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TITLE **REMOTE-CONTROLLED NDA SYSTEMS FOR FEED AND PRODUCT STORAGE AT AN AUTOMATED MOX FACILITY**

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REMOTE-CONTROLLED NDA SYSTEMS FOR FEED AND PRODUCT STORAGE AT AN AUTOMATED MOX FACILITY

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ABSTRACT

Nondestructive assay (NDA) systems have been developed for use in an automated mixed oxide (MOX) fabrication facility. Unique features have been developed for the NDA systems to accommodate robotic sample handling and remote operation. In addition, the systems have been designed to obtain International Atomic Energy Agency inspection data without the need for an inspector at the facility at the time of the measurements. The equipment is being designed to operate continuously in an unattended mode with data storage for periods of up to one month. The two systems described in this paper include a canister counter for the assay of MOX powder at the input to the facility and a capsule counter for the assay of complete liquid-metal fast breeder reactor fuel assemblies at the output of the plant. The design, performance characteristics, and authentication of the two systems will be described. The data related to reliability, precision, and stability will be presented.

INTRODUCTION

During the past decade, the International Atomic Energy Agency (IAEA) inspectors, national inspectors, and facility operators have used neutron coincidence counters[1] extensively to measure the plutonium content for various forms of nuclear materials in the fuel cycle. Of special importance for these verification measurements are the input and output of nuclear fabrication facilities.

This paper will focus on measurement systems for the input and output of an automated mixed oxide (MOX) fuel fabrication plant. The input is in the form of MOX powder and the output is full sized finished fuel assemblies that are sealed into steel protective capsules.

Prior work[2] at the Los Alamos National Laboratory had led to the development of the High Level Neutron Coincidence Counter (HLNC-II)[3] for measuring bulk samples of plutonium powder and the Universal Fast Breeder Counter[4] for verifying fast breeder reactor fuel assemblies. However, special features of new automated fabrication facilities required new nondestructive assay (NDA) technology. These facility features included:

- automated robotics fuel handling,
- remote operation,
- large sample masses with the possibility of high radiation levels, and
- most fuel inaccessible to inspector sampling.

These operational constraints are common to many of the modern facilities that have been designed for fabricating and processing plutonium fuel.

To accommodate these facility features and to reduce the inspector's work load, we have designed the NDA equipment to be automated, amendable to unattended operation, and with a size and fuel mass capability to match the robotics fuel manipulators. Authentication techniques have been incorporated into the NDA systems so that the data can be used by independent inspectors such as the IAEA.

CANISTER COUNTER DESCRIPTION

The canister counter was developed for measuring plutonium powder contained in storage canisters. The counter was designed for installation in the fabrication plant as part of the automated canister-transfer system. Each canister contains from one to four cans of mixed oxide or PuO_2. The neutron counter measures the spontaneous-fission rate from the plutonium, and when this is combined with the plutonium isotopic ratios, the plutonium mass is determined. The system can accommodate plutonium loadings up to 10 kg, with 5 kg being a typical loading. Software has been developed to permit the continuous unattended operation of the system.

The system consists of:

- detector head,
- security cap,
- electronics cabinet,
- JSR-11 coincidence counting electronics (2),
- COMPAQ Portable III computers (2), and
- Epson LQ-850 printer.

Figure 1 shows the position of these components inside the electronics cabinet. The electronics of the system are similar to those of the HLNC-II.[3]

To accommodate the shape and height of the sample container (canister), it was necessary to design the detector body to fit in an annulus defined by the canister cart-transfer barrel shown in Fig. 2. The detector fits between the central concrete shield and the outside steel wall.

The canister is lowered into the detector by an automated overhead manipulator. After the sample is released, the combined sample, detector, and transfer cart move horizontally for several meters to the measurement location. Thus, the power

