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Title: SAFEGUARDS INSTRUMENTATION FOR CONTINUOUS UNATTENDED MONITORING IN PLUTONIUM FUEL FABRICATION PLANTS

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**SAFEGUARDS INSTRUMENTATION FOR CONTINUOUS, UNATTENDED MONITORING IN PLUTONIUM FUEL FABRICATION PLANTS***

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## ABSTRACT

Nondestructive assay (NDA) systems have been developed for use in an automated mixed oxide 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 design, performance characteristics, and authentication of the NDA systems are described. The data related to reliability, precision, and accuracy are presented.

## INTRODUCTION

During the past decade, the International Atomic Energy Agency (IAEA) inspectors, national inspectors, and facility operators have used neutron coincidence counters[1,2] extensively to measure the plutonium content of various forms of nuclear materials in the fuel cycle. Of special importance for these verification measurements are the input, output, and in-process inventory of nuclear fabrication facilities.

Large, automated facilities for fabricating plutonium fuel present both difficulties and opportunities for improved control and inspection of nuclear materials. The traditional methods of sample measurements requiring the transfer of the sample from the production line to the measurement station are not possible in most cases. The robotics used for automation require special containers for nuclear material that cannot be easily removed from the production line. Also, safety and radiation protection considerations require that the measuring devices be installed in the fuel production lines because, in general, personnel cannot be in the fuel handling area with nuclear material. These operational constraints are common in 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 workload, we have designed the nondestructive assay (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.

The standardized containers and programmed fuel movements in automated facilities make it possible to perform more accurate nondestructive assay (NDA) measurements than are possible in conventional nonautomated facilities. The NDA instrumentation can be custom designed and optimized for the particular measurement goal in the automated facility.

## INSTRUMENTATION

At the Plutonium Fuel Production Facility (PFPF) in Japan, NDA instruments have been installed to give complete measurement coverage of all the plutonium in the facility. Table I lists the instruments and the measurement locations within the plant. In addition to the input and output locations, more difficult to access locations such as glove boxes, process equipment, and on a trial basis, waste containers are included in the measurement coverage.

TABLE I NDA Systems in Use at the MOX Fabrication Facility

| Location | Detector System |
| --- | --- |
| 1 | PCAS Canister input |
| 2 | FAAS Fuel assembly output |
| 3 | FPAS Fuel pin counter |
| 4 | MAGB Material accountancy glove box counter |
| 5 | GBAS Glove box holdup counter |
| 6 | WDAS Waste drum assay system |
| 7 | INVS(Ge) - Inventory sample neutron and gamma assay |

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Figure 1 shows a diagram of the NDA systems and their applications in the facility. The material categories that are measured include the input mixed-oxide (MOX) powder and the output fuel assemblies. The process-line MOX powder, pellet trays, and scrap are measured inside the glove-box lines using detectors outside the glove boxes. The MOX holdup in glove boxes, furnaces, and process equipment is measured using large slab detectors on the outside of the equipment. Small-grab samples destined for chemical analysis also are measured in the NDA systems before analysis.

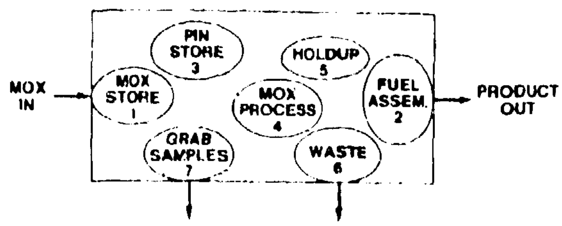



*Fig. 1. Diagram of the PFPF facility MOX material locations and the corresponding NDA systems. The numbers correspond to the measurement systems listed in Table I.*

All of the detector systems listed in Table I are based on passive neutron coincidence counting of the $^{240}Pu$-effective mass using $^{3}He$ counters. Neutron multiplication corrections are made as needed. The plutonium isotopic ratios are obtained by mass spectroscopy of grab samples and/or gamma-ray spectroscopy.

