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TITLE: REMOTE-CONTROLLED NDA SYSTEMS FOR PROCESS AREAS IN A MOX FACILITY

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## REMOTE-CONTROLLED NDA SYSTEMS FOR PROCESS AREAS IN A MOX FACILITY

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### ABSTRACT

Nondestructive assay (NDA) systems have been designed and installed in the process area of an automated mixed-oxide (MOX) fuel fabrication facility. These instruments employ neutron coincidence counting methods to measure the spontaneous-fission rate of plutonium in the powders, pellets, and fuel pins in the process area. The spontaneous fission rate and the plutonium isotopic ratios determine the mass of plutonium in the sample. Measurements can be either attended or unattended. The fuel-pin assay system (FPAS) resides above the robotic conveyor system and measures the plutonium content in fuel pin trays containing up to 24 pins (~1 kg of plutonium). The material accountancy glove-box (MAGB) counters consist of two slab detectors mounted on the sides of the glove box to measure samples of powder or pellets as they are brought to the load cell. Samples measured by the MAGB counters may contain up to 18 kg of MOX. This paper describes the design and performance of four systems: the fuel-pin assay system and three separate MAGB systems. The paper also discusses the role of Monte Carlo transport techniques in the detector design and subsequent instrument calibration.

### INTRODUCTION

Nondestructive assay systems have been developed for use in the process areas of an automated mixed oxide (MOX) fuel fabrication facility. Four instruments measure the plutonium content of various materials in the process area such as fuel pins, feed and recycle powder, and green and sintered pellets. These instruments employ neutron coincidence counting techniques<sup>1</sup> to measure the time-correlated neutron emission by the spontaneously fissioning isotopes of plutonium. When the measured coincidence rates are combined with the plutonium isotopics of the sample, the total plutonium is obtained. The fuel-pin assay system (FPAS) measures the plutonium content of fuel pins in trays containing up to 24 pins. The counter is mounted above the automatic conveyor system and measures both types of fuel pins (MONJU and JOYO) in the facility. Three material accountancy glove box (MAGB) counters are located throughout the process area to measure the plutonium content of various process powders and pellets. Figure 1 shows a schematic of the process layout with FPAS and MAGB systems labeled. MAGB-1 is at the feed powder station, MAGB-2 is at the recycle powder/green pellet press, and MAGB-3 is at the pellet press station. The MAGB systems are similar so that each can back-up the other two. Each system consists of two slab detectors mounted on the sides of the glove

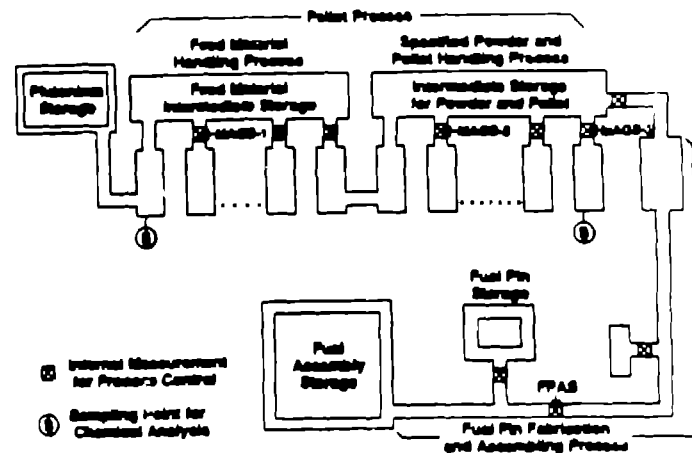


Fig. 1. Schematic of the PFPF process area showing location of FPAS and MAGB counters.

box. The Los Alamos transport code MCNP<sup>2</sup> was used to optimize the design of the FPAS and MAGB systems, and in the case of the MAGB counters, aided in calibrating them. The FPAS was installed at the Plutonium Fuel Production Facility (PFPF) in Japan during December 1988. International Atomic Energy Agency (IAEA) personnel first qualified this system in March 1989. The MAGB counters are scheduled to be installed and calibrated between July and August 1989.

