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ABSTRACT

The improved Plutonium Canister Assay System (iPCAS) is designed to detect gross and partial defects in the declared plutonium content of plutonium and MOX storage canisters during transfer to storage and process areas of the MOX fuel fabrication facility in Rokkasho, Japan. In addition, an associated Gamma Isotopics System (GIS) will be used to confirm facility-declared plutonium isotopics with accuracy sufficient to reduce the amount of destructive isotopic analysis needed. The design of the iPCAS instrument and its associated GIS is described and the expected performance of the instrument is discussed.

INTRODUCTION

The iPCAS as initially designed was intended to detect gross and partial defects in the declared plutonium content of plutonium and MOX storage canisters during transfer to the storage area and to the process area of the MOX fuel fabrication facility in Rokkasho, Japan[1]. To successfully meet this requirement the predicted accuracy for the design had to be better than 2%. Recently, a request was made to improve the system's capability to achieve a predicted accuracy of 0.85%. Efforts to meet this latter requirement are underway and will only be discussed briefly. In addition to the neutron detectors, an associated Gamma Isotopics System (GIS) will be used to confirm facility declared plutonium isotopics with accuracy sufficient to reduce the amount of destructive isotopic analysis needed.

The iPCAS is similar in function and measurement capability to previous PCAS systems fielded in the Japanese Nuclear Fuel Cycle Development Institute (JNC) Plutonium Fuel Production Facility (PFPF). Differences with previous PCAS systems include 1) lower efficiency (to be able to a handle larger plutonium sample mass), 2) lower dead-time by the use of more preamplifiers and a parallel derandomizer, 3) replacement of the central concrete pillar with steel in order to reduce the effect of unknown hydrogen content in the concrete, and 4) overall predicted accuracy improvement to better than 2% for the expected range of parameters. In addition to these improvements, the iPCAS will be networked to simplify data collection from the instrument.

Radiation Transport Calculations

The initial objective of the transport calculations was to provide a calculated basis for assurance that the iPCAS design will meet plutonium assay accuracy objective of better than 2% on plutonium oxide and Mixed Oxide (MOX) samples up to 18 kg with moisture contents up to 1%. The improvement of the design to meet this requirement is in progress.

The iPCAS was modeled using the standard MCNP[2] radiation transport code. The MCNP model was developed with sufficient detail to accurately reflect the radiation transport characteristics of the instrument while minimizing the modeling effort. Therefore, details such as electronics packages were not included in the model, but their omission does not impact the modeling results. A schematic diagram of a horizontal slice through the model is shown in Figure 1 and a vertical slice is shown in Figures 2 showing the three penetrations for the gamma isotopic system described later.

The original model, as shown in Figures 1 and 2, included 24 4-atm helium-3 detector tubes in the polyethylene moderator as well as six 4-atm. helium-3 detector tubes in the air gap between the steel shielding at the center of the detector and the polyethylene moderator. These six tubes in the air gap were included in the model to provide for a means to make corrections for varying moisture content of the MOX fuel.

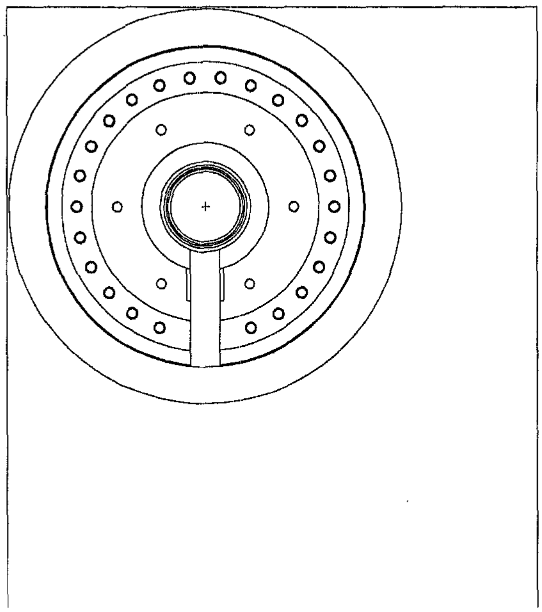

Fig. 1. Horizontal slice at a height of 82 cm through the PCAS MCNP model. Penetration for an HPGe detector is shown. This model preceded the final design containing 20 tubes in the outer ring and no tubes in the inner ring.

