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Capability and Limitation Study of the DDT Passive-Active Neutron Waste Assay Instrument

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**N. J. Nicholas*
K. L. Coop
R. J. Estep

**Staff Research Assistant at Los Alamos. Department of Physics, The Georgetown University, Washington, DC, 20052.*

MASTER

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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CAPABILITY AND LIMITATION STUDY OF THE DDT PASSIVE-ACTIVE NEUTRON WASTE ASSAY INSTRUMENT

by

N. J. Nicholas, K. L. Coop, and R. J. Estep

ABSTRACT

The differential-dieaway-technique passive-active neutron assay system is widely used by transuranic waste generators to certify their drummed waste for eventual shipment to the Waste Isolation Pilot Plant (WIPP). Stricter criteria being established for waste emplacement at the WIPP site has led to a renewed interest in improvements to and a better understanding of current nondestructive assay (NDA) techniques. Our study includes the effects of source position, extreme matrices, high neutron backgrounds, and source self-shielding to explore the system's capabilities and limitations and to establish a basis for comparison with other NDA systems.

I. INTRODUCTION

This report describes the nondestructive assay (NDA) of a variety of test drums; the analysis of these measurements; the resulting changes made to the data-handling software system; and the limits of the differential dieaway technique (DDT) passive-active neutron (PAN) system. We provide an account of the capabilities and limitations of the system and establish a basis for comparison with other NDA systems (specifically, the Cf Shuffler that has been developed by Group N-1 of Los Alamos National Laboratory).

II. SCIENTIFIC MOTIVATION

The DDT will be used primarily by transuranic (TRU) waste generators to ensure that their drummed waste meets the criteria of the Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico. Recently, the DOE and New Mexico state agencies have ruled that WIPP will have to redefine their waste acceptance criteria before they can open. The criteria for a waste shipment to and storage at the WIPP site are continuing to evolve, with a clear trend toward more restrictive requirements on the amount of transuranic isotopes allowed for both per drum and per shipment. This development has resulted in the need for more accurate assay instrumentation. Although Los Alamos National Laboratory (LANL) and other national and commercial laboratories are using second-generation PAN assay systems, there has been a renewed interest in improving NDA systems because of stricter WIPP criteria and because of an increasing awareness that currently used PAN systems may be less accurate than originally supposed.

III. HISTORY OF THE DDT SYSTEM

In 1978, initial development of a pulsed active neutron assay system began at the Advanced Nuclear Technology Group (N-2) at LANL,[1-3] and the project became part of the TRU waste program in 1980.[4-5] The term "differential dieaway technique" (DDT) was coined because of the large difference between the characteristic lifetimes of the interrogating thermal neutrons ($T_{1/2} = 0.5$ ms) and the detected fast neutrons ($T_{1/2} = 0.015$ ms), which makes highly sensitive assays possible. In an effort funded by DOE, the active assay unit was combined with a passive neutron coincidence-counting detection design; the combined system[6] was awarded the 1983 Industrial Research Council IR-100 award as one of the 100 outstanding inventions that year.

Three second-generation versions of the DDT/PAN system were developed for the DOE and its contractors to assay large volumes of drummed TRU waste. The second-generation design included improved waste matrix corrections, a drum-weight acceptance raised to 1500 lb, improved assay algorithms and software, and three different drum-loading schemes. Versions of the second-generation units have been installed and are being used at TRU waste generating and processing facilities, such as the Idaho National Engineering Laboratory, the Rocky Flats Plant, the Savannah River Site, and Hanford (WHC).[7] Recently, the first-generation unit at Oak Ridge has been dismantled to add additional helium detectors for improved accuracy and sensitivity.

IV. EQUIPMENT FOR THE DDT/PAN SYSTEM

For the experiments and measurements described below, we used a typical second-generation DDT/PAN mobile drum unit that was designed and built at Los Alamos by Group N-2. This device assays 55-gal. (208-L) drums in a central cavity surrounded by layers of graphite, polyethylene, borated polyethylene, and aluminum. For the active measurements, fast neutrons are generated by the $^{3}H(^{2}H,n)^{4}He$ reaction induced in a pulsed 14-MeV Zetatron,* which is situated in the back right corner of the cavity. Typically, ^{3}He detector packages, both shielded in cadmium and boron (against thermal neutrons) and bare, surround the cavity on all six sides and collect the coincidence neutron counts needed for passive mass analysis; the shielded-to-totals ratio is used in determining the moderator correction factor. In our mobile unit this arrangement applies to five sides of the chamber; however, the sixth side (the door) has five shielded and no bare detector packages.[8] In the active mode, only shielded detectors are used to detect the induced fission neutrons in the presence of the thermalized interrogating flux. There are also two thermal neutron flux monitors: a bare monitor that measures the thermal interrogating flux near the top of the chamber and a shielded and collimated monitor that measures the thermal flux emerging from the barrel. The ratio of these monitors is used to determine the absorption correction factor. Figure 1 contains a photograph and a schematic of the DDT/PAN system; Ref. 8 details its components.

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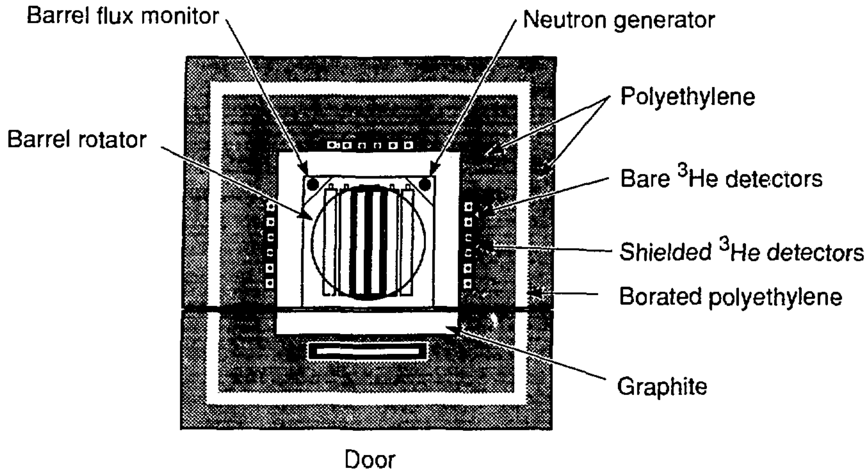
* The MA/65C Zetatron neutron generator used produces 14-MeV neutron bursts of 1 to 3 x 10^6 in a 10-µs-wide pulse at a rate of 50 pulses/s.

(a)



(b)

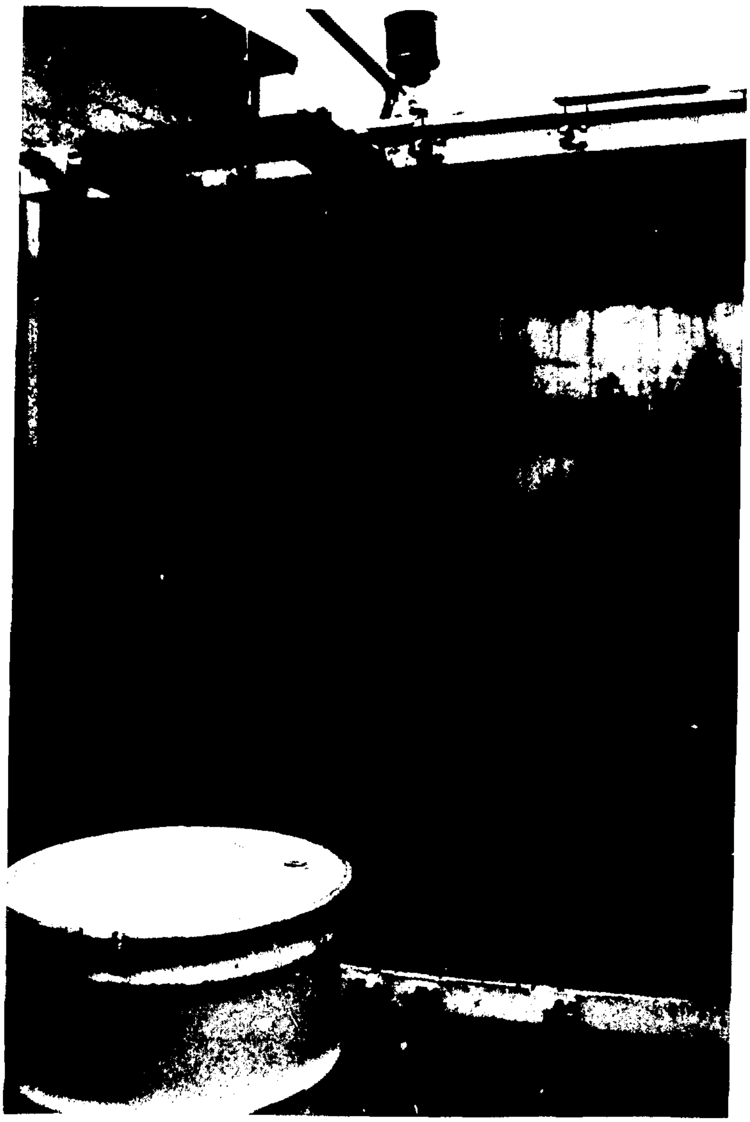


Figure 1. a) A schematic diagram of the mobile drum NDA-DDT unit (top view) and b) an interior photo (side view).

V. SOFTWARE DEVELOPMENT

To calibrate the mobile PAN system, we used the NEUT software (developed at Los Alamos for the neutron assay system, circa 1985) to acquire and analyze new data that were taken on drums with a variety of absorbing and moderating matrices, using a 30-g plutonium cylinder. For these assays, sixteen 55-gal drums filled to within 3 in. of the top (see Appendix A) were rotated about the vertical (azimuthal) axis, and active and passive assays were then taken with the source situated in 15 different positions throughout the drums to simulate a uniform, homogeneous fissile mass distribution. These positions were chosen so that the average of the acquired data would approximate the total volume average for each drum. From the floor of the 80-cm-tall drum, the positions were measured at heights of 8, 24, 40, 56, and 72 cm for radii of 12, 20, and 25 cm.

The active assays were performed with a standard 2000-pulse interrogation, and the passive assays had a run time of 400 s. The voltage settings for the neutron generator were 500 V for the source and 450 V for the target; the nominal output per pulse was typically 1 x 10^6 neutrons. The total mass of the plutonium cylinder was 29.745 g; and the isotopic enrichment for this material was 0.012% ^{238}Pu, 93.81% ^{239}Pu, 5.81% ^{240}Pu, 0.349% ^{241}Pu, and 0.022% ^{242}Pu. For each drum, a half-life reading of the flux monitor and the barrel flux monitor was also taken, using software developed by R. J. Estep, LANL.[9] For our system, passive mass estimates reflect the total plutonium mass while the active mass estimates the mass of the fissile material present .

A. Data Manipulation

We organized the database of results (DBAS) from the data acquisition program (NEUT) into a LOTUS-123 spreadsheet with the aid of IBM2LOT, a database transfer program designed by P. A. Vogel, LANL, for use with LOTUS spreadsheets. For each drum, one set of data was stored for each of the 15 source positions. The average values for each drum were obtained by first calculating the average matrix correction factors, then multiplying these by the average raw active- or passive-counting results. This procedure was designed to provide the results that would be obtained if sources were located simultaneously at all 15 positions and only one measurement were made. (It should be noted that multiplying the raw counting-data for each source location by the matrix correction factor obtained for that position, then summing and normalizing these results for all 15 positions does not yield the same "average" value as that obtained by the procedure described above.) These average values for each test drum, along with our data and calculated results, are provided in Appendix B. These averages were tabulated in one summary spreadsheet, shown in Fig. 2, and the values were then plotted and fitted, using commercial Math Cad software to recalibrate the previous version of the NEUT data acquisition Fortran code for our specific assay device.

Matrix	Active Signal	Absor. Corr.	Moder. Corr.	Active Mass	Passive Signal	250-Coin. Corr.	Passive Mass
Vermiculite	0.743	1.019	1.011	0.765	29.094	1.027	29.875
Empty	0.764	0.979	0.999	0.748	28.899	1.042	30.103
Verm. w/Liner	0.760	1.116	0.944	0.800	27.190	1.135	30.873
Peat Moss	0.677	1.288	0.908	0.792	15.496	1.854	28.728
0.3 Borax	0.586	1.200	1.011	0.710	29.154	1.027	29.937
0.6 Borax	0.516	1.455	1.011	0.758	28.968	1.027	29.745
0.9 Borax	0.415	1.834	1.011	0.769	28.893	1.027	29.668
1.2 Borax	0.393	1.922	1.011	0.764	28.486	1.027	29.251
1.5 Borax	0.301	2.571	1.011	0.782	27.825	1.027	28.571
1.8 Borax	0.304	2.329	1.011	0.715	28.185	1.027	28.942
Poly. shaving	0.730	1.207	0.898	0.791	24.265	1.304	31.647
Poly. beads	0.080	3.682	2.990	0.880	3.495	8.836	30.877
VP1	0.499	1.526	0.935	0.713	13.999	2.057	28.801
VP2	0.335	1.895	1.169	0.742	8.315	3.223	26.797
VP3	0.298	1.937	1.206	0.696	8.112	3.382	27.436
VP4	0.224	2.108	1.521	0.719	6.323	4.601	29.090
VP4B2	0.095	3.682	1.369	0.478	6.213	4.037	25.080
VP4B2D	0.219	2.987	0.964	0.631	13.197	2.231	29.445
Top	0.441	1.005	0.913	0.405	19.386	1.229	23.821
Bottom	0.437	2.655	1.165	1.350	19.546	1.448	28.311
Alumina	0.128	3.682	1.541	0.729	6.549	4.673	30.607
Iron	0.474	1.885	1.011	0.902	30.306	1.027	31.120
Poly. Chunks	0.252	2.111	1.063	0.566	7.651	2.748	21.022
Iron & Poly.	0.288	1.960	0.884	0.499	12.926	1.491	19.273
Junk	0.637	1.087	0.948	0.656	25.231	1.127	28.439

Figure 2. LOTUS 123 summary spreadsheet.

B. Plotting and Curve Fitting

In an attempt to find a simple algebraic method for converting detected signals into fissile mass values, we plotted our output and searched for clear correlations. For non-moderating matrices, the absorption index (see Sec. VI.A for a definition of terms) plotted against the uncorrected active mass was fitted with two straight lines: $y = -0.08885x + 0.9025$ when x, the absorption index, is < 5.468; and $y = -0.01096x + 0.47658$ when this index is > 5.468. At an absorption index of 5.468 the two lines cross (see Fig. 3). With a neutral matrix of vermiculite, we achieved the average active ^{239}Pu mass value of 0.746 g, which was used to normalize our data. (This estimate is much less than the actual fissile mass because of the self-shielding of the thermal interrogating neutrons; however, it is only used as a reference value. An absolute calibration was achieved with another fissile sample.) The absorption correction factor becomes 0.746 divided by the appropriate line. This process yields a relative standard deviation of 0.041 for an absorption-corrected mean active mass of 0.731 g.