### FUEL-PIN ASSAY SYSTEM

The FPAS measures the plutonium content of MOX fuel pins in trays containing up to 24 pins. The FPAS is similar in concept to the original pin-tray counter.<sup>3</sup> The FPAS counter accommodates both JOYO and MONJU fuel-pins with a single counter configuration, and so must have a relatively flat response for 1.2 m. Measurements may be taken either attended or unattended. (If unattended, provisions are being made for the counter to trigger a camera to automatically record the tray identification). Trays containing pins to be assayed are removed from the storage area and brought into the counter by a robotic conveyor. Figure 2 shows the detector head at the Los Alamos test area before shipment to the PFPF.

To allow the counter to remain stationary relative to a tray, regardless of the type of fuel pin located in the tray, it was



Fig. 2. FPAS detector head at Los Alamos test area.

necessary to obtain a uniform response by the counter over a length of ~1.2 m. This required  $^3\text{He}$  detector tubes with an active length of 1.7 m, the longest such tubes ever used in a safeguards instrument by the IAEA. In addition to requiring a flat response over 1.2 m, the counter also needed to be insensitive to changes in position over its width. To facilitate this aspect of the design, FPAS was modelled by MCNP. A simulation of the counter permitted the design to easily be changed and the response profile evaluated without the expense of fabricating the counter and then modifying it according to experiment. Figure 3 shows the final tube layout and response profile for the x-direction (width). Uniformity of response is achieved by extra  $^3\text{He}$  tubes on the sides and less than optimum spacing of the tubes across the top. Graphite end plugs and thicker polyethylene on the ends than in the middle flattened the response along the length (y-direction) of the counter. Figure 4 depicts the y-axis response and detector outline. Experimental data are plotted along with the normalized results obtained from the Monte Carlo calculations. The calculational data are normalized because the model did not simulate any source reflection other than the counter. The data were normalized by defining the ratio of calculated to observed totals rate for the center of the active zone to be one (y position of 90 cm on graph). It is important to note that Figs. 3 and 4 present the response of the counter to variation of a point source, whereas the actual samples are fuel pins, and thus only relative changes in the integrated response over the length of a pin are relevant to instrument performance. Figure 5 presents the variation in counter response to positional changes (x-axis) of a fuel pin. The profile was obtained by measuring a single pin at selected locations over the possible 24 pin slots. Sensitivity to pin displacement along the y-axis is less than a 1% effect as long as the active length of the fuel stays within the 1.2-m counting zone of the detector. Changes in the multiplication-corrected response from z-axis variation of fuel pins is <1% for displacements of 1 cm or less. Therefore normal positional variation of a pin tray relative to the detector should change the response by 1% or less.

The FPAS was calibrated by counting boiling water reactor (BWR) MOX pins (1.2-m active length) at Los Alamos. Because the BWR pins were larger than either MONJU or JOYO fuel pins, only 17 pins could be used at one time. This corresponds to a total plutonium loading of 500 g (compared to 600 g and 1000 g for JOYO and MONJU trays respectively). Table I presents the results of the precalibration. Simulating the effect of conveyor or tray structure was not attempted in the Los Alamos tests. However, calibrations were made with both constant heavy metal (U+Pu) and with variable heavy metal (pin removal).

Calibration data at PFFP were taken at the time of installation and in March 1989. Figure 6 shows the coincidence rate (R) vs the  $^{240}\text{Pu}$ -effective mass. Analysis of that data

