Test and Evaluation of the Dual-Range Coincidence Counter at the Savannah River Plant

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by

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ABSTRACT

This report describes the test and evaluation of a Los Alamos National Laboratory-designed dual-range neutron coincidence counter at the Savannah River Plant Separations Area. A variety of incoming plutonium metal and oxide shipments were assayed with the counter. Assay accuracies were 2% 1 σ for pure metal, about 10% 1 σ for impure metal, and 3% 1 σ for oxide that was analyzed on a batch-by-batch basis.

I. INTRODUCTION

The dual-range coincidence counter (DRCC) was designed at the Los Alamos National Laboratory for the assay of a wide variety of plutonium samples. The assay is based on passive coincidence counting of neutrons from the spontaneous fission of the even isotopes of plutonium. If the isotopic composition of the plutonium is known, the total mass of plutonium can be deduced. For large samples of metal or oxide, a count rate correction and (in some cases) a self-multiplication correction are applied to the data.

At the Savannah River Plant (SRP), efforts are under way to provide rapid, nondestructive methods to assay the plutonium product and scrap. Timely inventory verification measurements of stored materials are also needed. Such materials are usually plutonium metal or oxide contained in sealed stainless steel cans of various sizes. The plutonium content of these containers ranges

from 60 to 2000 g, with 6 to 20% ^{240}Pu content. The capability of the DRCC to provide assays and inventory verification of these materials was evaluated for the following four categories: (a) pure plutonium metal in the form of buttons or scrap, (b) impure metal with oxide or other coatings, (c) plutonium oxide, and (d) slag and crucible or other scrap materials. The results of this evaluation, including recommendations for future assay procedures, are reported in Secs. V through VIII below.

II. TEST AND EVALUATION PLAN PROCEDURE

Evaluation of the DRCC at SRP was initiated in February 1979, when the instrument was installed at the Separations Area. The results described in this report include all assays performed through July 1980. At SRP, Ann Gibbs, Cloyd Denard, and Paul Deason were the scientists using the DRCC. Also, Ken MacMurdo helped to establish the test and evaluation plan and install the instrument. At Los Alamos, Norbert Ensslin was the principal investigator. Wendell Belew of the Savannah River Office of the Department of Energy was the project coordinator.

Los Alamos was responsible for providing the DRCC and its associated electronics package to SRP. Los Alamos provided documentation describing the operation of the detector and the analysis of data. Los Alamos also provided assistance with calibration of the instrument, interpretation of measurement results, and repair of the equipment. Los Alamos personnel are available for consultation on future measurement problems with the DRCC.

SRP was responsible for the routine operation of the DRCC, including the performance of measurement control assays. SRP performed a sufficient number and variety of assays to determine the accuracy of neutron coincidence counting for much of the material passing through the Separations Plant. Some measurements were repeated to test assay reproducibility and precision. SRP maintained a record of all assays performed with the DRCC. This record included sample ID, sample type, isotopic composition, and plutonium mass as determined from total weight, stoichiometry, or plant by-difference values.

Lastly, SRP was responsible for providing independent confirmation, if possible, of some fraction of the samples measured in each material category.

In practice it was not possible to obtain calorimeter assays or destructive analyses of any of the samples measured during this period. Calorimeter assays of oxide and metal samples similar to those assayed in the DRCC were typically within 0.1 to 0.4% of the tag values. For pure metal samples, weight values were typically in good agreement with tag values. Thus it is not likely that the lack of independent confirmation introduced an appreciable error in the evaluation of the DRCC accuracy.

III. DRCC PHYSICAL DESCRIPTION AND PERFORMANCE

For in-plant applications, it is often necessary to assay samples ranging in size from less than 1 g to greater than 2 kg. To achieve this wide-range capability, the dual-range counter was designed with removable cadmium liners near the ^{3}He detectors. These liners absorb thermal neutrons and can be inserted for low-efficiency operation and removed for high-efficiency operation.

The geometry of the counter is shown in Fig. 1. The cadmium liners on both sides of the middle polyethylene cylinder are removable. The detector consists of 24 ^{3}He tubes of 2.54-cm diam filled to a pressure of 4 atm. The inner and outer moderators are each 3.5 cm thick. At this design thickness, an amount of hydrogen or other moderator equivalent to up to 1 cm of polyethylene can be added to the sample matrix with little change in the counting efficiency, as illustrated in Fig. 2. (The centimeters in this figure refer to the inner and outer moderator thicknesses.) The cadmium sleeve on the inside of the well stops low-energy neutrons from scattering back into the sample. This minimizes criticality problems and reduces multiplication for high-mass loadings. The outer cadmium shield improves the effectiveness of the exterior polyethylene shield. This 10-cm-thick shield reduces detector backgrounds significantly in plant environments, where a large amount of nuclear material is often close at hand.

In the high-efficiency mode of operation, with the cadmium liners removed, the DRCC efficiency is about 22%, with a die-away time of 52 μs. In the low-efficiency mode, with the cadmium liners in place, the efficiency is about 7% and the die-away time is about 16 μs. Although the low-efficiency mode was intended for large plutonium samples, it has been found that the new electronics package described below can accommodate the count rates produced by 2 kg or more