A critical aspect of the iPCAS design is the ability to achieve a flat efficiency profile over the length of the plutonium (or MOX) sample. Since the ends of the instrument, both at the top and the bottom, provide a pathway for neutrons from the sample to leak out of the counter, the efficiency at the center would be inherently greater than at the ends. Measures must therefore be employed to increase the efficiency near the ends and also to decrease the efficiency at the center.

The first step in optimizing the physics design was to determine whether or not additional polyethylene should be included at the top and bottom of the instrument. This would be placed between the polyethylene moderator in which the 24 tubes (20 tubes in the final design) are located and the outside steel wall of the instrument. The function of this additional polyethylene is to act as a reflector to enhance the neutron efficiency near the ends of the detector where neutron leakage is the most prevalent.

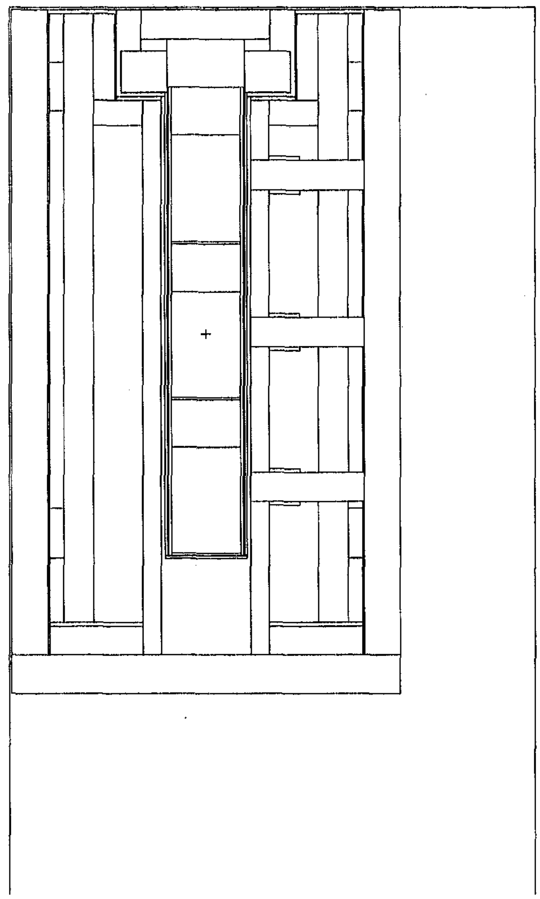

Fig. 2. Vertical slice through the PCAS MCNP model. HPGe detector penetrations are shown through the right side of the instrument.

Forty-two configurations were modeled with an additional thickness of 3.72 cm of polyethylene of various lengths placed at the top and bottom. The efficiency for the 42 source/polyethylene configurations was determined using MCNP-REN[3], a modified version of the well-established Monte Carlo code MCNP. The results from these runs were combined to obtain the axial efficiency profile with no additional polyethylene, 12.5 cm of polyethylene at both the top and bottom, and 25 cm of polyethylene at both positions. From Figure 3 one can see that the additional polyethylene does increase the efficiency at both ends of the detector and will be useful in establishing a flat efficiency profile over the region that will include cans of MOX fuel. All subsequent modeling included the 25-cm of additional polyethylene at both the top and bottom of the instrument.

The next step was to insert cadmium of various densities in regions along the length of the helium-3 tubes. Cadmium will be used to depress the efficiency near the center of the tubes. The purpose of this exercise was to establish the approximate distribution of cadmium that will be required to achieve a flat vertical efficiency profile in the instrument. An approximate distribution is adequate for the purpose of further performance calculations. The actual distribution will be determined by measurements and adjustments during the calibration of the instrument. Seven configurations were tested and the results of 98 MCNP runs are shown in Figure 4. Configuration 4 had an axial profile with an average efficiency of 0.1023 ± 0.0020. This configuration was used for all subsequent modeling. The final configuration of cadmium along the lengths of the tubes will be determined during the assembly, testing, and calibration of the instrument.