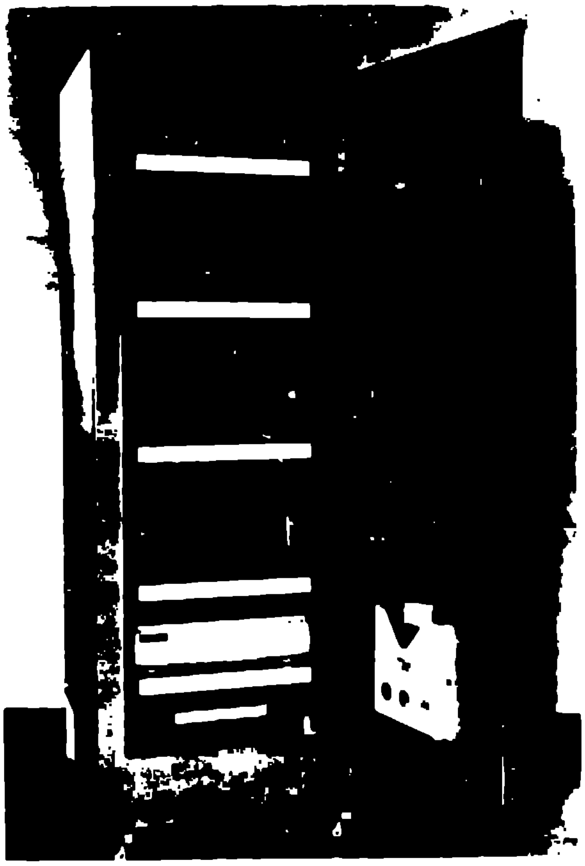

Fig. 1. Photograph of the electronics and cabinet used for the canister counter and the capsule counter.

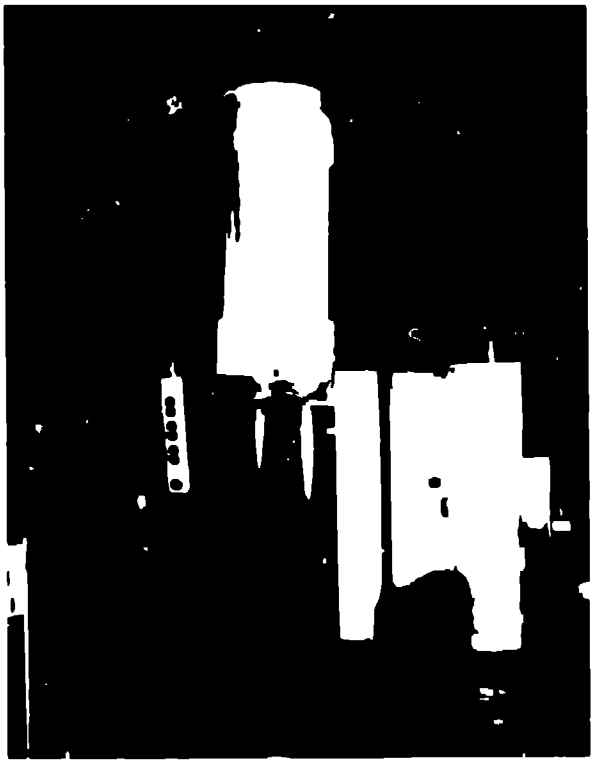

Fig. 2. The canister counter being lowered into the canister transfer cart prior to installation.

and signal lines connecting the detector to the electronics rack are designed to move with the robotics system.

A ^{252}Cf neutron source is used to check the calibration and performance of the system. The plant robotics system can automatically position this source in the detector for routine performance checks, control charting, and possible renormalization.

The canister counter uses the new fast-counting circuitry[5] based on the miniature AMPTEK hybrid chip. These chips are located near the end of the ^{3}He tubes (24) and contain the preamplifier, amplifier, and discriminator circuits. Six of these amplifier units are located in the detector. The electronic modules and their connections in the cabinet are shown in Fig. 3. The signal splitter takes the input logic signal from the detector head and routes it to both JSR-11s for redundancy against component failure. To avoid moisture buildup in the hv junction box of the detector, this space contains desiccant, and the openings are sealed with O-rings and silicone rubber.

The performance characteristics of the canister counter are given in Table I.

A uniform axial-efficiency zone was obtained in the detector design by adding polyethylene annular shims to the outside surface of the detector near the top and bottom as shown in Fig. 2. The extra polyethylene increases the neutron efficiency in the top and bottom zones. Also, cadmium absorbers were added between the polyethylene and concrete interface in the center area to further improve the flatness.

