A New 208 Liter Drum Neutron Coincidence Counter with Add-A-Source Matrix Correction*

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ABSTRACT

Stringent regulations require that transuranic waste be accurately quantified prior to disposal. Passive coincidence counting of the spontaneous fission neutrons emitted by the even isotopes of plutonium provides an accurate and reliable assay result. The new modular WM3100 Series has been characterized by measuring stationary point sources in a grid pattern throughout the chamber and again by simulating diffuse sources in homogeneous matrices. A description of the design criteria and the results of the performance tests are reported.

INTRODUCTION

Passive neutron coincidence counting is routinely used for characterization of Pu-bearing waste. Canberra's JCC-21 Passive Neutron Drum Counters with Los Alamos National Laboratory design Add-A-Source (AAS) were characterized and the performances are documented in detail in References 1 and 2. Space limitations in the JCC-21 prompted a redesign of the counter that allowed the addition of a rotator to the AAS which would provide a more uniform interrogation of the drum matrix. During the development of the new design, it was decided that a modular design would also provide more flexibility when responding to different waste applications and allow field-upgrades as new regulations are defined. This new modular design was designated the WM3100 Series and its options include a multiple-position AAS with rotator for matrix corrections, automated conveyor for high throughput applications, two doors for pass-through operation, weighing mechanism, and additional shielding for high background installations and maximum detection limit. Results of tests characterizing the performance of the WM3100 are reported in the following sections.

SYSTEM PERFORMANCE

The WM3100 Series has the same performance specifications as the JCC-21. It is designed to measure 100 nCi/g +/- 3σ in drums weighing more than 22.7 kg (50 pounds) in 1000 seconds with a 2 mSv/h (20 μR/h) background for a uniform source distribution. The ^{3}He detectors are positioned on all six sides of the sample cavity to maximize efficiency and provide a uniform response.

The manually-operated counter which was installed at Westinghouse Hanford is shown in Figure 1. The counter is characterized by several basic operating parameters. These parameters are determined by the neutron response characteristics of the assay cavity and signal processing electronics. These parameters are differentiated from more typical calibration parameters as they are determined without the need for actual plutonium samples.

HIGH VOLTAGE PLATEAU

The ^{3}He tubes are proportional counters and the optimal high voltage setting is

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Figure 1. WM3100 Passive Neutron Drum Counter

is determined in the traditional fashion for these types of detectors. A small ^{252}Cf source is placed within the counter and the voltage is slowly incremented and at each step the totals count rate is recorded. When the plateau region has been identified, the count rate vs voltage is plotted and the correct setting is obtained by choosing a value approximately 40 volts above the knee (see Figure 2). The operating high voltage is higher than the value for the JCC-21 because the WM3100 uses 4.5 atm ^{3}He rather than 4 atm ^{3}He proportional tubes.

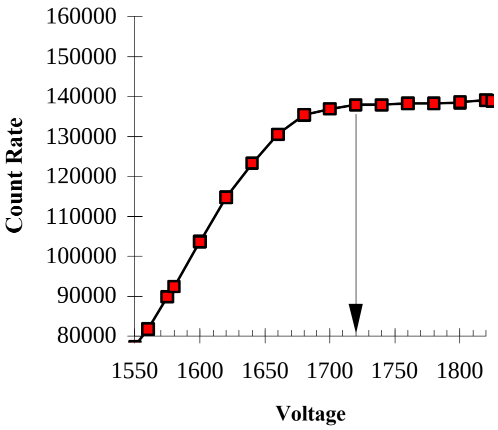

Figure 2. High Voltage Plateau

DIE-AWAY TIME

The Die Away Time is based on the time it takes for an emitted neutron to become thermalized within the counter and detected in one of the ^{3}He tubes. It is more accurately characteristic of the time difference for two coincident neutrons to become thermalized and detected. The coincidence rate as a function of the time difference of the detection pulses, N(t), is represented by an exponential of the form

$$N(t) = N_o \bullet e^{-t/\tau}$$

The reals rate as a function of gate width represents the integral of this distribution with respect to time and is given by

$$R(t_g) = R_o \bullet (1-e^{-t_g/\tau})$$

where τ is the die-away time and t_g is the gate width setting for the detector. The data are obtained by placing a small ^{252}Cf source in the detector and measuring the coincidence rate as the gate width is incremented. The data are then fit to the function for $R(t_d)$ to provide the value for τ. Alternatively, the function N(t) can be determined from the derivative of the reals rate. This function has been plotted in Figure 3 to illustrate the exponential relationship. The die-away time for the WM3100 is 71.9 µsec

