PASSIVE TIME COINCIDENCE MEASUREMENTS WITH HEU AND DU METAL CASTINGS

Seth McConchie*, Paul Hausladen, John Mihalczo, Michael Wright, Dan Archer
Oak Ridge National Laboratory
P.O. Box 2008, MS-6010, Oak Ridge, TN 37831-6010

ABSTRACT

A Department of Energy sponsored Oak Ridge National Laboratory/Y-12 National Security Complex program of passive time coincidence measurements has been initiated at Y-12 to evaluate the ability to determine the presence of highly enriched uranium (HEU) and distinguish it from depleted uranium (DU). This program uses the Nuclear Materials Identification System (NMIS) without an active interrogation source. Previous passive NMIS measurements with Pu metal and Pu oxide have been successful in determining the Pu mass, assuming a known ^{240}Pu content. The spontaneous fission of uranium metal is considerably lower than that of Pu, and time coincidence measurements have been performed on Pu at Lawrence Livermore National Laboratory [1]. This work presents results of measurements of HEU and DU metal castings using moderated ^{3}He detectors.

INTRODUCTION

The detection and characterization of HEU is important for applications related to nuclear material control and accountability and national security. Passive detection of HEU can be performed by detecting coincident neutrons from the same fission chain, induced by spontaneous fission of ^{235}U or ^{238}U. However, these measurements require long measurement times due to the low spontaneous fission rates of 1.6×10^{-4} fissions/s-g and 6.6×10^{-3} fissions/s-g for ^{235}U and ^{238}U, respectively. This paper discusses passive measurements made on HEU and DU annular storage castings. Various analyses were performed to investigate the ability to determine whether a nuclear material such as DU or HEU is present and whether HEU can be distinguished.

EXPERIMENTAL METHODS

The passive measurements were performed from one to five HEU metal annular storage castings with ~93 wt % (~18 kg) ^{235}U enriched uranium metal and one to three similar sized DU castings. All castings were in tight-fitting 0.063-cm-thick stainless steel cans to minimize contamination. The metal castings (12.7 cm outside diameter, 8.9 cm inside diameter, 15 cm length) were placed in a 1.27-cm thick lead box on a steel table. Two banks of sixteen ^{3}He tubes (5 cm diameter, 91 cm length, 4 atmosphere) were placed next to the table. The top of the table was 61 cm above the floor. The center of the banks was 30.5 cm from the center of the box and was centered vertically about the casting midplane. Figure 1 shows the experimental setup with five HEU castings.

* Corresponding author, mcconchiesm@ornl.gov, telephone: (865) 576-9376, fax: (865) 576-8380

The detector TTL outputs were input to gate and delay generators (Phillips Scientific 794) to produce a NIM logic pulse with a 6 μs width. An americium-beryllium source was used to ensure that the 6 μs pulse width was sufficient to eliminate double pulsing in the electronics. The 6 μs logic pulses were input to a leading edge discriminator (Phillips Scientific 710) such that the logic pulse width could be set for the data acquisition system.