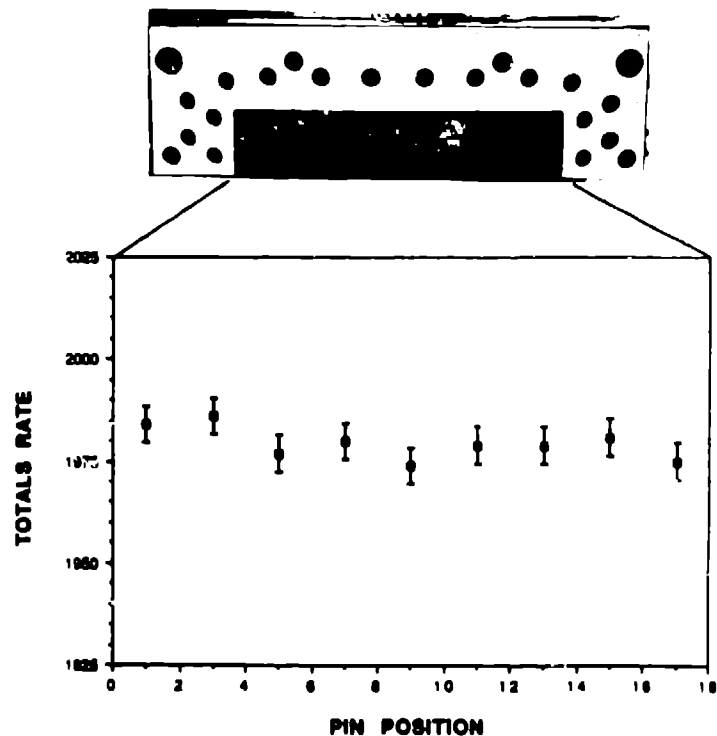


Fig. 3. Cross section showing  $^3\text{He}$  detector tube layout with corresponding plot of counter response vs pin position (x-axis) for  $^{252}\text{Cf}$  point source. Pin position relative to counter indicated by lines.

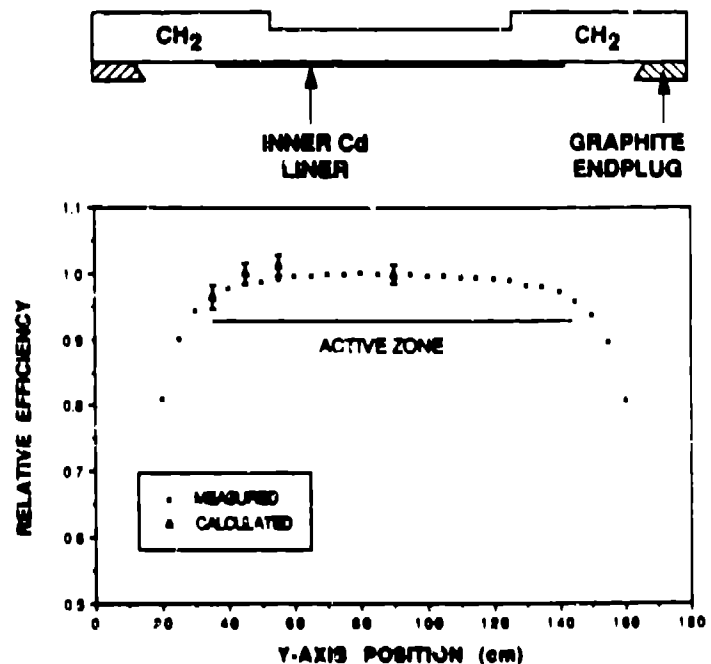


Fig. 4. Cross section showing polyethylene shape and graphite endplugs with corresponding plot of counter response vs y-axis position for  $^{252}\text{Cf}$  point source.

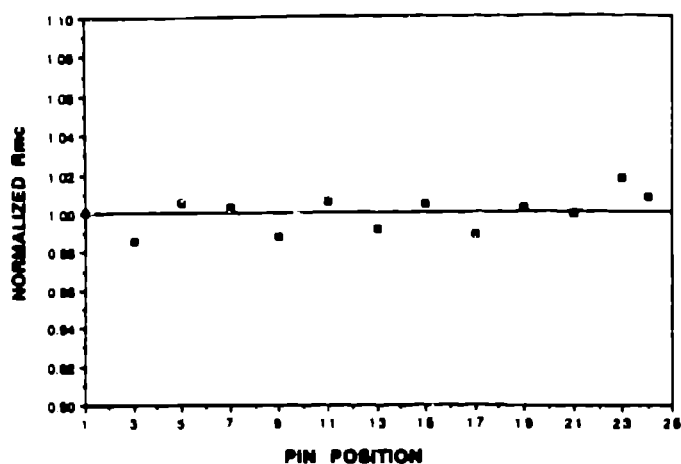


Fig. 5. Normalized multiplication-corrected reals vs pin position (x-axis) for MONJU fuel pin.

