AN OVERVIEW OF THE INTEGRATED CRATE INTERROGATION SYSTEM (ICIS) FOR USE AT THE SAVANNAH RIVER SITE

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ABSTRACT

The Integrated Crate Interrogation System (ICIS) was developed for use at the Savannah River Site to assay transuranic waste in large containers. The system comprises a Box Segmented Gamma Scanner (BSGS) providing high resolution gamma spectroscopy, and a Box Neutron Assay System (BNAS) providing passive neutron counting capability. The multi-modality approach is taken where the assay results from the gamma and neutron systems are combined to complement each other in satisfying Waste Isolation Pilot Plant (WIPP) criteria. This paper gives an overview of the system that has been built, factory calibrated, and delivered to the site.

The BSGS is similar to a standard Canberra Segmented Gamma Box Counter, but with the addition of a transmission option for ascertaining density and rudimentary fill-height information. This supplements the Multi-Curve approach based on efficiency in energy and density. The BSGS has a moving trolley which travels on rails through a passive emission counting station using large BEGe detectors, and a transmission counting station using NaI detectors in conjunction with high- and low-beam transmission stages. The assay result provides information on the Pu, Am and/or U isotopic ratios using standard isotopic analysis codes, quantitative measurement of Pu and U for low and medium density matrices, and direct measurement of other gamma emitters in the waste that are not identified in the isotopic measurement. It also provides basic positional information to improve the accuracy of both the gamma and the neutron measurement.

The BNAS is a passive neutron coincidence counter intended for use with multiplicity counting of items of various geometries. The counter utilizes 320 ^{3}He filled proportional counters arranged in a 4π geometry about the assay cavity and divided into 80 counting channels. The assay result provides the ^{240}Pu-effective mass with which the gamma isotopic measurement is combined to provide reliable reporting of Pu and other isotopes. It also provides the total alpha activity that must be reported as part of the characterization requirements for WIPP (or bounds on the alpha activity based on the chemical form of the alpha-emitter). The neutron assay also complements the gamma results where matrix effects, self shielding or self absorption effects, and the presence of high-Z material, severely limits accuracy. Matrix moderator corrections for the neutron assay are based on a multi-position Add-A-Source correction augmented by a Modified Hydrogen Correction. The data acquisition also incorporates a Local Coincidence Veto circuit.

Following the calibration of the system at the factory, confirmatory measurements were performed to demonstrate the validity of the calibrations, and to verify that the measurement system meets the Waste Acceptance Criteria established by DOE/WIPP.

INTRODUCTION

The shipment of transuranic (TRU) waste from various sites in the US DOE complex to the Waste Isolation Pilot Plant (WIPP) has traditionally been based on containers that could fit in the Nuclear Regulatory Commission (NRC) certified TRUPACT-II shipping container. It is estimated that approximately a quarter of the total volume of this retrievable stored waste, however, is in containers that exceed the size of the TRUPACT-II [1]. Since repackaging contents to fit the existing shipping containers is a costly and possibly hazardous process, the DOE has pursued both the development of larger shipping containers (TRUPACT-III), and the development of waste characterization systems to assay large containers. Following a feasibility study for an integrated waste assay system undertaken as part of a DOE Program Research and Development Announcement [2], the Integrated Crate Interrogation System (ICIS) was proposed and built for the characterization of large containers having possible TRU waste.

The waste stream for which the ICIS is intended is primarily heat-source and weapons-grade Pu scattered in items packaged in large wooden crates that were then placed in larger steel containers at the Savannah River Site (SRS). The dimensions of a steel container of this type are ~550cm x 366cm x 213cm (18' x 12' x 7') which is too large to be shipped to WIPP, and so the wooden crates are to be removed and placed in SLB-2 containers instead. The Standard Large Box-2 (SLB-2) has inner dimensions of ~259cm in length, 160cm in breadth, and 168cm in height (8.5' x 5.3' x 5.5'), and is the largest of the containers intended to be assayed with the ICIS. These dimensions, therefore, set the scale of the ICIS system. In order to provide the option of assaying other containers as well, including Ten Drum Over-Packs (TDOPs), Standard Waste Boxes (SWBs), and 208-liter (208ℓ) drums, the ICIS system is also required to be versatile over a wide range of possible matrix volumes. (The SLB-2 encompasses a volume ~30 times the volume of a 208ℓ drum.)