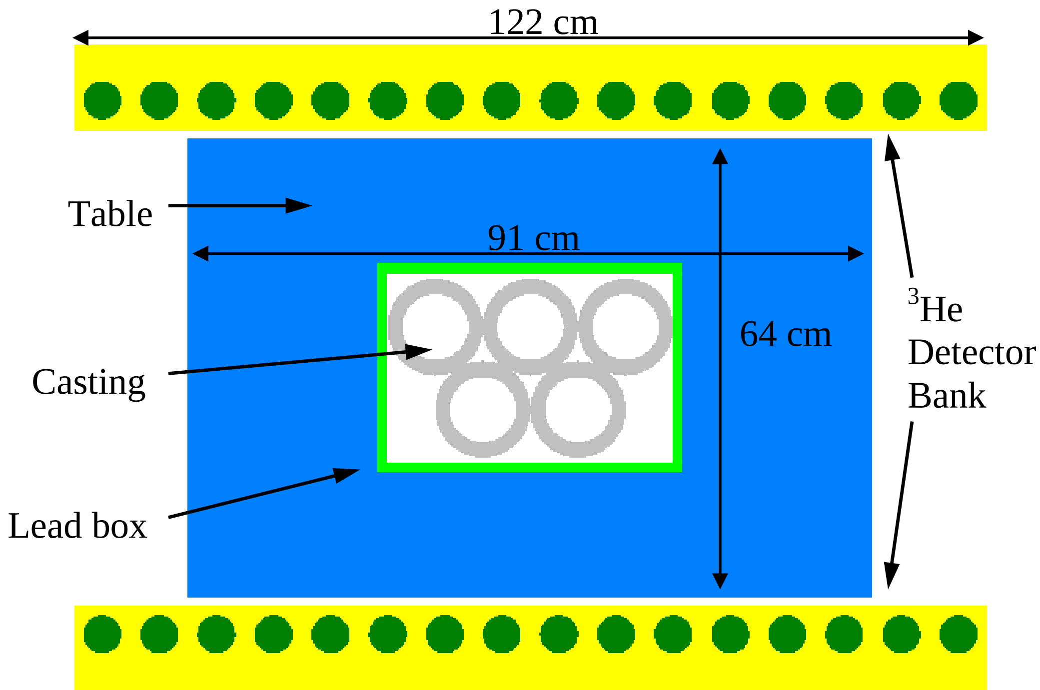

Figure 1. Experimental setup of five HEU castings in a lead box surrounded by two detector banks of 16 5-cm ^{3}He detectors.

The data acquisition was performed with the NMIS [2]. The NMIS processor acquires data in ten channels by synchronously sampling detector signals at 1 GHz rates in all input channels. Using the time of arrival of the signals, the NMIS calculated on line the time distribution of coincidences in any one signal with respect to a previous signal in the same channel or any other channel. The NMIS also recorded the time of arrival of each neutron event for offline analyses. The event list was then analyzed to determine the time correlation distributions between neutron events in the detectors.

The multiplet distribution [3] and Feynman variance (variance-to-mean) [4,5] were also calculated from the data. Multiplets of order *n* are the number of times *n* detection events (e.g., two neutrons, three neutrons) occur in the time window. The Feynman variance is related to the probability that two detected neutrons originated from the same fission chain. In this paper, the Y2F [5] is calculated and is equal to half the Feynman variance. Because the events randomly occur relative to the time window, a periodic time window was used to minimize the error in the Y2F calculation.

ANALYSIS AND RESULTS

When a ^{252}Cf source was used, the ^{3}He detector efficiency was determined to be ~10%. Data were collected for up to five HEU castings and up to three DU castings. The measurement times were from ~48 min to ~70 min for the HEU castings and ~191 min to ~874 min for the DU castings. It was possible to make longer measurements of the DU castings because they could be left unattended. The coincident neutron time distributions in the two detector banks for the various numbers of HEU and DU castings are shown in Figure 2. As expected, the integral of the coincident peak at time lag zero increases with the amount of HEU or DU. An exponential fit was performed to characterize the die-away for both count distributions. The fit was weighted by the square root of the raw number of correlation counts in each time bin. The HEU has a slightly higher die-away time constant (51.9 ± 0.6 μs) than DU has (43.1 ± 0.6 μs). The higher die-away time constant is due to the multiplication property of ^{235}U.

