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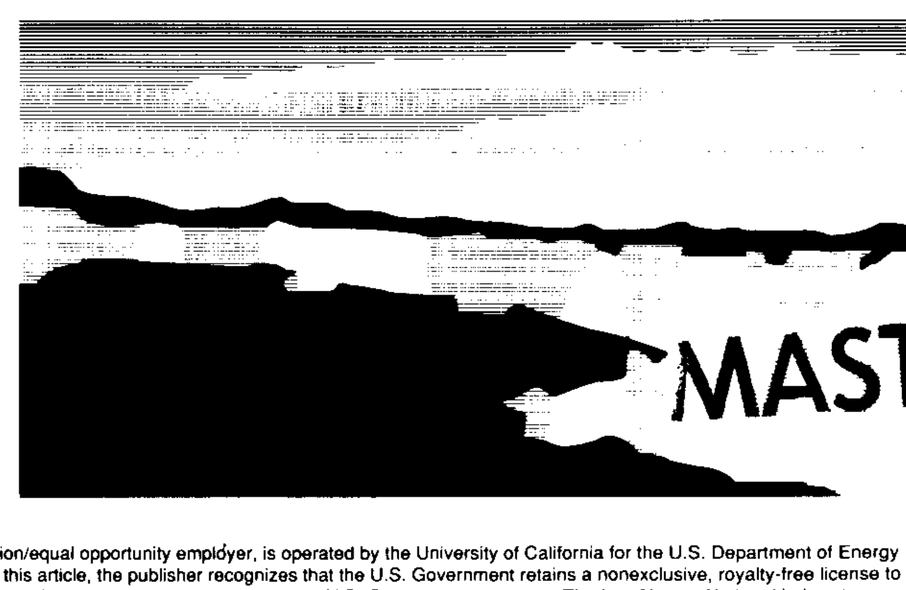

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DEVELOPMENT OF AN INTEGRATED, UNATTENDED ASSAY SYSTEM FOR LWR-MOX FUEL PELLET TRAYS*

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ABSTRACT

Four identical unattended plutonium assay systems have been developed for use at the new light-water-reactor mixed oxide (LWR-MOX) fuel fabrication facility at Hanau, Germany. The systems provide quantitative plutonium verification for all MOX pellet trays entering or leaving a large, intermediate store. Pellet-tray transport and storage systems are highly automated. Data from the "I-Point" (information point) assay systems will be shared by the Euratom and International Atomic Energy Agency (IAEA) Inspectorates.

The I-Point system integrates, for the first time, passive neutron coincidence counting (NCC) with electro-mechanical sensing (EMS) in unattended mode. Also, provisions have been made for adding high-resolution gamma spectroscopy. The system accumulates data for every tray entering or leaving the store between inspector visits. During an inspection, data are analyzed and compared with operator declarations for the previous inspection period, nominally one month.

Specification of the I-point system resulted from a collaboration between the IAEA, Euratom, Siemens, and Los Alamos. Hardware was developed by Siemens and Los Alamos through a bilateral agreement between the German Federal Ministry of Research and Technology (BMFT) and the US DOE. Siemens also provided the EMS subsystem, including software. Through the USSupport Program to the IAEA, Los Alamos developed the NCC software (NCC COLLECT) and also the software for merging and reviewing the EMS and NCC data (MERGE/REVIEW).

This paper describes the overall I-Point system, but emphasizes the NCC subsystem, along with the NCC COLLECT and MERGE/REVIEW codes. We also summarize comprehensive testing results that define the quality of assay performance.

INTRODUCTION

Large, automated facilities for fabricating power reactor fuel containing plutonium present both difficulties and opportunities for control and verification of nuclear material. Moving an item from a production line to a measurement station is often not possible. Modern, continuous, automated plutonium fuel production limits accessibility of nuclear material. Large quantities of in-process fuel are typically placed in secure, automated intermediate storage areas. Radiation protection and safety regulations prohibit routine unrestricted access to production lines and intermediate storage areas for verification measurements.