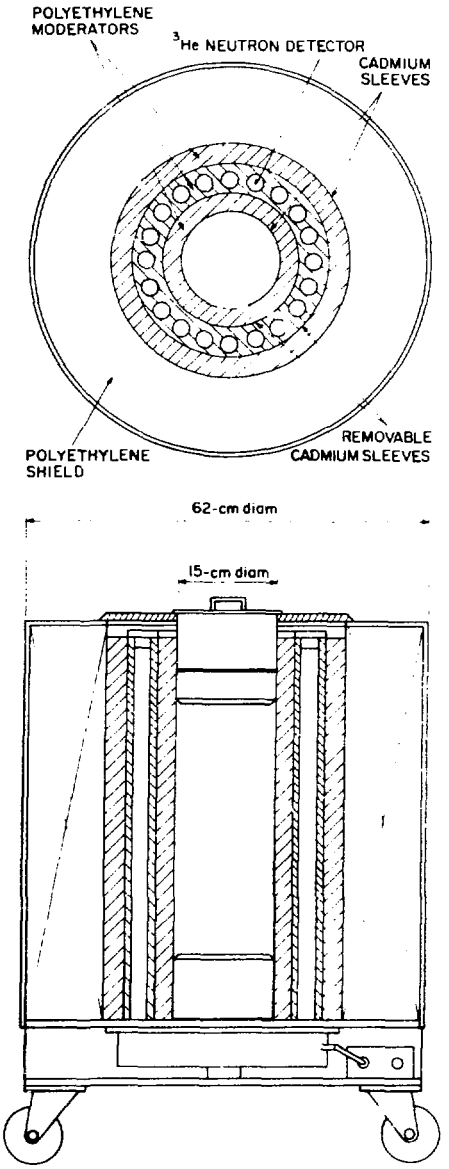

Fig. 1. Dual-range neutron coincidence counter chassis.

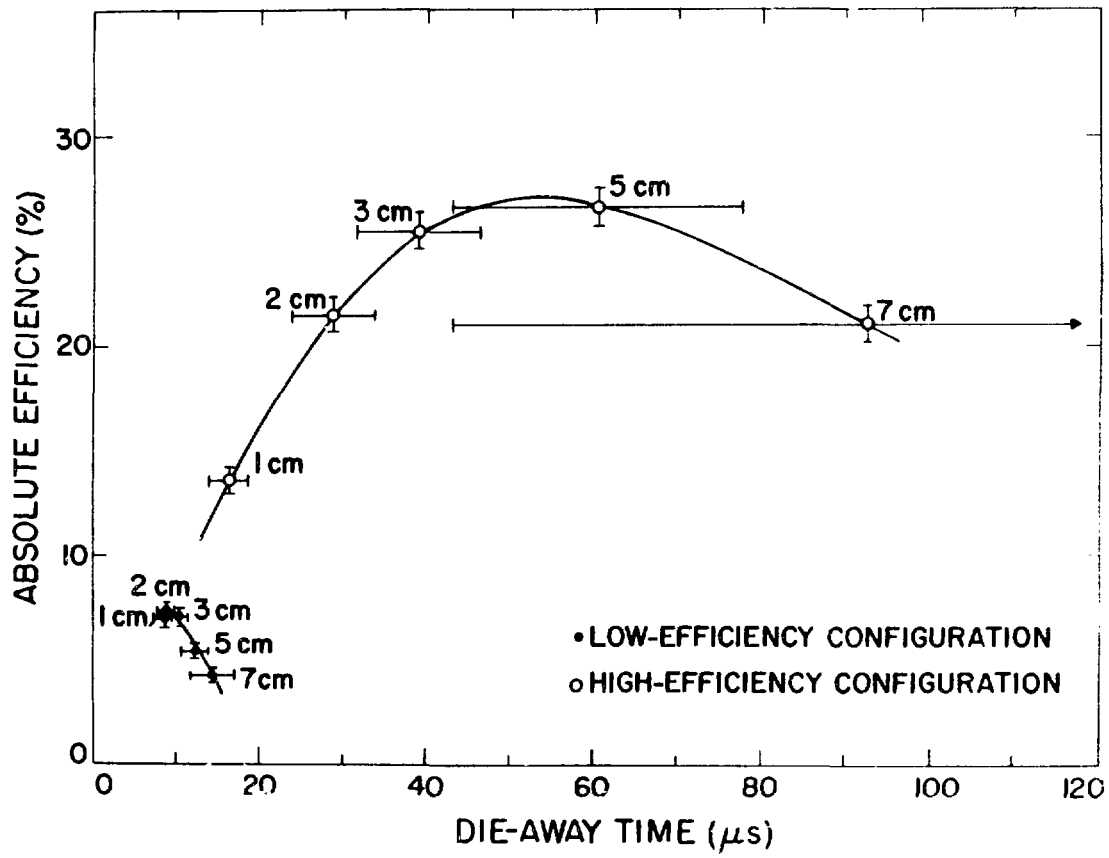

Fig. 2. Design data for the dual-range counter showing efficiency and die-away time as a function of polyethylene moderator thickness as determined from Monte Carlo studies.

of plutonium metal or oxide in the high-efficiency mode. Thus the measurements described in this report were all made in the high-efficiency mode.

The electronics package (Fig. 3) contains a high-voltage power supply, six amplifiers and discriminators, and a "shift register" coincidence circuit. This circuit records coincident events in a nearly deadtime-free manner. As a result, the electronics can operate at count rates of more than 100 000/s and can easily accommodate the count rate produced by 2 kg or more of plutonium oxide. The electronics package transmits the data received during the assay to a HP-97 calculator. At SRP the calculator was programmed to apply count-rate and self-multiplication corrections to the data, to calculate the statistical error, and to determine the mass of plutonium from a calibration curve.