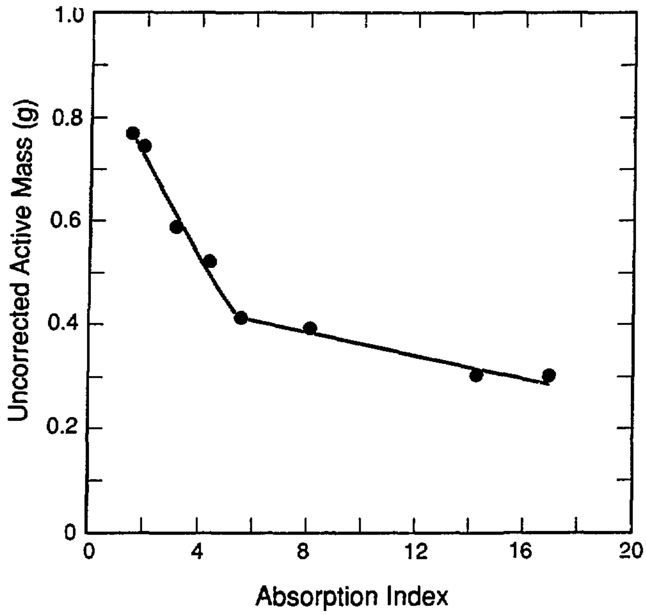


Fig. 3. Data for determining the absorption correction factor where $y = -0.0889x + 0.9025$ or $y = -0.01096x + 0.4766$.

To correct for moderation during active assays, all of the database was examined, and the drums whose moderator index fell within our system's original (i.e., before new calibration) acceptable range (17 in all, see Appendix A) were used. A plot of the moderator index vs the absorption-corrected active mass was fitted with the following curve: $0.752 + 1.099x - 2.808x^2$.* Results with moderator indices > 0.66 were deemed out of the range of this assay method for the current study. Again, to normalize to the vermiculite data, the moderator correction factor was defined as 0.760 divided by this curve (Fig. 4). The total active mass correction factor is the product of the moderator and the absorption correction factors. The mean absorption- and moderator-corrected active mass was 0.769 g, with a relative standard deviation of 0.069.

For the passive mass, a 250-µs coincidence factor (for the totals coincidence gate width of 250 µs) is obtained by fitting a quadratic curve to the plot of the moderator index vs the uncorrected passive mass data from all 17 drums of data set 3 in Appendix A. This fit is $y = 28.9326 - 50.2144x + 17.3814x^2$ (Fig. 5). It was used to correct all the data points; and the relative standard deviation to this fit was 0.032, after a multiplicative normalization correction factor of 0.99825 was applied to force the average corrected passive mass result to be 29.745 g. The 250-µs correction factor is calculated from the reciprocal of the above equation.

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* This curve is a very close approximation to the least squares fit to the data, $y = 0.749 + 1.189x - 2.954x^2$.

VI. TEST RESULTS

In general, calibration runs were taken at 15 positions throughout each drum, using the 30-g plutonium source along with a sourceless passive background run. In addition, we employed larger and smaller plutonium sources, uranium sources, self-shielding sources, and secondary sources that introduced high neutron backgrounds to test the system's response. The effects of nonhomogenous matrices and source-hiding materials were also evaluated. To check the equipment for consistent results, a set of ten measurements using a benign matrix was taken daily during a two-week period.

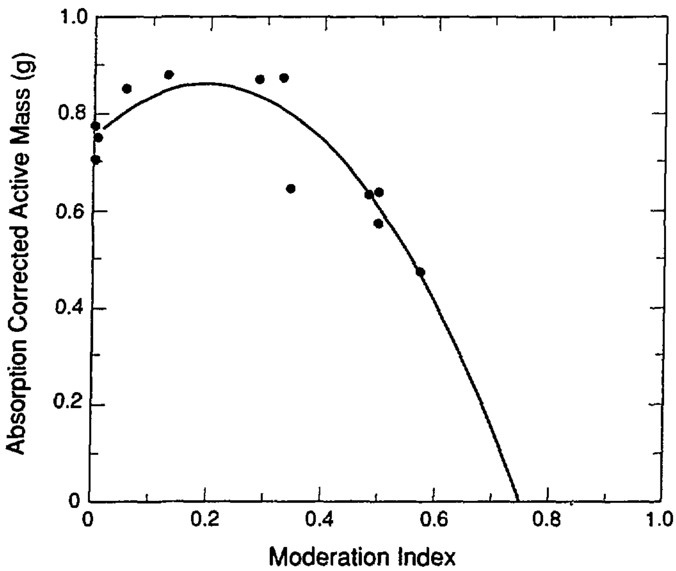

Fig. 4. Data plot for determining the moderation correction factor, where $y = 0.752 + 1.099x - 2.808x^2$. The error bars (not shown) on these data were a few percent or smaller. (Although 17 points were plotted, some are not shown because the data overlaps.)

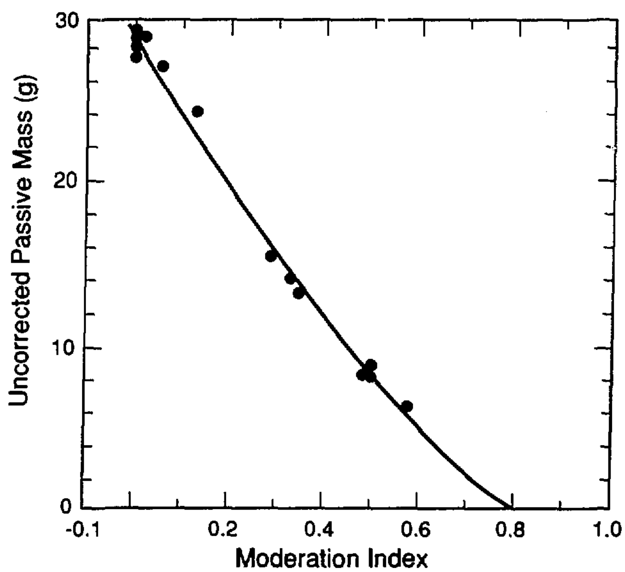

Fig. 5. Data plot for determining the 250-μs correction factor, where $y = 28.933 - 50.214x + 17.381x^2$. (Although 17 points were plotted, some are not shown because the data overlaps.)

At the end of both the active and the passive stage of each run, the data is routinely printed out as well as recorded in the DBAS file. Figure 6 shows a typical summary output for both an active and passive run. Theoretically, both the active and passive mass estimates should agree within the error range to 29.745 g, the actual total plutonium value of the source used, if both the active and passive systems are calibrated to give the *total* plutonium mass. However, because of the large self-shielding effects in concentrated plutonium metal sources, when interrogated with thermal neutrons, the measured active mass is more closely related to the surface-area fissile mass than the volume.

Flux monitor half-life readings are generally taken during two to three of the fifteen runs per drum. These readings are saved in computer files and may be used to help evaluate fissile masses in the case of weak passive signals; that is, when the fissile material is uranium, or a minute plutonium mass. (The half-life readings have not yet been analyzed.)

SUMMARY REPORT[a]

Run Number 40	Disk ID 1050872		Content Code 0.9KG	
Primary ID R12 Z24	Secondary ID Verm. & Borax			
Time and Date of Active	14:26:49	10/16/90		
Time and Date of Passive	14:28:17	10/16/90		
Passive Count Time (s)	400.09	No. of Active Pulses	2000	
System Totals Rate	229.27	± 0.83272		
Shielded Totals	82.028	± 0.50213		
70-μsec Coinc Rate	2.1375	± 0.83193E-01		
250-μsec Coinc Rate	22.678	± 0.32661		
Shielded Active Signal	1791.0			
Shielded Active Backgro	587.94			
Flux Monitor	9278.6			
Barrel Flux Monitor	1635.3			
Percent Pu-239	94.00	Container Weight (kg)		35.0
Passive Mass (g)	29.095	± 0.41904		
Active Mass (g)	0.49811	± 0.54173E-01		
nCi/g	3350.6	± 364.41		
Total Alpha Act (ci)	0.91710			
Thermal Power (W)	0.27513E-01			
Therm Pow Den (W/ft^3)	0.37432E-02			
Pu-238 Activity	No			

[a] The error calculations have *not* been improved as part of our new software developments. The errors presented by the computer-generated output may not be representative of the actual data calculations.

Fig. 6. A typical data acquisition summary output sheet.

A. Calibration Drum Measurements

As discussed above, the drums listed in data set 1 in Appendix A were used to calibrate the system. The active calibration was performed with two sources: a depleted uranium source (D38) situated at the standard 15 positions within the drums; and a set of seven vials [each containing 0.7 g of ^{235}U finely dispersed on the surface of small aluminum oxide (AlO) pellets] that filled the entire length of the shafts. An equivalent ^{239}Pu source of the same mass would give 1.5 times as many counts, and the system was calibrated accordingly. The equation for calculating the active mass is

$$\text{ACTIVE MASS} = \text{ACTIVE SIGNAL} \times \text{CORRECTION FACTOR},$$

where,

$$\text{ACTIVE SIGNAL} = 3.675 \times [(\text{SHSI} - 0.977 \times \text{SHBI})/\text{FMIN} - 0.003], \text{ and}$$

$$\text{CORRECTION FACTOR} = \text{ABS CORR} \times \text{MOD CORR}.$$

Here,

$$\text{ABS CORR} = 0.746/(-0.08885 \times \text{AI} + 0.9025), \quad \text{if AI} < 5.468, \text{ and}$$

$$= 0.746/(-0.01096 \times \text{AI} + 0.4766), \quad \text{if AI} > 5.468$$

$$\text{MOD CORR} = 0.76/(0.752 + 1.099 \times \text{MI} - 2.808 \times \text{MI}^2); \text{ and}$$

where the absorption index (AI) and moderator index (MI) are

$$\text{AI} = \text{FMIN/EFMIN}, \text{ and}$$

$$\text{MI} = [1 - (\text{SHRAT/SYRAT})/0.346] \times [0.76 + 0.47\ln(\text{AI})].$$

In the above equations, SHSI and SHBI are the shielded signal and background; SHRAT and SYRAT are the shielded and total system count rates; and FMIN and EFMIN are the net flux monitor and barrel flux monitor counts, respectively. These equations reflect the changes in the equations of Ref. 7, and the scaling factors have been altered according to the data fits given in Figs. 3 and 4.

For the passive mass calibrations we used the 30-g plutonium cylinder. These equations are the same as those in Ref. 7, except for the CF250 equation that was obtained using the empirical fits plotted in Fig. 5. The passive mass equation for assay with system rates of < 2000 counts/s is

$$\text{PASSIVE MASS} = \text{CO250R} \times \text{PMCAL1} \times \text{CF250} \times \text{ISOP};$$

and for assays with systems rates ≥ to 2000 counts/s:

$$\text{PASSIVE MASS} = \text{CO70R} \times \text{PMCAL2} \times \text{CF70} \times \text{ISOP},$$

where

$$\text{CF250} = 29.70/[28.93 - 50.21\,(\text{MI}) + 17.38\,(\text{MI})^2], \quad \text{and}$$

$$\text{CF70} = [0.796/(1 - \text{MI}) + 0.224]^2.$$

Here, the CO250R and CO70R are the 250-µs (totals) and 70-µs (shielded) coincidence rates. PMCAL1 and PMCAL2 are new passive mass calibration factors that are 1.283 and 12.270, respectively. Both the 250- and the 70-µs calibration factors depend on the moderator index defined above. Finally, the ISOP term is the passive plutonium isotopic factor. For our ^{239}Pu standards, an ISOP of unity was used to represent a 6% ^{240}Pu enrichment. Periodically, we performed assays using the neutral vermiculite drum to verify the week-to-week stability of our instruments.

B. Exploration of Matrix Limits

Measurements to determine the dependence on matrix uniformity and homogeneity were made with the 30-g plutonium source at the standard 15 positions within the drum. Several mixed matrices were used, ranging from mixtures such as iron chunks and air; to typical waste junk such as rubber gloves, paper, dry chemicals, and scrap metal; to divided drums containing, for example, benign vermiculite on the bottom and an absorbing as well as moderating mixture of vermiculite, polyethylene pellets, and borax powder on the top. Several drums containing unknown amounts of water and ice, which leaked in through the barrel lids, were also assayed.

Table I gives the results of this test. As expected, the PAN system assayed the mixtures such as iron chunks and air, or mock "junk," more accurately than it assayed the split volumes of benign and moderating or absorbing matrices. Relatively small, concentrated amounts of water (perhaps $\leq$ 1 gal.) had a marginal effect on assays: measurements of drums that had leaked rainwater differed slightly compared to the original measurements of those same drums when dry.

We also performed other tests to explore the limits of uniform matrices with high concentrations of strong moderators and/or absorbers. To recalibrate the software as described in Sec. V, cut-off values for the moderator and absorption indices were needed. We ran experiments adding borax powder (an absorber) or polyethylene pellets (a moderator) in small increments to a neutral vermiculite matrix to find these cut-off points. Results indicated that the highest moderator permitting accurate assays with our equations had a moderator index of 0.66, corresponding to some positions in a matrix of polyethylene in vermiculite (see test drum 14 of set 4 in Appendix A). The highest absorber index we could satisfactorily work with was 25; drums 12, 17, and 21 (set 4, Appendix A) exceeded this value. The lines in Fig. 3 can be extrapolated to fit our data for absorber indices < 25. For drums with absorber indices > 25 and/or moderator indices > 0.66 at any of our 15 standard positions, the software was designed to reset those indices to 25 and 0.66, respectively, and to print out a warning that the drum's matrix may exceed our capabilities.

To study the effect of small "pockets" of homogeneous and uniform waste, we employed a set of 18 "pillows" (approximately the size of a 1-gal. can) of ^{235}U wrapped in cotton. Each "pillow" nominally contains 5 g of uranium with a 92.88% enrichment of ^{235}U. We made runs, adding one "pillow" at a time to build a pile of pillows up from the floor of the drum. The results of this test are plotted in Fig. 7. Because the DDT system is calibrated for plutonium, a multiplicative uranium correction factor of 1.5 is needed. Although the effects of some self-shielding (Sec. C) can be seen, the data is quite linear and additive; that is, the data plotted in Fig. 7 do not demonstrate saturation, but continue to maintain a constant, increasing slope of 0.87 (without self-shielding a slope of 1.0 would be expected). However, the lower efficiency of the drum counter for sources near the bottom of an otherwise empty drum is apparent for the low mass values, as manifested by the negative intercept of the curve on the y-axis.

Appendix B of this report is a series of data spreadsheets from the LOTUS 123 software used to analyze all our raw data.