A third set of MCNP runs was made to determine the sensitivity of the design to the moisture content of the MOX fuel. A set of 16 moisture-polyethylene thickness combinations was modeled to determine the optimum thickness of polyethylene moderator for the instrument. Moisture affects the response of the instrument by a combination of factors, including:

1. increasing the sample multiplication (response increases),
2. increasing neutron absorption in Hydrogen (response decreases),
3. moderating the neutron energy (response increases or decreases),
4. and additional alpha-n production (response increases).

At the optimum polyethylene thickness the instrument response (multiplication-corrected reals-rate assay) will be the most insensitive to the moisture content. Variations from 0 to 2% moisture by weight were modeled to determine the effect of the first 3 factors on the totals rate. The source used in the MCNP model was distributed within 18 kg of plutonium located in three cans within the instrument. The model included both absorption and multiplication in the MOX fuel.

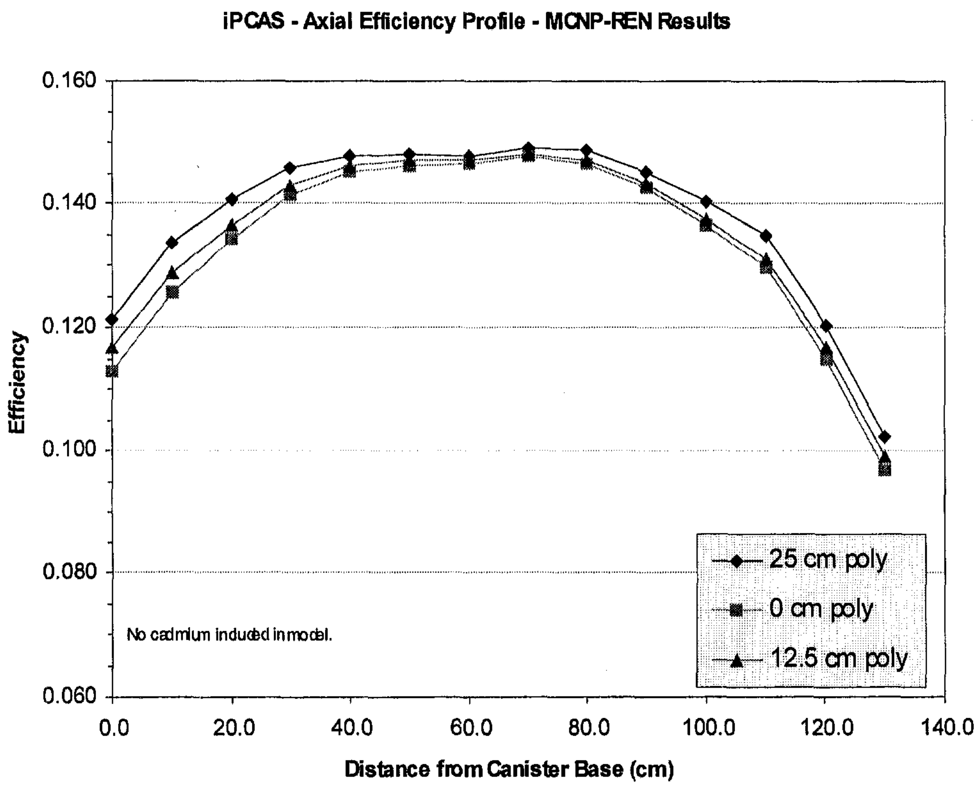

Fig. 3. Vertical efficiency profiles along the center axis demonstrating the effectiveness of additional polyethylene inserts at creating a flat profile. The region that may include MOX fuel extends from the base to approximately 110 cm above the base.