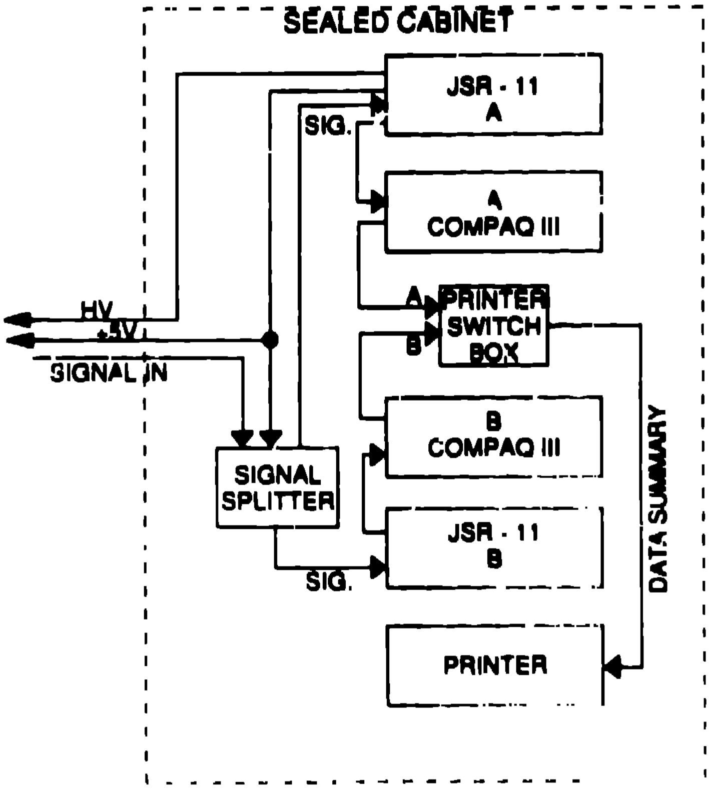

Fig. 3. A diagram showing the electronic components that are contained in the sealed cabinet for the canister counter.

TABLE I

PCAS PERFORMANCE CHARACTERISTICS OF THE CANISTER COUNTER

Parameter	Canister Counter
Efficiency (with canister)	15.1%
Die-away time (center)	57 µs
Gate setting	64 µs
High voltage	1680 V
Deadtime coefficient a	0.745 µs
Deadtime coefficient b	0.240 µs
Californium reference rate (CR5 on 880804)	484 counts/s

Because the canisters are filled with four or fewer separate cans, the PuO_2 distribution is guaranteed to be nonuniform along the axis. This makes it important to have a uniform counting efficiency. The calibration of the counter will be based on the multiplication-corrected reals rate (R_{mc}) because the heterogeneous samples and variable uranium content affect the multiplication. Thus, the most important response function to be uniform or flat is R_{mc}.

To test the system for the axial response of R_{mc}, we scanned a can of PuO_2 in 5-cm steps through the full height of the canister. The can contained 321.1-g plutonium (54.3-g ^{240}Pu-eff), and the fill height of the PuO_2 was ~3 cm. The scan was performed inside a dummy canister.

Figure 4 shows the R_{mc} axial profile for the can of PuO_2. The R_{mc} profile is flat to within ±1% over the 90-cm sample height of a normal canister.

To test the sensitivity of the PCAS to the radial distribution of the plutonium in the counter, a ^{252}Cf source was counted in the center of the detector and then recounted at 2-cm increments to the wall. The results were uniform to better than 0.5% in the totals rate. The reals rate showed a *decrease* of about 0.8% at the wall. However, the multiplication-corrected rates are uniform to better than 0.5% at all radial positions.

The 10-cm-thick concrete wall between the detector and the sample overmoderates the detector. Thus, the addition of H_2O to the MOX powder makes the *detection efficiency decrease*. This is opposite to the HLNC-II and the original canister counter, both of which are undermoderated. The overmoderation of the PCAS should make the system less sensitive to moisture content in the sample because the moisture still gives a net increase in (α,n) yields.

The standards often have a different can wall thickness and are of a different material than the facility cans. Measurements were performed to estimate this difference. A ^{252}Cf source was placed in the center of the detector and concentric steel cans were placed around the source to observe the change in the counting rate. A very small negative change was observed, as shown in Fig. 5. The multiplication-corrected results R_{mc} are even less sensitive to the wall effects than are R and T.

