MEASUREMENT RESULTS FOR THE IPAN/GEA BOXED WASTE ASSAY SYSTEM

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ABSTRACT

A boxed waste assay system, developed by BNFL Instruments Inc. (BII), was installed at the Waste Receiving and Packaging (WRAP) facility in Hanford, Washington in early 1997. The system combines imaging passive/active neutron (IPAN) techniques with gamma-ray energy analysis (GEA) to assay crates up to 2.5m x 2.5m x 6.5m in size. Two separate gamma-ray measurements are accomplished utilizing 16 arrayed NaI detectors and a moveable HPGe detector, while ^{3}He detectors acquire both active and passive neutron data. These neutron measurements employ the differential die-away technique and coincidence analysis, respectively. Both neutron measurements use BII's proprietary imaging methodology. Acceptance testing of the system was conducted at Hanford in January 1998. The system's operating performance was evaluated based on accuracy and sensitivity requirements for three different matrix types. For a "Medium" matrix, testing results include an average 13% active mode accuracy for 10 nCi/g loadings of Pu waste and 5% passive mode accuracy for 10g loadings of Pu waste. Sensitivity testing demonstrated an active mode lower limit of detection (LLD) of less than 5 nCi/g of ^{239}Pu for the medium matrix and less than 20 pCi/g of fission and activation products at 3σ above background. The results of the acceptance test program and the intended application of the system are discussed in this report.

INTRODUCTION

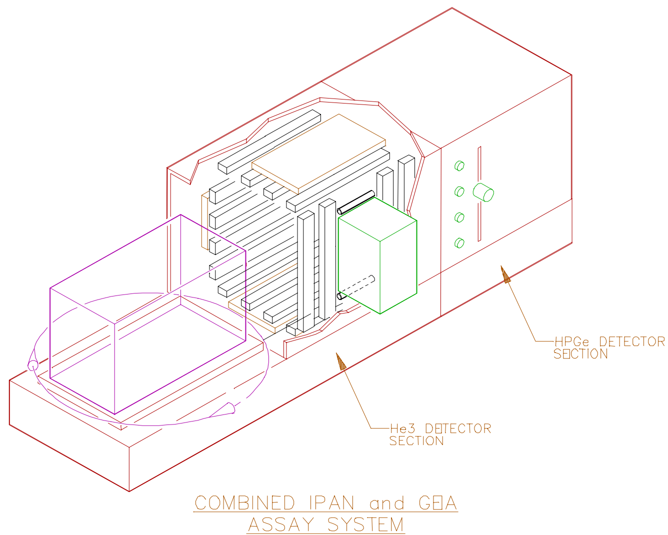
Waste Management Federal Services of Hanford, Inc. contracted with BNFL Instruments Inc. (BII) for the development and installation of a Boxed Waste Assay System (BWAS). This system incorporates imaging passive/active neutron (IPAN) techniques and gamma-ray energy analysis (GEA). The BWAS was installed early in 1997, and calibration was completed on-site during the later part of the same year.

As part of the operations at the Waste Receiving and Packaging (WRAP) facility in Hanford, Washington, the IPAN/GEA BWAS is expected to detect and quantify radioactive contaminants in both Standard Waste Boxes (SWB) and B-25 waste boxes.[1] Boxes at the facility contain a variety of waste forms and wide range of densities.

Three representative matrices, ranging from low density to high density material, were used as the basic guide for the calibration of the system and for determining the requirements for the Acceptance Test Plan, conducted in January 1998. The Acceptance Test Plan included control tests as well as sensitivity and accuracy tests for the active and passive neutron systems, which utilize arrayed ^{3}He detectors and the gamma system, which utilizes arrayed NaI detectors and an HPGe hotspot detector. Early testing of the system prior to installation at the WRAP facility suggested that the system would meet its requirements for operations.[2]