Nuclear material verification measurements have been integrated into automated mixed oxide (MOX) fuel production at the Japanese Plutonium Fuel Production Facility.[1-3] Reference 1 describes Monte Carlo methods for calculating calibration parameters for measurement of fast reactor MOX fuel assemblies using NCCs. These methods have reduced the need for calibration standards. Reference 2 describes two unattended NCCs; one for measuring plutonium powder in large storage canisters and the second for measuring finished assemblies in storage capsules. Reference 3 describes software for

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collecting and reviewing the unattended NCC measurement data. References 4, 5, and 6 are recent review papers covering, respectively, advances in passive neutron instruments and continuous, remote, unattended data collection systems for safeguards use.

Because of improved measurement control, unattended systems have yielded improved accuracy and precision compared to more traditional, manual systems. Also, inspection effort has been greatly reduced.

Based on experience with the unattended systems developed for the Japanese PFPF, a new, fully automated system was developed for the new Siemens LWR-MOX (MOX-II) facility at Hanau, Germany and is described by the present paper. Reference 7 is a comprehensive description of plutonium fuel production at Hanau. Figure 1 shows the principal flow of plutonium in one of two identical process lines in the new LWR-MOX facility.

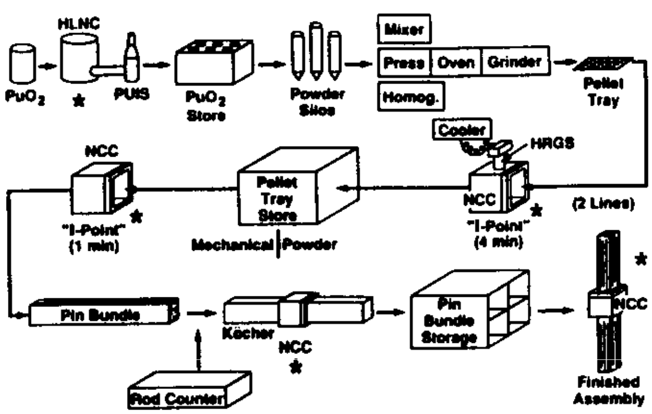

Fig. 1. Principal flow of plutonium in one of two identical process lines in the new Siemens LWR-MOX facility. Inspectorate verification points are shown with asterisks (*).

Inspectorate verification measurements are scheduled for the following:

- single PuO_2 containers;
- canisters containing multiple PuO_2 containers;
- pellet trays entering or exiting the intermediate storage area on the ceramic side of the process;
- pellet trays exiting or entering the intermediate storage area on the mechanical side of the process;
- fuel pin bundles; and
- finished assemblies.

The input PuO_2 containers are verified using standard methods; the High-Level Neutron Coincidence Counter (HLNC) for ^{240}Pu-effective mass ($^{240}Pu_{eff}$) and high-resolution gamma spectrometry (HRGS) for plutonium isotopics analysis (PUIS). Also, an advanced two-detector HRGS system has been developed for measurements of plutonium isotopics, ^{235}U, ^{238}U, ^{241}Am, ^{237}Np, and fission products in canisters containing multiple PuO_2 containers.[8] Fuel pins in bundles and finished assemblies will be verified using NCCs similar to the passive neutron coincidence collar but modified for integration with process equipment.

Pellet trays will be automatically verified for $^{240}Pu_{eff}$ content using large NCCs surrounding the sealed pellet-tray transport system. Inside the transport system, electromechanical sensors will collect the tray identification number and tray movement data. At the review station, NCC and EMS data are merged, plutonium isotopic values are supplied, and plutonium values are compared with operator declarations. This paper describes these pellet-tray verification systems.

SYSTEM DESCRIPTION

In 1988, when the Siemens-MOX safeguards project started, the I-Point Measuring System (IPMS) was conceived for the safeguards control of the pellet tray store in the Siemens MOX-II plant at Hanau.[9] Specifications were developed by the Euratom Safeguards Directorate (Euratom), the International Atomic Energy Agency (IAEA), Siemens, and the Los Alamos National Laboratory.