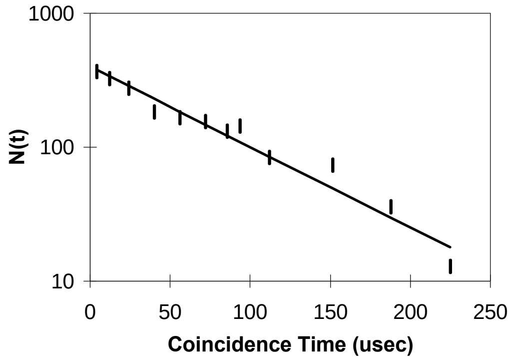

Figure 3. Determination of Die-away Time

GATE WIDTH

The detector gate width is determined from the same data as the die-away time. Since the real coincidence events fall off as a function of time while the random events do not, there is an optimal window width which minimizes the uncertainty in the reals rate. Figure 4 shows the error due to counting statistics as a function of gate width for the WM3100. The gate width is chosen such that the error in the reals rate is at a minimum or at a point where significant gains are no longer achieved. The gate width recommended for this counter is 100 µsec for high count rate applications or 128 µsec for waste assay.

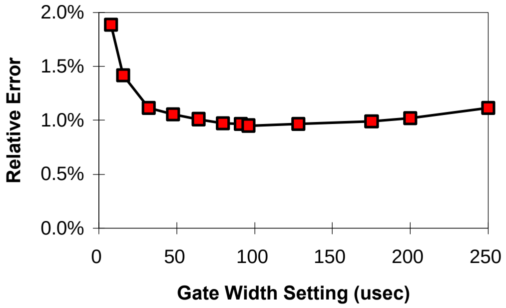

Figure 4. Determination of Gate Setting

NEUTRON COINCIDENCE COUNTING DEADTIME PARAMETERS

The dead time parameters are determined by measurement of multiple ^{252}Cf sources. The sources span a range in size such that the smallest introduces only negligible deadtime into the system and the largest causes a totals rate in excess of the largest expected totals rate, typically greater than 10^5 n/s. The deadtime correction takes the form of

$$CF_T = e^{(a + bT)T/4}$$
$$CF_R = e^{(a + bT)T}$$

where T is the measured totals rate. The parameters *a* and *b* are related by an empirically determined constant factor related to the number of JAB-01 amplifier boards. For the WM3100, this value is equal to 3.1E+6. Therefore,

$$a = \ln(R_{exp}/R_{meas})/((T_1 - T_2)+(T_2^2 - T_1^2)/C_r)$$
$$= 0.4600 \ \mu\text{sec}$$

where

$R_{exp} = R_1/R_2$

$b = a/C_r = 0.1484$ psec

and R_{exp} and R_{meas} are the expected and measured ratios, T_1 and T_2 are the totals rates from the two samples, and C_r is the coefficient ratio.

EFFICIENCY

The neutron detection efficiency is given in terms of the counter response to neutrons emitted from a source located in the center of the empty assay cavity. The source G-351 was cross-calibrated at Los Alamos National Laboratory and used to determine the efficiency for the counter. Based upon this measurement the detection efficiency is 19.34%.

The efficiency for a source distributed over the volume of a 208 liter drum has been estimated by measuring a single ^{252}Cf source in 3 vertical and 6 radial positions while the drum is rotating. The volume averaged efficiency for the WM3100 is 20.04%.

Preliminary measurements indicate a slight increase in the counter's efficiency for plutonium spontaneous fission neutrons compared the spontaneous fission neutrons from ^{252}Cf. This may be due to the lower average energy for the neutrons from plutonium. The plutonium was in the form of a diffuse sample but did not occupy the full volume of a drum. The increase in efficiency, not attributable to spatial effects, was less than 0.5%.

LOWER LIMIT OF DETECTION

The detectability limit is stated using the form of Ref.1, using the equation

$$d = (3/a)\cdot\left(\frac{B+ad}{t}\right)^{1/2}$$

where **a** is the reals per gram ^{240}Pu-effective, **B** is the reals background rate and **t** is the counting time. The reals background rate is given by

$$B = B_s \cdot t_g^2 + B_R$$

where B_s is the singles background rate, t_g is the gatewidth and B_r is the net reals background rate.

At the Canberra facilities in Meriden the room background levels were 7 cps totals and 0.2 cps reals. For the WM3110 operated with a gate width of 128 μsec the parameter **a** is 20.6 cps/g ^{240}Pu. The LLD is then 2.3 mg ^{240}Pu-effective. For totals counting the LLD is 0.73 mg ^{240}Pu-effective. By installing the WM3100 in a shielded facility, such as the JCC-21 at PFPF[1], detection levels of 0.8 mg ^{240}Pu-effective can be achieved.