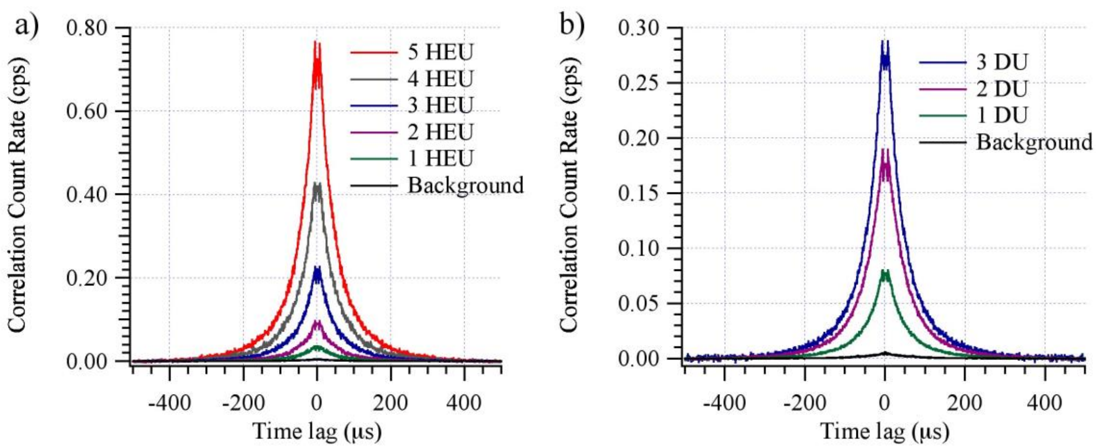

Figure 2. Coincident neutron time distributions in the two detector banks for the various numbers of (a) HEU and (b) DU castings. The accidental correlation rate has been subtracted. The integral of the peak at time lag zero increases with the amount of HEU or DU, as expected.

Figure 3 shows the Y2F calculated as a function of a periodic time window for the various numbers of castings. The curves were fit with the functional form [5]:

$$\mathrm{Y2F} = A\left(1 - \frac{1-\exp(-\lambda T)}{\lambda T}\right) \tag{1}$$

where A contains information about the neutron detection efficiency, source fission strength, and multiplication of the fission source. As the number of HEU castings increases, the multiplication, and therefore the Y2F, also increases as $T \rightarrow \infty$. As shown in Figure 3, the asymptotic value of the Y2F increases as a function of HEU casting number, as expected. Because the DU castings are expected to have much less multiplication, the asymptotic Y2F values are very similar for one, two, and three castings. Table 1 shows the fit values of the Y2F as $T \rightarrow \infty$. A comparison of the Y2F curves for one to three castings is shown in Figure 4. For all numbers of castings, the HEU is distinguishable from the DU.

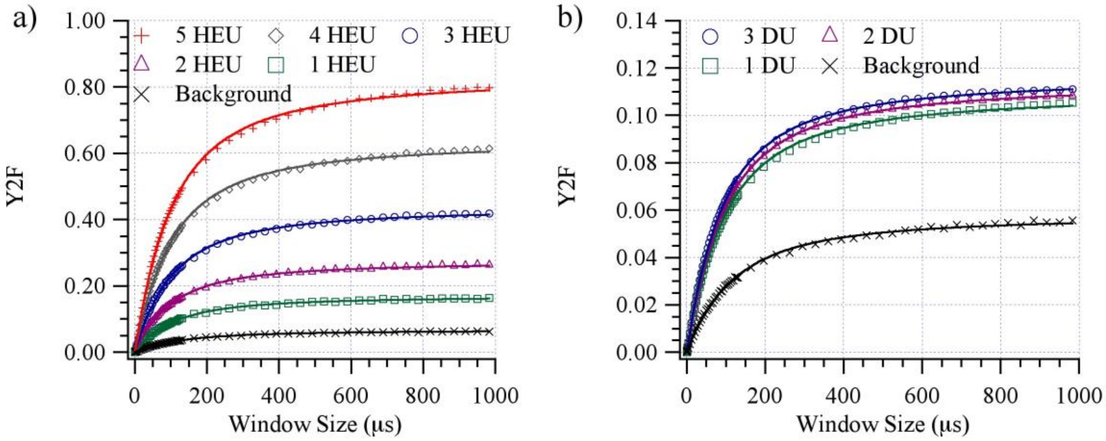

Figure 3. Y2F calculated as a function of periodic time window for the various numbers of (a) HEU and (b) DU castings. The multiplication of the HEU castings is evident when the HEU Y2F values are compared with those for the DU castings.

Table 1. Asymptotic values of the Y2F as a function of the amount of material.