Table I. Summary of Matrix Limitation Test Results

Matrix	Volume Average Masses: Passive (g)	Volume Average Masses: Active (g)	Absorption Index	Moderator Index
Empty	30.103	0.748	1.58	0.008
Vermiculite	29.875	0.765	1.92	0.000
Verm. w/ Liner	30.873	0.800	2.63	0.056
Peat Moss	28.728	0.792	3.64	0.285
0.3 kg Borax	29.937	0.710	3.16	0.000
0.6 kg Borax	29.745	0.758	4.39	0.000
0.9 kg Borax	29.668	0.769	5.58	0.000
1.2 kg Borax	29.251	0.764	8.09	0.000
1.5 kg Borax	28.942	0.715	14.34	0.000
1.8 kg Borax	28.571	0.782	17.10	0.000
Poly. Shavings	31.647	0.791	3.20	0.218
Poly. Beads	30.877	0.880	25.00[a]	0.660[a]
VP1	28.801	0.713	4.66	0.325
VP2	26.797	0.742	7.58	0.469
VP3	27.436	0.696	8.36	0.481
VP4	29.090	0.719	11.20	0.554
VP4B2	25.080	0.478	25.00[a]	0.525
VP4B2 Dilute	29.445	0.631	20.70	0.355
Top: VP4B2D	23.821	0.405	1.80	0.098
Bottom: VP4B2D	28.311	1.350	17.84	0.179
Alumina	30.607	0.729	25.00[a]	0.557
Iron Chunks	31.120	0.902	7.38	0.000
Poly. Chunks	21.022	0.566	11.25	0.423
Iron & Poly. Chunks	19.273	0.499	3.96	0.192
Mock Junk	28.439	0.656	2.43	0.052

[a] Maximum permitted value; calculated index value from data exceeded this.

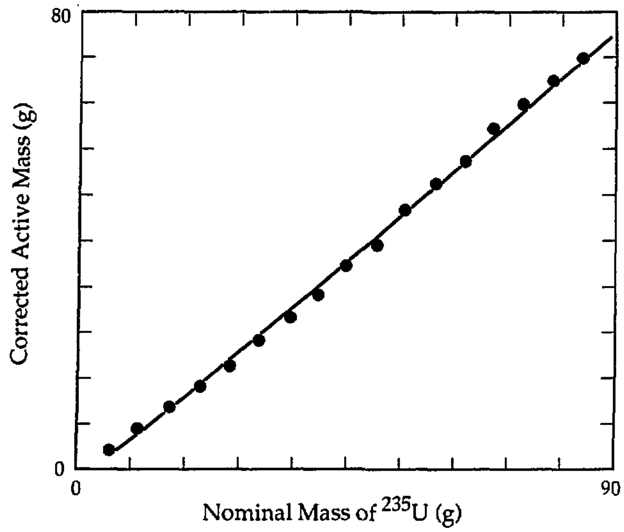

Fig. 7. Passive mass estimates as a function of the number of pillows. The solid line fit is $y = 0.87x - 2.618$.

C. Self-Shielding of Fissile Material

In analyzing the results of an assay, it is necessary to evaluate the state of the fissile material as well as that of the surrounding matrix. To simplify analysis, it is generally assumed not only that the fissile material is uniformly distributed throughout the waste, but also that there are no "lumps" or pieces present. It has been well established that self-shielding will occur whenever such "lumps" are present; hence, the active mass assay will be more representative of the surface area than the total mass.[10]

To measure the effects of self-shielding sources on passive and active DDT assays, we used a set of five plutonium cylinders, varying in mass from 1 to 100 g, as well as a 0.5-g sphere. These samples were made of weapons-grade (delta phase) plutonium, having a density of 15.8 g/cm^3, and are described in Table II. One or more runs were taken for each source in three different drum matrices: one neutral, one strong moderator, and one strong absorber. The source position for this experiment was near the center of the drum at a radius of 12 cm and a height of 40 cm.

The results of this test (see Table III) show that the effect of self-shielding becomes obvious at very small volumes. For the 0.5-g sphere of plutonium in vermiculite, our passive mass estimate was quite good (that is, 0.499 g), while our active mass estimate (0.049 g) was low by a factor of 10. For the 100-g Pu cylinder, the passive estimate was high, 116 g; however, this is not surprising because we calibrated the system for a 30-g source and made no corrections for multiplication effects that are appreciably greater in the 100-g cylinder. The active mass estimate for this 100-g source in a benign matrix was 2.10 g, which is low by about 2 orders of magnitude as a result of self-shielding. The mass of any source whose thickness is comparable to or greater than the mean-free-path length of thermal neutrons will be underestimated by the active assay component of the DDT system. For more details on the self-shielding effect, see Ref. 11.

Table II. Height = Diameter Cylindrical Plutonium Samples

Nominal Mass Total Pu (g)	Nominal Diameter (cm)	Finished Mass Total Pu (g)	Surface Area (cm^2)
0.5[a]	0.374	0.538	0.439
1.0	0.431	1.066	0.875
3.0	0.621	2.938	1.817
10.0	0.928	9.820	4.058
30.0	1.339	29.745	8.449
100.0	2.000	98.933	18.850

[a] Smallest sample is a sphere of density 19.6 g/cm^3.

Table III. Self-Shielding Neutron Tests

Matrix	Nominal Mass (g)	Passive Mass Total Pu (g)	Active Mass ^{239}Pu (g)
Vermiculite: Benign			
	0.5	0.499	0.049
	1.0	0.956	0.087
	3.0	2.51	0.190
	10.0	9.304	0.443
	30.0	30.779	0.792
	100.0	115.710	2.095
VP4: High Moderator			
	0.5	-0.364	0.070
	1.0	-0.132	0.117
	3.0	1.849	0.221
	10.0	5.289	0.693
	30.0	20.324	1.112
	100.0	92.602	2.694
1.8 kg of Borax: High Absorber			
	0.5	0.429	0.044
	1.0	0.805	0.030
	3.0	2.242	0.111
	10.0	8.303	0.250
	30.0	27.135	0.344
	100.0	103.860	0.706

D. High Neutron Backgrounds

The PAN assays described in this paper are sensitive to the background neutron flux in the immediate area of the measurement. A background subtraction is made on both the active and passive counts, but generally the background count is taken at the beginning of the day and is assumed to be constant for the passive count. To investigate the effect of high neutron backgrounds resulting from (α, n) reactions in the waste and other neutron sources, we made a series of measurements with a second, neutron-generating source inside the vermiculite drum.

As the primary (fissile) source, the 30-g plutonium standard was positioned at a radius of 20 cm and a height of 40 cm. Each one of our background neutron sources (^{252}Cf, $^{239}PuBe$, and $^{238}PuLiF$) was situated at a height of ~ 55 cm (except the $^{239}PuBe$, which was placed at the top because of its size) in the center of the drum (r = 0). Table IV displays the results of these tests.

For backgrounds on the order of 10^4 n/s or lower, such as those simulated with the ^{252}Cf, our active results were acceptable; although our passive detectors directly reflected the presence of a secondary spontaneous-fission neutron source. The passive results of the runs made with just the 30-g plutonium source plus those of the runs made with just the californium source add up approximately to the passive results achieved with both the 30 g of plutonium and the californium in the drum.

The $^{239}PuBe$ source we used to generate a background level of 6×10^4 n/s contained 0.5 g of ^{239}Pu; however, the passive mass results we achieved with just this source in place were on the order of 20 g. When both the 30 g of plutonium and the $^{239}PuBe$ were in the drum, the 30-g source could be detected, but reliable detection with this background source would only hold for a quantity of 100 g or more of weapons-grade plutonium. This background presented a problem for detecting active masses less than a few hundred milligrams.

When the 5×10^5 n/s $^{238}PuLiF$ "background" source was employed, the passive results were unsuitable because the extraneous neutrons interfered greatly with the neutron coincidence count rate; hence, no valid correction was possible. The active results for this "background" test (again using a uniform matrix) were valid, but only for masses of gram-sized quantities or more.

We should note that the passive count rates were > 2000 counts/s for all measurements made with added neutron sources; therefore, the corresponding passive masses were calculated from the 70-µs coincidence data.

Table IV. High-Neutron-Background Test Results

Primary Fission Source: 30 g of ^{239}Pu   position: r = 20, z = 40
Matrix: Vermiculite
Background Sources:

1) ^{252}Cf   position: r = 0, z = 50   source strength: 2 x 10^4 n/s
2) ^{239}PuBe   position: top of drum   source strength: 6 x 10^4 n/s
3) ^{238}PuLiF   position: r = 0, z = 50   source strength: 5 x 10^5 n/s

Sources	Passive Mass (g)	Active Mass (g)
30 g Pu	30.92	0.828
30 g Pu	31.50	0.800
30 g Pu	31.20	0.763
30 g Pu	31.03	0.800
30 g Pu	31.13	0.824
Cf	765.10	0.074
Cf	771.13	0.042
Cf	767.90	0.113
Cf	770.81	0.041
Cf	783.10	0.028
Pu & Cf	805.99	0.819
Pu & Cf	800.02	0.878
Pu & Cf	800.62	0.818
Pu & Cf	805.95	0.784
Pu & Cf	806.63	0.793
PuBe	24.66	0.267
PuBe	31.04	0.253
PuBe	11.01	0.219
PuBe	17.47	0.266
PuBe	23.72	0.258
PuBe & Pu	53.70	1.025
PuBe & Pu	47.08	1.061
PuBe & Pu	60.66	0.980
PuBe & Pu	43.61	1.069
PuBe & Pu	44.09	1.017
PuLiF	95.70	0.537
PuLiF	-55.61	0.553
PuLiF	165.66	0.514
PuLiF	45.94	0.499
PuLiF	31.18	0.418
PuLiF & Pu	-43.68	1.437
PuLiF & Pu	47.11	1.317
PuLiF & Pu	88.30	1.480
PuLiF & Pu	-7.38	1.163
PuLiF & Pu	-67.40	1.250

E. Source Hiding

In another effort to explore the limits of the DDT, we "hid" a 100-g uranium source (with an actual mass of 98.9328 g and isotopic enrichments of 0.998% ^{234}U, 93.26% ^{235}U, 0.421% ^{236}U, and 5.38% ^{238}U) in the assay chamber inside 2, 4, and 6 in. of polyethylene. We then made a second set of measurements with the uranium source "hidden" inside a cadmium box (which has a large thermal-neutron-absorption cross section) of double thickness totaling 3/32 in. The box fits snugly inside the polyethylene layers. Because it was known that self-shielding effects would be seen, a control run was taken with the 100-g uranium source in an empty chamber for comparison. To test for a possible background effect associated with the cadmium itself, a run with just the box (no source) was made, and the active mass result was slightly less than zero. Table V gives all of the active mass results of this set of experiments.

A similar "hiding" procedure was carried out using a 100-g plutonium source inside both polyethylene and the cadmium box. For plutonium, the passive mass results were examined, because, as we expected, the active mass results were effectively zero in the presence of substantial moderators and absorbers. We used a 30-g plutonium source to calibrate our PAN assay device, which makes the device quite accurate for estimating plutonium masses near 30 g; however, the results of this test using the 100-g plutonium source are informative. Another difference between the 30-g and 100-g plutonium cylinders is their multiplication (M), or the ratio of the total number of neutrons emitted by the sample to the number of neutrons in spontaneous fissions. For the 30-g plutonium sample, M = 1.089, while M = 1.143 for the 100-g sample. After hiding the 100 g of plutonium inside the cadmium box and just 2 in. of solid polyethylene, the estimated passive mass result was decreased by 36%. Inside 4 in. of polyethylene plus the box, the reduction in the estimated passive mass was 87%. All of the results of this plutonium-hiding test are found in Table V.

Table V. Source-Hiding Test Results

Container	100 g of Uranium Active Mass (g)
None	3.2902
Cd Box	- 0.0022
2 in. Poly.	0.4280
4 in. Poly.	0.0285
6 in. Poly.	0.0110
2 in. Poly. and Cd Box	0.0005
4 in. Poly. and Cd Box	- 0.0001
6 in. Poly. (No ^{235}U)	0.0016
Cd Box (No ^{235}U)	- 0.0004

Container	100 g Plutonium Passive Mass (g)
None	107.79
Cd Box	110.13
2 in. Poly.	68.689
4 in. Poly.	18.226
6 in. Poly.	2.9124
8 in. Poly.	0.4219[a]
2 in. Poly. and Cd Box	68.932
4 in. Poly. and Cd Box	13.922
6 in. Poly. and Cd Box	2.8472
8 in. Poly. and Cd Box	- 0.9447[a]

[a] Moderator index was outside of the acceptable range.

F. Source Position Analysis

We simulated a well-dispersed fissile material by selecting 15 volume-defining positions in each calibration drum and averaging both their passive and active mass estimates. To test the necessity of this condition, we then calculated the ratio of the maximum to the minimum values for the active and passive mass (see Table VI (a) for the results of this study) and the ratios of the maximum and the minimum to the average values [see Tables VI(b) and (c)]. The passive maximum or minimum values differed by more than 20% in six cases for the drums within our matrix limitations. For the active case, the difference was more than 20% for most of the drums; clearly, if the fissile material is not evenly dispersed, poor assay values will result in many cases.

More specifically, we examined the effect of source position within the matrix to determine the importance of the standard assumption that the fissile material is uniformly spread throughout the drum. Table VII gives the results for a tabular comparison of the active and passive mass results as a function of spatial variations within the drums for the neutral matrix of vermiculite, the highly moderating mixture of 4 gal. of polyethylene beads to 10 lb of vermiculite (VP2), and the absorbing matrix of

1.5 kg of borax soap powder in vermiculite. In each case, the high and low values are flagged by a superscript (a), and the average of the 15 mass estimates and a standard deviation are provided. As previously noted, the average values obtained for the vermiculite drum were used to calibrate our system. Only a small amount of variation can be seen in these results for both the active and the passive mass estimates.

In the drum with a moderating matrix, VP2, the active mass results are highest with the source located deep within the matrix. To reach a source at this radial depth, the interrogating neutrons must pass through a large amount of this matrix material, which gives them a better chance of being moderated, thus making them more likely to interact with the fissile material. Conversely, when the source is located near the wall of the barrel, lower active mass estimates result because the interrogating neutrons, passing through less moderating material are faster and less effective. This depth variation does not hold for the passive mass results in the VP2 drum. Rather, the data demonstrates a trend in which all three radii produce lower passive mass estimates when the source is near the bottom of the drum, and higher estimates when it is near the top. Although our array of passive ^{3}He detectors has a 4-π design (except in the door), both the drum-rotation mechanism at the bottom and a void of air at the top of the assay chamber can cause asymmetrical results (see Table VII).