In order to meet the performance requirements dictated by the WIPP Waste Acceptance Criteria (WAC), and in order to account for the possibility large volume contents and the consequential impact of moderating materials on the measurement, a combined gamma and neutron assay solution was proposed. A passive neutron counting method was selected over an active method on the grounds that the overall cost of ownership outweighed the improvement in performance.

Quantitative gamma analysis gives reliable results for low density or uniform waste containers, provides good sensitivity, and is not severely impacted by moderating matrices. The gamma measurement also provides the only reliable method for the determination of radio-nuclides not directly associated with the Pu content of the container (i.e. not directly scalable from measurement of Pu). It is also the means by which the Pu isotopics will be determined where accepted knowledge (AK) is unavailable, and confirmed when available.

Passive neutron coincidence counting (PNCC) is typically the most accurate method for measuring higher Pu mass loadings. In addition high atomic number (high-Z) materials provide little interference to PNCC. The determination of the Pu mass content does, however, require

knowledge of the Pu isotopics, and full characterization of the results requires data on the non-Pu isotopes as well.

The complementary nature of the two measurement approaches led to the proposal of a Box Segmented Gamma Scanner (BSGS) providing high resolution gamma spectroscopy, and a Box Neutron Assay System (BNAS) providing passive neutron counting capability. The BSGS design is based on standard box counting systems [3] with the addition of a transmission measurement capability. The BNAS design is based on the SuperHENC [4] and HENC [5 (and references therein)] designs and incorporates scaler bank data, a local coincidence veto circuit, and a modified hydrogen correction algorithm to supplement the multi-position add-a-source matrix correction. The BSGS and BNAS counters are described below along with the key new features, followed by a discussion of the calibration and verification efforts performed at the factory prior to transport to the SRS.

BOX SEGMENTED GAMMA SCANNER

Figure 1 is a layout diagram of the Box Segmented Gamma Scanner (BSGS).