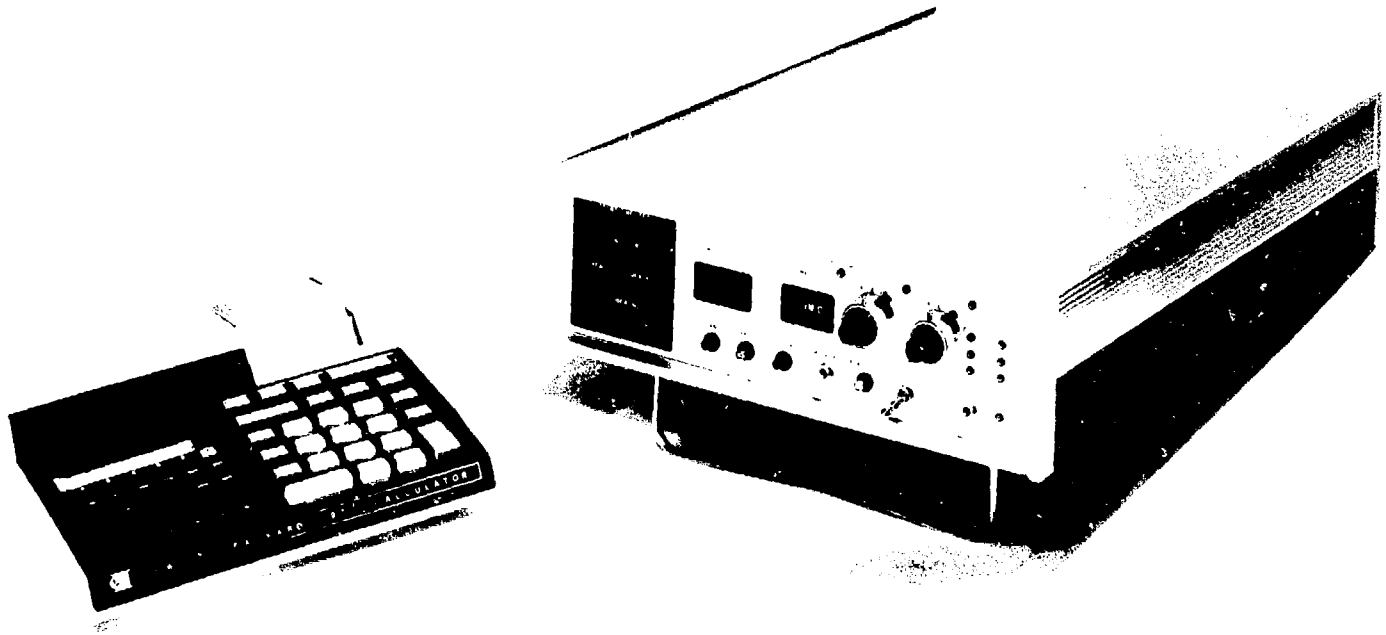

Fig. 3. Neutron coincidence counting electronics package and HP-97 calculator used with the DRCC.

The performance of the DRCC during the test and evaluation period was good. Repair was required twice: once to replace a preamplifier and once to replace a high-voltage cable. The stability of the instrument was also good. No long-term drifts were observed, and from month to month the efficiency was stable to 0.9% 1 σ. These measurements were made with a californium neutron source and are subject to a statistical uncertainty of 0.5% 1 σ. Thus the actual stability is probably better than 0.9% 1 σ. Assay reproducibility was checked by remeasuring 14 samples after a one-month interval, with the result that the average change was 0.4 ± 0.2% 1 σ.

IV. DATA ANALYSIS PROCEDURES

This section describes the procedures used to treat the data collected with the DRCC. These procedures consist of the following steps.

(1) perform measurement control assays before counting unknown samples,
(2) for each unknown sample, collect coincidence and total neutron count-rate data,
(3) apply count-rate corrections,
(4) apply self-multiplication correction (if warranted),
(5) calculate the mass of ^{240}Pu from a calibration curve based on earlier assays, and
(6) calculate the total mass of plutonium from the known isotopic composition of the sample.

The measurement control procedure consisted of counting room background, a californium neutron source, and a PuBe neutron source before every series of sample assays. The background varied between 300 and 8000 cps, depending on the location of the DRCC with respect to the vault. This background count rate was subtracted from the observed total neutron count rate of each assayed sample so that the net total count rate could be used for the self-multiplication correction. At 8000 cps the background is an appreciable fraction of the sample emission rate. These measurement control data suggest that extra shielding

should be stacked around the detector when it is used near the vault. The coincident and total neutron data obtained from the californium source were used to verify that the efficiency was stable to within 1%, as described in the preceding section. The PuBe source provided a high total neutron count rate and a very low coincidence count rate. These data helped verify that the coincidence circuitry was functioning properly.

For each unknown sample, the assay data consisted of time t (300 s was used), total neutron counts T, real-plus-accidental coincidences R + A, and accidental coincidences A. The HP-97 calculator program converted these raw data to

$$\text{total count rate } \dot{T} = T/t,$$

$$\text{coincidence count rate } \dot{R} = [(R + A)-(A)]/t, \text{ and}$$

$$\text{coincidence count rate error } \sigma_{\dot{R}} = \sqrt{(R + A)+(A)}\ /t \quad .$$

The coincidence deadtime for the DRCC, 2.4 μs, was determined at Los Alamos before shipment to SRP. Then the count rate correction applied at SRP was

$$\dot{T} = \dot{T}(\text{measured}) \exp(1.2\ \dot{T}) - \text{bkg} \quad \text{and}$$

$$\dot{R} = \dot{R}(\text{measured}) \exp(2.4\ \dot{T}) \quad .$$

A self-multiplication correction was then applied to the metal data and to most of the oxide data. The magnitude of this correction was based on a measurement made at Los Alamos of the ratio of coincident to total neutron count rates for a small, nonmultiplying metal sample, $\dot{R}_o/\dot{T}_o = 0.122$. Then, for each sample assayed, the calculator computed the ratio

$$r = \frac{\dot{R}/\dot{T}}{\dot{R}_o/\dot{T}_o}\ (1 + \alpha) \quad . \tag{1}$$

$\dot{R}/\dot{T}$ will be greater than $\dot{R}_o/\dot{T}_o$, and r will be greater than 1, if the sample is undergoing self-multiplication. The α is the ratio of neutrons produced by (α, n) reactions to neutrons produced by spontaneous fission. $\alpha = 0$ for pure metal. For oxide, α was calculated from the equation

$$\alpha = \frac{14000f\text{-}238 + 43f\text{-}239 + 160f\text{-}240 + 2960f\text{-}Am\text{-}241}{k_1(2.5f\text{-}238 + f\text{-}240 + 1.6f\text{-}242)} \quad . \tag{2}$$

The weight fraction of each plutonium isotope is denoted by f-238, etc. The coefficients in the numerator are the neutron production rates from (α, n) reactions in the oxide of each plutonium isotope.[1] k_1 = 1017 is the value chosen for the neutron emission rate per gram of ^{240}Pu. This value is within experimental error of published values but was actually selected to be self-consistent with the measured efficiency, measured $\dot{R}_o/\dot{T}_o$ ratio, and measured response per gram of pure metal in the DRCC. This self-consistency constraint is described in the following paragraph. Lastly, the isotopic fractions in the denominator denote the effective ^{240}Pu fraction of the plutonium.[1] This allows for spontaneous fission in the other even isotopes.