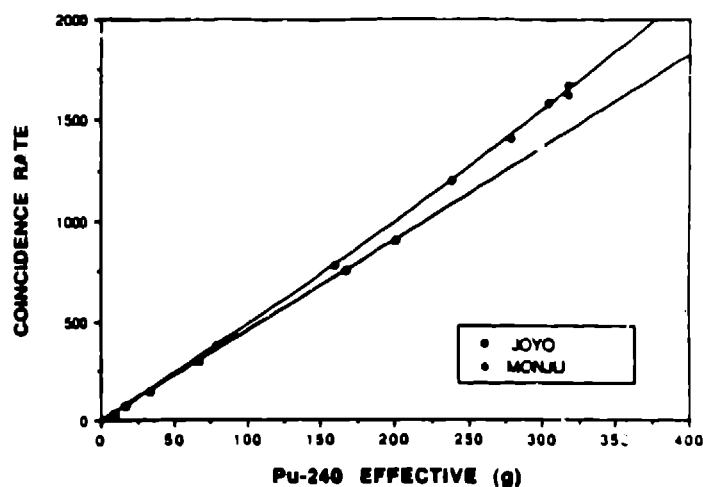


Fig. 6. Coincidence rate ( $R$ ) vs  $^{240}\text{Pu}$ -effective mass for JOYO and MONJU fuel pins.

TABLE I  
SUMMARY OF CALIBRATION RESULTS

MOX Parameters	Rod Removal $R_{mc} = aM_{240} + b$	Constant Heavy Metal $R_{mc} = aM_{240}$
Precalibration (BWR pins)	$a = 4.193 \pm 0.013$	$a = 4.184 \pm 0.004$
$\rho_0 = 0.0448$	$b = -3.684 \pm 0.25$	

yields calibration parameters as given in Table II. Pellet samples taken during the March qualification will be chemically analyzed in August 1989, and at this time parameters for multiplication-corrected reals ( $R_{mc}$ ) vs  $^{240}\text{Pu}$ -effective mass will be determined.

### MAGB COUNTERS

Three MAGB counters have been developed for use in PFPF. Each system consists of two slab detectors mounted outside the glove box, and the associated electronics (JSR-11, computer, and printer). Samples of powder and pellets from the various process areas are positioned on the load cell inside the glove box by the robotic transfer system; the MAGB counter measures the plutonium content. Samples may contain up to 18 kg MOX. Figure 1 shows the location of the MAGB counters. MAGB-1 measures primarily feed powder, MAGB-2 measures primarily recycle powder and green pellets, and MAGB-3 assays primarily sintered pellets. All MAGB systems have similar detectors so that each counter may serve as a back-up for the other two. Figure 7 is a photograph of MAGB-1 at Los Alamos before it was shipped to PFPF. Software allows for either attended or unattended operation. When operated in unattended mode, the computer will trigger a camera for sample identification.

A detailed Monte Carlo simulation of the MAGB counter was part of the design of the detector to account for the affect on counter response of materials surrounding the detector

(for example, glove box, load cell, and concrete wall). In addition to facilitating the counter design, the MCNP model also aided in calibration. Figure 8 is a cross-sectional view of the MCNP input geometry for MAGB-1. Monte Carlo calculations were used to determine the extra polyethylene at the top of both slabs and the reduced polyethylene thickness on the slab nearest the concrete wall. The extra polyethylene at the top of each slab helps flatten the detector response due to positional variation of plutonium inside the glove box. The reduced polyethylene thickness in the slab nearest the concrete wall offsets the enhanced response from neutrons reflected by the concrete. Figure 9 presents the relative change in detector response for various possible fill-heights for samples of powder and sintered pellets.

The Monte Carlo model generated input data for estimating totals and coincidence count rates for calibrating the MAGB counters. This hybrid Monte Carlo-analytical approach has recently been demonstrated with good success for fuel assembly measurements by Stewart.<sup>4</sup> In addition to estimating calibration parameters, this calculational approach can also provide information for determining physical standards for calibration by identifying the most relevant parameters (for example, moderation effects). Initial calibration parameters were estimated for dry powder and sintered pellets for conditions of variable and constant heavy metal. Table III contains the base case data used for the powder and pellet samples.