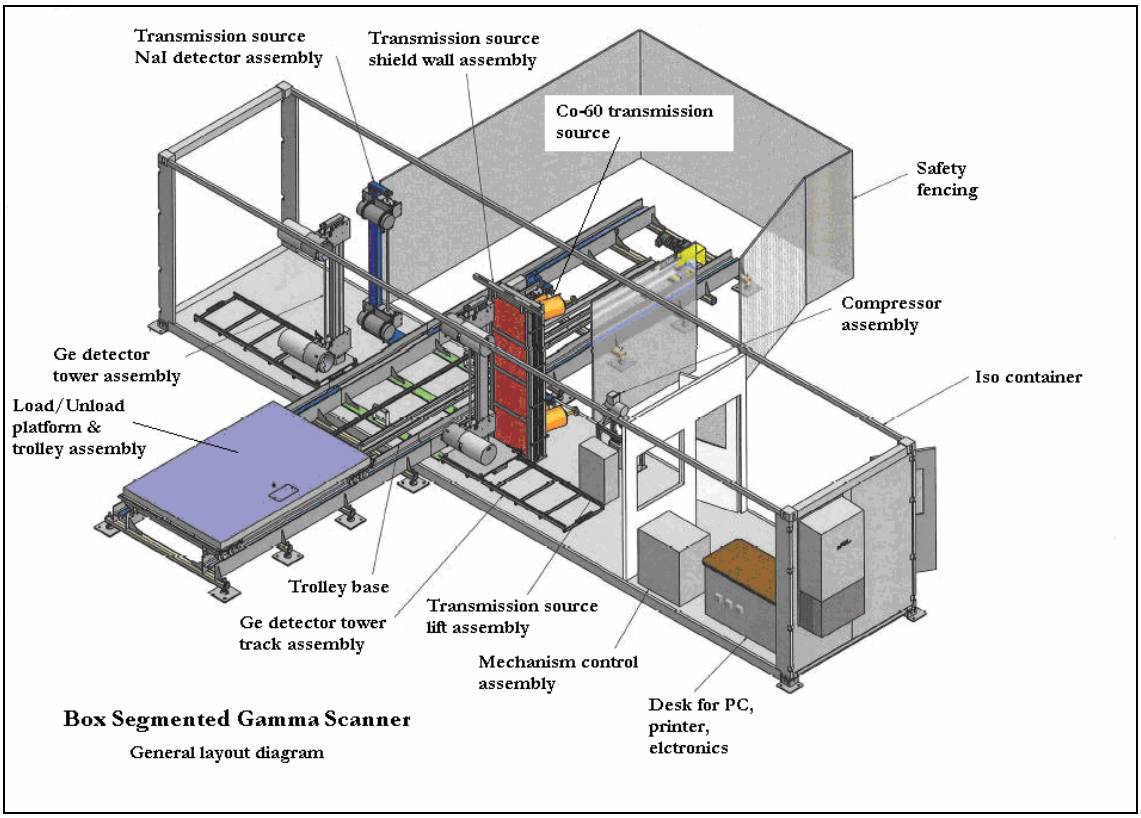

Fig. 1. BSGS general layout.

The waste container is loaded on the platform (shown in Fig. 1) which is then automatically transported on rails in accordance with a pre-defined scanning protocol. The protocol involves moving the container to a specific position, making a measurement for a pre-defined count time, and then repeating the process for the next position. The number of positions chosen for a given

sized container, is a compromise between the size of the container, the time allotted for the total measurement, and the statistical precision desired at each measurement position. The container passes through two counting stations; a passive emission measurement takes place at one station, and a ^{60}Co transmission measurement takes place at the other, with the container stationary during each measurement. Figure 2 shows the BSGS in the process of assaying an SWB container.

Fig. 2. BSGS assay of an SWB container

The passive emission measurement station is designed in the style of a standard gamma box counter [3] where the container is positioned between two detector towers, each tower holding two high purity germanium (HPGe) detectors mounted one above the other, and each shielded with a thick Pb shield. The HPGe detectors used in the BSGS are 'Broad Energy' Ge (BEGe) detectors designed to offer good energy resolution over a broad energy range (few keV to several MeV). Typical resolutions are 0.70 keV at 122 keV and 2.1 keV at 1332 keV. Each detector had a front surface area of 38 cm^2 and a thickness of 20 mm, with a nominal relative efficiency of 21%. For a passive measurement the spectra from the four detectors are summed to quantify radioactive constituents. The vertical spacing between the detectors on each tower, as well as the horizontal spacing between the towers is adjustable, but must be defined and fixed prior to the measurement.

The transmission measurement station, located approximately 2 m away from the emission station, is also made up of two towers, with one tower holding two NaI(Tl) detectors and the opposite tower holding two transmission sources. Each NaI(Tl) detector is 5" diameter by 4"

thick and is housed in an actively temperature-stabilized enclosure at 40°C. Each transmission source was a 250 mCi (nominal at the initial date of installation) ^{60}Co source housed in a large lead shield, and lined up opposite to one of the NaI(Tl) detectors. Each lead shield is equipped with an automated assembly of two sintered tungsten shutters that can be moved independently in and out of the transmission beam. The cylindrical shutters (2" in diameter) are 7" and 1.2" in length, and allow for a high beam/low beam transmission option depending on the density of the container. Prior to beginning the transmission measurement, a 'snapshot' measurement with both shutters out provides dead-time information which if too high (above a pre-defined threshold) can automatically trigger insertion of the 1.2" tungsten block in order to keep the NaI(Tl) detector from being saturated. For this reason the smaller block is referred to as the 'attenuator', while the larger block is called the 'shutter' as its primary purpose is to 'turn the transmission beam off' when inserted into the beam path. For high-density matrices both 'shutter' & 'attenuator' are removed from the beam path to take advantage of the full-strength of the ^{60}Co source. For the large containers where non-uniformity in the matrix is likely, and stratification or settling may have taken place, the two transmission attenuators can be independently controlled and optimized for the measurement. In order to prevent accidental exposure to personnel, the counter is equipped with pressure sensor mats, and on power loss the shutters are configured to automatically close via gravity. There is also a retractable position for the source with even greater shielding for situations where personnel may be required to work in close proximity to the shields.

Figure 3 illustrates the segmented scan protocol using the SLB-2 container as an example.