Once r and α are determined, the net leakage multiplication M is computed from the equation

$$3(1 + \alpha)M^2 - (3.022 + 4.192\alpha + 0.869r)M + (1.192\alpha + 0.891) = 0 \quad . \tag{3}$$

This equation is similar to one given in Ref. 2, but is based on an improved derivation (to be published). The self-multiplication correction factor is then Mr, or

$$m_{240} = \dot{R}/k_2 Mr \quad , \tag{4}$$

if a linear calibration constant k_2 is used. For the pure metal samples assayed in the DRCC, k_2 was observed to be 27.3 coincidences/s-g ^{240}Pu. Also, the measured totals rate may be represented by

$$\dot{T} = M(1 + \alpha)ek_1 m_{240} \quad . \tag{5}$$

Equations (1), (4), and (5) are self-consistent only if

$$\epsilon k_1 = k_2/(\dot{R}_o/\dot{T}_o) \quad . \tag{6}$$

From Eq. (6), k_1 = 1017 n/s-g ^{240}Pu if the DRCC neutron detection efficiency ϵ = 0.22 and the other constants have the measured values given above.

The general data analysis procedure actually used in the HP-97 calculator program was to correct $\dot{R}$ for count rate losses and self-multiplication and then calculate the mass of ^{240}Pu effective from the nonlinear relationship

$$m_{240} = \text{corrected } \dot{R}/(A + B\dot{R}) \quad . \tag{7}$$

The coefficients A, B, σ_A, σ_B, and covariance (A, B) were calculated at Los Alamos using a nonlinear least-squares-fit code. No standards were available at SRP to provide the input data. Thus the first 10 to 20 samples of metal and oxide were used to generate the coefficients, assuming the plant values for their masses. Then all further samples were assayed using these coefficients. For each sample assayed, plant data on the sample isotopic composition were used to compute the fraction of ^{240}Pu effective. Then the total mass of plutonium was determined from the relation

$$m_{total} = m_{240}/(2.5f_{238} + f_{240} + 1.6f_{242}) \quad . \tag{8}$$

V. RESULTS FOR PURE METAL

Table I summarizes the accuracies obtained for the four categories of material assayed with the DRCC. The results for the 78 samples of pure metal are discussed in this section.

The pure metal samples ranged in mass from 100 to 400 g of ^{240}Pu. The isotopic composition varied from 6 to 18% ^{240}Pu. Sixty-three of the samples were in the form of buttons, and 15 consisted of chopped scrap metal. These are

TABLE I

SUMMARY OF DRCC TEST AND EVALUATION RESULTS

Material Category	No. of Assays	Total Neutron Accuracy	Coincidence Counting Accuracy	Coincidence Counting Accuracy with Self-Mult. Correction
Pure metal	78	7% 1 σ	16% 1 σ	2% 1 σ
Impure metal	49	9%	13%	11%
Oxide	42	9%	8%	9%
Slag and crucible, scrap	28	5-1000%	5-25%	---

geometries for which self-multiplication effects are large. With the formulas described in the preceding section, values of 1.9 to 2.3 were obtained for the net leakage multiplication of all neutrons emitted by the samples. The correction factors for coincidence counting ranged from 7 to 11. This illustrates the fact that self-multiplication affects the coincidence response more than the total neutron response. As a consequence, the measured coincidence response (before self-multiplication correction) showed a one-standard deviation scatter of 16%, whereas the total neutron response showed a scatter of only 7% 1 σ.

With self-multiplication correction, the 63 metal buttons were assayed with an accuracy of 1.8% 1 σ. Included in this figure is a statistical precision of 0.2% and a detector stability of 0.9% or better. The 15 samples of metal scrap assayed about 5% higher. Both sets of data are illustrated in Fig. 4, with the metal scrap at 400 g ^{240}Pu. All of the data can be fit with a nonlinear calibration curve, as illustrated, with an accuracy of about 2% 1 σ. Or, all data up to 350 g ^{240}Pu can be fit with a linear calibration curve with A = 27.3, σ_A = 0.5, and B = 0. It is not unreasonable to attribute the slight curvature in the data to an error in the self-multiplication formulas. It is also possible that the scrap metal has undergone some oxidation, which would cause the self-multiplication correction to be underestimated. For now, it is recommended that a linear self-multiplication-corrected calibration curve with A = 27.3 coincidence counts/s-g ^{240}Pu be used for all pure metal buttons, and that scrap metal be studied further.