TABLE II  
PRELIMINARY CALIBRATION PARAMETERS FOR  
JOYO AND MONJU FUEL PINS

Fuel-Pin Type	Pellet Diameter (mm)	Active Length (cm)	Calibration <sup>1</sup> Coefficients
JOYO	4.63	55	a = -1.830 ± 0.753 b = 4.409 ± 0.052 c = 5.93 × 10 <sup>-4</sup> ± 4.17 × 10 <sup>-4</sup>
MONJU	5.4	93	a = -1.225 ± 1.465 b = 4.578 ± 0.078 c = 1.90 × 10 <sup>-3</sup> ± 2.82 × 10 <sup>-4</sup>

<sup>1</sup>Functional form is  $R = a + bM_{240} + cM_{240}^2$ .



Fig. 7. Photograph of MAGB-1 at the Los Alamos test area.

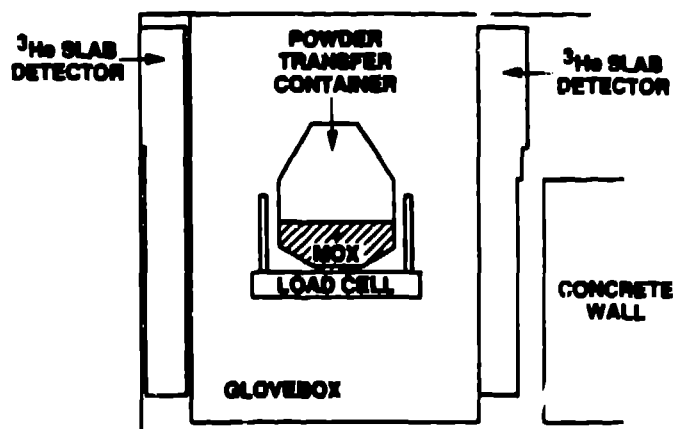


Fig. 8. Cross-sectional view of MCNP input geometry for MAGB-1.

Fig. 9. Calculated relative efficiency as function of fill height for powder and pellets.

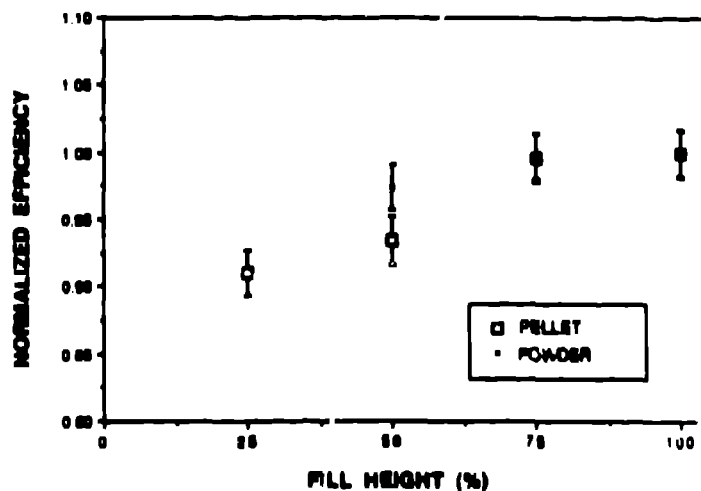


TABLE III  
BASE CASE DATA FOR POWDER AND PELLET SAMPLES

Isotopics (%)		<sup>235</sup> U/U	
<sup>238</sup> Pu	1.20	18%	JOYO
<sup>239</sup> Pu	62.70	0.2%	MONJU
<sup>240</sup> Pu	23.83		
<sup>241</sup> Pu	8.50		
<sup>242</sup> Pu	3.77		
<sup>241</sup> Am	0.82		
		Pu/Pu + U	
		50%	powder
		20%	pellet
Density (g/cm <sup>3</sup> )		Sample Mass	
2.3 g/cm <sup>3</sup>	powder	10 kg	powder
9.4 g/cm <sup>3</sup>	MONJU pellet	11 kg	pellet
10.4 g/cm <sup>3</sup>	JOYO pellet		

Tallies for efficiency, gate fraction, multiplication and average multiplicity were input into a basic code, which, in turn, calculated count rates. Table IV contains the results for the base powder and pellet samples for the variable heavy metal case (variable fill height). These data are also plotted in Fig. 10. The best fit of  $R_{\text{meas}}$  vs <sup>240</sup>Pu-effective is a straight line with a nonzero intercept for both powder and pellet samples and variable heavy metal because variation in the fill height changes the efficiency of the counter, thus violating the assumption of constant efficiency in the multiplication-correction algorithm. Table V compares the relative change in the efficiency times gate fraction ( $\epsilon f_g$ ) with the relative change in  $\rho_0$  needed to give a constant multiplication-corrected response per gram for the pellet samples in Table IV.