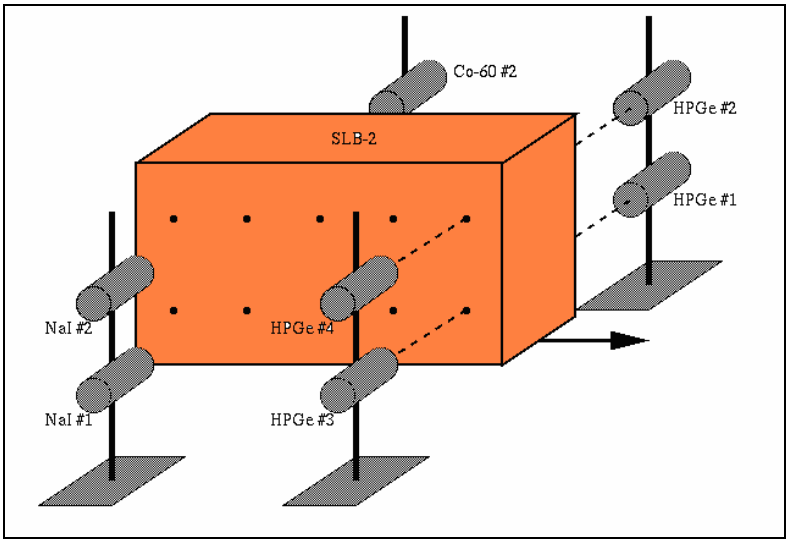

Fig. 3. Schematic of BSGS scanning protocol.

The SLB-2 container is in effect sub-divided into five approximately equal-sized segments, each uniquely identified in the NDA-2000 [6] assay control software. A measurement for any given segment takes place with each detector pointing at a spot on the vertical center line of the segment, positioned so that full coverage of the segment is achieved. Since it is undesirable to make the emission and transmission measurements simultaneously (due to the possibility of interfering down-scatter from the transmission sources), a two-pass scanning protocol was defined. (The mechanism control allows for different scanning protocols by container which can

result in different spacing between segments as well as number of segments.) First, the container is positioned so that the transmission measurement is performed for segment #1, and then the container is repositioned for the transmission measurements on each of the subsequent segments. Once complete, an identical sequence of steps is carried out for the emission measurements. The container is moved to the same discrete positions used for the transmission measurements, and the centerlines of the HPGe detectors intersect the item container in the same spots as did the transmission beams. The advantage of proceeding in this order is that the results from the transmission measurement are already available when the emission measurement is made, and so the emission data can be appropriately transmission corrected and analyzed, segment by segment "on the fly". Once the series of emission measurements is completed, the container is returned to the home position (which is also the load/unload position).

The analysis of the transmission spectra is based on a simple Region of Interest (ROI) method for the 1173 and 1332 keV gamma rays from ^{60}Co. A passive assay is also performed with the NaI(Tl) detectors to check for possible interferences from 'bleed-through' of the transmission source with the shutters closed, or from ^{60}Co in the sample itself. The NaI(Tl) passive measurement also offers the advantage of extending the energy range available to the HPGe spectra so that high energy reaction gamma rays may be identified if present. The results from the two peaks are used together with an assumed representative Mass Attenuation Curve (e.g. combustibles, concrete, iron) to obtain a transmission correction at any energy via extrapolation. The transmission correction is made following the Parker [7] model for matrix self-attenuation, where the emission peak rates in each segment are corrected for transmission to a "zero" density count rate, and then analyzed. (The software supports both the equivalent slab and the equivalent sphere models.) In the event that meaningful transmission information is unavailable (e.g. the container is too dense), the system reverts to a simple self-attenuation correction based on the average density of the container and the multi-density efficiency curve. Both options are available and add value as consistency checks during expert review.

The passive emission measurements with the HPGe detectors are analyzed using standard gamma spectroscopy methods (in this case the GENIE 2000 [8] software). The good resolution at the lower energies with the BEGe detectors allows for isotopic analysis using the MGA/MGAU method [9]. These results are stored and conveyed to the neutron system (BNAS) for use with the results of the neutron assay. Results are available both on a segment by segment basis, or on an analysis of the summed spectrum.