Sample	Y2F ($T \rightarrow \infty$)
5 HEU	0.841
4 HEU	0.644
3 HEU	0.441
2 HEU	0.277
1 HEU	0.172
3 DU	0.117
2 DU	0.115
1 DU	0.110
Background	0.059

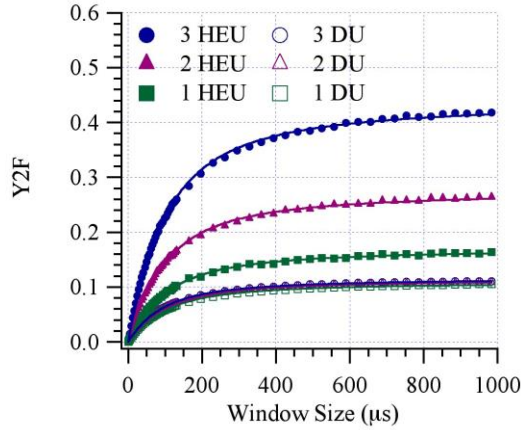

Figure 4. Y2F curves for one to three castings of HEU and DU. The HEU castings are distinguishable from the DU castings.

Figure 5 shows the background-subtracted multiplet distributions normalized to 1 s of measurement time for the various numbers of castings. The multiplet plot shows the number of times each second when no neutrons were detected after the initial neutron that triggered counting (single), one neutron was detected (double), two neutrons were detected (triple), and so on for 131 µs after a neutron event triggered the detectors. The multiplet rates are larger at high order for HEU than for DU. Figure 6 shows the multiplet distribution comparisons for one through three castings. The doubles and triples count rates are higher for the DU castings because of the higher spontaneous fission rate. However, the quadruples count rate is typically higher for the HEU castings due to the multiplication. Using the quadruples count rates would be a simple way of distinguishing DU from HEU for this geometry.

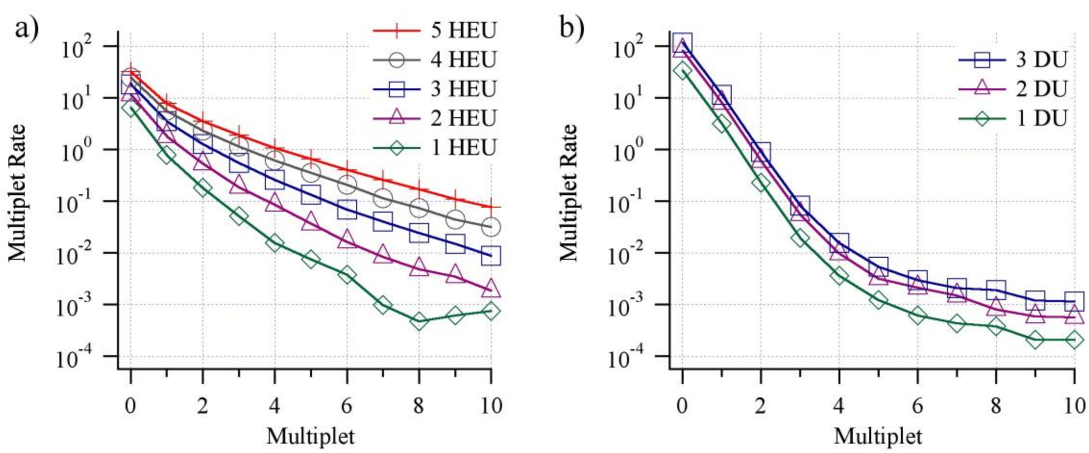

Figure 5. Background-subtracted multiplet distributions normalized to 1 s of measurement time for the various numbers of (a) HEU and (b) DU castings. At least five neutrons were detected after the initial trigger neutron in the HEU castings, and approximately three were detected for the DU castings.

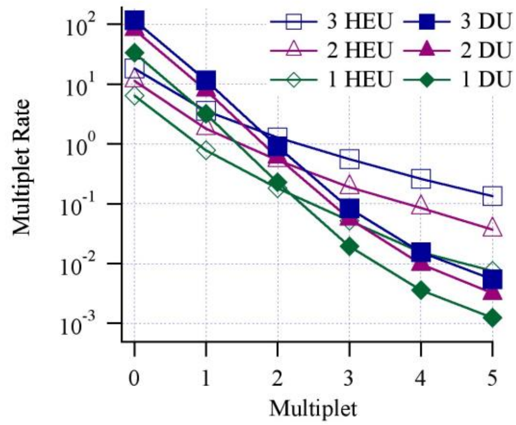

Figure 6. Multiplet rate distribution comparisons for one to three castings. While the doubles and triple rates are higher for the DU castings, the quadruples rates are higher for the HEU castings due to multiplication.