Similar calculations were made for constant heavy metal in both powder and pellets. Because the scattering properties and spatial distribution of the plutonium in the sample remain fixed, the response per gram for the multiplication-corrected results is constant, and therefore the best fit of the multiplication-

corrected data is a line with zero intercept. Table VI presents results of the calculations for the case of constant heavy metal. The data in Table VI are also presented in Fig. 11.

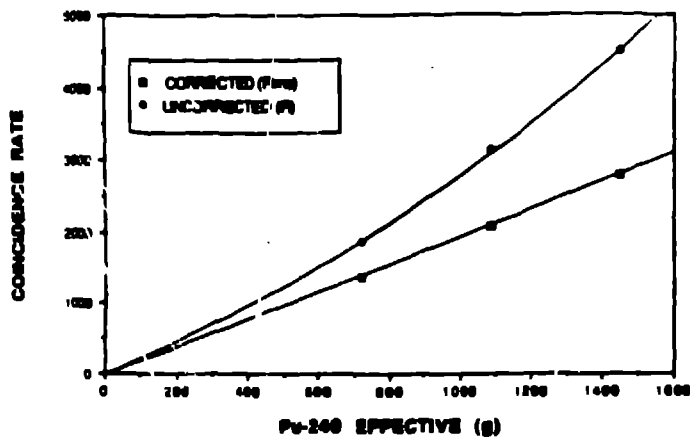
## CONCLUSIONS

The FPAS and MAGB counters can measure process materials in the PFPF in a nonintrusive and timely manner. These instruments complement similar measurement capabilities at the facility input and output provided by the canister counter and capsule counter.<sup>5</sup> Although initially FPAS and MAGB counters will be attended, they can operate unattended. Calculational techniques in detector design and in the estimation of calibration parameters are powerful tools, which may not only enhance instrument performance, but also serve to reduce the number of physical standards required for calibration. In some cases, a calculational approach to parameter study is the only practical or possible method and may provide guidance for experimental work.

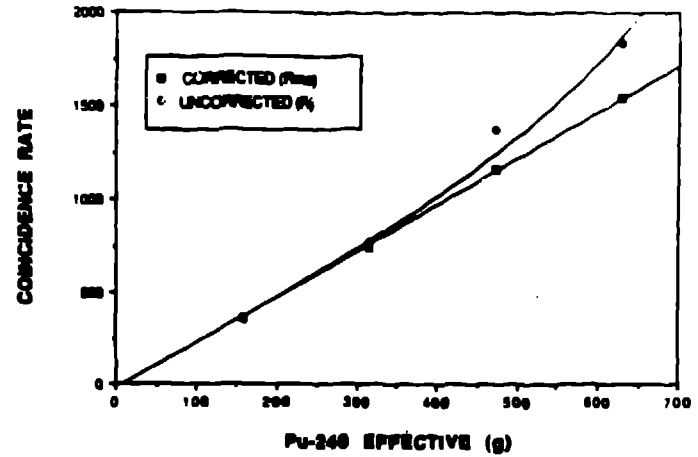
TABLE IV  
CALIBRATION SIMULATION RESULTS FOR VARIABLE HEAVY METAL

Sample Type	Fill Fraction	<sup>240</sup> Pu eff (g)	T	R	$R_{\text{meas}}^1$
Powder	1.0	1 447	168 541	4 496	2 786
	0.75	1 085	124 286	3 148	2 082
	0.50	723	79 767	1 872	1 362
Pellet (MONJU inner core)	1.0	630	77 769	1 832	1 542
	0.75	472	58 244	1 373	1 155
	0.50	315	36 296	772	737
	0.25	157	17 580	363	359

<sup>1</sup>Based on  $\rho_0$  of 0.031 and 0.035 for powder and pellet, respectively.