BOX NEUTRON ASSAY SYSTEM

Figure 4 shows the Box Neutron Assay System (BNAS) with an SLB-2 container loaded on the conveyor system in preparation for an assay. After a container has been assayed in the BSGS it is then moved to the BNAS where it is placed on the outer conveyor. The assay automatically initiates the loading of the container into the assay chamber, followed by the raising of the roller drawbridge that connects the outer conveyor to the inner-chamber conveyor, and the closing of the chamber door. With ^{3}He proportional tubes on all six sides of the rectangular assay cavity, the BNAS provides a 4π geometry for the passive neutron assay. The drawbridge system allows for the counter to have a truly 4π assay geometry with the door providing sensitive detection area along the entire front surface of the chamber. The assay cavity is 305cm long, 206cm deep, and

201cm tall (10' x 6.8' x 6.6') with the height being measured from the top of the conveyor, and so can accommodate an SLB-2 container comfortably. The internal height was set by the dimension of the TDOP container. In order to ensure that the container is centered in the assay cavity, guide bars are installed on the sides of the conveyor, and for the smaller containers a loading palette is used.

Fig. 4. BNAS general layout.

A total of 320 10-atmosphere ^{3}He filled proportional counters are used in the BNAS with 60 counters each in the top, bottom, rear, and front (door) of the chamber, and 40 counters in each of the two sides. Each counters has a 185 cm active length and 2.54 cm diameter. The counter positions in the surrounding high-density polyethylene (HDPE) moderator were chosen to maximize sensitivity, and to minimize response to metal content. Groups of four counters are 'or'ed together into a JAB-01 A111 based amplifier/pre-amp/discriminator board, to give a total of 80 counting channels. The signals are passed through a de-randomizer board (to minimize dead-time) into a JSB-96 signal processing unit, and are counted using a JSR-14 multiplicity shift register. The JSB-96 module offers scaler channels which allow for the tracking of count rates from individual channels (i.e. each group of four counters), providing a diagnostic tool for the state of health of the system, and also providing basic source distribution information. The module also contains a Local Coincidence Veto (LCV) circuit described below. The BNAS has a detection efficiency of 30% for ^{240}Pu(sf, n), a die-away time of 55 μs, and a sensitivity of 53 Reals/sec/g $^{240}Pu_{eff}$. The dead-time for the counter is 40 ns.

The LCV circuit is configured to veto events where signals may occur in adjacent channels. Each time an event is detected in a given channel, the LCV vetoes that channel and its two

neighboring channels for a period of time commensurate with the coincidence gate-width (128 μs), effectively vetoing events where neutrons would have been detected in a group of neighboring channels. The vetoed signal is counted separately with a second JSR-14 shift register, and since the LCV signal processing occurs completely independently of the normal signal, the BNAS is always counting in two modes simultaneously. The purpose of the LCV is two-fold. The primary aim is to minimize the effect of spallation events on the detection sensitivity of the counter. Since these events typically produce localized showers of neutrons, the monitoring of adjacent channels in the system can be used to preferentially veto these events. The importance of this feature is greatest close to the detection limit. The other potential benefit of the LCV is response flattening since a point source close to the assay cavity wall will give rise to a greater rejection probability than an interior point source which would be alternatively suppressed by matrix effects.

Similar to the HENC design, the BNAS is equipped with a ^{252}Cf Add-a-Source (AAS) which is used to provide a correction for the effects of moderating matrices in the containers. For the large containers the impact of moderating materials can result in under-reporting of the fissile mass by an order of magnitude (or more). The AAS correction technique uses a pre-determined correlation (via calibration) between the perturbative effects of a matrix on an external interrogation source (the ^{252}Cf AAS), and the volume perturbation response for that matrix previously measured during the AAS calibration process [10]. When a container is measured the assay consists of two parts. For a short period of time the ^{252}Cf AAS is introduced into the assay chamber and the AAS perturbation measurement is performed. Based on the measured response and using the previously defined AAS calibration, an AAS correction factor is established. Following the brief interrogation measurement the ^{252}Cf AAS is retracted and is housed outside the assay chamber in a shielded HDPE well. The assay then continues with the longer passive neutron measurement the result of which then gets corrected by the AAS correction factor.