For the highly absorbing matrix containing 1.5 kg of borax, our active results are lowest when the plutonium source is deep within the drum, which is due to the partial absorption of the interrogating flux of neutrons by the matrix before it reaches the source. The highest active mass estimate for this drum corresponds to a source position at the bottom of the drum, near the drum wall, where the interrogating neutrons could arrive without traversing through much absorbing material. The passive mass results for this matrix show little spatial variation. Borax has a large absorption cross section for thermal neutrons such as those produced for our system's active interrogation. However, our passive counters also detect faster epithermal neutrons that are less readily absorbed by the borax in this matrix. From these spatial variation studies, we can again conclude that the fissile material within a drum must be well dispersed if accurate results are to be achieved for active assays of drums with "difficult" waste matrices.

Table VI(a). Ratios of Maximum to Minimum Values for Passive and Active Mass Estimates

Matrix	Max/Min	
	Passive Mass	Active Mass
Empty	1.078	1.288
Vermiculite	1.116	1.256
Verm. w/Liner	1.125	1.211
Peat Moss	1.242	1.894
0.3 kg Borax in Verm.	1.106	1.449
0.6 kg Borax in Verm.	1.115	1.594
0.9 kg Borax in Verm.	1.125	2.629
1.2 kg Borax in Verm.	1.131	2.141
1.5 kg Borax in Verm.	1.103	3.892
1.8 kg Borax in Verm.	1.131	4.147
Poly. Shavings	1.183	1.498
Poly. beads[b]	3036.000	48.655
2 gal. Poly./10 lbs Verm.	1.423	1.721
4 gal. Poly./10 lbs Verm.	2.190	2.593
6 gal. Poly./10 lbs Verm.	2.434	2.538
8 gal. Poly./10 lbs Verm.	2.241	2.535
Verm., Poly., and Borax[b]	3.077	10.158
VPB Diluted[a]	1.532	3.828
Top: VPB Diluted[a]	1.162	5.824
Bottom: VPB Diluted[a]	1.265	5.701
Alumina[b]	4.367	2.154
Iron Chunks	1.149	1.518
Poly. Chunks	1.870	1.818
Iron & Poly.	1.789	2.406
Mock Junk	1.141	1.678

[a] These matrices were diluted with additional vermiculite.

[b] The moderator index was outside of the acceptable range.

Table VI(b). Active Mass Results

Matrix	Average(g)	Max/Avg	Min/Avg
Vermiculite	0.765	1.086	0.864
Empty	0.748	1.106	0.858
Verm. w/Liner	0.800	1.062	0.877
Peat Moss	0.792	1.418	0.749
0.3 kg Borax in Verm.	0.710	1.151	0.794
0.6 kg Borax in Verm.	0.758	1.260	0.791
0.9 kg Borax in Verm.	0.769	1.311	0.499
1.2 kg Borax in Verm.	0.764	1.318	0.616
1.5 kg Borax in Verm.	0.715	1.758	0.452
1.8 kg Borax in Verm.	0.782	1.808	0.436
Poly. Shavings	0.791	1.203	0.803
Poly. Beads[b]	0.880	1.603	0.033
2 gal. Poly./10 lbs Verm.	0.713	1.296	0.753
4 gal. Poly./10 lbs Verm.	0.742	2.075	0.801
6 gal. Poly./10 lbs Verm.	0.696	2.141	0.844
8 gal. Poly./10 lbs Verm.	0.719	1.829	0.721
Verm., Poly., and Borax[b]	0.478	2.147	0.212
VPB Diluted[a]	0.631	1.552	0.406
Top: VPB Diluted[a]	0.405	1.554	0.268
Bottom: VPB Diluted[a]	1.350	1.537	0.269
Alumina[b]	0.729	1.397	0.648
Iron Chunks	0.902	1.215	0.800
Poly. Chunks	0.566	1.552	0.854
Iron & Poly.	0.499	1.519	0.631
Junk	0.656	1.187	0.707

[a] These matrices were diluted with additional vermiculite.

[b] The moderator index was outside of the acceptable range in some positions within these drums.

Table VI(c). Passive Mass Results

Matrix	Average (g)	Max/Avg	Min/Avg
Vermiculite	29.88	1.048	0.939
Empty	30.10	1.030	0.955
Verm. w/Liner	30.87	1.054	0.937
Peat Moss	28.73	1.132	0.912
0.3 kg Borax in Verm.	29.94	1.043	0.943
0.6 kg Borax in Verm.	29.75	1.037	0.930
0.9 kg Borax in Verm.	29.67	1.046	0.930
1.2 kg Borax in Verm.	28.25	1.047	0.926
1.5 kg Borax in Verm.	28.94	1.032	0.935
1.8 kg Borax in Verm.	28.57	1.053	0.931
Poly. Shavings	31.65	1.051	0.889
Poly. Beads[b]	30.88	2.163	0.001
2 gal. Poly./10 lbs Verm.	28.80	1.160	0.815
4 gal. Poly./10 lbs Verm.	26.80	1.627	0.743
6 gal. Poly./10 lbs Verm.	27.44	1.687	0.693
8 gal. Poly./10 lbs Verm.	29.09	1.484	0.662
Verm., Poly., and Borax[b]	25.08	1.567	0.509
VPB Diluted[a]	29.45	1.234	0.805
Top: VPB Diluted[a]	23.82	1.068	0.920
Bottom: VPB Diluted[a]	28.31	1.167	0.922
Alumina[b]	30.61	1.725	0.395
Iron Chunks	31.12	1.048	0.912
Poly. Chunks	21.02	1.333	0.713
Iron & Poly.	19.27	1.244	0.696
Junk	28.44	1.048	0.919

[a] These matrices were diluted with additional vermiculite.

[b] The moderator index was outside of the acceptable range in some positions within these drums.

Table VII. Spatial Variations within Drum Matrix: Vermiculite

	Position	Active Mass	Passive Mass
	r=12 z=8	0.670	28.91
	r=12 z=24	0.758	29.43
	r=12 z=40	0.808	30.81
	r=12 z=56	0.831	30.12
	r=12 z=72	0.831[a]	30.17
	r=20 z=8	0.712	28.06[a]
	r=20 z=24	0.757	29.81
	r=20 z=40	0.805	30.56
	r=20 z=56	0.813	31.25
	r=20 z=72	0.782	29.94
	r=25 z=8	0.661[a]	28.71
	r=25 z=24	0.708	29.85
	r=25 z=40	0.765	31.32[a]
	r=25 z=56	0.787	30.81
	r=25 z=72	0.758	29.54
Av:		0.763[b]	29.95[b]
Std Dev:		0.054	0.932

Spatial Variations within Drum Matrix: VP2

	Position	Active Mass	Passive Mass
	r=12 z=8	0.913	19.90[a]
	r=12 z=24	1.361	24.11
	r=12 z=40	1.540[a]	29.20
	r=12 z=56	1.245	43.59[a]
	r=12 z=72	0.649	30.14
	r=20 z=8	0.752	22.22
	r=20 z=24	0.937	23.34
	r=20 z=40	0.836	27.27
	r=20 z=56	0.871	38.08
	r=20 z=72	0.635	34.52
	r=25 z=8	0.664	23.31
	r=25 z=24	0.681	22.51
	r=25 z=40	0.671	25.13
	r=25 z=56	0.594[a]	30.89
	r=25 z=72	0.628	30.09
Av:		0.865[b]	28.29[b]
Std Dev:		0.294	6.55

Table VII. (cont)

Spatial Variations within Drum Matrix: 1.5 kg of Borax

	Position	Active Mass (g)	Passive Mass (g)
	r=12 z=8	0.596	27.83
	r=12 z=24	0.323[a]	28.62
	r=12 z=40	0.370	29.58
	r=12 z=56	0.393	29.85
	r=12 z=72	0.648	29.35
	r=20 z=8	0.876	27.69
	r=20 z=24	0.656	28.76
	r=20 z=40	0.704	29.28
	r=20 z=56	0.535	29.65
	r=20 z=72	0.747	29.09
	r=25 z=8	1.257[a]	27.07[a]
	r=25 z=24	0.930	28.69
	r=25 z=40	0.777	29.88[a]
	r=25 z=56	0.873	29.67
	r=25 z=72	1.043	29.13
Av:		0.715[b]	28.92[b]
Std Dev:		0.258	0.84

[a] High and low values
[b] Unweighted average

G. Consistency Test

As previously noted, during a two-week period we assayed a drum of vermiculite once a day for 10 nonconsecutive days with the standard 30-g plutonium cylinder located at a height of 40 cm and a radius of 20 cm. Table VIII provides the results of this study for the ten assays. Our test results showed excellent agreement and were entirely satisfactory. The errors here are negligible compared to the errors present in the assay of real waste.

Table VIII. 10-Day Consistency Test Results

Day	Active Mass (g)	Passive Mass (g)
1	0.784	31.42
2	0.793	31.31
3	0.786	31.26
4	0.773	31.27
5	0.798	31.12
6	0.757	31.06
7	0.758	30.91
8	0.766	30.76
9	0.757	31.41
10	0.763	31.13
Av:	0.774	31.17
Std Dev:	0.016	0.21

H. PAN Sensitivity

The active DDT device is capable of detecting a few milligrams of fissile material under ideal conditions. Residual cosmic-ray neutrons as well as neutrons from the sources within the drum contribute to the observable active signal background, which limits our sensitivity. Because the dieaway half-life curves associated with the DDT are not generally a single exponential, we used broad foreground and background regions to maximize sensitivity. We gate our active total signal at 910 to 4100 μs with a background at 4240 to 10230 μs after each 2000-neutron pulse from our Zetatron. Our sensitivity at the 3-σ background level for a 2000-pulse irradiation is 3.6 mg for ^{235}U and 2.4 mg for ^{239}Pu uniformly dispersed in a matrix of vermiculite.

Table IX shows the active mass sensitivity in terms of minimal detectible plutonium masses for a benign matrix compared to a highly absorbing one in the presence of various neutron background sources. For this study we assumed the plutonium mass to be concentrated at the position in each matrix for which we obtained the lowest (worst) mass estimate according to our results of Sec. F (Table VIb). For example, with the absorbing matrix of 1.8 kg of borax powder mixed with vermiculite, we calculated the lowest detectible amount of ^{239}Pu (22.6 mg) positioned at the point of lowest response (a radius of 12 and a height of 24 cm). Then we assumed the presence of a high background of random neutrons for our calculations. A PuBe background source of 6×10^4 n/s in the drum as employed in Sec. D would yield a background subtraction of ~ 7900 counts in the region of interest. With this background, our sensitivity becomes worse by about a factor of 10; for a source of 5×10^5 n/s, we lose approximately a factor of 40 in sensitivity (see the last two columns of Table IX). The time for the measurements in this table corresponds to the standard active DDT 2000-pulse interrogation time of 40 s. With an irradiation four times as long, our sensitivity would be twice as good. Of course, a plutonium sample with 6% ^{240}Pu would generate spontaneous fission neutrons in the background region; however, compared to the large number of extraneous neutrons produced by the PuBe and PuLiF sources, this is also negligible.

Because of matrix effects and self-shielding, the active results are not accurate for many waste drums. In our PAN system, 400 s of passive counting always follows the active DDT assay *(note: the passive count rate from spontaneous fissions in uranium is virtually undetectible)*. However, these passive measurements are most accurate for waste containing several grams of low-burnup plutonium (6% ^{240}Pu). Typically our 3-σ detection limit for passive counting in a benign matrix is ~ 0.4 g of plutonium (6% ^{240}Pu) at our site in Los Alamos (elevation 6800 ft). This detection limit could be significantly reduced by (1) measuring the background for much longer periods than the usual 400 s, and/or (2) assaying at elevations closer to sea level where the cosmic-ray background would be greatly reduced.

Table IX. Calculated Minimum Detectible ^{239}Pu Masses

(a) Average Counts/2000 Pulses in Background Collection Region

Neutron Background:	Natural	PuBe (6 x 10^4 n/s)	PuLiF(5 x 10^5 n/s)
Vermiculite (benign)	64	1.47 x 10^4	1.52 x 10^5
1.8 kg Borax in Verm. (absorber)	53	1.42 x 10^4	1.44 x 10^5

(b) Calculated "Worst Case" Minimum Detectible ^{239}Pu Masses (mg)

Neutron Background:	Natural	PuBe (6 x 10^4 n/s)	PuLiF(5 x 10^5 n/s)
Vermiculite (benign)	3	44	142
1.8 kg Borax in Verm. (absorber)	23	370	1174

I. Assay Uncertainties

There are both systematic and statistical uncertainties associated with the passive and active DDT assay results. The total assay uncertainty is usually calculated as the square root of the sum of the squares of the systematic and statistical uncertainties.

Statistical uncertainty is a measure of the precision of an instrument. For the PAN/DDT, this is primarily determined by the Poisson counting fluctuations; hence, the magnitude will depend largely on the amount of fissile material present. For example, with the 30-g plutonium source, both the active and passive measurements generally give relatively small standard deviations, ≤ 2%, as demonstrated in Table VIII. Of course, for amounts of fissile material near the lower limit of detection, the relative statistical errors can be as large as several tens of percent.

Systematic uncertainties are inherent in any measuring procedure involving data acquisition and interpretation. Our systematic uncertainties are, for the most part, due to the errors in our calibration curves, to our normalization of the acquired data, to the stability and reliability of the Zetatron neutron generator, and to variations in the geometry and composition of our sample test drums. It is difficult to generalize about the magnitude of the systematic errors in the PAN assays, except to say that they can be quite large in specific cases, as demonstrated by much of the data described this report. For assays involving gram-sized quantities or more of fissile material, the systematic error term will usually dominate the total error of the measurement. However, we should point out that not all of the sources of systematic error are accounted for in the PAN devices currently employed to measure TRU waste at DOE facilities, and the total error may be considerably larger than the error reported by the computerized data analysis program. For a more detailed analysis of the systematic uncertainties of the PAN/DDT system, see Ref. 6.

J. Active Assays for Drums with Very Low Passive Count Rates

The passive singles-count rates are a measure of detectible neutrons that arise from spontaneous fission, from (α,n) reactions, or from cosmic-ray reactions. In the case where a waste drum contains only uranium or very small (on the order of 0.5 g or less) amounts of plutonium, the passive neutron count rate is generally insufficient to obtain a statistically reliable shielded-to-totals count rate ratio, which is used to obtain the moderator correction factor (see Sec. IV A).

In low-passive-count situations, it would be desirable to flag the inadequacy of the passive measurement and have the computerized analysis program provide a default value for the moderator correction factor used in the active mass calculations. Presumably, this default correction factor would depend upon the use for which the measurement is intended and/or available information about the expected moderating characteristics of the waste drum. For example, if the waste stream being measured has previously been characterized, average values from previous measurements on other drums might be used. The moderator correction factor can vary from approximately 0.9 to 3.0 (see Fig. 2), so a conservative mass estimate would be achieved by choosing a high default correction factor. Conversely, choosing 0.9 as the default value would provide an estimate of the lower limit of the fissile mass. A standard method of choosing a default value is not practical; for specific scenarios, the appropriate choice for achieving a "best-estimate" mass determination may be unique. Generally, no such default values are made for the moderator correction factor by the PAN/DDT units.