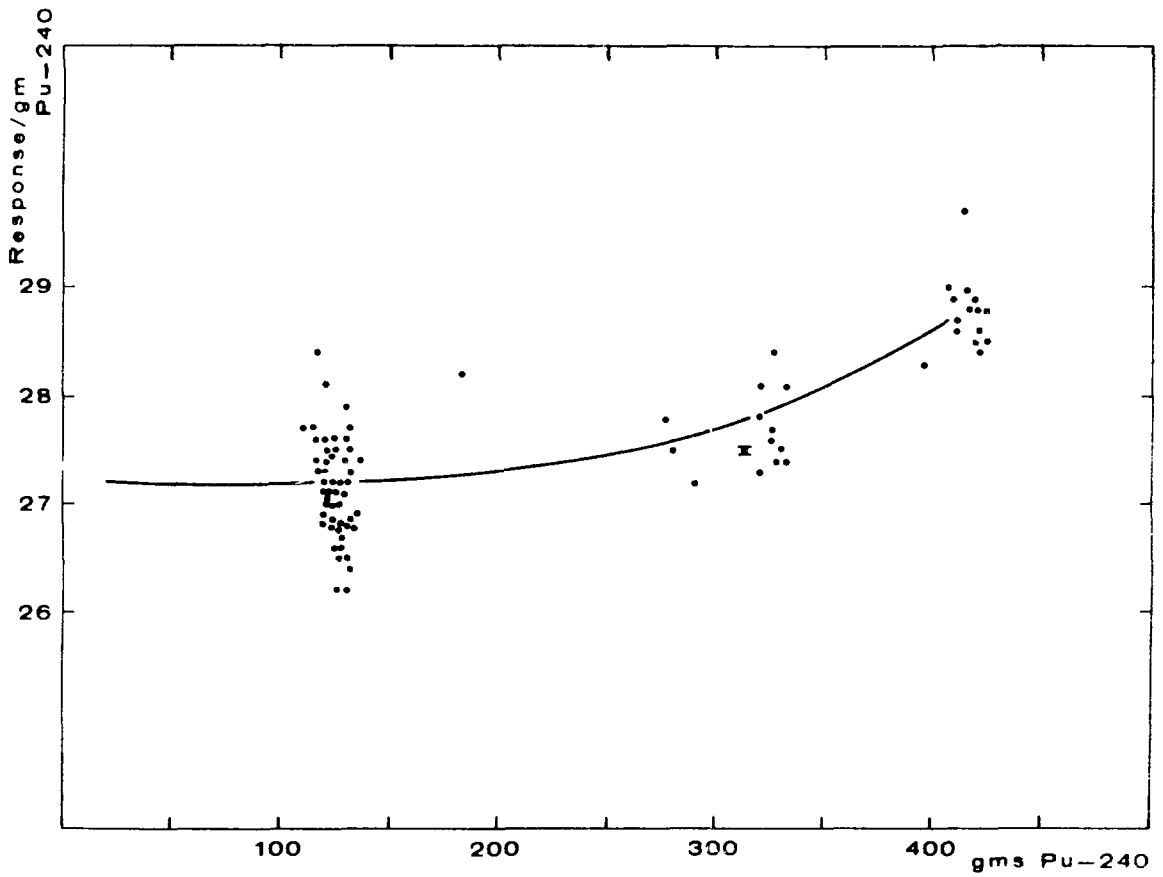

Fig. 4. Self-multiplication-corrected coincidence response per gram ^{240}Pu for SRP pure metal samples.

VI. RESULTS FOR IMPURE METAL

A series of 49 metal buttons known to have coatings of magnesium and other impurities were assayed with the DRCC. For these samples the total neutron counting accuracy was 9% 1 σ. The measured coincidence response was accurate to 13%, and the self-multiplication-corrected coincidence response was accurate to 11%. Statistical precision was again 0.2% 1 σ in 300 s. For these samples most of the loss of accuracy occurred on about 10 "outliers." However, some of these assays were repeated and found to be reproducible.

The loss of accuracy for the self-multiplication-corrected assays, from 2% for pure metal to 11% for impure metal, is attributed to an increase in the total neutron count rate caused by (α, n) reactions in the impurities. Because the self-multiplication correction is based on the ratio of coincident to total neutrons (Eq. 1), the origin of all neutrons must be assumed known. This requirement is embodied in the parameter α described in Sec. IV. For pure metal $\alpha = 0$, but for impure metal there is no a priori way to estimate α. Thus a multiplication correction based on the assumption that $\alpha = 0$ may be in substantial error.

In order to investigate this further, the data were reanalyzed by accepting the mass values based on weight as correct. Then the coincident and total neutron count rates were used to solve for the net leakage multiplication M and for α. As expected, most samples gave a small value for α, roughly 0.1 or less. This is consistent with small coatings of magnesium or other impurities. The outliers gave values for α of roughly 0.5. These high values did not correlate with high magnesium impurity concentrations, and the low-α values did not correlate with low-magnesium concentrations. It is not known if other impurities are responsible for the high-α values.

At this time, it is not possible to obtain very accurate assays of impure metal. The total neutron count rate is affected by (α, n) reactions, and the coincidence count rate requires a large self-multiplication correction which is also affected by (α, n) reactions. The samples measured to date, including other samples assayed after the test and evaluation period, yielded slightly better assays by total neutron counting. However, it is recommended that coincidence counting data also be collected and analyzed as a diagnostic for unusual levels of multiplication or oxidation.

VII. RESULTS FOR PLUTONIUM OXIDE

Forty-two samples of plutonium oxide were assayed during the period of this evaluation. The isotopic composition of these samples varied from weapons grade to high burnup. The ^{240}Pu content varied from 30 to 230 g. Container dimensions varied from 9.5- to 11-cm diam and 10- to 16-cm height. The measured coincidence response per gram, illustrated in Fig. 5, varied from 42 to 56. The statistical precision of the assays was on the order of 0.7% 1 σ. Fluctuations