THE BWAS IPAN/GEA SYSTEM

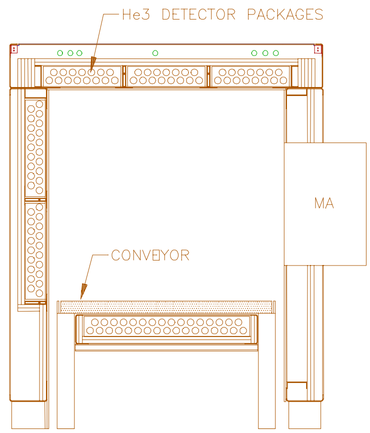
Figure 1 Combined IPAN/GEA Crate System



The BWAS developed by BII, Figure 1, performs four separate measurements that are integrated into a single, comprehensive, characterization of boxed waste than can be accomplished by any one of the techniques used independently. Two of these are based on neutron measurement techniques, while the remaining two are based on gamma measurement techniques. Matrix corrections are made based on the absorbing and moderating characteristics of the waste. Absorbing effects are measured using cavity flux monitors (CFM). As the amount of absorbing material increases, the interrogating flux measured by the cavity flux monitors (CFM) decreases. The ratio of the flux out (CFM) to the flux in, measured by the moderator assembly flux monitor (MAFM), determines the absorbing characteristics of the matrix. Epithermal neutron measurements provide information about the moderating effects of a matrix. The count rate of epithermal neutrons exiting the side of the waste box opposite the neutron generator decreases with increasing moderator effects.

Once a box has been loaded onto the conveyor system, the box will automatically be moved into the cavity and set at its beginning position. The BWAS contains 150 ^{3}He tubes configured as shown in Figure 2. During the passive neutron measurements, these detectors, in conjunction with a programmable multi-channel coincidence module (PMCCM), are used to perform neutron coincidence analysis to provide a quantification of the ^{240}Pu$_{eff}$ present in the waste. In addition, imaging data is obtained from each of the detectors as the crate is moved past them in ten one foot increments. The imaging allows source position corrections that increase the accuracy of the assay.

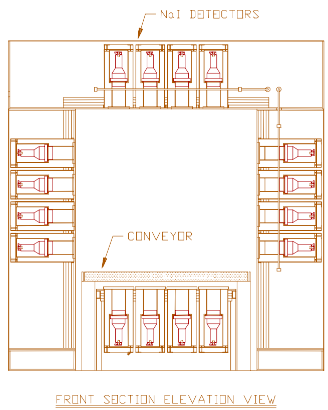
Figure 2 IPAN Cross Section



The active neutron measurement, also performed using the imaging ^{3}He detectors, is based on the differential die-away technique (DDT). Interrogating neutrons from the neutron generator, housed in the moderating assembly (MA), see Figure 2, thermalize in the waste box inducing fission reactions in isotopes such as ^{239}Pu and ^{235}U. The distinct die-away times of the interrogating flux and the induced fission signal allows for a quantification of the fission isotopes.[3] In order to obtain a symmetric measurement, the waste box is removed from the cavity, rotated 180 degrees, conveyed back into the cavity, and the active and passive neutron measurement repeated. This also allows both halves of the waste box to be evenly interrogated with the thermal flux from the MA.

In addition to the ^{3}He detectors, the BWAS contains 16 NaI detectors configured as shown in Figure 3. This system has been calibrated to quantify primarily ^{60}Co and ^{137}Cs[2]. As with the neutron measurements, the crate is moved past the detectors in set increments in order to obtain imaging data allowing for greater assay accuracy with "hot spot" identification. Since the detectors are symmetrically located around the cavity, it is not necessary to make a second measurement after rotation of the box.

Figure 3 NaI Detector Configuration



Automatic analysis of the NaI data allows the system to quantify and rank all "hot spots" identified in the waste. The four strongest sources can then be measured using the 40% HPGe detector. This detector is mounted on an assembly that allows it to automatically be moved vertically. The system positions the crate and the HPGe detector so that the detector is as close as possible to the source. The HPGe analysis software is currently configured to identify and quantify ten gamma emitting isotopes including ^{239}Pu, ^{235}U, ^{60}Co, and ^{137}Cs using count rates and matrix attenuation characteristics obtained during assay.

ACCEPTANCE TEST REQUIREMENTS

All of the components in the BWAS were required to meet accuracy and sensitivity limits based on the operational requirements for the system. Three matrix types were defined in the Acceptance Test Plan[1] that would simulate homogeneous light, medium, and heavy matrices. The following materials were used for each.

- Lab waste or Light matrix: 1 part peat moss; 8 parts vermiculite
- Medium matrix: 1 part peat moss; 5 parts vermiculite; 4 parts wood chips
- Heavy matrix: 1 part scrap iron; 18 parts sand; 16 parts concrete rubble

Using these materials, a density of 7.67 lbs/ft^3, 14.58 lbs/ft^3, and 68.04 lbs/ft^3 was achieved in the SWB for the light, medium, and heavy matrix, respectively. For the B-25 waste box, a density of 7.03 lbs/ft^3, 12.98 lbs/ft^3, and 78.08 lbs/ft^3 was achieved for the light, medium, and heavy matrix, respectively.

