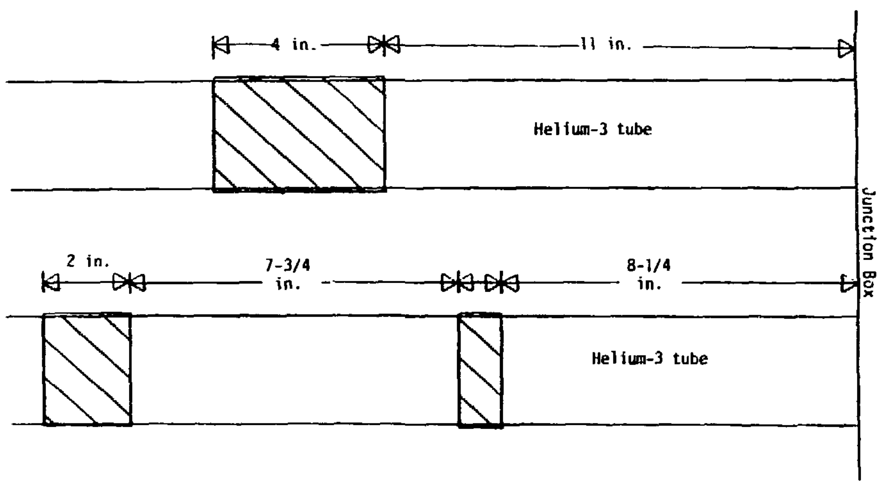


Fig. 6. Placement of cadmium liners on ^{3}He tubes.

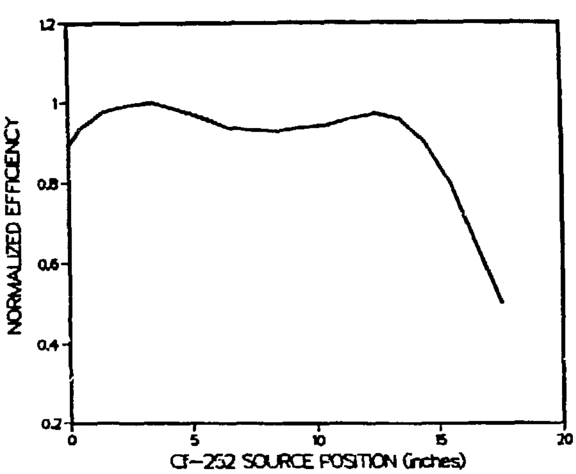


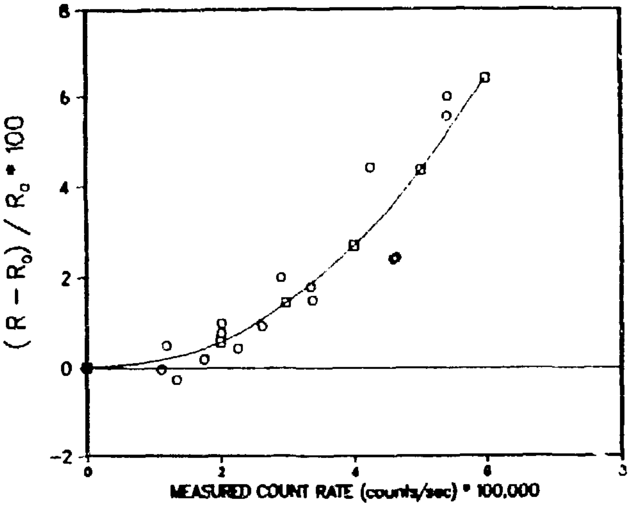
Fig. 7. Flattened axial efficiency profile.

IV. ANALYSIS OF RESULTS

As mentioned earlier, the operating voltage was chosen to be 1680 V, because it was the voltage in the most stable region of the voltage plateau. The totals count rate in the plateau region is very insensitive to small voltage drifts. For drifts smaller than 20 V in the negative direction and 40 V in the positive direction the totals count rate varies by only 0.012% per volt, thus indicating that the RAM is highly insensitive to small voltage drifts.