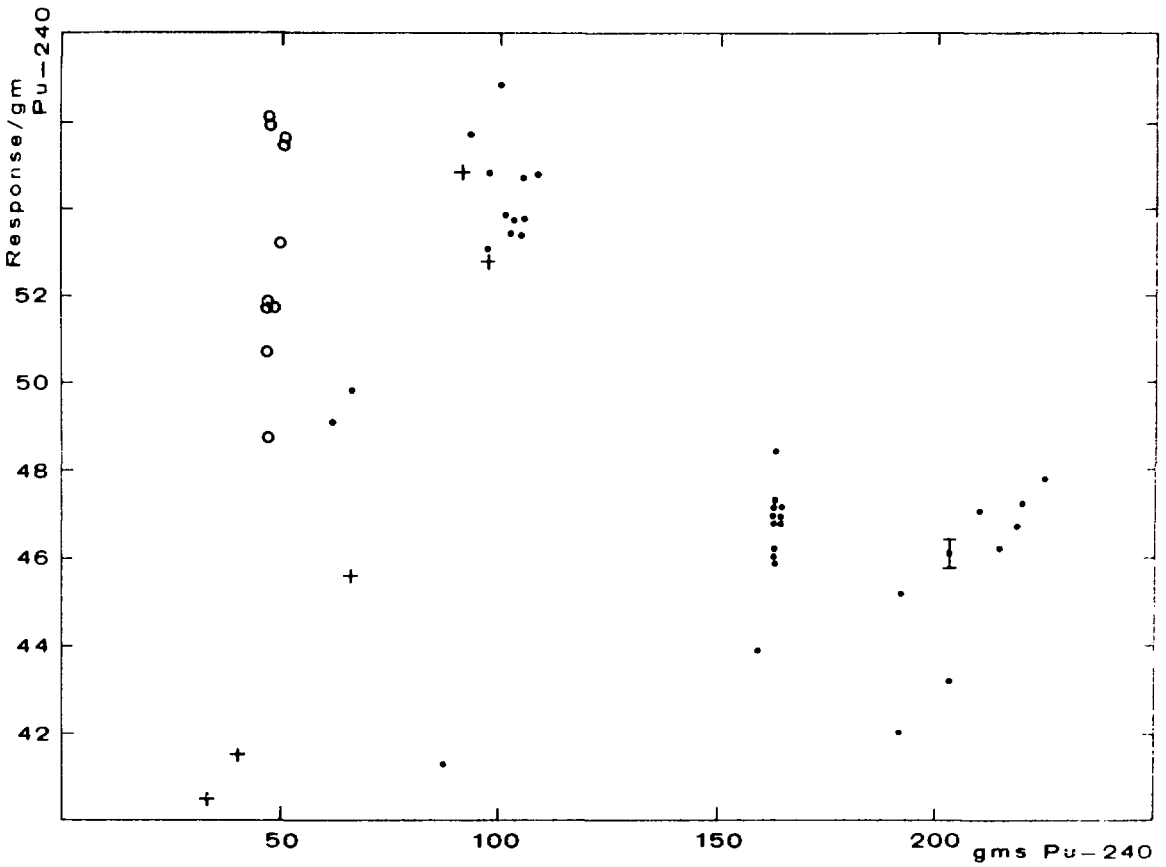

Fig. 5. Measured coincidence response per gram ^{240}Pu for SRP oxide. Oxide batches of varying ^{240}Pu enrichment or origin are designated by different symbols.

in the ^{240}Pu isotopic fraction from can to can were about 1%. Thus the variation in the measured response is due primarily to variations in oxide enrichment, container size, density, and impurity concentration. In Fig. 5, different symbols are used to help segregate different types of oxide. In Table II the oxide samples are grouped into four batches: two containing 6% ^{240}Pu oxide, one containing 18% ^{240}Pu samples, and one containing 21% ^{240}Pu samples.

As summarized in Table II, the oxide samples were first analyzed using linear calibration curves based on total neutron response, coincidence response,

TABLE II

INITIAL ANALYSIS OF OXIDE DATA
WITH LINEAR CALIBRATION CURVES

Type of Oxide	No. of Assays	Total Neutron Accuracy	Coincidence Counting Accuracy	Observed α	Coincidence Counting Accuracy with Self-Mult. Correction
6% ^{240}Pu	15	5% 1 σ	3% 1 σ	1.0-1.6	7% 1 σ
6% ^{240}Pu	5	2%	14%	1.1-1.2	5%
18% ^{240}Pu	13	1%	4%	1.2-1.3	1%
21% ^{240}Pu	9	4%	4%	0.6-0.8	5%
All oxide	42	9%	9%		9%

and coincidence response with self-multiplication correction. All three techniques yielded only about 9% 1 σ accuracy if a single calibration constant was used for all oxide samples. If the four oxide categories were analyzed separately, no technique gave very good accuracies, although total neutron counting was best.

Multiplication effects in the oxide samples were large. The net leakage multiplication M was on the order of 1.1, and the coincidence correction factor Mr was on the order of 1.7. However, application of the self-multiplication correction did not make it possible to fit all oxide samples with a single calibration constant. Figure 6 illustrates the corrected response per gram. The response of all samples has been corrected down towards the corrected response of pure metal, 27.3 coincidence counts/s-g ^{240}Pu. However, the average scatter is still 9% 1 σ. This lack of improvement is again attributed to variations in the total neutron emission rate of the samples due to (α, n) reactions in oxide and in impurities. The observed value of the parameter α is listed in Table II for the four oxide batches. The variation in α is greater than that calculated from Eq. (2). Since the self-multiplication correction is based on Eq. (2), this will introduce a significant error.