SPATIAL RESPONSE

For the spatial characterization, a ^{252}Cf source was positioned on an 18 cm grid using 3 cm increments. At each point, 11 measurements were taken vertically using 4 cm increments. When looking at the response for a point source located anywhere in the drum, the standard deviation for the totals response is 2%. Plots of the axial and radial responses through the center of the sample cavity are shown in Figures 5 and 6. The dip at the top of the axial response is caused by gaps in the ^{3}He detector coverage where the high voltage junction boxes for the top and side banks meet. The response at the bottom of the sample cavity is increased due to improved detector coverage and possible scatter off the steel in the rotator. Monte Carlo calculations are underway to determine if the axial response can be flattened by eliminating detectors in the bottom bank or decreasing the length of the corner detectors.

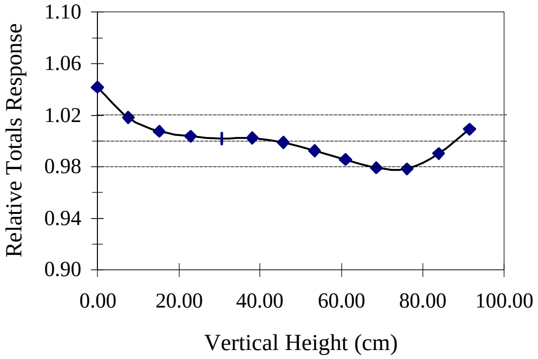

Figure 5. Axial response through the center of the sample cavity.

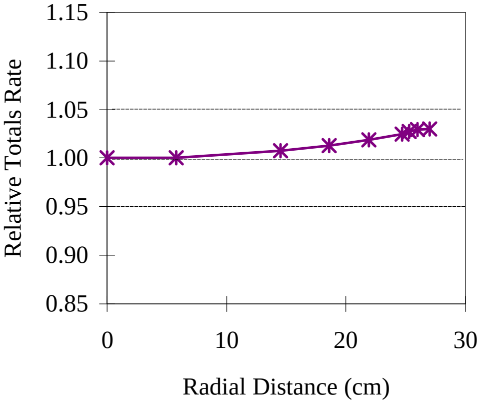

Figure 6. Radial response at the axial centerline of the sample cavity.

BACKGROUND EFFECTS

The effect of increased background due to sources stored near the counter was tested. A 0.3 µg ^{252}Cf source (roughly equivalent to 1200 grams of ^{240}Pu-effective or about 5 kg of high burnup Pu) was placed at various distances from the counter and measured. The totals and reals rates are shown in Figure 7. The impact of a large Pu source on the performance of the counter was estimated from this data.

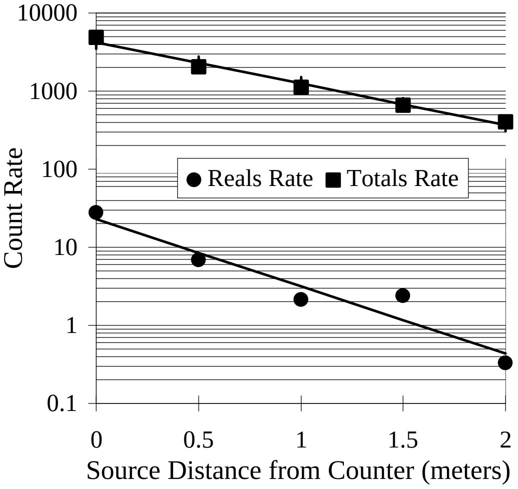

Figure 7. Totals and Reals rates from a ^{252}Cf source positioned outside of the counter.

For example, a 2 kg source of moderate burnup Pu (22% ^{240}Pu) stored one meter from the counter would raise the MDA from 2 mg to 55 mg ^{240}Pu. This same source moving past the counter at a speed of 1 meter per second (closest approach 1 m) during an assay would increase the reported mass by only 2 mg ^{240}Pu-effective.

An additional 20 cm of high density polyethylene shielding is available as an option for this counter. With this additional HDPE the 2 kg source would have no significant impact of the assay results.

MATRIX EFFECTS AND ADD-A-SOURCE CORRECTION

The WM3100 AAS uses multiple positions and includes a drum rotator to provide a more uniform interrogation of the drum matrix. Up to five positions along the side of the drum may be used for the AAS correction. Testing thus far has been limited to homogenous waste matrices. The results of this testing are presented in Table 4 and Figure 8. For each waste matrix a single point source was assayed in 21 positions throughout the rotating drum. The measurements were combined based upon a volume average, where each point is weighted by the volume of the drum represented by its radial and vertical position. The standard deviation of the corrected relative reals rates was 0.7%, comparable to the results for the JCC-21.