The inability to determine the moderator index (and thus calculate the moderator correction factor) will increase the uncertainty in active assays in low-passive-count situations. This should be taken into consideration when one uses the active assays to screen waste at the 100-nCi/g level.

As mentioned earlier, the flux monitor half-life readings we obtained could also be analyzed to assist in making a mass estimate in low-passive-count situations. At the present time, however, these data have been neither analyzed nor incorporated in our mobile PAN/DDT system's computer-printout results.

VII. SUMMARY AND CONCLUSION

Our research and development efforts have resulted in the successful calibration of the DDT nondestructive PAN assay system and a demonstration of the capabilities and inherent limitations of this method. We are confident that within our established limitations on the absorption and moderator indices, the thermal neutron interrogation DDT method, coupled with a passive assay, can satisfactorily characterize waste drums for shipment to the WIPP site, provided the assumptions of a uniform matrix and fissile distribution and non-self-shielding waste are met. The results of the active assay are generally more affected than the passive if these assumptions are not met. ("Lumps" of plutonium are usually not a problem for passive assays.)

The strong points of this system are numerous. The concept of incorporating duel passive and active assay systems, whose individual results can stand alone as a means of comparison for non-self-shielding wastes with known plutonium isotopes, provides a straightforward verification of assay information. A dramatic difference in the results of the active and passive measurements can alert assayers to a possible problem in the waste characterization assumptions. For example, if a waste drum is known to contain plutonium, and the active mass estimate is much lower than the passive, then self-shielding within the plutonium can be suspected.

Another strong point of the DDT device is the consistency of our results as seen in the systematic study (see Sec VI.G). Because background measurements are made daily, changes in the external conditions of the assay environment have little effect on the accuracy of our results. Furthermore, the results of our studies involving high neutron backgrounds show that for gram-size masses or larger, we can compensate for adverse background conditions.

Under agreeable conditions (uniform, homogeneous distributions of fissile and matrix material; no self-attenuation), the DDT/PAN system produces highly sensitive assay results. The milligram-level assay sensitivity that can be achieved with the active DDT measurements makes this system quite adequate for discriminating between low-level and TRU waste at the 100-nCi/g level. The passive sensitivity is less (typically, 0.4 g of weapons-grade plutonium at Los Alamos), although much of the waste bound for the WIPP site contains enough SNM to permit reliable passive measurements. The passive measurement is most useful for waste containing several grams or more of plutonium. On the other hand, results from the source-hiding tests demonstrate that the sensitivity of the DDT device can be greatly reduced by moderators and absorbers in close proximity to the fissile material. Although unusually high flux monitor signals during the active assay could indicate the possibility of hidden fissile material in an unknown matrix, we cannot generalize by saying these occurrences mark the presence of fissile material.

As a final note, this report will serve as a basis for a future comparison of the PAN assay system with the 55-gal. Cf shuffler, developed by Group N-1 at LANL.

ACKNOWLEDGMENTS

The mobile DDT system was made available for our use by WIPP/WEC. Funding for the measurements and analysis was provided by the DOE Office of Safeguards and Security. We appreciate the assistance we received on this project from many of the personnel at Group N-2. Phil Rinard of Group N-1 provided valuable assistance in obtaining a final version of this document. Lastly, a special note of thanks is due to our publications section (Gerry Edwards, Randi Bagley, and AnnMarie Dyson) for their patience with our many attempts to obtain a final version.

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APPENDIX A: MOCK "WASTE" DRUMS USED IN THIS STUDY

Set 1 Calibration Matrices

1) Peat moss
2) Empty
3) Vermiculite
4) Vermiculite with liner
5) 0.3 kg borax in vermiculite
6) 0.6 kg borax in vermiculite
7) 1.2 kg borax in vermiculite
8) 0.9 kg borax in vermiculite
10) 1.8 kg borax in vermiculite
11) 1.5 kg borax in vermiculite
12) Polyethylene shavings
[a]13) VP1: 2 gal. of polyethylene per 10 lb vermiculite
[a]14) VP2: 4 gal. of polyethylene per 10 lb vermiculite
[a]15) VP3: 6 gal. of polyethylene per 10 lb vermiculite
[a]16) VP4B2 dilute VP4B2 mixed 5 parts to 4 of vermiculite

Set 2 Non-moderating Matrices

1) Empty
2) Vermiculite with a liner
3) 0.3 kg borax in vermiculite
4) 0.6 kg borax in vermiculite
5) 1.2 kg borax in vermiculite
6) 0.9 kg borax in vermiculite
7) 1.5 kg borax in vermiculite
8) 1.8 kg borax in vermiculite

Set 3 Acceptable Moderating Matrices

1) Vermiculite
2) Empty
3) Vermiculite with liner
4) Peat moss
5) 0.3 kg borax in vermiculite
6) 0.6 kg borax in vermiculite
7) 0.9 kg borax in vermiculite
8) 1.2 kg borax in vermiculite
9) 1.5 kg borax in vermiculite
10) 1.8 kg borax in vermiculite
11) Polyethylene shavings
[a]12) VP1: 2 gal. of polyethylene per 10 lb vermiculite
[a]13) VP2: 4 gal. of polyethylene per 10 lb vermiculite
[a]14) VP3: 6 gal. of polyethylene per 10 lb vermiculite
[a]15) VP4B2 dilute: VP4B2 mixed 5 parts to 4 of vermiculite
[b]16) Alumina
17) Iron chunks in air

Set 4 All 25 Matrices

1) Vermiculite
2) Empty
3) Vermiculite with a liner
4) Peat moss
5) 0.3 kg borax in vermiculite
6) 0.6 kg borax in vermiculite
7) 1.2 kg borax in vermiculite
8) 0.9 kg borax in vermiculite
9) 1.5 kg borax in vermiculite
10) 1.8 kg borax in vermiculite
11) Polyethylene shavings
12) Polyethylene beads
[a]13) VP1: 2 gal. of polyethylene per 10 lb vermiculite
[a]14) VP2: 4 gal. of polyethylene per 10 lb vermiculite
[a]15) VP3: 6 gal. of polyethylene per 10 lb vermiculite
[a]16) VP4: 8 gal. of polyethylene per 10 lb vermiculite
17) VP4B2: VP4 plus 2 pints of borax
18) VP4B2 dilute: VP4B2 mixed 5 parts to 4 of vermiculite
19) Top: VP4B2D: bottom: vermiculite
20) Top: vermiculite; bottom: VP4B2D
[b]21) Alumina
22) Mock junk (rubber gloves, paper, dry chemicals, etc.)
23) Iron chunks in air
24) Polyethylene chunks in air
25) Iron and polyethylene chunks in air

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[a] The quoted ratios describe the "recipes" for the mixtures that were used to fill each 55-gal. drum.

[b] Al_2O_3 plus H_2O

APPENDIX B: DDT/PAN DATA

This appendix contains summary spreadsheets for the bulk of the data taken for this report. While it is not necessary to read through all these tables to appreciate the contents of the report, some explanation of the data presented is required.

The headings and "Set-up Data" for each table are self-explanatory and are primarily for the authors to facilitate looking up the original printouts or database files. The section labeled "Ace Data" contains a summary of the half-life data, which, as previously stated, has not yet been analyzed. A multichannel scaler spectrum of counts vs (10-μs channel) time is made for the flux monitor (FM) and the barrel flux monitor (BFM) data. The region of interest (ROI) is defined to include the "dieaway" region for that detector, and the "Area" refers to the area under the curve in the region. The half-life is determined from the negative of the slope in the ROI, and the activity A_0 is found from the y-intercept (channel 0) of the data. The Chi^2 value given for the data is per degree of freedom.

The eight-column table at the bottom of each data sheet contains the actual PAN data and assay calculations used to develop this report. The position (cm) of the test source within the 55-gal. drum is given in cylindrical coordinates (with the bottom center of the drum as the origin) in the first column. These are the 15 volume-defining source positions discussed in the text of this report. Columns 2 and 6 contain the summed, uncorrected active and passive masses (g). By multiplying the absorption and moderator correction factors (Abs. Corr. and Mod. Corr.) for the active signal or the 250-μs correction factor (250 Corr.) for the passive signal, the final, corrected mass estimates for each source position are achieved (columns 5 and 8). It should be noted that the average masses listed below the table are not simply the average of the 15 numbers above, but rather the product of the average uncorrected number and the average correction factors. The "Max" and "Min" data are the highest and lowest values in each column. This data was used to create Tables VI a, b, and c in the report.

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/03/90
Spreadsheet: 10/04/90

spreadsheet name: CP100390.WK1

Set-up Data

Matrix Description	Empty Drum
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	542.4	676
A_0	770.6	328.5
Chi**2	1.09	1.04
Area	15400	15032
ROI:	101-300	51-200

Run ID	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.710	0.978	0.993	0.690	27.410	1.049	28.755
R12 Z24	0.749	0.980	1.003	0.735	28.664	1.037	29.724
R12 Z40	0.756	0.978	1.011	0.747	29.270	1.027	30.056
R12 Z56	0.797	0.979	1.008	0.787	29.246	1.030	30.125
R12 Z72	0.838	0.981	1.005	0.827	29.801	1.033	30.793
R20 Z8	0.678	0.979	0.982	0.652	28.241	1.065	30.084
R20 Z24	0.758	0.981	0.997	0.741	28.874	1.044	30.143
R20 Z40	0.772	0.979	1.006	0.760	29.301	1.032	30.249
R20 Z56	0.794	0.979	0.994	0.773	29.122	1.048	30.533
R20 Z72	0.774	0.981	0.997	0.757	29.709	1.044	31.006
R25 Z8	0.665	0.980	0.985	0.642	27.296	1.060	28.945
R25 Z24	0.755	0.979	1.005	0.742	28.960	1.034	29.955
R25 Z40	0.787	0.981	1.004	0.775	29.241	1.035	30.252
R25 Z56	0.807	0.980	1.010	0.799	29.368	1.028	30.192
R25 Z72	0.823	0.977	0.983	0.791	28.981	1.064	30.827
average	0.764	0.979	0.999	0.748	28.899	1.042	30.103
std dev	0.012	0.000	0.002	0.013	0.183	0.003	0.155
Max	0.838	0.981	1.011	0.827	29.801	1.065	31.006
Min	0.665	0.977	0.982	0.642	27.296	1.027	28.755

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/05/90

spreadsheet name: CP100590.WK1

Spreadsheet: 10/05/90

Set-up Data

Matrix Description	Vermiculite with Liner
Source Description	30 g Pu
Source Voltage	450V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	542.3	500.4
A_0	929.5	405.3
Chi**2	0.97	1.05
Area	18616	12753
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.704	1.112	0.934	0.731	25.472	1.160	29.555
R12 Z24	0.783	1.121	0.942	0.827	25.338	1.142	28.929
R12 Z40	0.798	1.112	0.952	0.844	28.200	1.119	31.554
R12 Z56	0.799	1.126	0.945	0.850	28.274	1.133	32.048
R12 Z72	0.783	1.113	0.959	0.836	28.400	1.105	31.387
R20 Z8	0.698	1.109	0.925	0.716	25.150	1.187	29.841
R20 Z24	0.749	1.109	0.936	0.778	27.251	1.154	31.452
R20 Z40	0.793	1.117	0.941	0.834	27.424	1.142	31.319
R20 Z56	0.788	1.124	0.947	0.839	28.222	1.128	31.840
R20 Z72	0.777	1.108	0.948	0.817	27.321	1.127	30.789
R25 Z8	0.673	1.119	0.932	0.702	25.275	1.167	29.496
R25 Z24	0.785	1.117	0.955	0.837	27.176	1.112	30.225
R25 Z40	0.771	1.106	0.952	0.812	29.101	1.119	32.555
R25 Z56	0.784	1.125	0.959	0.847	28.605	1.105	31.602
R25 Z72	0.711	1.116	0.941	0.747	26.637	1.143	30.447
average	0.760	1.116	0.944	0.800	27.190	1.135	30.873
std dev	0.042	0.002	0.003	0.013	0.333	0.006	0.267
Max	0.798	1.126	0.959	0.850	29.101	1.187	32.555
Min	0.673	1.106	0.925	0.702	25.150	1.105	28.929

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 09/27/90

spreadsheet name: CP092790.WK1

Spreadsheet: 10/01/90

Set-up Data	
Matrix Description	Peat Moss
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	538.6	369.5
A_0	1229.1	794.4
Chi**2	1.08	1.04
Area	24134	15554
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.705	1.289	0.924	0.840	13.258	1.976	26.194
R12 Z24	0.917	1.285	0.953	1.123	12.378	2.167	26.822
R12 Z40	0.884	1.282	0.979	1.109	13.095	2.318	30.355
R12 Z56	0.747	1.294	0.959	0.927	14.501	2.203	31.942
R12 Z72	0.575	1.290	0.892	0.661	17.589	1.694	29.796
R20 Z8	0.611	1.294	0.901	0.712	14.648	1.789	26.208
R20 Z24	0.749	1.284	0.920	0.885	14.087	1.947	27.422
R20 Z40	0.728	1.302	0.924	0.876	14.498	1.977	28.664
R20 Z56	0.652	1.284	0.927	0.777	16.245	2.003	32.532
R20 Z72	0.561	1.281	0.887	0.638	18.644	1.619	30.191
R25 Z8	0.567	1.295	0.894	0.656	15.399	1.721	26.502
R25 Z24	0.687	1.269	0.893	0.779	15.776	1.709	26.966
R25 Z40	0.657	1.296	0.900	0.765	16.110	1.777	28.632
R25 Z56	0.582	1.286	0.895	0.669	17.813	1.722	30.680
R25 Z72	0.517	1.296	0.886	0.593	18.394	1.578	29.033
average	0.677	1.288	0.908	0.792	15.496	1.854	28.728
std dev	0.117	0.008	0.029	0.162	1.969	0.225	2.083
Max	0.917	1.302	0.979	1.123	18.644	2.318	32.532
Min	0.517	1.269	0.886	0.593	12.378	1.578	26.194