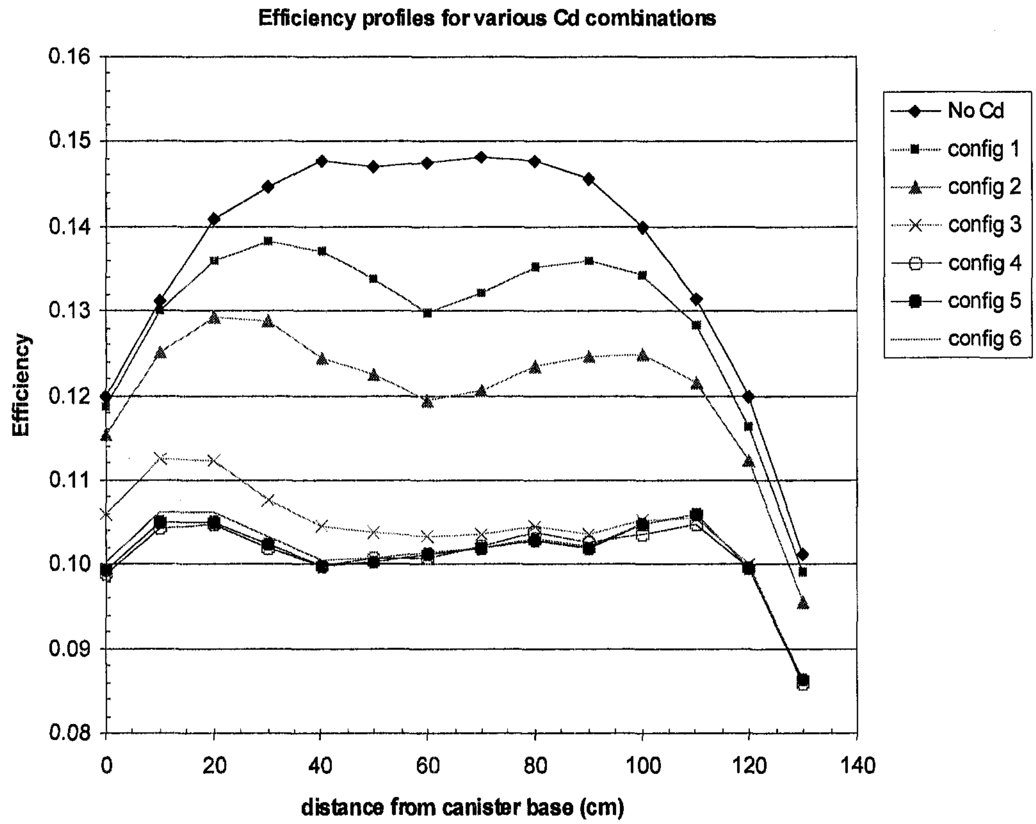

Fig. 4. Vertical efficiency profiles along the center axis for various cadmium configurations. The region that may include MOX fuel extends from the base to 110 cm.

The efficiency with a polyethylene thickness of 7.62 cm was 0.1256 ± 0.0002 at all four moisture levels modeled. The variation of the efficiency was well within the uncertainty of the modeling results. As expected, for moderator thickness greater than this value, the addition of water results in a drop in efficiency. It was thought that this effect could be used to overcome the net change from factors 1, 2, and 4 together. A series of very time consuming computer simulations were undertaken to simulate the net effect of all four factors together.

The alpha-n total production and neutron energy spectrum as a function of water content was predicted using the SOURCES 4A[4] code. The total mass of Pu was chosen to be 18 kg. The calculations were performed using MCNP-REN. It was assumed that the calibration (Dmc vs. Pu mass) would be performed using samples with zero moisture content.

It was determined that the total measurement error (using multiplication-corrected reals rate assay) accounting for moisture from 0 to 1% by weight is minimized at a polyethylene thickness of 8.62 cm. As expected, this thickness is larger than that which would have been chosen by a simple efficiency calculation. The error presented accounts for only the error components that change with a change in moderator thickness, factors 1 - 4, and the random (statistical counting) error, which is affected because the die-away time increases with increasing moderator thickness. The error component as presented is the worst possible error from moisture effects and random error. It is the error that one would encounter if the calibration was performed with a sample containing no moisture content whatsoever. In practice, calibrating with a canister containing the average moisture content can minimize this error component. If the average moisture content is 0.5%, this error component would be reduced to about 1/2 of the maximum error, or about 1%.