Because the system is operating in an unattended mode without IAEA inspectors in the facility, we designed tamper-indicating features into the NDA system. These include the following:

- detector head under inspector seal;
- visible and unbroken cable runs between detector head and electronics cabinet;
- sealed electronics cabinet;
- modular electronic components that are compatible for replacement with standard IAEA equipment;
- continuous data collection;
- software replaceable by the inspectors;
- software diagnostics for interruption of or tampering with the signal;

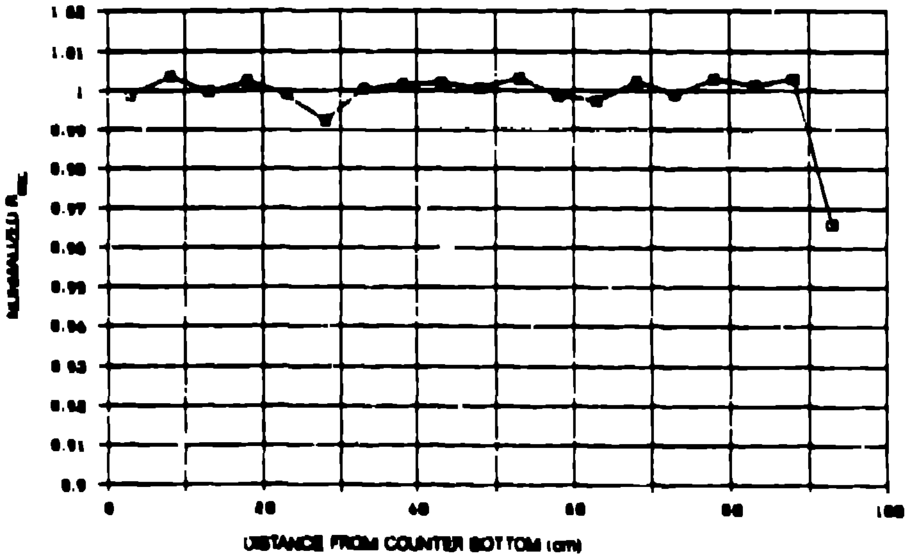

Fig. 4. The multiplication-corrected response R_{mc} profile for the canister counter measured with a can of PuO_2.

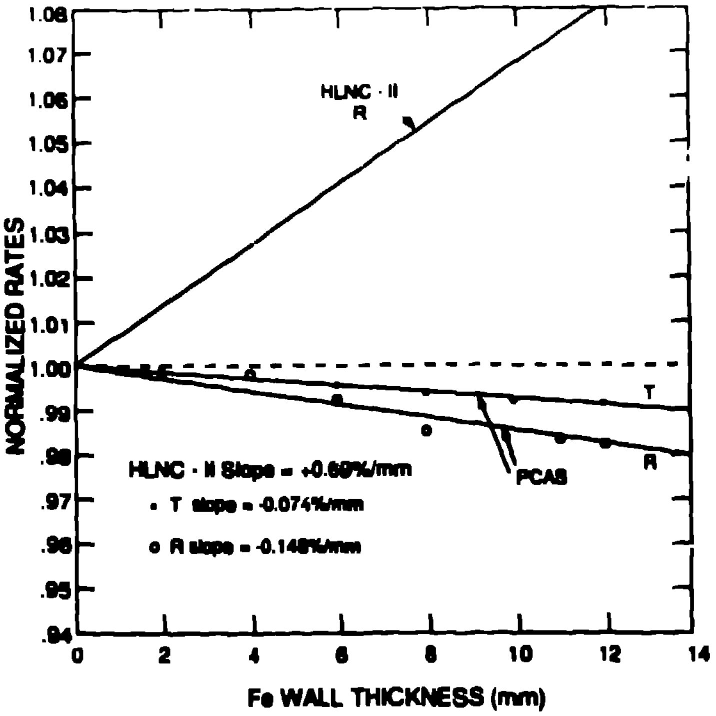

Fig. 5. The normalized totals and reals rates as a function of the sample container wall thickness.

- californium-252 check sources and normalization sources for verification of total system performance; and
- containment and surveillance (C/S) system overview of detector and electronics cabinet.

These measures give an in-depth redundancy in authenticating the NDA system.