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/10/90
Spreadsheet: 10/11/90

spreadsheet name: CP101090.WK1

Set-up Data

Matrix Description	Verm. & Borax (0.3 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	433.1	395.1
A_0	907.7	340.8
Chi**2	0.96	1.14
Area	10886	7531
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.533	1.209	1.011	0.651	28.246	1.027	29.004
R12 Z24	0.544	1.193	1.011	0.656	27.739	1.027	28.483
R12 Z40	0.567	1.208	1.011	0.692	29.241	1.027	30.026
R12 Z56	0.625	1.205	1.011	0.761	29.240	1.027	30.025
R12 Z72	0.630	1.180	1.011	0.751	30.100	1.027	30.908
R20 Z8	0.467	1.197	1.011	0.564	28.018	1.027	28.770
R20 Z24	0.554	1.199	1.011	0.671	29.372	1.027	30.160
R20 Z40	0.551	1.202	1.011	0.670	29.952	1.027	30.756
R20 Z56	0.639	1.211	1.011	0.782	29.850	1.027	30.651
R20 Z56	0.668	1.212	1.011	0.818	29.106	1.027	29.887
R25 Z8	0.571	1.204	1.011	0.695	27.498	1.027	28.236
R25 Z24	0.637	1.210	1.011	0.779	29.641	1.027	30.436
R25 Z40	0.585	1.205	1.011	0.712	30.409	1.027	31.225
R25 Z56	0.575	1.192	1.011	0.693	29.693	1.027	30.490
R25 Z72	0.641	1.178	1.011	0.763	29.209	1.027	29.993
average	0.586	1.200	1.011	0.710	29.154	1.027	29.937
std dev	0.054	0.003	0.000	0.016	0.222	0.000	0.227
Max	0.668	1.212	1.011	0.818	30.409	1.027	31.225
Min	0.467	1.178	1.011	0.564	27.498	1.027	28.236

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/11/90
Spreadsheet: 10/11/90

spreadsheet name: CP101190.WK1

Set-up Data	
Matrix Description	Verm. & Borax (0.6 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	403.7	337
A_0	814.1	268.3
Chi**2	1.04	1.34
Area	8199	4458
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.442	1.464	1.011	0.653	26.940	1.027	27.663
R12 Z24	0.429	1.466	1.011	0.635	28.480	1.027	29.245
R12 Z40	0.503	1.472	1.011	0.748	29.808	1.027	30.608
R12 Z56	0.480	1.478	1.011	0.718	29.992	1.027	30.796
R12 Z72	0.543	1.495	1.011	0.821	29.879	1.027	30.681
R20 Z8	0.468	1.442	1.011	0.682	27.688	1.027	28.432
R20 Z24	0.452	1.431	1.011	0.653	29.066	1.027	29.846
R20 Z40	0.454	1.464	1.011	0.671	29.235	1.027	30.019
R20 Z56	0.406	1.462	1.011	0.599	30.052	1.027	30.858
R20 Z72	0.571	1.437	1.011	0.829	29.325	1.027	30.112
R25 Z8	0.553	1.487	1.011	0.831	27.199	1.027	27.929
R25 Z24	0.584	1.435	1.011	0.847	29.173	1.027	29.956
R25 Z40	0.569	1.446	1.011	0.831	29.626	1.027	30.421
R25 Z56	0.624	1.444	1.011	0.910	29.298	1.027	30.085
R25 Z72	0.669	1.409	1.011	0.952	28.757	1.027	29.529
average	0.516	1.455	1.011	0.758	28.968	1.027	29.745
std dev	0.078	0.023	0.000	0.109	0.990	0.000	1.016
Max	0.669	1.495	1.011	0.955	30.052	1.027	30.858
Min	0.406	1.409	1.011	0.599	26.9401	1.0267	27.663

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/16/90

spreadsheet name: CP101690.WK1

Spreadsheet: 10/17/90

Set-up Data

Matrix Description	Verm. & Borax (0.9 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	381.2	314.6
A_0	893.5	243.2
Chi**2	1.01	1.11
Area	7720	3529
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.213	1.779	1.011	0.384	27.842	1.027	28.589
R12 Z24	0.300	1.823	1.011	0.552	27.643	1.027	28.385
R12 Z40	0.381	1.841	1.011	0.708	29.651	1.027	30.447
R12 Z56	0.339	1.806	1.011	0.618	29.491	1.027	30.282
R12 Z72	0.411	1.843	1.011	0.765	29.251	1.027	30.036
R20 Z8	0.396	1.840	1.011	0.736	27.209	1.027	27.939
R20 Z24	0.471	1.873	1.011	0.891	29.095	1.027	29.876
R20 Z40	0.476	1.801	1.011	0.867	29.484	1.027	30.275
R20 Z56	0.494	1.872	1.011	0.935	30.214	1.027	31.025
R20 Z72	0.555	1.798	1.011	1.009	28.744	1.027	29.515
R25 Z8	0.396	1.753	1.011	0.701	26.868	1.027	27.589
R25 Z24	0.429	1.787	1.011	0.775	29.543	1.027	30.336
R25 Z40	0.464	1.809	1.011	0.848	30.209	1.027	31.020
R25 Z56	0.392	1.761	1.011	0.698	29.506	1.027	30.298
R25 Z72	0.509	1.828	1.011	0.941	28.643	1.027	29.412
average	0.415	1.834	1.011	0.769	28.893	1.027	29.668
std dev	0.087	0.036	0.000	0.164	1.049	0.000	1.078
Max	0.555	1.873	1.011	1.009	30.214	1.027	31.025
Min	0.213	1.753	1.011	0.384	26.868	1.027	27.589

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/15/90
Spreadsheet: 10/16/90

spreadsheet name: CP101590.WK1

Set-up Data

Matrix Description	Verm. & Borax (1.2 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	366.5	297.3
A_0	858.9	176.4
Chi**2	0.88	1.17
Area	6655	2341
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.286	1.932	1.011	0.559	27.905	1.027	28.654
R12 Z24	0.261	1.895	1.011	0.499	27.985	1.027	28.736
R12 Z40	0.274	1.933	1.011	0.536	29.246	1.027	30.031
R12 Z56	0.240	1.934	1.011	0.470	29.425	1.027	30.215
R12 Z72	0.453	1.901	1.011	0.871	29.354	1.027	30.141
R20 Z8	0.492	1.953	1.011	0.972	26.519	1.027	27.230
R20 Z24	0.402	1.915	1.011	0.779	28.484	1.027	29.248
R20 Z40	0.322	1.922	1.011	0.626	28.820	1.027	29.594
R20 Z56	0.278	1.950	1.011	0.548	29.010	1.027	29.788
R20 Z72	0.403	1.901	1.011	0.775	28.317	1.027	29.077
R25 Z8	0.515	1.918	1.011	0.998	26.388	1.027	27.097
R25 Z24	0.480	1.947	1.011	0.944	28.216	1.027	28.973
R25 Z40	0.509	1.906	1.011	0.981	29.839	1.027	30.640
R25 Z65	0.468	1.914	1.011	0.906	29.082	1.027	29.862
R25 Z72	0.517	1.926	1.011	1.006	28.708	1.027	29.478
average	0.393	1.922	1.011	0.764	28.486	1.027	29.251
std dev	0.105	0.018	0.000	0.204	0.993	0.000	1.019
Max	0.517	1.953	1.011	1.006	29.839	1.027	30.636
Min	0.241	1.895	1.011	0.470	26.388	1.027	27.097

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/19/90

spreadsheet name: CP101990.WK1

Spreadsheet: 10/19/90

Set-up Data	
Matrix Description	Verm. & Borax (1.5 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	344.1	302.9
A_0	880.1	84.7
Chi**2	1.04	1.02
Area	5688	1207
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.263	2.245	1.011	0.596	27.097	1.027	27.825
R12 Z24	0.137	2.329	1.011	0.323	27.872	1.027	28.620
R12 Z40	0.152	2.416	1.011	0.370	28.810	1.027	29.583
R12 Z56	0.168	2.319	1.011	0.393	29.066	1.027	29.846
R12 Z72	0.275	2.335	1.011	0.648	28.580	1.027	29.347
R20 Z8	0.366	2.366	1.011	0.876	26.963	1.027	27.686
R20 Z24	0.280	2.321	1.011	0.656	28.013	1.027	28.764
R20 Z40	0.295	2.362	1.011	0.704	28.511	1.027	29.276
R20 Z56	0.235	2.259	1.011	0.535	28.873	1.027	29.648
R20 Z72	0.310	2.381	1.011	0.747	28.329	1.027	29.089
R25 Z8	0.536	2.318	1.011	1.257	26.367	1.027	27.074
R25 Z24	0.404	2.278	1.011	0.930	27.943	1.027	28.693
R25 Z40	0.330	2.333	1.011	0.777	29.099	1.027	29.880
R25 Z56	0.364	2.371	1.011	0.873	28.891	1.027	29.666
R25 Z72	0.444	2.327	1.011	1.043	28.365	1.027	29.126
average	0.304	2.329	1.011	0.715	28.185	1.027	28.942
std dev	0.110	0.046	0.000	0.258	0.822	0.000	0.844
Max	0.536	2.419	1.011	1.257	29.099	1.027	29.880
Min	0.137	2.245	1.011	0.323	26.367	1.027	27.074

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/18/90
Spreadsheet: 10/19/90

spreadsheet name: CP101890.WK1

Set-up Data	
Matrix Description	Verm. & Borax (1.8 kg)
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	347.1	314.4
A_0	883.2	69.6
Chi**2	1.15	1.05
Area	5944	1087
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.178	2.666	1.011	0.481	26.937	1.027	27.660
R12 Z24	0.134	2.523	1.011	0.341	27.600	1.027	28.341
R12 Z40	0.213	2.587	1.011	0.557	28.229	1.027	28.987
R12 Z56	0.260	2.514	1.011	0.661	28.364	1.027	29.125
R12 Z72	0.434	2.588	1.011	1.135	29.087	1.027	29.867
R20 Z8	0.240	2.740	1.011	0.666	26.553	1.027	27.266
R20 Z24	0.198	2.367	1.011	0.473	27.858	1.027	28.606
R20 Z40	0.249	2.529	1.011	0.635	28.729	1.027	29.500
R20 Z56	0.221	2.513	1.011	0.561	29.299	1.027	30.085
R20 Z72	0.382	2.658	1.011	1.027	28.438	1.027	29.201
R25 Z8	0.337	2.611	1.011	0.889	25.966	1.027	26.662
R25 Z24	0.364	2.546	1.011	0.938	27.868	1.027	28.616
R25 Z40	0.312	2.508	1.011	0.791	25.907	1.027	26.602
R25 Z56	0.466	2.658	1.011	1.252	28.421	1.027	29.184
R25 Z72	0.523	2.677	1.011	1.414	28.113	1.027	28.867
average	0.301	2.571	1.011	0.782	27.825	1.027	28.571
std dev	0.114	0.093	0.000	0.313	1.050	0.000	1.078
Max	0.523	2.740	1.011	1.414	29.299	1.0268	30.085
Min	0.134	2.367	1.011	0.341	25.907	1.0268	26.602

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/22/90
Spreadsheet: 10/23/90

spreadsheet name: CP102290.WK1

Set-up Data

Matrix Description	Poly Shavings from Group N-1
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	569.5	431.4
A_0	1034.5	580.5
Chi**2	0.96	1.01
Area	22829	14689
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.675	1.206	0.891	0.725	23.627	1.352	31.941
R12 Z24	0.851	1.211	0.887	0.915	23.447	1.400	32.828
R12 Z40	0.882	1.206	0.894	0.951	24.460	1.333	32.604
R12 Z56	0.846	1.217	0.899	0.925	25.660	1.297	33.276
R12 Z72	0.758	1.215	0.908	0.835	26.276	1.250	32.844
R20 Z8	0.629	1.208	0.892	0.677	22.109	1.349	29.832
R20 Z24	0.732	1.215	0.894	0.795	23.467	1.333	31.290
R20 Z40	0.791	1.202	0.898	0.854	24.452	1.299	31.765
R20 Z56	0.757	1.212	0.899	0.825	25.452	1.293	32.922
R20 Z72	0.715	1.206	0.900	0.776	24.889	1.291	32.142
R25 Z8	0.590	1.200	0.897	0.635	21.502	1.308	28.120
R25 Z24	0.656	1.198	0.900	0.707	24.061	1.291	31.064
R25 Z40	0.678	1.201	0.903	0.735	24.962	1.271	31.716
R25 Z56	0.727	1.209	0.905	0.794	25.072	1.264	31.704
R25 Z72	0.672	1.206	0.907	0.735	24.542	1.254	30.772
average	0.730	1.207	0.898	0.791	24.265	1.304	31.647
std dev	0.085	0.006	0.006	0.093	1.285	0.041	1.345
Max	0.882	1.217	0.908	0.951	26.276	1.400	33.276
Min	0.590	1.198	0.887	0.635	21.502	1.250	28.120

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition:
10/31/90

spreadsheet name: CP103190.WK1

Spreadsheet:
11/01/90

Set-up Data

Matrix Description	High-Density Poly Beads
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	453.900	235.500
A_0	1210.500	221.000
Chi**2	1.170	1.960
Area	******	1989.000
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.044	3.682	2.990	0.482	0.871	8.836	7.692
R12 Z24	0.019	3.682	2.990	0.205	0.105	8.836	0.924
R12 Z40	0.003	3.682	2.990	0.029	0.002	8.836	0.022
R12 Z56	0.007	3.682	2.990	0.079	0.489	8.836	4.322
R12 Z72	0.103	3.682	1.918	0.726	6.017	5.935	35.708
R20 Z8	0.064	3.682	2.990	0.705	2.288	8.836	20.217
R20 Z24	0.067	3.682	2.990	0.739	1.492	8.836	13.184
R20 Z40	0.041	3.682	2.990	0.449	1.631	8.836	14.408
R20 Z56	0.034	3.682	2.990	0.372	1.873	8.836	16.547
R20 Z72	0.128	3.682	2.990	1.411	7.559	8.836	66.791
R25 Z8	0.121	3.682	1.624	0.726	4.901	4.966	24.336
R25 Z24	0.139	3.682	1.503	0.769	4.197	4.536	19.037
R25 Z40	0.120	3.682	1.686	0.742	5.004	5.178	25.907
R25 Z56	0.105	3.682	2.990	1.156	5.315	8.836	46.963
R25 Z72	0.203	3.682	1.538	1.148	10.675	4.660	49.746
average	0.080	3.682	2.990	0.880	3.495	8.836	30.877
std dev	0.057	0.000	0.658	0.395	3.090	1.868	19.296
Max	0.203	3.682	2.990	1.411	10.675	8.836	66.791
Min	0.003	3.682	1.503	0.029	0.002	4.536	0.022

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/02/90
Spreadsheet: 11/05/90

spreadsheet name: CP110290.WK1

Set-up Data

Matrix Description	VP1: 20 lbs Verm. to 4 gal. Poly.
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	507.1	314.9
A_0	1288.4	917.1
Chi**2	1.25	1.13
Area	22306	13338
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.460	1.557	1.004	0.719	10.251	2.455	25.170
R12 Z24	0.561	1.496	1.056	0.886	10.257	2.714	27.841
R12 Z40	0.568	1.517	1.072	0.924	10.939	2.787	30.492
R12 Z56	0.514	1.523	1.033	0.809	12.851	2.600	33.411
R12 Z72	0.498	1.515	0.901	0.680	17.507	1.787	31.276
R20 Z8	0.427	1.534	0.950	0.622	12.276	2.151	26.402
R20 Z24	0.552	1.548	0.956	0.817	11.860	2.187	25.935
R20 Z40	0.571	1.515	0.956	0.828	13.308	2.187	29.110
R20 Z56	0.514	1.526	0.954	0.748	15.074	2.174	32.768
R20 Z72	0.500	1.516	0.901	0.683	18.148	1.789	32.466
R25 Z8	0.386	1.543	0.902	0.537	13.021	1.803	23.477
R25 Z24	0.493	1.550	0.906	0.692	14.178	1.837	26.045
R25 Z40	0.459	1.517	0.913	0.636	14.761	1.895	27.968
R25 Z56	0.487	1.484	0.902	0.652	16.683	1.798	30.000
R25 Z72	0.496	1.552	0.890	0.685	18.869	1.670	31.502
average	0.499	1.526	0.935	0.713	13.999	2.057	28.801
std dev	0.052	0.021	0.061	0.106	2.802	0.370	3.079
Max	0.571	1.557	1.072	0.924	18.869	2.787	33.411
Min	0.386	1.484	0.890	0.537	10.251	1.670	23.477