In order to be less sensitive to the varying aggregations of material inside the large containers, the location of the AAS inside the assay chamber was allowed to be programmable, and multiple positions could be defined for a given perturbation measurement depending on the size of the container. For this purpose a U-shaped track inside a steel reflector was designed at the bottom of the assay chamber, with each leg of the "U" equidistant from the lengthwise symmetry axis of the counter. The ^{252}Cf point source attached to the end of a steel cable, could then be moved to any location along the track. In practice for the SLB-2 container ten AAS positions are defined with five positions on each leg of the "U"; the perturbation measurement then comprises ten sub-measurements of equal time, with the AAS in a different location for each measurement. The results from the sub-measurements are then merged to give an average AAS perturbation for the container. In the case of the 208ℓ drum, the smallest container to be assayed with the BNAS, a choice of one AAS position directly below the drum, required that the drum be placed slightly off-center relative to the center of the assay cavity. Consequently all measurements of the 208ℓ drum (calibration & item assay), are made with the drum in this off-set position. Since the volume of the drum is a small fraction of the volume of the assay cavity, the off-centered position has little to no effect on the assay results. The reproducible positioning of the drum for all assays is easily achieved using the loading palette mentioned previously, where the drum placement location is inscribed on the pallet.

An additional feature implemented in the BNAS is a Modified Hydrogen Correction (MHC) algorithm to be used as an alternative and complementary technique to the AAS correction when the matrix is severe and a sufficient quantity of Pu is present. The MHC technique uses the ratio of measured Triples and Doubles rates, and was inspired by the Los Alamos (LANL) Hydrogen Correction developed previously but is different in form. The MHC offers a reduction in bias for certain measurement conditions.

The multiple analysis and correction techniques available are combined in the NDA-2000 software to offer what is termed Automated Waste Analysis (AWA). The AWA technique uses a decision-tree approach to choose the most likely Pu mass based on inputs and filters from the various analysis modules.

CALIBRATION EFFORTS AND PERFORMANCE

The calibration efforts for the BSGS and BNAS systems were based on extensive experience with previous gamma and neutron counters. The gamma system would require a multi-curve efficiency calibration and a transmission calibration; the neutron system would require an AAS calibration, the MHC calibration, a high-Z content calibration, and a system characterization (a determination of the operating parameters) which would be independent of container type. In addition, a quantification of the total measurement uncertainty (TMU) [11] would be carried out for both systems.

For the container-specific calibrations the complexity of the calibration effort was immediately apparent. With four container types, each calibration would have to be repeated four times. Furthermore, as the container size increased the calibration measurement times would increase as well; first, the representation of a uniformly distributed source with a limited number of point or rod sources would require repeated series of measurements, and second the increase in moderating material would require longer count times for good counting precision.

As an example for the BSGS multi-curve efficiency calibration it is necessary to construct an energy-efficiency calibration with containers spanning a range of densities, using as best an approximation as possible to a uniform source distribution for each container-matrix combination. A uniform source distribution in the 208ℓ drum can be reasonably approximated by a set of six rod sources and assayed in one measurement. Using a spacing of no more than 20 cm between rod sources, and with a set of seven rod sources, 8 measurements are required to cover the volume of an SWB container; with an added rod source and the same 20 cm spacing requirement, for an SLB-2 container the number of measurements required to cover the total volume becomes 28. If a count time of one hour is required for the case of the empty 208ℓ drum in order to obtain good statistical precision, the total count time (number of measurements plus precision goal) for a dense SLB-2 matrix could require several days. For this reason an alternative calibration approach was sought, and so the In-Situ Object Calibration Software (ISOCS) [12] was chosen to complement the calibration measurements where possible.

The capability of the ISOCS software to use the response characterization for a specific HPGe detector as a "look-up" table to obtain peak efficiencies in vacuum at any given spatial location, and then factor in the attenuation factors due to absorbers (external and internal to the source), allowed a tremendous savings in measurement time when determining the calibrations for the

BSGS. First, efficiency calibration measurements were made for the empty containers by using reference rod-source standards to cover the entire volume of the containers in a comprehensive fashion. ISOCS was then used to generate efficiencies for the measurement geometries, thereby establishing a baseline level of agreement. The software was then used to establish the extent to which the discrete rod source measurements diverged from a true uniform source distribution. This was necessary since it is the uniform-source based efficiencies that are used in the multi-curve efficiency calibration, and for the larger containers the accuracy of the measured representation of the uniform case is impacted more by the use of the discrete sources. Once this effect was understood based on the empty container comparison, the software was used to generate the efficiency calibrations for uniform-source distributions over a range of densities as required for the multi-curve efficiency calibration. Once the calibration was loaded on the system, verification measurements were performed for the various containers and matrix types using the rod source standards to mimic a uniform source distributions as described previously.