Table 1 contains the complete set of accuracy requirements for the SWB and B-25 waste box. Some of the requirements have been converted from activity densities using the densities achieved for each appropriate configuration. All of the Pu equivalent values are calculated assuming WGPu isotopics of 6% ^{240}Pu and 94% ^{239}Pu.[1] The active neutron measurement requirements have been divided into two different requirements representing two different Pu mass loadings. The difference in the measurement uncertainty represents the higher degree of difficulty in measuring small quantities of Pu embedded in highly absorbing matrices.

Table 1 Accuracy Requirements

Measurement Method	Measurement Level SWB	Measurement Level B-25	Waste Contents	Measurement Uncertainty
TRU Active	40 mg (Pu)	54 mg (Pu)	Lab Waste	±50%
TRU Active	76 mg (Pu)	101 mg (Pu)	Medium Matrix	±70%
TRU Active	399 mg (Pu)	546 mg (Pu)	Lab Waste	±20%
TRU Active	759 mg (Pu)	1009 mg (Pu)	Medium Matrix	±50%
TRU Passive	10 g (Pu)	10 g (Pu)	Lab Waste	±20%
TRU Passive	400 g (Pu)	400 g (Pu)	Medium Matrix	±10%
TRU Passive	400 g (Pu)	400 g (Pu)	Heavy Matrix	±18.75%
TRU GEA	400 g (Pu)	400 g (Pu)	Medium Matrix	±10%
Fission/Act Prod GEA	47 μCi (^{60}Co, ^{137}Cs)	64 μCi (^{60}Co, ^{137}Cs)	Lab Waste	±50%
Fission/Act Prod GEA	2 mCi (^{60}Co, ^{137}Cs)	2 mCi (^{60}Co, ^{137}Cs)	Medium Matrix	±25%

In the lower limit of detection (LLD) region of the BWAS, it is only necessary to test the sensitivity of the active neutron and the GEA measurements. Sensitivity requirements for both of the box configurations for a medium type matrix were established to be:

- 20 pCi/g of ^{60}Co, using GEA
- 20 pCi/g of ^{137}Cs, using GEA
- 5 nCi/g of ^{239}Pu using active neutron interrogation

MEASUREMENT RESULTS

The procedure for the accuracy testing involved using Depleted Uranium (.2% ^{235}U by weight) sources of sufficient strength as a surrogate for ^{239}Pu during the active neutron measurements and a ^{252}Cf source of sufficient strength as a surrogate for ^{240}Pu during the passive neutron measurements. Actual ^{60}Co and ^{137}Cs sources were used for the fission/activation product GEA testing.[1] The TRU GEA testing requirements have not been completed at this time due to unavailability of appropriate Pu sources. These measurements will be performed as soon as appropriate sources are available to WRAP.

For each measurement, the appropriate source was placed in each of the required representative matrices and assayed twice for a replicate measurement. The process was then repeated for several source positions. The fission and activation product sources were placed in their matrices along with the passive neutron surrogate for assay. The heavy matrix type only has a passive neutron accuracy requirement, so only the ^{252}Cf source was present in the boxes during testing for this matrix. The results for each of the boxes are summarized in Table 2 and Table 3. An overall average negative bias of 14% was observed during testing. This is believed to be due to the poor counting statistics compared to the source used for calibration, however this has yet to be confirmed. The % error was determined using the equation

$$\%\text{error} = \frac{|\text{measured mass - tag value mas}|}{\text{tag value mass}} \times 100.$$

Table 2 Accuracy Measurement Results for SWB

Measurement Method	WGPu Equivalent Mass Loading	Waste Contents	Absolute Average Measurement Uncertainty	Acceptance Test Requirement
TRU Active	17.3 mg	Lab Waste	43%	±50%
TRU Active	36.3 mg	Medium Matrix	12.8%	±70%
TRU Active	201.3 mg	Lab Waste	19%	±20%
TRU Active	255.2 mg	Medium Matrix	6.7%	±50%
TRU Passive	133.7 g	Lab Waste	4.2%	±20%
TRU Passive	424.2 g	Medium Matrix	9.1%	±10%
TRU Passive	424.2 g	Heavy Matrix	4.9%	±18.75%
Fission/Act Prod GEA	48 µCi ^{60}Co, 47 µCi ^{137}Cs	Lab Waste	5.3%	±50%
Fission/Act Prod GEA	54 µCi ^{60}Co, 75 µCi ^{137}Cs	Medium Matrix	7.4%	±25%