The continuous monitoring of the room background gives a record of any movement of MOX in the room. Because the recording of MOX movement also is part of the C/S system, the detector gives an independent method to partially authenticate the system.

Only the multiplication-corrected results R_{mc} will be used for assay because of the heterogeneous samples and the variable uranium content. The R results are collected for consistency and comparison.

The calibration equation is given by

$$R_{mc} = a\, M_{240}$$

where a = 11.94 and M_{240} is the grams of ^{240}Pu-eff[1].

Figure 6 shows a typical calibration curve for MOX in the mass range from 1-5 kg Pu. The canisters contained from two to four cans of MOX, and the number of cans made no difference in the response per gram.

CAPSULE COUNTER DESCRIPTION

The capsule counter was designed for measuring plutonium fuel assemblies contained in storage capsules. The

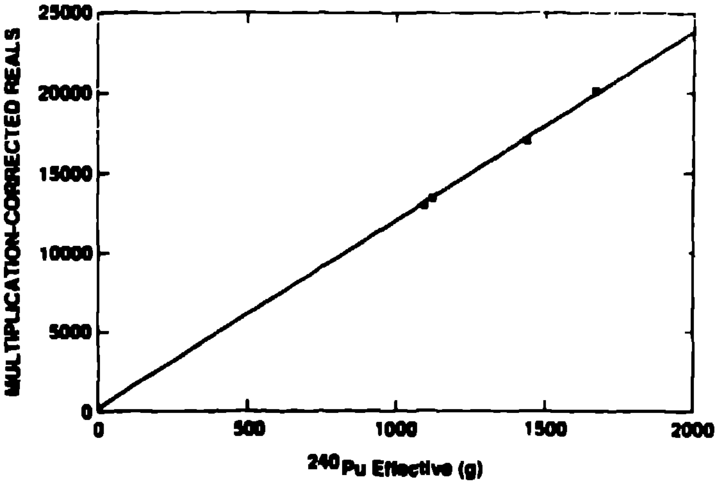

Fig. 6. The R_{mc} calibration line for cans of MOX measured in the canister counter.

coupled to the automated capsule transfer system. Each capsule contains one Liquid Metal Fast Breeder Reactor (LMFBR) fuel assembly. The neutron counter measures the spontaneous-fission rate from the plutonium, and when this is combined with the plutonium isotopic ratios, the plutonium mass is determined. The system can accommodate plutonium loadings up to 10 kg.

The electronics and software for the capsule counter are identical to the components for the canister counter in the canister counter description section.

The capsule counter is designed to accommodate the 5-m-long capsules that hold the fuel assemblies. The capsules are lowered into the detector from overhead by the capsule robotics system. When the bottom of the capsule reaches the floor level, the plutonium zone is several meters above it; thus, it was necessary to build a support stand for the detector to lift it up to the fuel zone.

A guide tube with a funnel top guides the capsule through the detector so that the capsule never touches the detector. The total plutonium fuel zone for the capsules is 1.6 m long: longer than the flat efficiency zone of the detector. Thus, it was necessary to have an elevator to move the detector between the measurement positions. The distance between the lower and upper positions is approximately 50 cm.

The capsule counter is shown in Fig. 7. The detector is split into halves to allow installation around the facility guide tube. The detector body is made of CH_2 with through holes for 12 ^{3}He tubes. Figure 8 shows a diagram of the detector body. The increase in CH_2 thickness at both ends of the detector increases the efficiency at the ends and flattens the response profile. A cadmium liner, placed on the inside of the detector head, prevents thermal neutron reflection back into the plutonium fuel. No cadmium is on the outside surface of the detector because it is also used to monitor the movement of plutonium in the room.

The measured performance characteristics of the capsule

Fig. 7. Photograph of the capsule counter detector head and security cover.

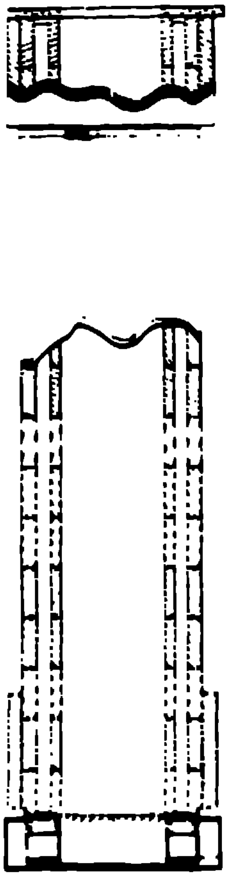

Fig. 8. Schematic diagram of the capsule counter.