Based on this result, it was felt that the initial iPCAS design would achieve an average error of approximately 1.5%. Efforts are currently underway to reduce the average error to 0.85%. To meet this requirement, it will be necessary to include the six tubes located in the air gap for an explicit moisture correction based on the different response between these tubes and the poly moderated tubes as a function of moisture.

Gamma-Ray Isotopic System (GIS)
The GIS was designed to be a system for confirmatory measurement of the facility declared plutonium isotopics. For the iPCAS, as there are up to 3 cans of Pu or MOX powder in each canister, three gamma-ray isotopic systems are needed. Special software and hardware is also needed to encrypt and authenticate the data, transmit the data over a network, and store the data.

The gamma-ray isotopic system will determine isotopic fractions and/or ratios in samples of plutonium including americium and samples containing mixed uranium/plutonium oxides (MOX). The measurement is performed using high-purity germanium (HPGe) detectors and associated data acquisition electronics to collect gamma-ray spectra. The local gamma-ray isotopic system computer, which also authenticates the data, initially collects the spectra. The local gamma-ray system computer then sends the authenticated spectra over Ethernet to the Multi-Instrument Collect computer where all of the spectra, awaiting further analysis, are stored.

The analysis software for the GIS will be a version of the FRAM (Fix Energy Response Function Analysis with Multiple Efficiencies) software that has been widely used for more than a decade. This software is available commercially and improvements and enhancements are under development by Safeguards Science and Technology Group (NIS-5) at LANL. FRAM will analyze the intensities of the gamma rays produced by the different plutonium, americium, and uranium isotopes. Specific power and the effective ^{240}Pu fraction ($^{240}Pu_{eff}$) will be calculated from the measured isotopic fractions.

It was determined that if the gamma rays must pass through 56 mm of steel, as included in the design for the neutron counter, the maximum count rate would be less than 12 kHz and the precision of ^{240}Pu effective would be about 7%. This estimate was conducted for a detector with 50% efficiency and 6-kg of SNM with the Pu/U ratio of 1. This detector response is unacceptable. So the design was modified to include three holes through the 5-cm steel shielding wall. These holes will also partially act as collimators and thus eliminate the large fluctuation of the count rate due to different plutonium masses.

The gamma ray isotopic equipment consists of three HPGe detectors, three Multi-Channel Analyzers (MCA), and a computer. The detectors will use electromechanical cooling instead of liquid nitrogen. Each detector is connected to a cooling compressor through the in/out refrigerant lines.

Calculations and experiments show that for these gamma-ray isotopic systems, the steel shielding will block most of the low-energy gamma rays. It is therefore necessary to use large detectors (i.e. coaxial detectors instead of planar detectors). Also, the electromechanical cooling pumps will not be as effective as liquid nitrogen cooling of the detectors. The result is that the resolution will be somewhat worse than if the liquid nitrogen were used. For systems like these, it is determined that the DSPEC Plus would be the best MCA to use.[5,6] Figure 5 shows the predicted accuracy of the GIS system.

SUMMARY

The iPCAS initial design to detect gross and partial defects in the declared plutonium content of plutonium and MOX storage canisters during transfer to storage and process areas of the MOX fuel fabrication facility met the requirement of an accuracy better than 2%. Efforts are underway to further improve the design of the detector to achieve bias defect levels. We expect to complete the enhanced design in late 2001.

A Gamma Isotopics System (GIS) will be used to confirm facility-declared plutonium isotopics with accuracy sufficient to reduce the amount of destructive isotopic analysis needed. The installed system will require some modification to existing LANL software for isotopic analysis and integration with the neutron counter design described.
outside the enclosure.