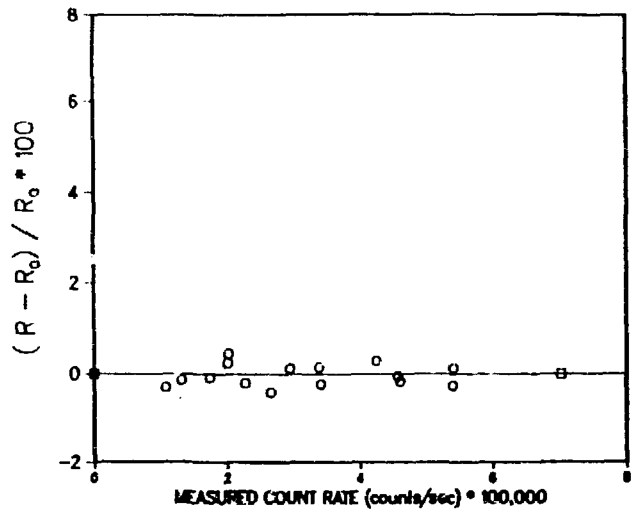
Comparison of the three deadtime measurements yields interesting results. Recall that two measurements were required to determine a single deadtime; one measurement was performed with a ^{252}Cf source alone, the other with both a ^{252}Cf source and a large AmLi source. When each of the three deadtime models is applied to a set of data points and the error in the true coincidence rate is calculated {percentage of error = $[(R - R_0)/R_0] \times 100$}, we obtain the results shown in Figs. 8(a), (b), and (c). The data shown in Fig. 8(a) obviously indicate that the first deadtime model in which calculated values of deadtime were plotted at the largest measured totals rate (T) is incorrect; it overcorrects the coincidence count rate. The data shown in Fig. 8(b) were calculated using the second deadtime correction in which calculated deadtimes were plotted at the sum of the measured totals rates. In both Fig. 8(b) and Fig. 8(c) the small random errors observed in corrected coincidence rates can be attributed to counting statistics and other uncontrollable measurement parameters. The new method of deadtime measurements performed equally as well as the old method, as shown in Fig. 8(c).

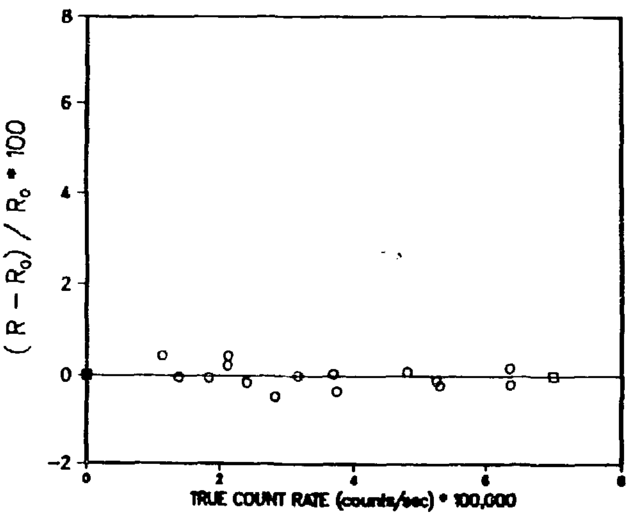
Although the nature of the measurements made with the RAM makes a flat axial efficiency profile very desirable, a completely flat profile is usually unattainable. In examining Fig. 5, one might conclude that the entire profile could be completely flattened if enough cadmium was wrapped around the ^{3}He tubes in appropriate locations. The flat profile would then correspond to the efficiency at a height of 17 in. (40%). However, this is not the case, as can be seen in Fig. 9. The upper curve represents the original axial efficiency profile, and the lower curve represents the flattened profile renormalized to the maximum value of the initial profile. Figure 9 also shows the position of the cadmium sheets relative to the source position. The figure shows that cadmium wrapped around the tubes depresses the axial efficiency throughout



(a)

(b)





(c)

Fig. 8. Resulting errors in dead-time-corrected coincidence counting rates for (a) the old approach applied incorrectly, (b) the old approach applied correctly, and (c) the new approach. The circles indicate experimental data. In (a), the squares indicate a least-squares fit; in (b) and (c), the squares indicate a linear fit.