(a)



(b)

Fig. 10. Calculated coincidence rates vs  $^{240}\text{Pu}$ -effective mass for (a) powder and (b) pellets for case of variable heavy metal.

TABLE V

COMPARISON OF  $\rho_0$  vs  $ef_g$  FOR VARIABLE  
HEAVY METAL CASE (Pellet)

Fill Fraction	$\rho_0(x)/\rho_0(\text{full})^1$	$ef_g(x)/ef_g(\text{full})$
0.75	0.921	0.923
0.50	0.929	0.928
0.25	1.016	1.017

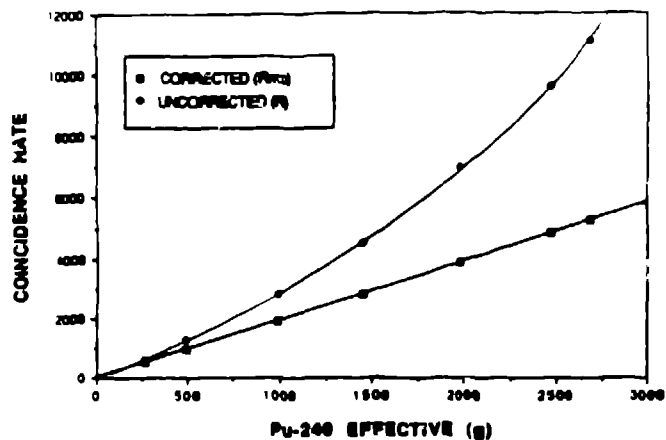
<sup>1</sup>Ratio of  $\rho_0$  required for constant  $R_{ms}/g$   $^{240}\text{Pu}$  eff.

TABLE VI

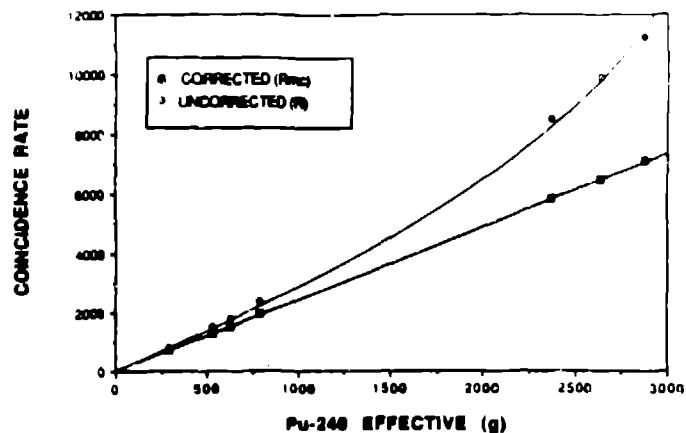
CALIBRATION SIMULATION RESULTS FOR CONSTANT HEAVY METAL

Sample Type	Uranium/Plutonium	$^{240}\text{Pu}$ eff (g)	T	R	$R_{ms}$
Powder	10/1	269	29 718	645	517
	5/1	494	55 484	1 264	954
	2/1	987	113 108	2 788	1 908
	1/1	1 447	168 541	4 496	2 786
	1/2	1 975	237 575	6 968	3 831
	1/5	2 468	302 508	9 592	4 777
	1/10	2 693	334 220	11 078	5 213
Pellet (MONJU inner core)	10/1	288	35 444	809	708
	5/1	528	65 489	1 525	1 302
	4/1	630	77 769	1 832	1 542
	3/1	792	98 928	2 396	1 949
	1/3	2 376	304 191	8 483	5 790
	1/5	2 640	343 764	9 924	6 486
	1/10	2 880	378 475	11 240	7 090

<sup>1</sup>Based on  $\rho_0$  of 0.031 and 0.035 for powder and pellet, respectively.



(a)



(b)

Fig. 11. Calculated coincidence rates vs  $^{240}\text{Pu}$ -effective mass for (a) powder and (b) pellets for case of constant heavy metal.

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