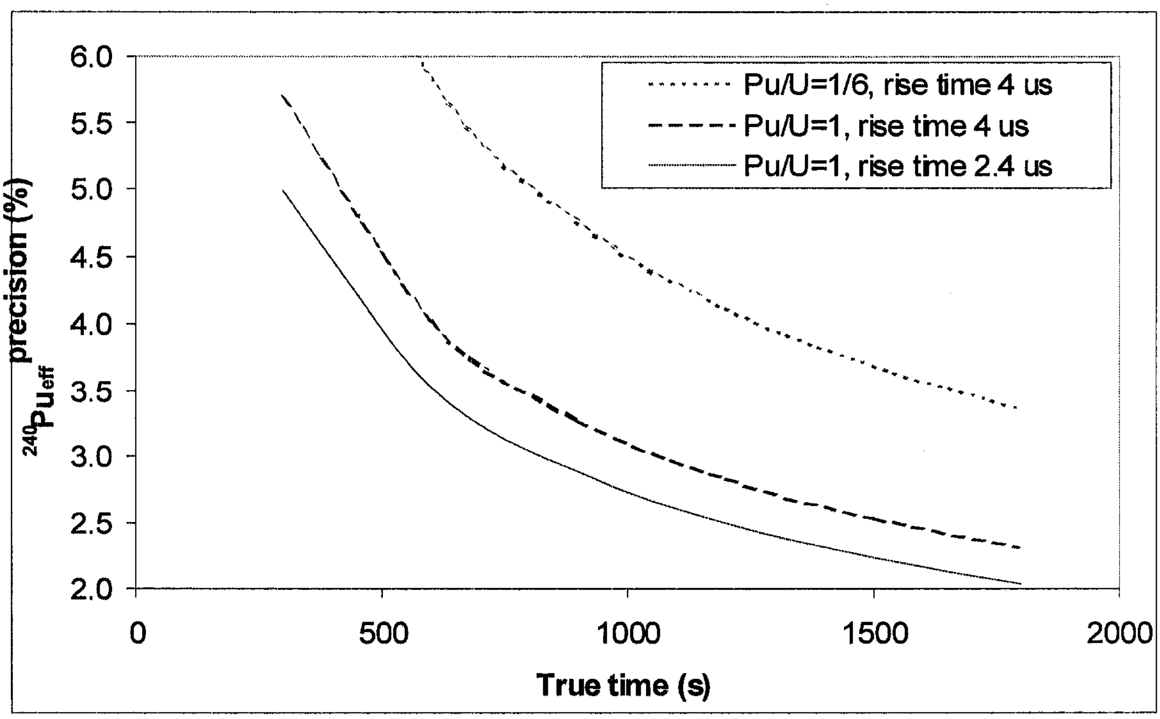

Fig. 5. $^{240}Pu_{eff}$ precision as a function of acquisition time. The absorber thickness is assumed to be 6 mm of steel.

REFERENCES

1. M. E. Abhold, M. C. Baker, S. C. Bourret, P. Polk, and D. T. Vo, "Design of the Improved Plutonium Canister Assay System (iPCAS)," Los Alamos National Laboratory Report LA-UR-00-5383, October, 2000.

2. J. F. Briesmeister, "MCNP – A General Monte Carlo N-Particle Transport Code," Los Alamos National Laboratory Report LA-12625-M, Version 4A, November 1993.

3. M. E. Abhold and M. C. Baker, "MCNP-REN – A Monte Carlo Tool for Neutron Detector Design Without Using the Point Model," Institute of Nuclear Materials Management 40th Annual Meeting, Phoenix, AZ, July 25-29, 1999.

4. W.B. Wilson, R.T. Perry, W.S. Charlton, T.A. Parish, G.P. Estes, T.H. Brown, E.D. Arthur, M. Bozoian, T. R. England, D. G. Madland, and J. E. Stewart, "SOURCES 4A: A Code for Calculating (alpha,n), Spontaneous Fission, and Delayed Neutron Sources and Spectra," Los Alamos National Laboratory Report LA-13639-MS, Sept. 1999.

5. D. T. Vo, "Extended Evaluations of the Commercial Spectrometer Systems for Safeguards Applications," Los Alamos National Laboratory report LA-13604-MS, August 1999.

6. D. T. Vo, "Comparisons of the DSPEC and DSPEC Plus Spectrometer Systems," Los Alamos National Laboratory report LA-13671-MS, November 1999.