Table 4. Add-A-Source Correction Results

Matrix	Volume Average R_0/R	Relative Response (R)	CF	Relative R (corr)
Empty Drum	1.000	1.000	0.999	0.999
Packing Foam (.02 g/cc)	0.994	1.006	1.002	1.008
Softboard (0.22 g/cc)	1.118	0.894	1.110	0.993
Softboard (0.43 g/cc)	1.940	0.515	1.950	1.005
Hardboard (0.76 g/cc)	3.833	0.261	3.833	1.000
Plastic (~0.07g/cc)	1.063	0.941	1.076	1.012

Hardboard is equivalent to 0.4 g/cc CH_2.
Plastic sample was not weighed.

The performance of the AAS for homogenous drums is excellent. However, the results for point sources in highly moderating matrices are less impressive. Figure 9 shows the response as a function of radial position of a point source located at the vertical center of various waste drums. As expected the source in the center of a highly moderating drum has a significantly attenuated response. Figure 10 shows the same data with the AAS correction applied. While there is on average improvement in the reported results there is still the potential for substantial errors for highly moderating matrices. Correction/diagnostic software is being developed to reduce these errors or flag obvious problem drums with nonuniform source distributions.

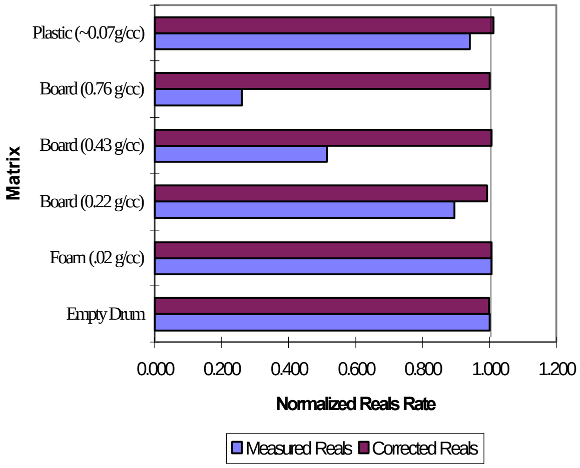

Figure 8. Add-A-Source Matrix Correction Results.

SUMMARY

The WM3100 Series matches, or exceeds, the performance of the JCC-21 and provides a design platform for the next-generation high-efficiency multiplicity waste counter. The new modular design also provides a standard product that can be reconfigured to meet varying waste applications with a guaranteed performance. The accuracy of these counters is achieved through the uniformity in the response of assay chamber and with the straight forward matrix corrections possible for the neutron counter. Monte Carlo modeling and detailed performance characterizations with the new Genie-PC based neutron application software are underway to determine error bounds from uniform/nonuniform source distributions and homogeneous/heterogeneous matrices.

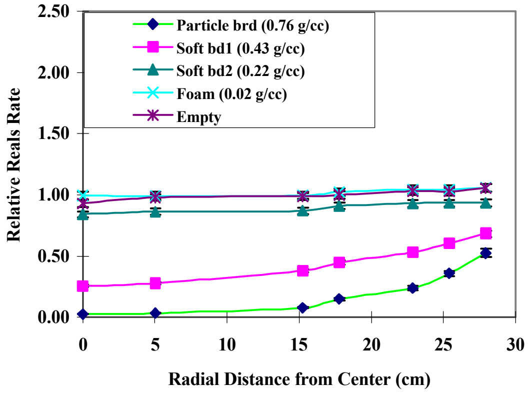

Figure 9. Relative response as a function of radius for a point source located at the vertical center of a waste drum.

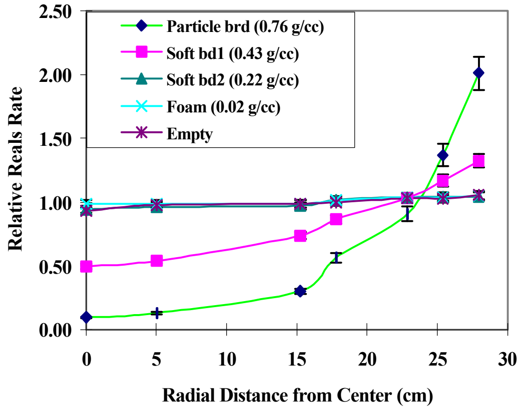

Figure 10. Relative response as a function of radius for a point source located at the vertical center of a waste drum with the AAS correction applied.

REFERENCES

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2. H.O. Menlove, L.A. Foster, J. Baca, "NBC Operation Manual Including the Multi-position Add-A-Source Function", Los Alamos National Laboratory Report LA-12737-M, March 1994.