Four IPMS stations are positioned around two intermediate pellet-tray stores as shown in Fig. 2. The principal flow of nuclear material consists of full pellet trays (5.5 kg of MOX, maximum) moving from the ceramic area through one of the stores to the mechanical area. A secondary flow consists of rejected MOX pellets on trays moving back to the ceramic area through one of the stores. Empty trays are also recycled from the mechanical area to the ceramic area through the stores.

Each IPMS station provides the following functions:

- confirms the correct location inside the measurement cavity of all trays moving through the IPMS (EMS and NCC subsystems);
- confirms the direction of movement, and the arrival/departure of all trays moving through the measurement cavity (EMS subsystem);
- obtains the correct identity of all trays moving through the measurement cavity (EMS subsystem);

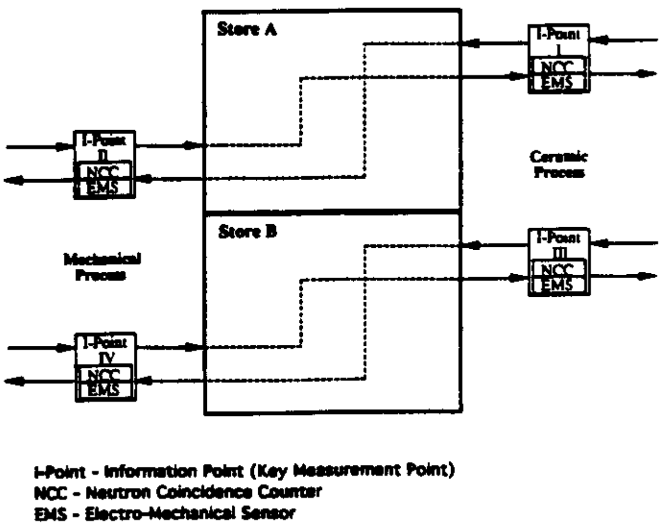

Fig. 2. Positions of four IPMS stations around two intermediate pellet-tray stores. Paths of pellet-tray movements are shown by lines and arrows.

- reports passage of equipment other than trays (EMS subsystem);
- generates alarms, for example, when two trays are present within the measurement cavity (EMS and NCC subsystems);
- performs a 4-min $^{240}Pu_{eff}$ assay of all trays entering a store (NCC sub-system);
- performs a 1-min $^{240}Pu_{eff}$ assay of all trays leaving a store (NCC subsystem); and
- measures a ^{252}Cf source for performance monitoring and normalization (NCC sub-system).

Furthermore, mechanical provisions have been made to integrate a separate HRGS subsystem with the NCC subsystem.

Figure 3 is a graphic illustration of the NCC neutron detector panels, their support system, and a segment of the pellet-tray transport system (for testing) inside the measurement cavity. Note that the NCC sub-system measures trays at positions on either the upper or lower conveyor.

Figure 4 is a sectional view of the I-Point NCC showing details of the placement of ^3He detectors in polyethylene slabs, positions of the upper and lower conveyors, and the gamma-ray detector collimator. One