TABLE II

CAPSULE COUNTER PERFORMANCE

CHARACTERISTICS

(date 88-08-03)

Parameter	Capsule Counter
Efficiency (no fuel)	16.1%
Die away time (center)	57 µs
Gate setting	64 µs
High voltage	1680 V
Deadtime coefficient a	0.686 µs
Deadtime coefficient b	0.221 µs
Californium reference rate (on 880804)	
T(CR5)	3725 counts/s
R(CR5)	555.8 counts/s

The calibration of the counter is based on the multiplication-corrected reals rate (R_{mc}) because of the variable uranium content, which affects the multiplication. Thus, the most important response function to be uniform or flat is R_{mc}.

To test the system for the axial response of R_{mc}, we scanned a can of PuO_2 in 5-cm-steps through the full height of the counter. The T, R, and R_{mc} data were taken at each step. The results of the PuO_2 scan are given in Fig. 9 where the T, R, and R_{mc} profiles are all normalized to unity in the central region of the detector.

To evaluate the radial position sensitivity, measurements were performed during the precalibration in which a Fast Flux Test Facility (FFTF) fuel assembly was positioned both in the center of the detector and then touching the side wall. The R_{mc} value changed by 0.3% for the two positions. Table III summarizes the results. We conclude that the radial centering of the fuel assemblies in the capsule is not an important variable.

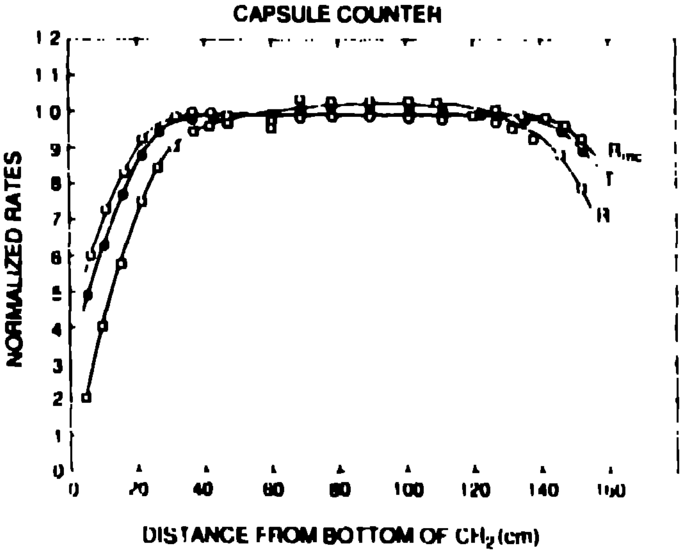

Fig. 9. The normalized response profiles for T, R, and R_{mc} as a function of height for a can of PuO_2 in the capsule counter.

TABLE III

RADIAL GEOMETRIC VARIATIONS OF THE RESPONSE
IN THE CAPSULE COUNTER FOR AN FFTF FUEL ASSEMBLY
(MATERIAL:FFTF SUBASSEMBLY No. 16433)

Assembly Position	T (counts/s)	R_c (counts/s)	R_{mc} (counts/s)	M mult. fact	T/T_0	R/R_0	R_{mc}/R_{mc0}
CENTER	270 333	24 457	13 298	1.132	1.000	1.000	1.000
AGAINST WALL	272 585	25 105	13 342	1.137	1.008	1.026	1.003

The detector is operating in the continuous mode with data dumps every minute. The totals rate in the counter thus gives a time history of the movement of PuO_2 in the room or nearby areas. The detector is unshielded and has an exterior surface area of about 18 000 cm^2, with an intrinsic efficiency of about 16%, so the sensitivity is high for detecting neutron source material in the vicinity of the detector.

The precalibration of the detector was performed at the Westinghouse Hanford Company using FFTF fuel assemblies. Table IV summarizes the results. As with the canister counter, the calibration function is

$$R_{mc} = a\, M_{240} \ ,$$

where the slope a is 14.9 counts/s-g ^{240}Pu-eff for FFTF fuel assemblies (see Fig. 10). This calibration changes by less than 2% for other typical LMFBR fuel assemblies.