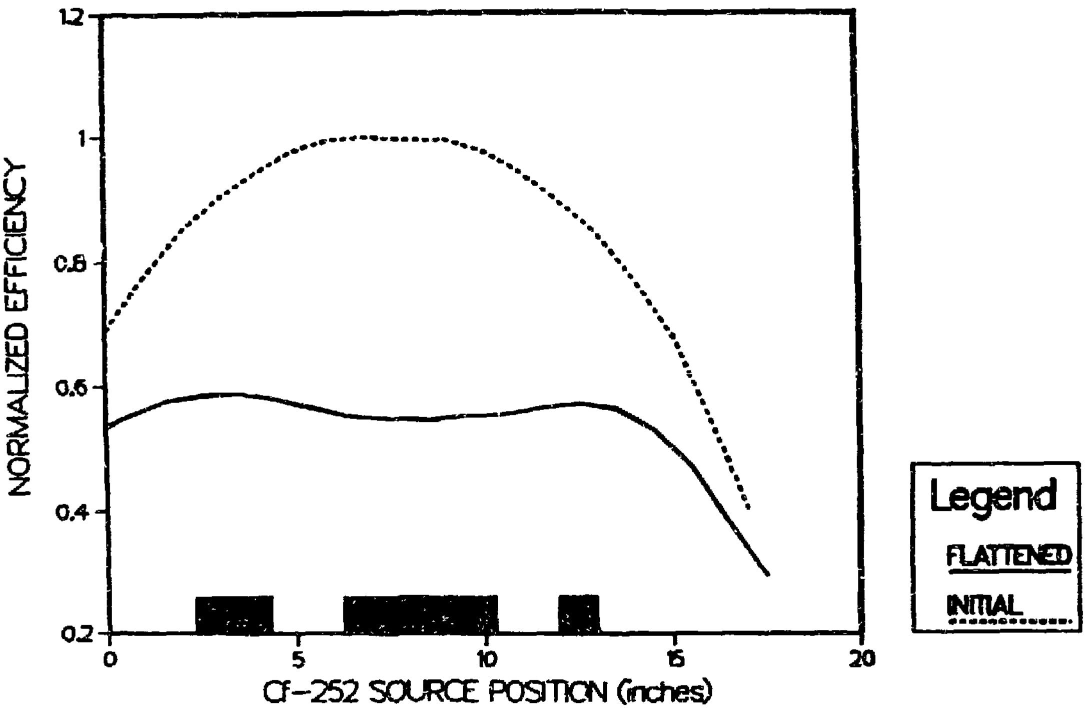


Fig. 9. Comparison of original and final axial efficiency profiles with flattened profile renormalized to maximum value of initial profile.

the sample. Although the greatest depression of efficiency occurs in the immediate vicinity of the cadmium, the cadmium affects the efficiency in other locations as well. For example, no cadmium was placed between 0 and 2-1/4 in. or between 13 and 17 in., yet the efficiency in these regions was reduced. Thus, a completely flat efficiency profile is unattainable unless end caps that help scatter neutrons back into the detector are used or unless the overall detector efficiency is drastically lowered.

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REFERENCES

1. J. E. Stewart and H. O. Menlove, "Direct Fissile Assay of Highly Enriched UF_6 Using Random Self-Interrogation and Neutron Coincidence Response," in Proc. ANS/INMM Conf. Safeguards Technol.: Process Safeguards Interface, Hilton Head Island, South Carolina, November 28-December 2, 1983 (US DOE/New Brunswick Laboratory, August 1984), CONF-831106, pp. 222-235.

2. J. E. Stewart, N. Ensslin, H. O. Menlove, L. R. Cowder, and P. J. Polk, "Confirmatory Measurements of UF_6 Using the Neutron Self-Interrogation Method," Nucl. Mater. Manage. XIV, p. 606 (July 1985).

3. H. O. Menlove, J. E. Swansen, and E. L. Adams, "Coincidence Counting Dead-time Study," Los Alamos National Laboratory memorandum Q-1-83-461/0070H (June 27, 1983).

4. J. E. Stewart and J. J. Weingardt, "Coincidence and Totals Counting Dead-time Corrections for the Receipts Assay Monitor," Los Alamos National Laboratory memorandum Q-1-86-55 (January 29, 1986).

5. G. F. Knoll, Radiation Detection and Measurements (John Wiley and Sons, New York, 1979).