An attempt was made to circumvent this problem by assuming a value for the leakage multiplication M of each sample. As illustrated in Fig. 7, the dependence of M on mass followed two fairly well-defined curves, one for weapons-grade

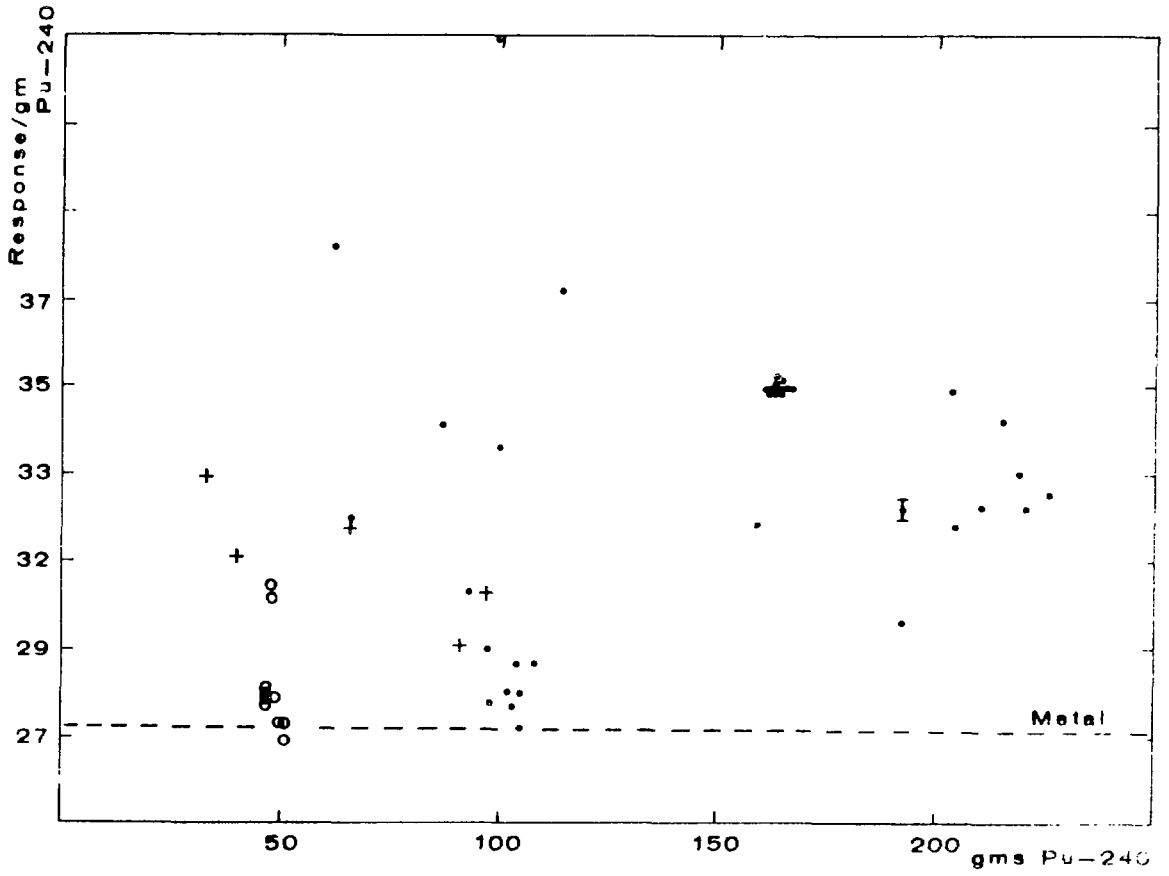

Fig. 6. **Self-multiplication-corrected coincidence response per gram ^{240}Pu for SRP oxide. The dashed line represents the corrected response for pure metal.**

and one for high-burnup oxide. The data were thus reanalyzed by estimating m_{240} from the measured coincidence response and then calculating M. Then σ, the self-multiplication correction factor Mr, and a revised value for m_{240} were calculated. However, with this approach the overall accuracy for all oxide samples was still 9% 1 σ. Either M is too sensitive a parameter to be estimated in this fashion, or the correct algorithm has not yet been discovered.