SUMMARY

Passive neutron coincidence counters have been designed and implemented to measure the plutonium input and output of an automated MOX fabrication facility. The counters operate in a continuous and unattended mode with full authentication for independent inspection agencies.

The reliability of the systems has been good with no failure leading to loss of inspection data during the initial nine months of use. The accuracy and precision of the systems that are installed in the automated facility are better than can be obtained with portable NDA equipment. Repeat measurements with the ^{252}Cf control sources have demonstrated a precision of 0.1% (standard deviation) without any normalization over the initial six months of operation.

The continuous mode operation with automated data collection, storage, and convenient retrieval has made it possible for inspectors to spend less time in the plutonium facility without any loss of measurement capability. In fact, the sample constraints in size, mass, and containment dictated by the plant robotics system have made it possible to obtain a higher accuracy and precision with the NDA systems than has been possible for older conventional facilities.

TABLE IV

CALIBRATION DATA OF THE CAPSULE COUNTER-1
FOR FFTF ASSEMBLIES AT WHC (88-08-15)

Subass ID No.	Updated Pu (g)	Updated M_{240}	T (counts/s)	R (counts/s)	M	α	R_{mc} (counts/s)	Ratio R_{mc}/M_{240}
16433	7 280	890	270 495	24 625	1.134	0.599	13 267	14.90
16452	8 254	1 019	306 900	29 091	1.142	0.564	15 107	14.83
16448	8 291	1 016	307 989	29 019	1.141	0.571	15 095	14.86
4128	8 993	1 097	346 687	32 711	1.150	0.638	16 381	14.93
4150	9 608	1 178	363 004	36 334	1.158	0.556	17 718	15.04
							Avg	14.91
							RSD	0.08

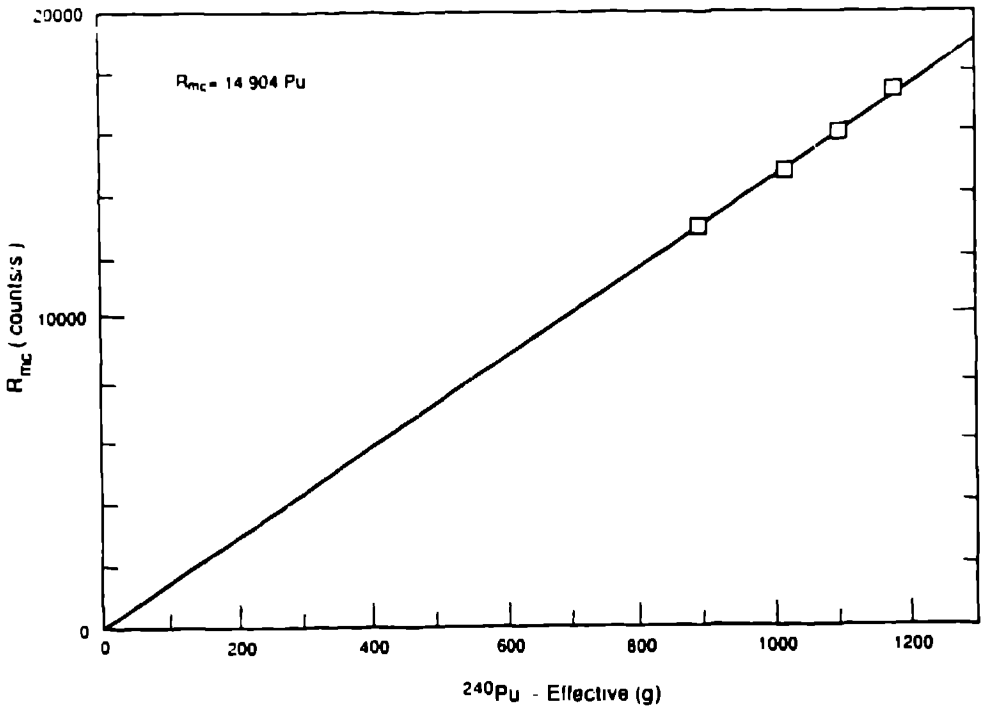

Fig. 10. The R_{mc} calibration line for FFTF fuel assemblies.

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