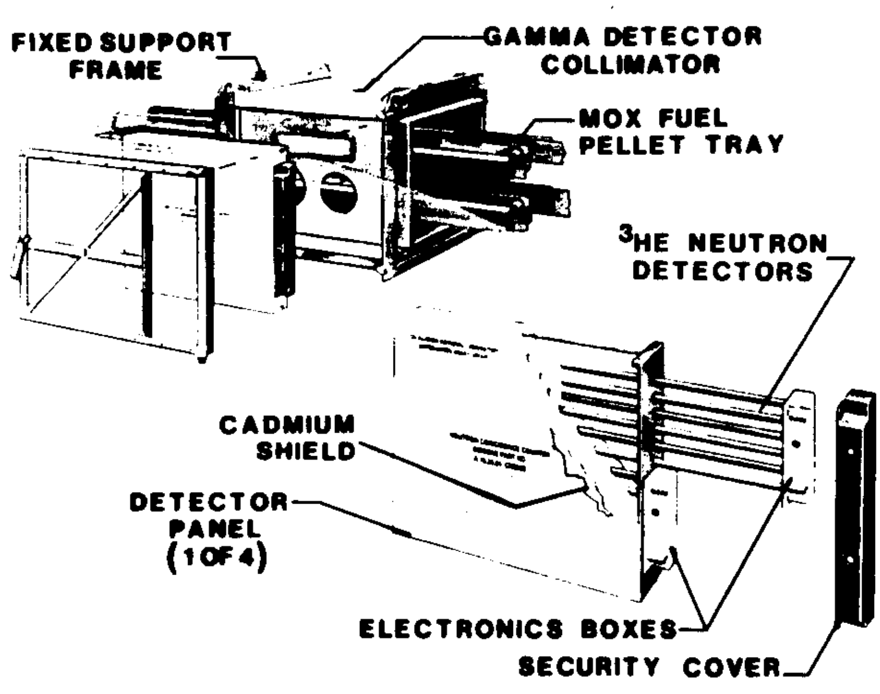

Fig. 3. Illustration of the I-Point NCC neutron detector panels, their support system, and a portion of the pellet-tray transport system inside the measurement cavity.

of the physics design goals was to have the response of the NCC be the same (to within 1%) for both upper and lower tray positions. Another was that the neutron response over the surface of a tray (either upper or lower) be uniform to within ±4% (1 σ). An extensive set of Monte Carlo design calculations was performed to achieve these goals.[10] The design was made modular and as simple as possible to reduce fabrication costs for the four systems and to facilitate component replacement.

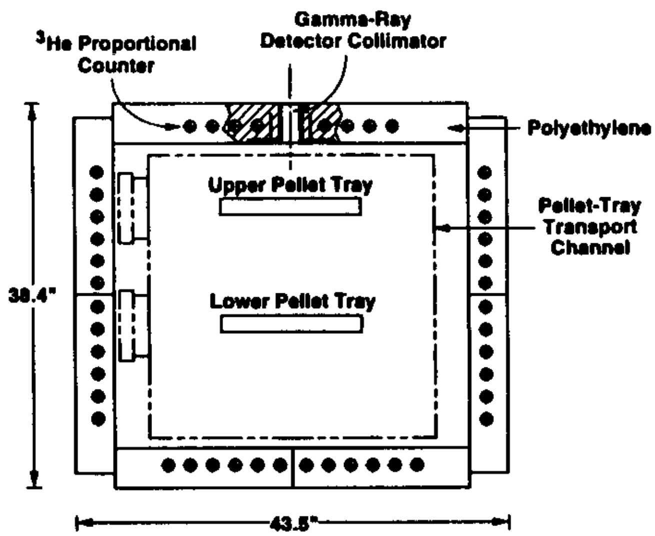

Fig. 4. Sectional view of the I-Point NCC showing the locations of ^{3}He detectors in polyethylene slabs, the upper and lower conveyors, and the gamma-ray detector collimator.

Because the four I-Point systems will operate continuously in the facility with only monthly attendance by inspectors, the following security features were incorporated:

- detector-head electronics junction boxes and all cable connections covered by sealed, tamper-indicating enclosures;
- visible, continuous cable runs from detectors to interconnecting boxes and from interconnecting boxes to cabinets;
- NCC and EMS electronics, computers, and power supplies enclosed in sealed, tamper-indicating, tamper resistant cabinets;
- all software packages under control of inspectors;
- NCC, EMS, and MERGE/REVIEW software packages include diagnostics to indicate and report inconsistencies;
- password protection, range checking, and uninterrupted data collection during user interactions included in NCC software;
- time synchronization of NCC and EMS data collection computers;
- redundant indication of tray position by NCC and EMS systems; and
- ^{252}Cf neutron source to verify total system performance.

The security features above combine to provide high confidence for authenticating NCC and EMS data.