After multiplication corrections, the coincidence neutron yield is directly proportional to the $^{240}Pu$ effective mass. Thus, by measuring the coincidence neutron yield from all of the plutonium in the facility, we can verify the entire plutonium inventory. Of special significance for the PFPF facility is the capability to make routine quantitative measurements of the holdup and waste materials.

## Canister Counter Description

The canister counter (PCAS) 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 MOX or $PuO_2$. The neutron counter measures the spontaneous fission rate from the plutonium, and, when this is combined with the 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 2 shows the position of these components inside the electronics cabinet. The electronics of the system are similar to those of the HLNC-II.[3]

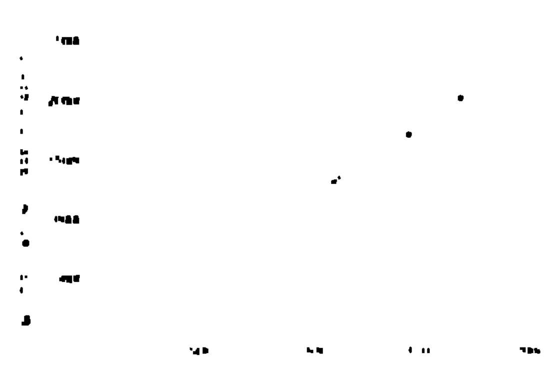
To accommodate the shape and height of the sample container (canister), it was necessary to design the detector body to fit in an annulus defined by the canister cart-transfer barrel shown in Fig. 3. The detector fits between the central concrete shield and the outside steel wall.

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 sample identification camera. The neutron measurement is performed during the travel of the transfer cart. Thus, the power and signal lines connecting the detector to the electronics are designed to move with the robotics system.

A $^{252}Cf$ neutron source located inside an empty canister is used to check the calibration and performance of the system. The plant robotics system can automatically

*Fig. 2. Photograph of the electronics and cabinet used for the canister counter and the capsule counter.*

## Capsule Counter Description



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.

The capsule counter is shown in Fig. 6. The detector is split into halves to allow installation around the facility guide tube. The detector body is made of polyethylene with through holes for twelve $^{3}He$ tubes. The neutron counting efficiency of the detector is 16.1%.

Because of the well-defined fuel composition and good standards, the accuracy for fuel assembly assay is better than 1%.

The detector operates in the continuous mode with data dumps every minute. The totals rate in the counter

*Fig. 6. Photograph of the capsule counter detector head and security cover.*

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.

**Fuel-Pin Assay System**

The fuel pin assay system (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. The FPAS counter accommodates both JOYO and MONJU fuel pins with a single counter configuration, and so must have 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.

**Material Accountancy Glove Box (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 contents. Samples may contain up to 18 kg MOX. 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 backup for the other two. Software allows for either attended or unattended operation. When operated in unattended mode, the computer will trigger a camera for sample identification.

The accuracy of the MAGB counters is in the range of 1-3% depending on the fuel category.

**Glove-Box Holdup Counters**

A technique has been developed to accurately measure the plutonium holdup inside large glove box lines (1 m wide by 3 m tall by 6 m long). The procedure is to position two large slab detectors containing $^{3}He$ tubes on opposite sides of the glove box. The two detectors are electronically coupled to count neutrons in the coincidence or time correlation mode.

To measure the glove box line, the detector pair is moved in unison over the exterior surface of the glove box using a 12 position scan for a full size box. The integration of the scan is proportional to the mass of $^{240}Pu$ effective inside the glove box.

The glove box assay system (GBAS) calibration measurements show a remarkable independence from the particular glove box. The new scanning procedure averages out differences in the scattering between boxes containing hoppers, blenders, calciners, grinders, and filters. A comparison of the calibration coefficients for all of the glove boxes gave the remarkable result that the average variation in the separate calibrations was only ±5%.

With this new measurement capability for glove-box holdup, IAEA inspectors can treat the holdup as verified inventory. A sample identification number will be assigned to each glove box. During routine monthly inspections at the facility, the IAEA will include these glove-box samples as part of the measured inventory. Thus, a large source of inventory uncertainty will be eliminated, and criticality control during process operations will be improved.

