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Report No.: **Y/LB-16,056**

VERIFICATION OF URANIUM MASS AND ENRICHMENTS OF HIGHLY ENRICHED URANIUM (HEU) USING THE NUCLEAR MATERIALS IDENTIFICATION SYSTEM (NMIS)

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April 7, 2000

Prepared by the
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 37831
managed by
Lockheed Martin Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Verification of Uranium Mass and Enrichments of Highly Enriched Uranium (HEU) Using the Nuclear Materials Identification System (NMIS)

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ABSTRACT

This paper describes how the Nuclear Materials Identification System (NMIS), developed by the Oak Ridge National Laboratory (ORNL) and the Oak Ridge Y-12 Plant, was used to verify the mass and enrichment of hundreds of Highly Enriched Uranium (HEU) metal items in storage at the Y-12 Plant. The verifications had a relative spread of ±5% (3 sigma) with relative mean deviations from their declared values of +0.2% for mass and -0.2% for enrichment. NMIS's capability to perform quantification of HEU enabled the Y-12 Plant to meet their nuclear material control and accountability (NMC&A) requirements. These verifications were performed in the storage vault in a very time and cost effective manner with as many as 55 verifications in one shift of operation.

1. INTRODUCTION

NMIS[1] has been used for a variety of NMC&A applications at the Y-12 plant. Current applications include: confirmation of receipts of weapon components, confirmation of HEU metal receipts, in-situ confirmation of weapon components in storage, and quantitative verification of the declared uranium mass and enrichment of HEU metal in storage.

For measurements of HEU and shielded HEU, NMIS operates as an active interrogation system. The interrogation source is a small ^{252}Cf source in an ion chamber (1 μg or less) coupled with plastic scintillation detectors sensitive to gamma and neutron radiation. NMIS can acquire a variety of time correlation signatures that depend on various properties of the fissile material. The spontaneous fission of ^{252}Cf in the ion chamber provides a timed source from which the arrival of prompt gamma rays and neutrons in the detectors can be correlated in time. These time correlated radiations will reach the detector in the following order: prompt gamma rays, scattered gamma rays, prompt neutrons, scattered neutrons, fission induced gamma rays, and fission induced neutrons. Correlations between counts in pairs of detectors provide another type of time correlation measurement that consists of gamma-gamma correlations, neutron-neutron correlations, and gamma-neutron correlations. The gamma-gamma correlations occur at time lag zero since both gamma rays from fission arrive at the detector simultaneously. In addition, NMIS measures multiplicities as defined by Hage and Cifarelli[2] with the additional feature that the time windows can be source event triggered and delayed.

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† Managed by UT-Battelle, LLC, for the U. S. Department of Energy under contract DE-AC05-00OR22725.

Active interrogation permits measurements in areas with significant levels of background radiation since only the truly correlated detection events are from the source. Thus, the high background levels in the storage areas are not a significant factor for NMIS measurements. (Background events appear as uncorrelated events, which are easily removed by NMIS.) Correlated background events can be removed by third order correlations, i.e., between a pair of detectors and the source.[5]

Currently, three portable NMIS systems on carts are in operation at the Y-12 Plant and are moved to the fissile material which results in less impact on operations since no permanent floor space need be assigned. Although these systems typically use standard 120 VAC line power, NMIS has also operated by battery power. The battery-powered NMIS system performs data acquisition at high throughput on all channels at ORNL, operating off a 12 VDC battery/inverter. Continuous operation time was three hours. NMIS technology has provided new capabilities for Y-12 NMC&A not previously possible or practical with standard nondestructive analysis techniques. Specifically, NMIS has greatly enhanced NMC&A's capability to verify containerized weapon components and shielded HEU. This paper concentrates on the operational use of NMIS for verification of HEU metal in storage. The complete methodology of these verifications is described in other papers at this conference.[3, 4, 5]

2. PURPOSE

This set of NMIS verifications was performed to meet the following goals:

- fulfill an NMC&A requirement to verify the declared mass and enrichment of HEU items in storage to within ±5% relative uncertainty,
- reduce potential personnel contamination by minimizing handling of HEU items by performing the measurements in the storage vault with the HEU in birdcages,
- provide an accurate means to verify both the declared mass and enrichment via a single measurement in a timely cost-effective manner.

The Y-12 plant is required to verify the declared mass and enrichment of all the HEU items in storage. Normally this requires opening the birdcage in which they are stored and removing the item for measurement. This direct handling of the item is not desirable from a radiological viewpoint due to the risk of contaminating both the worker and the work area. The use of NMIS, obviated the requirement to remove the items from their birdcages or the storage vault.

3. MEASUREMENT SETUP

The HEU items were measured using NMIS as an active interrogation system using a small ^{252}Cf source in an ionization chamber and plastic scintillation detectors. The source induces fission in the HEU item and by triggering on the source fissions detected by the ionization chamber, correlation events in the detectors can be measured within ±1 nanosecond of the source fission event. Although NMIS is capable of collecting source/detector correlations and detector/detector cross correlations plus many frequency domain signatures, only the source/detector correlations were used for these verifications.

Operationally this verification proceeded as follows. A birdcage was placed on a steel table (Figure 1), the source and detector were positioned, data acquisition was initiated, previous birdcage was returned to storage array, next birdcage was placed on the floor near the table, data acquisition completed, and next birdcage was placed on the table restarting the procedure. For ease of operation, the HEU metal in birdcages was placed on a steel table which was located adjacent to the storage arrays in the vault. Birdcages were lined up in production line fashion so that they could be put in place and removed quickly. The time for each measurement was 4.5 min. of data acquisition plus 1.5 min. to change out the birdcages. The operation required two people for positioning the birdcages and performance of the measurements. The radiation dose from the unshielded source of 0.5 μg of ^{252}Cf was ~ 1.2 mr/hr at one meter. Use of this source requires a radiation work permit and neutron dosimetry with the appropriate training.