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/09/90
Spreadsheet: 11/09/90

spreadsheet name: CP110990.WK1

Set-up Data

Matrix Description	VP2: 10 lbs Verm. to 4 gal. HD Poly Beads
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	480.3	280.5
A_0	1294.9	715.1
Chi**2	0.89	0.9
Area	19825	8191
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.380	1.[illegible]11	1.258	0.913	5.532	3.597	19.898
R12 Z24	0.412	1.887	1.752	1.361	4.466	5.399	24.112
R12 Z40	0.311	1.889	2.617	1.540	3.686	7.921	29.201
R12 Z56	0.220	1.891	2.990	1.245	4.933	8.836	43.586
R12 Z72	0.325	1.915	1.041	0.649	11.419	2.639	30.140
R20 Z8	0.352	1.898	1.126	0.752	7.316	3.038	22.225
R20 Z24	0.412	1.884	1.207	0.937	6.892	3.387	23.340
R20 Z40	0.324	1.900	1.360	0.836	6.820	3.998	27.268
R20 Z56	0.266	1.894	1.730	0.871	7.151	5.325	38.082
R20 Z72	0.319	1.891	1.051	0.635	12.840	2.688	34.516
R25 Z8	0.358	1.901	0.976	0.664	10.128	2.302	23.312
R25 Z24	0.358	1.895	1.003	0.681	9.197	2.447	22.509
R25 Z40	0.346	1.893	1.026	0.671	9.795	2.565	25.128
R25 Z56	0.282	1.894	1.111	0.594	10.404	2.969	30.889
R25 Z72	0.351	1.891	0.946	0.628	14.145	2.128	30.094
average	0.335	1.895	1.169	0.742	8.315	3.223	26.797
std dev	0.052	0.009	0.621	0.294	3.125	2.060	6.553
Max	0.412	1.915	2.990	1.540	14.145	8.836	43.586
Min	0.220	1.884	0.946	0.594	3.686	2.128	19.898

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/07/90
Spreadsheet: 11/07/90

spreadsheet name: CP110790.WK1

Set-up Data

Matrix Description	VP3: 10 lbs Verm. to 6 gal. HD Poly Beads
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	473.8	2669.7
A_0	1388.7	738.4
Chi**2	1.13	1.01
Area	20623	7792
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.340	1.954	1.559	1.034	4.729	4.735	22.391
R12 Z24	0.335	1.932	2.306	1.490	3.526	7.085	24.980
R12 Z40	0.232	1.945	2.990	1.350	3.209	8.836	28.352
R12 Z56	0.226	1.938	2.990	1.310	5.237	8.836	46.274
R12 Z72	0.310	1.938	1.019	0.612	12.555	2.530	31.765
R20 Z8	0.294	1.917	1.215	0.686	7.006	3.419	23.950
R20 Z24	0.326	1.930	1.222	0.770	5.508	3.450	19.004
R20 Z40	0.266	1.939	1.683	0.869	6.238	5.166	32.234
R20 Z56	0.260	1.945	1.779	0.901	7.991	5.488	43.858
R20 Z72	0.326	1.929	0.994	0.624	14.348	2.399	34.422
R25 Z8	0.310	1.953	0.991	0.600	8.970	2.382	21.367
R25 Z24	0.292	1.950	1.088	0.620	7.628	2.866	21.863
R25 Z40	0.292	1.914	1.050	0.587	9.029	2.686	24.255
R25 Z56	0.294	1.931	1.169	0.664	10.818	3.226	34.897
R25 Z72	0.3667	1.949	0.931	0.665	14.893	2.026	30.171
average	0.298	1.937	1.206	0.696	8.112	3.382	27.436
std dev	0.039	0.012	0.702	0.305	3.685	2.301	8.100
Max	0.367	1.954	2.990	1.490	14.893	8.836	46.274
Min	0.226	1.914	0.931	0.587	3.209	2.026	19.004

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/08/90
Spreadsheet: 11/08/90

spreadsheet name: CP110890.WK1

Set-up Data

Matrix Description	VP4: 10 lbs Verm. to 8 gal. Poly
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	471	256.9
A_0	1355.8	635.1
Chi**2	1.09	1.13
Area	19917	5992
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.261	2.095	1.877	1.025	3.794	5.806	22.027
R12 Z24	0.210	2.091	2.990	1.315	2.181	8.836	19.267
R12 Z40	0.153	2.123	2.990	0.970	2.371	8.836	20.954
R12 Z56	0.118	2.106	2.990	0.743	2.794	8.836	24.688
R12 Z72	0.207	2.111	1.406	0.615	9.087	4.174	37.929
R20 Z8	0.289	2.075	1.366	0.819	5.614	4.025	22.596
R20 Z24	0.254	2.113	1.592	0.855	4.765	4.853	23.123
R20 Z40	0.223	2.106	1.819	0.854	4.660	5.618	26.180
R20 Z56	0.152	2.122	2.990	0.967	4.887	8.836	43.180
R20 Z72	0.246	2.118	1.223	0.636	11.312	3.454	39.071
R25 Z8	0.262	2.128	1.115	0.622	7.752	2.986	23.147
R25 Z24	0.300	2.105	1.112	0.703	7.278	2.975	21.655
R25 Z40	0.257	2.139	1.161	0.638	7.434	3.192	23.732
R25 Z56	0.186	2.085	1.336	0.519	8.616	3.905	33.651
R25 Z72	0.250	2.118	1.165	0.618	12.292	3.207	39.422
average	0.224	2.108	1.521	0.719	6.323	4.601	29.090
std dev	0.053	0.017	0.773	0.211	3.128	2.366	8.128
Max	0.300	2.139	2.990	1.315	12.292	8.836	43.180
Min	0.118	2.075	1.112	0.519	2.181	2.975	19.267

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/19/90

spreadsheet name: CP111990.WK1

Spreadsheet: 11/19/90

Set-up Data

Matrix Description	VP4B2: 2 pts. Borax plus VP4
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	441.5	264
A_0	1146.5	107.3
Chi**2	1.07	2.32
Area	14562	1313
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.047	3.682	2.335	0.406	3.077	7.167	22.053
R12 Z24	0.017	3.682	1.663	0.101	2.505	5.098	12.772
R12 Z40	0.013	3.682	2.789	0.132	2.130	8.355	17.792
R12 Z56	0.018	3.682	2.990	0.193	3.248	8.836	28.699
R12 Z72	0.113	3.682	1.239	0.517	8.908	3.519	31.345
R20 Z8	0.106	3.682	1.520	0.593	5.821	4.596	26.754
R20 Z24	0.045	3.682	1.245	0.208	4.589	3.543	16.258
R20 Z40	0.026	3.682	2.791	0.263	3.468	8.360	28.993
R20 Z56	0.042	3.682	2.990	0.464	4.223	8.836	37.317
R20 Z72	0.170	3.682	1.219	0.763	9.956	3.437	34.219
R25 Z8	0.148	3.682	1.032	0.563	8.260	2.597	21.449
R25 Z24	0.147	3.682	0.987	0.535	7.673	2.362	18.123
R25 Z40	0.135	3.682	1.029	0.509	8.204	2.579	21.158
R25 Z56	0.137	3.682	1.450	0.730	8.335	4.340	36.175
R25 Z72	0.246	3.682	1.134	1.026	12.796	3.071	39.301
average	0.095	3.682	1.369	0.478	6.213	4.037	25.080
std dev	0.070	0.000	0.780	0.259	3.193	2.481	8.367
Max	0.246	3.682	2.990	1.026	12.796	8.836	39.301
Min	0.013	3.682	0.987	0.101	2.130	2.362	12.772

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/20/90
Spreadsheet: 11/20/90

spreadsheet name: CP112090.WK1

Set-up Data

Matrix Description	VP4B2D: Diluted Poly + Boron + Verm.
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	447.6	243.4
A_0	1116	309
Chi**2	1	2.52
Area	14623	4945
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.248	3.059	1.048	0.794	10.154	2.674	27.151
R12 Z24	0.078	2.946	1.264	0.289	8.650	3.623	31.340
R12 Z40	0.073	3.066	1.146	0.256	10.145	3.123	31.681
R12 Z56	0.106	2.918	1.136	0.350	11.792	3.082	36.339
R12 Z72	0.209	2.917	0.937	0.571	16.099	2.066	33.259
R20 Z8	0.246	2.963	0.953	0.693	11.958	2.167	25.908
R20 Z24	0.180	3.146	0.990	0.559	11.577	2.378	27.531
R20 Z40	0.165	2.972	0.946	0.465	13.027	2.126	27.690
R20 Z56	0.176	3.050	0.976	0.523	14.343	2.304	33.040
R20 Z72	0.286	3.032	0.928	0.804	17.116	2.006	34.335
R25 Z8	0.344	3.147	0.906	0.980	12.938	1.833	23.716
R25 Z24	0.260	2.996	0.915	0.714	13.110	1.911	25.054
R25 Z40	0.257	2.866	0.913	0.673	13.837	1.893	26.189
R25 Z56	0.295	2.920	0.936	0.805	15.661	2.062	32.288
R25 Z72	0.338	2.883	0.911	0.889	17.549	1.883	33.045
average	0.219	2.987	0.964	0.631	13.197	2.231	29.445
std dev	0.087	0.089	0.108	0.219	2.619	0.542	3.897
Max	0.344	3.147	1.264	0.980	17.549	3.623	36.339
Min	0.073	2.866	0.906	0.256	8.650	1.833	23.716

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 11/30/90

spreadsheet name: CP113090.WK1

Spreadsheet: 11/30/90

Set-up Data

Matrix Description	split: top: VP4B2D bottom: Verm.
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	443.7	426.6
A_0	1013.6	614.7
Chi**2	1.03	0.94
Area	12997	15244
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.643	1.007	0.965	0.625	21.266	1.094	23.273
R12 Z24	0.632	1.001	0.938	0.593	20.745	1.150	23.859
R12 Z40	0.308	1.012	0.892	0.278	16.659	1.347	22.446
R12 Z56	0.122	1.004	0.885	0.108	15.113	1.449	21.905
R12 Z72	0.326	1.002	0.900	0.294	18.563	1.287	23.890
R20 Z8	0.648	1.004	0.961	0.625	20.916	1.101	23.037
R20 Z24	0.650	1.007	0.945	0.618	21.083	1.134	23.902
R20 Z40	0.328	0.997	0.894	0.292	17.995	1.330	23.924
R20 Z56	0.210	1.004	0.887	0.187	16.568	1.400	23.190
R20 Z72	0.305	1.003	0.894	0.274	19.162	1.328	25.450
R25 Z8	0.641	1.007	0.958	0.618	21.138	1.107	23.405
R25 Z24	0.649	1.006	0.963	0.629	22.483	1.097	24.665
R25 Z40	0.413	1.007	0.910	0.379	19.917	1.239	24.671
R25 Z56	0.314	1.005	0.899	0.284	19.003	1.294	24.586
R25 Z72	0.430	1.004	0.906	0.391	20.181	1.257	25.363
average	0.441	1.005	0.913	0.405	19.386	1.229	23.821
std dev	0.185	0.003	0.031	0.185	2.081	0.119	1.004
Max	0.650	1.012	0.965	0.629	22.483	1.449	25.450
Min	0.122	0.997	0.885	0.108	15.113	1.094	21.905

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 12/03/90

spreadsheet name: CP120390.WK1

Spreadsheet: 12/04/90

Set-up Data

Matrix Description	split: bottom:VP4B2D top: Verm.
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	506.3	293.4
A_0	1036.2	229.4
Chi**2	1.11	1.68
Area	17832	3116
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.204	2.617	1.340	0.715	12.005	2.526	30.330
R12 Z24	0.098	2.681	1.381	0.364	12.323	2.681	33.035
R12 Z40	0.458	2.803	1.164	1.495	20.564	1.466	30.139
R12 Z56	0.608	2.621	1.200	1.912	22.328	1.232	27.515
R12 Z72	0.635	2.574	1.269	2.075	23.860	1.094	26.105
R20 Z8	0.232	2.707	1.238	0.779	14.368	2.093	30.070
R20 Z24	0.201	2.659	1.184	0.632	16.241	1.779	28.888
R20 Z40	0.531	2.619	1.168	1.624	21.553	1.398	30.122
R20 Z56	0.599	2.613	1.223	1.914	23.438	1.173	27.501
R20 Z72	0.599	2.625	1.248	1.962	24.159	1.126	27.192
R25 Z8	0.342	2.640	1.204	1.086	15.232	1.910	29.087
R25 Z24	0.311	2.658	1.182	0.978	17.278	1.765	30.489
R25 Z40	0.519	2.680	1.185	1.648	22.053	1.285	28.335
R25 Z56	0.619	2.659	1.209	1.990	23.602	1.207	28.491
R25 Z72	0.589	2.701	1.228	1.955	24.179	1.161	28.081
average	0.437	2.655	1.165	1.350	19.546	1.448	28.311
std dev	0.186	0.054	0.062	0.590	4.493	0.516	1.724
Max	0.635	2.803	1.381	2.075	24.179	2.681	33.035
Min	0.098	2.574	1.164	0.364	12.005	1.094	26.105