Table 3 Accuracy Measurement Results for B-25 Waste Box

Measurement Method	WGPu Equivalent Mass Loading	Waste Contents	Absolute Average Measurement Uncertainty	Acceptance Test Requirement
TRU Active	24.5 mg	Lab Waste	37%	±50%
TRU Active	53.9 mg	Medium Matrix	19%	±70%
TRU Active	255.2 mg	Lab Waste	23%	±20%
TRU Active	519.9 mg	Medium Matrix	18%	±50%
TRU Passive	133.7 g	Lab Waste	4.4%	±20%
TRU Passive	424.2 g	Medium Matrix	6.8%	±10%
TRU Passive	424.2 g	Heavy Matrix	12.3%	±18.75%
Fission/Act Prod GEA	54 μCi ^{60}Co, 65 μCi ^{137}Cs	Lab Waste	9.3%	±50%
Fission/Act Prod GEA	54 μCi ^{60}Co, 75 μCi ^{137}Cs	Medium Matrix	9.6%	±25%

The Pu equivalent source strengths were chosen out of the BII inventory as the closest to the actual source strength testing requirements listed in Table 1 under Measurement Level. In most cases, the sources available were either weaker than the measurement requirement or very close to the measurement requirement. Despite some of the weaker source strengths, all of the average measurements, save one, passed. In the case of the TRU active neutron measurement in the lab waste matrix, the source strength used was half that required. This weaker source strength is believed to have caused the average error to be slightly above the testing requirement. The expectation is that a stronger source for this measurement would put it within the acceptable error range. The BWAS accuracy testing has therefore passed with this expectation taken into consideration.

The sensitivity measurements for the active neutron system utilized a low enriched ^{235}U surrogate for a 5 nCi/g ^{239}Pu loading. If GFSS is the gross fissile signal from the source, GFSB is the average gross fissile signal from five measurements of the background, and SDB is the standard deviation of the five background measurements, then a sensitivity of 5 nCi/g at 3σ above background can be demonstrated using the equation

$$\#\ \text{of}\ \sigma\ \text{above background} = \frac{\text{GFS - GSB}}{\sqrt{2}\ \text{SDB}}.$$

The BWAS demonstrated a net fissile signal above background average of 5σ for eight measurements in the SWB medium matrix and an average of 20σ for eight measurements in the B-25 waste box medium matrix. The system's 3σ sensitivity is therefore considerably better than 5 nCi/g for this matrix type.

Sensitivity measurements for the gamma system used a 6.8 μCi ^{60}Co source and a 9.3 μCi ^{137}Cs source to demonstrate the 20 pCi/g sensitivity at 3σ above background. The required sensitivity can be demonstrated using the equation

$$\#\ \text{of}\ \sigma\ \text{above background} = \frac{\text{CGI - CBT}}{\sqrt{\text{CGI} + \text{CBT}}},$$

where CGI is the gross signal from a source of intensity I and CBT is the ambient background plus the added background from a source of intensity I. For four measurements in the SWB medium matrix, the BWAS demonstrated an average of 6σ above background for the ^{60}Co source and an average of 12σ above background for the ^{137}Cs source. In the B-25 medium matrix, the four measurements averaged 6σ above background for the ^{60}Co source and 11σ above background for the ^{137}Cs source. Again, the system successfully demonstrated sensitivity better than its requirement of 20 pCi/g.

CONCLUSION

The BWAS has successfully passed its acceptance testing to date. In most cases, its performance for passive neutron, active neutron, and gamma-ray analysis exceeded requirements by wide margins. The system has successfully demonstrated sensitivity better than 5 nCi/g for ^{239}Pu and better than 20 pCi/g for ^{137}Cs and ^{60}Co for a medium type matrix. Its accuracy ranges from an average of 5% to 43% depending on the matrix type and source strength. For a medium matrix in an SWB, an average accuracy of 7% for 255 mg WGPu equivalent mass, 54 μCi ^{60}Co and 75 μCi ^{137}Cs was demonstrated.

Possible future plans for the BWAS include implementation of an expanded gamma isotope library and completion of the HPGe detector acceptance testing utilizing certified Pu standards. Additional future efforts may include WIPP certification for this system. Currently, the BWAS performs a fully integrated gamma and neutron data analysis for a complete characterization of the WRAP facility boxed waste.

REFERENCES

1. BII Document BWAS-FATP-002 WRAP Facility BWAS Acceptance Test Plan.
2. R.F. Lucero and J.T. Caldwell, "Technical Report on the Boxed Waste Assay System." 4th Nondestructive Assay Waste Characterization Conference, Salt Lake City, Utah, 24-26 October 1995.
3. M.R. Newell and J.T. Caldwell, "Imaging Boxed Waste Assay System." IEEE Nuclear Science Symposium and Medical Imaging Conference, San Francisco, California, 2-4 November 1993.