Figure 5 is a diagram showing the arrangement of data-collection electronics and computers inside the sealed, secure cabinet. Also shown is the Data Review Station, which will reside outside the process area.

Because of the importance of the measurement results, the following maintenance and reliability features were incorporated:

- industrial-grade data-collection computers;

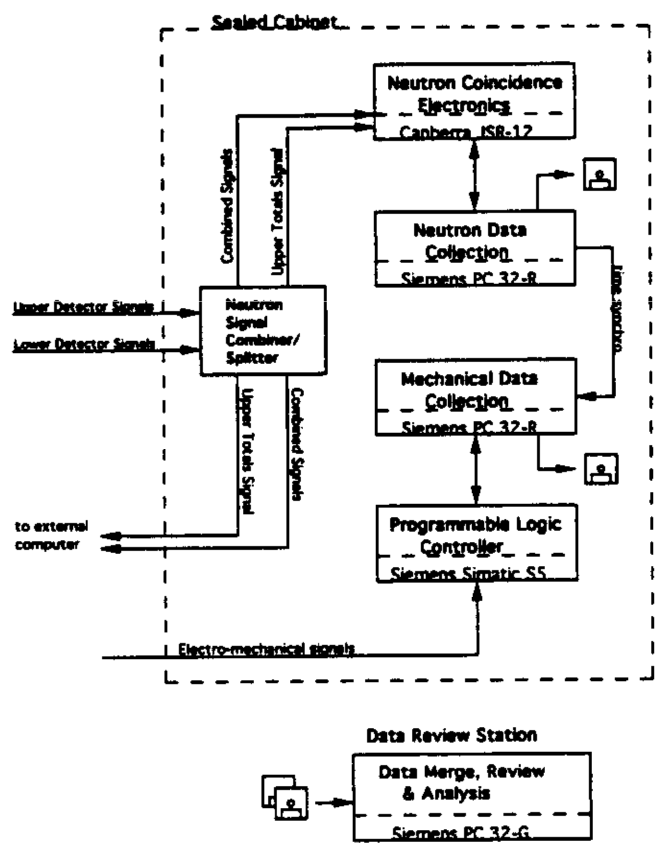

Fig. 5. Diagram showing the arrangement of data-collection electronics and industrial-grade computers inside the sealed, secure cabinet. Also shown is the Data Review Station, which will reside outside the process area.

- uninterruptible power supply;
- spare parts, including ^{3}He detectors, Amptek preamp/amp/discriminators, junction boxes, computers, and cables;
- o-ring seals on junction box covers;
- easily replaceable desiccant holders for junction boxes;
- a background-averaging algorithm to reduce the size of data files; and
- high-capacity data storage media.

To meet the stringent requirements for plant safety and quality control, the following features were included:

- all exposed surfaces meet or exceed surface-roughness requirements for decontamination;
- polyethylene is encapsulated with stainless steel sheeting for fire protection;
- thermal expansion of polyethylene is accommodated in the panel-frame construction;
- all stainless steel welds are certified; and
- stainless steel fasteners are used on all safety-significant components.

Also, detailed, comprehensive, and traceable documentation was generated for all components, including separate quality control (QC) documentation.

TESTING RESULTS

Figure 6 is a photograph of an I-Point system under test at Los Alamos. Siemens engineers constructed a simulation of a portion of the pellet-tray transport system for testing. Visible in Fig. 6 are three of four NCC panels (top, bottom, and door side) in the support frame surrounding a section of the transport channel. Drive mechanisms for movement of pellet trays are also shown. Siemens engineers also wrote simulation software to control tray movements and generate EMS error conditions. The experimental test bed, partially shown in Fig. 6, was used for all preliminary performance and reliability testing at Los Alamos.

Of primary importance to the quality of nuclear material verification at Siemens MOX-II are the performance characteristics of the I-Point NCC systems. Table I summarizes test results for the most important parameters of the system, together with specified values, where applicable.