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 12/10/90

spreadsheet name: CP121090.WK1

Spreadsheet: 12/11/90

Set-up Data	
Matrix Description	Alumina
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	442.6	218.7
A_0	1319.8	390.9
Chi**2	1.03	1.97
Area	16708	2812
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.065	3.682	2.918	0.700	2.618	8.665	22.685
R12 Z24	0.053	3.682	2.990	0.582	1.369	8.836	12.092
R12 Z40	0.043	3.682	2.990	0.473	1.536	8.836	13.567
R12 Z56	0.046	3.682	2.990	0.509	3.039	8.836	26.856
R12 Z72	0.132	3.682	1.587	0.770	8.733	4.836	42.237
R20 Z8	0.109	3.682	1.774	0.711	4.979	5.470	27.238
R20 Z24	0.117	3.682	1.828	0.786	4.047	5.648	22.860
R20 Z40	0.107	3.682	2.223	0.872	5.220	6.851	35.763
R20 Z56	0.096	3.682	2.885	1.019	6.148	8.588	52.794
R20 Z72	0.189	3.682	1.167	0.812	12.414	3.218	39.945
R25 Z8	0.197	3.682	1.086	0.789	7.555	2.853	21.556
R25 Z24	0.185	3.682	1.053	0.717	7.947	2.697	21.432
R25 Z40	0.176	3.682	1.079	0.700	8.495	2.821	23.967
R25 Z56	0.174	3.682	1.251	0.804	10.084	3.569	35.984
R25 Z72	0.250	3.682	1.066	0.981	14.051	2.763	38.820
average	0.128	3.682	1.541	0.729	6.549	4.673	30.607
std dev	0.064	0.000	0.823	0.151	3.827	2.583	11.336
Max	0.250	3.682	2.990	1.019	14.051	8.836	52.794
Min	0.043	3.682	1.053	0.473	1.369	2.697	12.092

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 12/12/90
Spreadsheet: 12/12/90

spreadsheet name: CP121290.WK1

Set-up Data	
Matrix Description	Junk
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	553.1	442.5
A_0	874.1	592.2
Chi**2	1.05	0.87
Area	18308	15662
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.539	1.088	0.929	0.545	23.867	1.175	28.038
R12 Z24	0.613	1.089	0.942	0.629	24.203	1.140	27.583
R12 Z40	0.651	1.076	0.945	0.662	25.780	1.134	29.236
R12 Z56	0.726	1.079	0.973	0.762	26.041	1.079	28.105
R12 Z72	0.733	1.091	0.974	0.779	26.417	1.078	28.470
R20 Z8	0.471	1.099	0.897	0.464	22.330	1.305	29.149
R20 Z24	0.612	1.086	0.926	0.615	24.407	1.182	28.841
R20 Z40	0.646	1.110	0.935	0.670	25.757	1.158	29.816
R20 Z56	0.677	1.084	0.949	0.697	25.921	1.124	29.133
R20 Z72	0.718	1.083	0.968	0.753	26.187	1.089	28.505
R25 Z8	0.526	1.081	0.946	0.538	23.082	1.132	26.132
R25 Z24	0.634	1.101	0.954	0.665	24.688	1.115	27.523
R25 Z40	0.640	1.084	0.977	0.677	26.420	1.073	28.352
R25 Z56	0.701	1.078	0.971	0.734	27.024	1.083	29.258
R25 Z72	0.664	1.084	0.966	0.695	26.339	1.092	28.763
average	0.637	1.087	0.948	0.656	25.231	1.127	28.439
std dev	0.076	0.009	0.022	0.089	1.384	0.060	0.911
Max	0.733	1.110	0.977	0.779	27.024	1.305	29.816
Min	0.471	1.076	0.897	0.464	22.330	1.073	26.132

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 12/13/90
Spreadsheet: 12/14/90

spreadsheet name: CP121490.WK1

Set-up Data	
Matrix Description	Iron
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	396.5	340.3
A_0	854.4	157.3
Chi**2	1.02	1.16
Area	8247	2663
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.475	1.898	1.011	0.910	29.597	1.027	30.391
R12 Z24	0.381	1.874	1.011	0.722	30.476	1.027	31.294
R12 Z40	0.394	1.894	1.011	0.755	30.793	1.027	31.619
R12 Z56	0.457	1.891	1.011	0.874	30.185	1.027	30.996
R12 Z72	0.523	1.890	1.011	0.998	31.486	1.027	32.332
R20 Z8	0.423	1.868	1.011	0.799	27.646	1.027	28.388
R20 Z24	0.405	1.882	1.011	0.770	30.605	1.027	31.426
R20 Z40	0.435	1.879	1.011	0.826	31.242	1.027	32.080
R20 Z56	0.437	1.883	1.011	0.831	31.772	1.027	32.625
R20 Z72	0.572	1.897	1.011	1.096	30.409	1.027	31.225
R25 Z8	0.548	1.861	1.011	1.031	28.478	1.027	29.242
R25 Z24	0.443	1.889	1.011	0.846	29.410	1.027	30.199
R25 Z40	0.488	1.882	1.011	0.928	31.686	1.027	32.536
R25 Z56	0.533	1.903	1.011	1.025	31.344	1.027	32.185
R25 Z72	0.569	1.895	1.011	1.090	29.468	1.027	30.259
average	0.474	1.885	1.011	0.902	30.306	1.027	31.120
std dev	0.062	0.011	0.000	0.119	1.163	0.000	1.194
Max	0.572	1.903	1.011	1.096	31.772	1.027	32.625
Min	0.381	1.861	1.011	0.722	27.646	1.027	28.388

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 03/25/91
Spreadsheet: 03/25/91

spreadsheet name: CP032591.WK1

Set-up Data	
Matrix Description	Poly Chunks
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data:

	FM	BFM
half-life	463.47	291.9
A_0	1408.9	407.2
Chi**2	1.27	1.52
Area	19959	5304
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.198	2.106	1.323	0.552	4.557	3.856	17.573
R12 Z24	0.161	2.116	1.926	0.657	3.530	5.960	21.037
R12 Z24	0.141	2.083	2.990	0.879	2.871	8.836	25.369
R12 Z56	0.157	2.098	1.704	0.563	4.678	5.237	24.499
R12 Z72	0.316	2.134	1.009	0.680	11.314	2.477	28.030
R20 Z8	0.225	2.109	1.021	0.483	6.512	2.539	16.537
R20 Z24	0.202	2.160	1.109	0.484	5.062	2.961	14.988
R20 Z40	0.198	2.137	1.148	0.487	5.754	3.135	18.039
R20 Z56	0.234	2.112	1.182	0.584	7.263	3.278	23.810
R20 Z72	0.340	2.116	0.963	0.693	12.441	2.230	27.746
R25 Z8	0.315	2.162	0.942	0.641	8.830	2.097	18.513
R25 Z24	0.304	2.062	0.934	0.586	8.017	2.045	16.398
R25 Z40	0.295	2.159	0.956	0.608	9.053	2.186	19.790
R25 Z56	0.322	2.079	0.985	0.659	11.341	2.352	26.677
R25 Z72	0.372	2.067	0.935	0.719	13.543	2.053	27.804
average	0.252	2.111	1.063	0.566	7.651	2.748	21.022
std dev	0.075	0.033	0.558	0.105	3.361	1.906	4.696
Max	0.372	2.162	2.990	0.879	13.543	8.836	28.030
Min	0.141	2.062	0.934	0.483	2.871	2.046	14.988

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition:
02/28/91

spreadsheet name: CP022891.WK1

Spreadsheet:
02/28/91

Set-up Data	
Matrix Description	Iron & Poly Chunks
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	402.2	284.6
A_0	1269.5	3.852
Chi**2	1.06	1.55
Area	12732	4821
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.172	1.974	0.934	0.317	6.559	2.044	13.409
R12 Z24	0.175	1.984	0.975	0.339	7.014	2.296	16.106
R12 Z40	0.176	1.953	0.916	0.315	8.531	1.917	16.358
R12 Z56	0.221	1.968	0.892	0.387	11.750	1.695	19.911
R12 Z72	0.315	1.968	0.888	0.550	15.966	1.393	22.246
R20 Z8	0.278	1.959	0.904	0.492	14.021	1.269	17.791
R20 Z24	0.211	1.983	0.895	0.375	14.571	1.323	19.273
R20 Z40	0.228	1.979	0.890	0.401	14.840	1.361	20.197
R20 Z56	0.235	1.967	0.885	0.409	14.318	1.460	20.898
R20 Z72	0.363	1.954	0.885	0.627	15.791	1.446	22.839
R25 Z8	0.344	1.984	0.884	0.603	11.460	1.510	17.310
R25 Z24	0.407	1.996	0.888	0.721	13.147	1.396	18.349
R25 Z40	0.353	1.971	0.893	0.622	13.844	1.340	18.545
R25 Z56	0.414	1.970	0.885	0.722	14.772	1.454	21.472
R25 Z72	0.431	1.977	0.888	0.758	17.307	1.386	23.984
average	0.288	1.960	0.884	0.499	12.926	1.491	19.273
std dev	0.093	0.012	0.025	0.157	3.260	0.302	2.839
Max	0.431	1.996	0.975	0.758	17.305	2.296	23.984
Min	0.172	1.953	0.884	0.315	6.559	1.269	13.409

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 10/04/90

spreadsheet name: CP100490.WK1

Spreadsheet: 10/04/90

Set-up Data	
Matrix Description	Vermiculite
Source Description	30 g Pu
Source Voltage	450 V
Target Voltage	500 V

Ace Data

	FM	BFM
half-life	524.9	475.8
A_0	823.1	528.3
Chi**2	1.02	0.8
Area	15390	8032
ROI:	101-300	51-200

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.660	1.018	1.998	0.670	27.179	1.043	28.907
R12 Z24	0.736	1.020	1.011	0.758	28.657	1.027	29.426
R12 Z40	0.787	1.017	1.011	0.808	30.002	1.027	30.808
R12 Z56	0.813	1.014	1.007	0.831	29.194	1.032	30.120
R12 Z72	0.807	1.019	1.011	0.831	29.385	1.027	30.174
R20 Z8	0.699	1.017	1.003	0.713	27.063	1.037	28.057
R20 Z24	0.733	1.026	1.008	0.757	28.948	1.030	29.814
R20 Z40	0.777	1.024	1.011	0.805	29.758	1.027	30.557
R20 Z56	0.789	1.020	1.011	0.813	30.433	1.027	31.250
R20 Z72	0.759	1.020	1.011	0.782	29.156	1.027	29.939
R25 Z8	0.647	1.017	1.004	0.661	27.748	1.035	28.714
R25 Z24	0.687	1.020	1.011	0.708	29.070	1.027	29.850
R25 Z40	0.743	1.019	1.011	0.765	30.502	1.027	31.321
R25 Z56	0.765	1.017	1.011	0.787	30.002	1.027	30.807
R25 Z72	0.738	1.017	1.011	0.758	28.771	1.027	29.543
average	0.743	1.019	1.011	0.765	29.094	1.027	29.875
std dev	0.049	0.003	0.004	0.054	0.970	0.005	0.932
Max	0.813	1.026	1.011	0.831	30.502	1.037	31.321
Min	0.647	1.014	1.003	0.661	27.063	1.027	28.057

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 02/20/91
Spreadsheet: 02/21/91

spreadsheet name: CP022191.WK1

Set-up Data	
Matrix Description	Vermiculite
Source Description	Pidie 7 (PuO_2)
Source Voltage	450 V
Target Voltage	500 V

Ace Data: none taken

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
R12 Z8	0.0697	1.0183	0.9639	0.0684	1.7169	1.0956	1.8810
R12 Z24	0.0591	1.0203	0.9694	0.0584	1.5526	1.0858	1.6858
R12 Z40	0.0651	1.0196	1.0001	0.0664	1.6048	1.0400	1.6691
R12 Z56	0.0688	1.0193	1.0106	0.0708	1.9309	1.0268	1.9827
R12 Z72	0.0694	1.0207	1.0106	0.0716	1.7897	1.0268	1.8377
R20 Z8	0.0562	1.0220	0.9725	0.0558	1.7969	1.0807	1.9418
R20 Z24	0.0615	1.0176	0.9968	0.0624	1.8817	1.0444	1.9653
R20 Z40	0.0760	1.0157	0.9913	0.0765	1.7744	1.0520	1.8666
R20 Z56	0.0747	1.0149	1.0106	0.0766	1.4963	1.0268	1.5364
R20 Z72	0.0674	1.0202	1.0060	0.0692	1.6024	1.0325	1.6545
R25 Z8	0.0513	1.0198	0.9985	0.0523	1.7124	1.0421	1.7845
R25 Z24	0.0672	1.0135	0.9919	0.0676	1.4413	1.0512	1.5151
R25 Z40	0.0633	1.0205	1.0106	0.0653	2.0189	1.0268	2.0730
R25 Z56	0.0656	1.0197	0.9924	0.0664	1.9971	1.0504	2.0977
R25 Z72	0.0671	1.0159	1.0106	0.0689	1.8724	1.0268	1.9227
average	0.0655	1.0185	0.9957	0.0664	1.7459	1.0473	1.8276
std dev	0.0065	0.0025	0.0159	0.0069	0.1786	0.0230	0.1817
Max	0.0760	1.0220	1.0106	0.0766	2.0189	1.0956	2.0977
Min	0.0513	1.0135	0.9639	0.0523	1.4413	1.0268	1.5151

MOBILE DRUM PASSIVE/ACTIVE NEUTRON ASSAY SYSTEM

Data Acquisition: 02/25/91
Spreadsheet: 02/25/91

spreadsheet name: CP022591.WK1

Set-up Data

Matrix Description	Empty
Source Description	U Pillows: 18 @ 5 g of ^{235}U
Source Voltage	450 V
Target Voltage	500 V

Ace Data: none taken   true pillow mass: 4.64 g

Position	Raw Act.	Abs. Corr.	Mod. Corr.	Act. Mass	Raw Pass.	250 Corr.	Pass. Mass
1 Pillow	4.142	0.974	1.011	4.076	0.351	1.027	0.360
2 Pillow	8.125	0.979	0.918	7.305	0.056	5.870	0.327
3 Pillow	12.179	0.991	0.918	11.088	-0.010	1.208	-0.012
4 Pillow	16.640	0.991	0.935	15.422	0.060	1.157	0.069
5 Pillow	20.402	0.993	0.939	19.029	-0.230	1.147	-0.264
6 Pillow	25.010	1.004	0.892	22.379	0.420	1.351	0.568
7 Pillow	29.127	1.020	0.886	26.301	-0.011	1.433	-0.016
8 Pillow	33.453	1.021	0.888	30.330	0.225	1.395	0.314
9 Pillow	37.928	1.050	0.949	37.814	-0.200	1.125	-0.224
10 Pillow	41.237	1.058	0.934	40.753	0.069	1.161	0.080
11 Pillow	46.659	1.088	0.941	47.761	-0.039	1.143	-0.045
12 Pillow	50.236	1.099	0.909	50.183	0.043	1.243	0.054
13 Pillow	54.546	1.096	0.911	54.453	0.089	1.236	0.110
14 Pillow	59.425	1.105	0.891	58.540	0.275	1.355	0.372
15 Pillow	63.685	1.114	0.922	65.408	0.029	1.196	0.035
16 Pillow	68.018	1.107	0.884	66.584	0.061	1.500	0.091
17 Pillow	71.595	1.111	0.903	71.820	0.467	1.271	0.593
18 Pillow	75.218	1.115	0.901	75.590	-0.089	1.282	-0.114
average	39.868	1.051	0.918	39.158	0.087	1.506	0.128
std dev	22.043	0.052	0.030	22.608	0.188	1.067	0.239