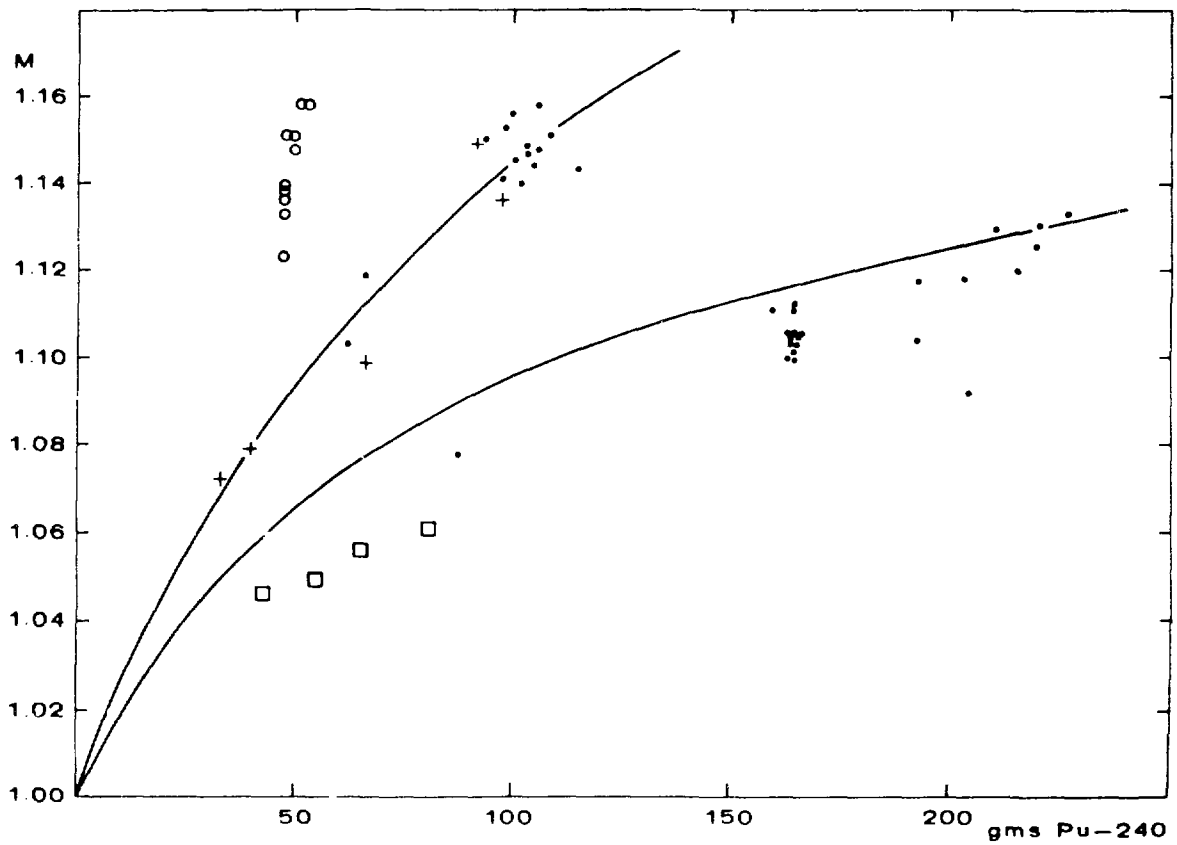

Fig. 7. Calculated values of the net leakage multiplication M as a function of plutonium oxide mass.

Finally, the oxide samples were analyzed with two nonlinear calibration curves based on the measured coincidence response (without a self-multiplication correction). Again the samples seemed to divide naturally into weapons grade and high-burnup oxide. These two nonlinear curves, summarized in Table III, fit the available data with an accuracy of about 3% 1 σ. (One outlier was deleted from each fit.) It is not known whether all future oxide samples at SRP will fall into one of these two categories. The only known physical basis for the two different curves is that the self-multiplication correction factors differ

TABLE III

FINAL ANALYSIS OF OXIDE DATA
WITH NONLINEAR CALIBRATIONS

Type of Oxide	No. of Assays	A	σ_A	B	σ_B	cov(A, B)	Accuracy
Weapons grade	19	39.3	1.5	-0.0027	0.0003	0.00008	3% 1 σ
High burnup	21	42.6	1.7	-0.0005	0.0002	0.00006	3% 1 σ

by about 5% for such large differences in ^{240}Pu content (as determined by Monte Carlo calculations).[2] Density, can diameter, fill height, and impurity concentrations also affect self-multiplication, but there are not enough data available on these oxide samples to calculate these corrections. At the present time, it is recommended that these two nonlinear calibration curves be used for future oxide assays, and that additional calibration curves be derived if different types of oxide are encountered.

VIII. RESULTS FOR SCRAP

Twenty-eight samples of scrap were assayed during this evaluation period. This number of samples is not enough to support a general conclusion regarding the accuracy of the DRCC for scrap, but specific statements can be made about the samples that were assayed.

Ten samples consisted of scrap oxide and contained about 50 g of ^{240}Pu each. The accuracy of both total neutron and coincidence counting was about 5% 1 σ. These scrap oxide samples are included in Figs. 5 and 6 (open circles) and could be regarded as a third class of oxide samples requiring a separate nonlinear calibration curve. It is not known if other scrap oxide samples would lie on such a curve.

Twelve small samples contained about 10 g apiece of weapons-grade plutonium. These were assayed for only 300 s each, so that both the total neutron response and the coincidence response were subject to 30 to 50% counting statistics. Within these statistical errors the assays agreed with the plant values for the contents. Longer assay times may have revealed some bias, but

300 s was sufficient to verify that each scrap can contain only a small quantity of plutonium.

Three samples of impure oxide contained about 30 g of ^{240}Pu each. The assay based on the coincidence response was accurate to about 17% 1 σ, and the assay based on the total neutron response was accurate to about 46%. For this impure material the total neutron response was significantly affected by the presence of (α, n) reactions. A more extreme example of this behavior was provided by three slag and crucible samples containing 1 to 3 g of ^{240}Pu. This material contained calcium, magnesium, fluorine, or other elements with large (α, n) cross sections. The coincidence response was accurate to about 25%, whereas the total neutron response was too high by a factor of 10. Similar results have been obtained on larger samples of slag and crucible assayed in a large rectangular neutron coincidence counter employing the same electronics package.

It is recommended that slag and crucible and other scrap materials be assayed by neutron coincidence counting. The total neutron response may be equally accurate, or may be too high by large factors if certain impurities are present.

IX. CONCLUSIONS

During the test and evaluation period, the dual-range counter operated with good reliability and stability. For large metal and oxide samples, assay precision based on counting statistics and reproducibility was better than 1% 1 σ. Assay accuracy was 2% 1 σ for pure metal samples if a self-multiplication correction was used. Assay accuracy was 5% 1 σ for plutonium oxide if separate nonlinear calibration curves, without self-multiplication corrections, were used for each type of oxide. Assay accuracy was on the order of 10% 1 σ for impure metal samples. For a limited number of scrap samples the accuracy varied between 5 and 25% 1 σ. More assays are needed to better determine the accuracy for scrap materials. However, many scrap containers are too large to be assayed in the 15-cm-diam well of the DRC, so that the larger rectangular counter recently supplied to SRP by Los Alamos may be more useful for this category.

For oxide and impure metal, the expected clear-cut advantage of coincidence counting over total neutron counting did not materialize. This is because the

self-multiplication correction was useful only for pure metal and very well-characterized oxides where geometry effects were greater than (α, n)-induced multiplication effects. For other large, multiplying samples, the total neutron response often provided a more accurate assay because it was less sensitive to multiplication. On the other hand, for scrap materials with low multiplication where it was necessary to discriminate against neutrons from strong (α, n) reactions or high room backgrounds, the coincidence response was more accurate. For a wide range of plant material categories, it is generally useful to measure both the coincidence and the total neutron response.

At SRP the dual-range counter has been used to measure the nuclear material content of a variety of incoming metal and oxide shipments. This information can be used to satisfy DOE requirements for a verification within 10 days of receipt of material. At SRP, the information was used for accountability until the samples were dissolved. A possible future application of the counter is verification of all material moving in or out of the vault. For such applications, or in cases where material is assayed at both the shipping and the receiving points, very accurate verification may be obtainable because many of the factors that influence assay accuracy will not change.

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