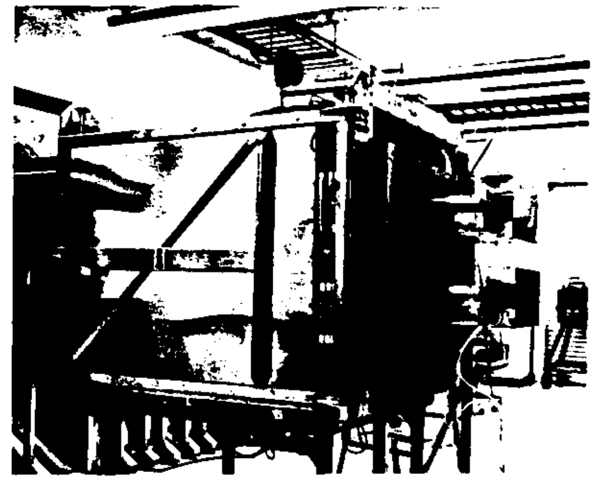

Fig. 6. Photograph of the first I-Point system under test at Los Alamos.

Figure 7 is a 3-dimensional plot of measured ^{252}Cf efficiencies on a 7 by 7 grid covering the surface of the upper pellet tray. The precision of each of these points is approximately 0.25%. One relative standard deviation of the 49 points is 2.0% as reported in Table I.

A comprehensive study of plutonium mass sensitivity was conducted using an algorithm published in Ref. 11. Sensitivity is defined as the plutonium mass resulting in a percentage error of 33% in the background-corrected reals coincidence count rate ("reals rate"). Tray measurement time and reals background rate are variable for the I-Point NCC systems. Actual measured values of detector efficiency, die-away time, calibration parameters, and reals errors were used in the sensitivity calculations. Two sets of calculations were made—one for ambient background conditions at the Los Alamos NDA laboratories and one for simulated worst-case background conditions at the Siemens MOX-II facility. Using ^{252}Cf and AmLi sources, three plant background conditions were simulated—the pellet-tray store, the nearest fuel-pin bundle, and an adjacent full pellet tray. The latter case provided the highest (worst-case) background rates. Three counting times for trays were considered: 4 min (trays entering store), 1 min (trays leaving store), and 10 s (trays passing through a measurement cavity without stopping—an inconsistency). Results are shown in Table II.

Table I I-Point NCC Performance Testing Summary		
Parameter	Specified Value	Test Value
Pu-mass sensitivity (Pu-total)	5 g (60 s count time)	0.7 g for Los Alamos ambient background 3.6 g for simulated worst-case MOX-II background
Absolute efficiency averaged over upper tray (^{252}Cf).	11 %	11.4%
Absolute efficiency averaged over lower tray (^{252}Cf).	11 %	11.6%
Ratio (upper/lower) of average efficiencies (^{252}Cf).	1.0 ± 0.01	0.99
Standard deviations (1 σ) of axial and radial efficiencies measured over surface areas of upper and lower trays (^{252}Cf source).	± 4%	±2.0% (upper pellet tray) ±2.1% (lower pellet tray)
Preliminary Calibration	na	a = 7.062 (multiplication-corrected reals) $\rho_0 = 0.06$
Accuracy of $^{240}Pu_{eff}$ assay	na	1.4 % (for 4.8 g $^{240}Pu_{eff}$)
Die-away time (upper center)	na	63.7 ± 2.0 µs
Gate setting	64 µs	64 µs
High voltage	1680 V	1680 V
Deadtime coefficient a	na	0.91 µs
Deadtime coefficient b	na	0
^{252}Cf reference rates: (CR7/W786/W787 top center on 93.10.27/93.10.28/93.10.29	na	402.6 ± 0.4/197.1 ± 0.2/189.6 ± 0.8