### Waste-Drum Assay System

The process-line wastes are placed in 200-ℓ drums and measured before leaving the plant. The waste-drum assay system (WDAS)[5] uses the classical NDA method of passive neutron coincidence counting of plutonium but has a new "add-a-source" feature to improve the accuracy for matrix corrections and new statistical techniques to improve the low-level detectability limits.

The add-a-source technique introduces a minute source of $^{252}Cf$ ($10^{-8}$ g) to the external surface of the sample drum, and the perturbation by the drum of the $^{252}Cf$ coincidence counting rate provides the data to make a matrix correction for the plutonium inside the drum. The errors introduced from matrix materials in 208-ℓ drums have been reduced by an order of magnitude using the add-a-source technique. In addition, the add-a-source method can detect the presence of unexpected neutron shielding material inside the drum that might hide the presence of SNM. For the in-plant installation at the PFPF MOX facility in Japan, the detectability limit is 0.7 mg $^{240}Pu$ (or 2.4 mg plutonium) for a 15-min measurement. For a drum containing 100 kg of waste, this translates to about 7 nCi/g. This excellent sensitivity was achieved using a special low-background detector design, good overhead shielding, and statistical techniques in the software to selectively reduce the cosmic-ray neutron background.

### Inventory Sample Counter

The inventory sample coincidence counter (INVS)[6] was developed to passively assay small plutonium samples by using neutron coincidence counting techniques. The INVS counter has been widely used by the IAEA in its inspection activities at various nuclear facilities throughout the world. At the PFPF in Japan, the INVS counter is coupled to a sample well underneath a glove box in the analytical area. The isotopic composition of the sample is determined by gamma-ray spectroscopy in this area as well.

The INVS (Mod III)[7] in Japan has a diameter of 30 cm and a height of 5[illegible] cm. The polyethylene body contains eighteen $^{3}He$ tubes resulting in a neutron counting efficiency of 42%.

A 15-min measurement gives a precision of about 0.5% and the assay accuracy varies from 0.5 to 3% depending on the fuel category.

## SOFTWARE

The software consists of two main programs.[8] COLLECT controls the shift register to collect data continuously in the unattended mode. REVIEW is run about once a month to examine the large amounts of data collected. The REVIEW program also creates data files that can be input into the IAEA high-level neutron coincidence program to calculate grams of plutonium in the sample. Separating the software into two programs allows the inspector to spend minimal time in the radiation area collecting data. The data from the COLLECT program can be examined in a more comfortable environment with the REVIEW workstation computer.

### Data Collection

The COLLECT program operates on the computers in the electronics cabinet located near each detector.

The main function of COLLECT is to gather data continuously, but it has additional capabilities. In addition to collecting data during a measurement campaign, this program allows the inspector to copy the data files to a floppy disk for transfer to the REVIEW program for further analysis, to print campaign summaries of previous data, to set parameters used in the collection analysis, and to delete old data from the hard disk. No operator interaction is necessary during data collection. After each 60-s run, COLLECT reads data from the shift register and writes it to the computer hard disk.

### Data Review

The REVIEW program operates on the computers located in the workstation area of the PFPF. The primary functions of the REVIEW program are to store the raw count data from the COLLECT program in a database, to rapidly inspect and observe these data, and to generate data files for input to IAEA codes. Large amounts of data are produced by the unattended operation. A campaign of one month produces 43 000 raw data runs for each shift register/computer system. If each run were printed on a line, the results for one detector would cover 780 pages. The REVIEW program displays the data graphically so the inspector can quickly and easily examine it.

## AUTHENTICATION

Because the system is operating in an unattended mode without IAEA inspectors in the facility, we designed tamper-indicating features into the NDA system for authentication. 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;
- 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 C/S system.

## SUMMARY

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

The systems have been reliable with no failure leading to loss of inspection data during the initial three years 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 two years 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. The precision and stability of the neutron systems is 0.1% to 0.2% and the accuracy depends on the fuel category. Most of the NDA systems listed in Table I operate continuously in the unattended mode giving near real time information on the plutonium inventory in the facility.


## ACKNOWLEDGMENTS

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