Another useful analysis is to normalize the multiplet rate normalized to probability. Figure 7 shows the probability that a neutron event is associated with a double, triple, quadruple, and so on. The DU multiplet probability distributions are the same as would be expected for a nonmultiplying spontaneous fission neutron source, while the multiplication in the HEU castings is evident.

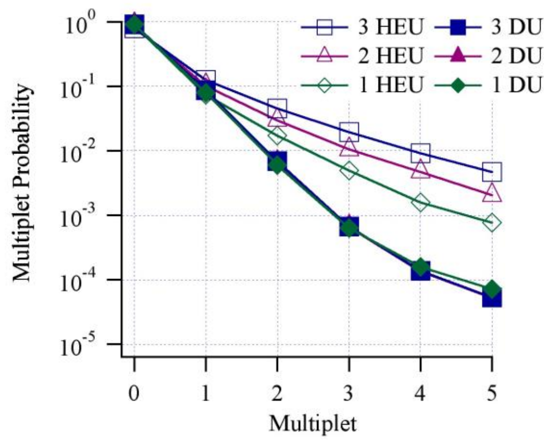

Figure 7. Multiplet probability distribution comparisons for one to three castings. While the doubles and triples rates are higher for the DU castings, the quadruples rates are higher for the HEU castings due to multiplication.

Due to the long measurement times of these experiments and the proximity of sources in nearby rooms at Y-12, there could have been an issue with the background stability. Figure 8 shows the multiplet distribution normalized to probability of several backgrounds taken over the course of two months. The background does not vary significantly.

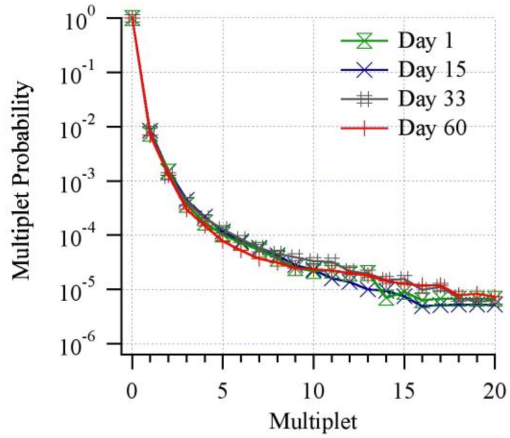

Figure 8. Background multiplet probability distributions over the course of two months. The background does not vary significantly.

FUTURE WORK

This paper discusses the passive measurements of various numbers of HEU (~93 wt %) and DU metal castings. The ability to distinguish HEU from DU was investigated using coincident neutron time correlation distributions, Feynman variances, and multiplet distributions. Future analytical work includes using the mathematical formalisms given in [3] and [5] to calculate the source fission strength and multiplication of the casting geometries. The estimations will be checked with Monte Carlo calculations with the Monte Carlo N-Particle Transport Code. In addition, a large plastic scintillator will be placed near the setup to count the cosmic rays. Events in the scintillator may provide information that will help eliminate the contribution of cosmic rays to the multiplet distributions.

REFERENCES

1. J. M. Verbeke, et al., "Neutron Correlations in Special Nuclear Materials, Experiments and Simulations," UCRL-PROC-231582, 2007.
2. J. T. Mihalczo, J. A. Mullens, J. K. Mattingly and T. E. Valentine, "Physical description of nuclear materials identification system (NMIS) signatures," Nuclear Instruments and Methods in Physics Research A 450, pp. 531–55, 2000.
3. R. Dierckx and W. Hage, "Neutron signal multiplet analysis for the mass determination of spontaneous fission isotopes," Nuclear Science and Engineering 85, pp. 325–38, 1983.
4. R. E. Uhrig, *Random noise techniques in nuclear reactor systems*, Ronald Press Company, New York, 1970.
5. M. K. Prasad and N. J. Snyderman, "Statistical theory of fission chains and generalized Poisson neutron counting distributions," UCRL-ID-148010, 2002.