Figure 1. NMIS Measurement Setup

NMIS is very sensitive to the geometrical configuration of the source, detectors, and the measured item. To reduce systematic errors produced by random variations in the relative positioning of these components with respect to each other, the source was placed on one side of the item and the detectors on the other side such that the item completely shadows the detectors from the source radiations. In other words, source radiations pass through the item before reaching the detectors. To reduce variations in right/left and up/down positioning of the detectors with respect to the item and source, the detectors were arranged in a 2x2 array such that the center of the detector array was aligned with the centerline of the item and source. All detector responses were summed together to form an aggregate response for the processing analysis algorithms. In this way, systematic errors due to variations from positioning were minimized.

4. CALIBRATIONS

Prior to the start of the verifications, calibrations were performed using a small subset (10) of the items. These calibrations had a three fold purpose. The first purpose was to test the method and develop procedures for the verification process. The second purpose was to determine the repeatability of the measurements which was reflected in the variance of the signatures from item to item. The third purpose was to establish calibration signatures. The enrichment and uranium mass of the 10 HEU items was also verified by independent methods.

Since this calibration set of HEU items had very small variations in the uranium mass and enrichment, a set of computer simulations were performed to develop the sensitivity coefficients for a wider range of uranium masses and enrichment values. A customized Monte Carlo neutron-photon transport program developed at Oak Ridge National Laboratory, MCNP-DSP,[6, 7] was used to obtain sensitivity coefficients. These calibrations with the calculational sensitivity of features of the NMIS signatures to uranium mass and enrichment were used to obtain these quantities from the NMIS measurements. [3, 4, 5]

5. VERIFICATION PROCEDURE

The daily NMIS verification procedure for the remaining HEU items consisted of:

1. performing a time-of-flight (TOF) daily before the start of measurements,
2. computing the detector efficiencies from the TOF signatures,
3. measure the HEU items,
4. determine online that the signatures measured were within specific limits to assure that the HEU mass and enrichment were with a ±5% relative spread (3 sigma),
5. off-line processing to obtain the HEU mass and enrichment and their uncertainties (this could have been done on-line if time for this software development was allowed), and
6. comparison of measured values with declared.

The TOF and detection efficiency procedures were performed each day, prior to verifying any HEU items. This verifies the proper operation of the detection systems and the total NMIS. The TOF is simply the source/detector correlation for each detector measured at a fixed source/detector spacing in air. Another purpose of the TOF was to verify that the timing of correlated events in the processor is correct. This is done by verifying that the prompt gamma rays arrive at the detector at the correct flight time from the source. The detector efficiencies are then computed from the TOF signatures. Daily adjustments (typically of 1%) maintained all detector efficiencies within ±1% of their desired values.

6. RESULTS

The verification proceeded as planned with no deviations from the plan nor significant contamination problems. In Figures 2 and 3, a subset of the relative deviations from declared values is shown for both HEU enrichment and mass. The results appear randomly distributed about zero.

The measurements had a total relative spread of ±5% (3 sigma) from the declared values with relative mean deviations from their declared values of +0.2% for mass and -0.2% for enrichment.

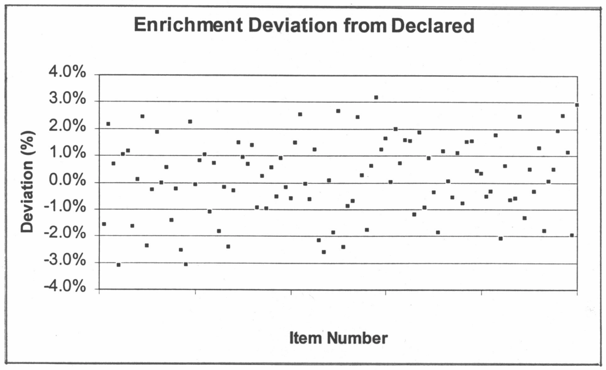

Figure 2. Percent Deviation of NMIS HEU Enrichment from Declared

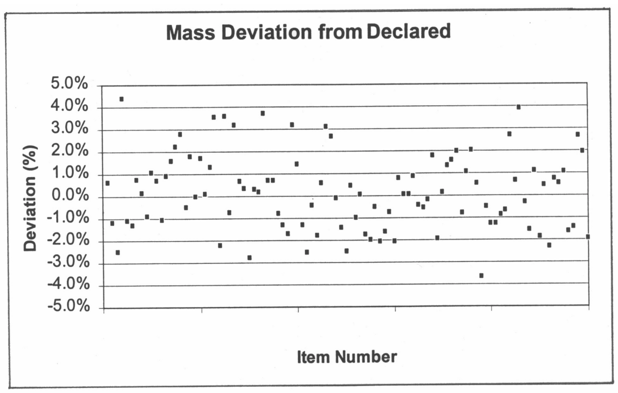

Figure 3. Percent Deviation of NMIS HEU Mass from Declared

7. CONCLUSION

The NMIS measurement system successfully measured, for the first time, both the enrichment and uranium mass of HEU metal in storage at the Oak Ridge Y-12 Plant. This resolved a Department of Energy finding for NMC&A. Operationally, by measuring in the storage vaults, NMIS minimized air-borne radiation contamination and measurement time. In addition, it eliminated the need for contact gamma-ray spectrometry using NaI detectors to verify enrichment. Thus, facility operations were not significantly impacted during NMIS measurements which reduced Y-12's costs.

8. REFERENCES

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