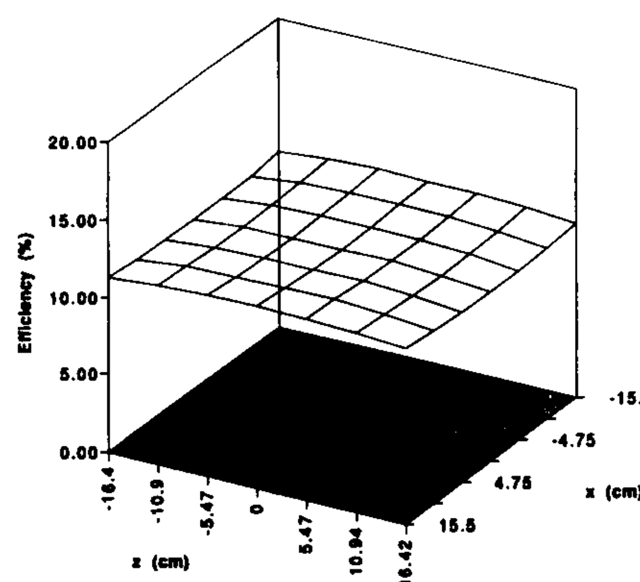

Fig. 7. Three-dimensional plot of measured ^{252}Cf efficiencies on a 7 by 7 grid covering the surface of the upper pellet tray. The 1 σ scatter is 2.0% as shown in Table I.

Table II Siemens MOX-II I-Point System Total Pu-mass Sensitivity Limits Background Count Time = 10 s		
Tray Count Time	Los Alamos Ambient Background	Simulated Worst-Case MOX-II Background
4 min	0.6 g	3.2 g
1 min (5 g specification)	0.7 g	3.6 g
10 s	1.4 g	6.9 g

Table III Siemens MOX-II I-Point System Total Pu-mass Sensitivity Limits Background Count Time = 500 s		
Tray Count Time	Los Alamos Ambient Background	Simulated Worst-Case MOX-II Background
4 min	0.2 g	0.9 g
1 min (5-g specification)	0.3 g	1.7 g
10 s	1.1 g	5.8 g

Note that these are worst-case limits, that is, the shortest possible (10 s) background count time. Note also that the 5-g specification value is bettered, even for the simulated worst-case background condition. A much more common situation is that at least 500 s would be available for background counting. Table III gives sensitivity limits for this case.

Note that an average LWR-MOX pellet produced at the MOX-II facility contains 0.33 g of plutonium, and an average tray contains 242 g of plutonium (733 pellets). Table III shows that for ambient background conditions and a background count time of 500 s, the I-Point NCC can detect the presence of a single, average pellet in a 60-s count time. The precision of the reals rate for a full, average tray will be approximately 2.8%.

The NCC system was designed to independently verify the location of a pellet tray within the measurement cavity—either on the upper or the lower conveyor. This was done by splitting the signals from the upper and lower detector banks. Californium-252 sources W786 and W787 were used for tests of this capability. These are the normalization sources for the Siemens I-Point systems and are nearly equal in intensity. W786 was placed at the center of the top tray and W787 at the center of the bottom tray. The sources were measured separately and together to demonstrate the performance of the I-Point systems in verifying full tray location (upper or lower conveyor or both). Results of measurements of total count rates ("totals") are shown in Table IV below:

Table IV Tray Position Verification Measurements	
Source/Position	Upper/Lower Totals Ratio
W786/top center	1.79
W787/bottom center	0.78
W786/top center and W787/bottom center	1.18

The values obtained show that the upper/lower neutron totals ratio is a reliable indicator of tray position. Therefore, the neutron counter verifies tray position independently of the EMS system.

CONCLUSIONS

Remote, unattended, and continuously operating NCC and EMS systems for LWR-MOX fuel-pellet verification have been developed, integrated, and thoroughly tested prior to facility installation. The systems represent evolutionary advances compared with the already successful systems operating in Japan. The four I-Point systems permit real-time plutonium and item inventories to be obtained for large, intermediate pellet-tray stores. They integrate, for the first time, electromechanical sensors and neutron coincidence counting. Data security, reliability, maintainability, safety, and quality control have all been given special attention according to modern inspectorate and German nuclear facility requirements. The I-Point system may be further integrated with a separate HRGS subsystem. This capability has been designed into the top panel of the NCC subsystem.

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