For the neutron system the complexity of the calibration measurement process was equally apparent. The AAS calibration process requires a volume perturbation measurement for each matrix type associated with every container. These measurements are typically obtained by measuring a point source at several spatial locations within the container in order to map out the variation in moderating effects over the entire volume of the container. The reference calibration condition is for activity uniformly distributed throughout a homogeneous matrix filling the container. Under this condition equal volumes of the container hold equal matrix mass of equal activity. A weighting scheme can then be used to account for the representative volume associated with each spatial location of the measured point source, and a volume weighted average (VWA) activity can be extracted. Since the weighting scheme effectively creates the VWA from the experimental scan pattern, care must be given to the number and choice of point source spatial locations within the container. For a 208ℓ drum typically 20 spatial locations are used with each location no more that 20-25cm away from the nearest adjacent location. For the SLB-2 container a mapping with similar spacing would require over 500 measurements. Even with a 5-minute measurement time (reasonable for empty & low-density matrices), this requires ~40 hours of measurement time, not accounting for time spent in-between measurements to re-position the source. A reduction in the calibration time to a more manageable figure was therefore sought, and was achieved through a combination of methods without a significant compromise in the quality of the calibration.

First, by virtue of the 4π coverage and axial symmetry of the BNAS, measurements were made in only one quadrant of the matrix. Full symmetry was assumed in the horizontal plane, but because of the presence of the conveyor rollers at the bottom of the assay cavity, symmetry was not assumed *about* the horizontal plane (i.e. along the vertical axis). (In practice, however, chamber mapping measurements had revealed that the variation was at most only 5% at the extremes, and of the order of 2% in-between). The volume perturbation measurements were made in the front-right quadrant of the matrix and were made along the full height of the matrix. The choice of quadrant itself was based on proximity to where the door to the chamber opened, thus minimizing the time spent in opening and closing the door between measurements. A second savings in time was achieved by pre-drilling small entrance holes in the lids of the containers, thereby allowing repositioning of the source without the need for removal of the lid, a process that also required considerable time and man-power as the container had to be fully

unloaded from the chamber, and the lid could only be removed with the aid of a fork-lift. A third choice was to extend the distance between source positions to 40cm (instead of the preferred 20cm). The impact of this choice was on the determination of the appropriate weighting factors for the volume perturbation measurements. Here it was felt that analytical or Monte Carlo methods could be used to determine the appropriate weighting factors, without the need for the additional measurements.

The choice and construction of the actual matrices used for the calibrations also required careful consideration. While the construction of standard PDP and Q^2 calibration 208ℓ drums is well established, construction of the matrices for the larger containers was a new venture. For the BSGS the large calibration modules were to serve as uniform matrix simulants over a range of several densities to allow the ISOCS calculations to be benchmarked quickly and conveniently with a controlled geometrical configuration. For the BNAS the aim was to provide a range of hydrogen concentrations to allow as wide a range as possible for the AAS calibration. Based on these aims, plywood, polyethylene, and cardboard, were chosen as representative materials, but maximum allowable density for the matrices was limited by the maximum weight limit for each container type. For the SLB-2 container this corresponded to 0.6 $kg.\ell^{-1}$ density limit. For the SWB container a the most dense matrix was 0.9 $kg.\ell^{-1}$. Other considerations were ease of construction, and a 'modular' approach to filling the container volumes with a matrix, so that the individual matrix modules could be handled more easily.

For both the gamma and neutron systems the TMU analysis is intended to capture the extent to which the approximation to uniform sources, and the heterogeneity in the actual sample matrices impact the final results. To study the response in the presence of heterogeneous matrices, approximately 200 small matrix modules were constructed using the same materials as the large modules as well as steel and lead, and formulated to fit into standard ~30ℓ (8-USgallon) drum. Varied combinations of the ~30ℓ drums could then be used to produce heterogeneous matrices that could be used in all the container types.

Finally, the calibration campaign itself was carefully planned to allow for both systems to share the available containers and matrices without conflicts. In order to reduce the overall calibration time, additional personnel were trained in making the calibration measurements so that two 8-hour shifts could be filled each day. Procedures were clearly outlined so that all personnel performed measurements in reproducible fashion, and so that regular Quality Assurance (QA) and background measurements were performed on a regular basis. The full suite of calibration measurements was performed over a four-month period with little to no problems of any kind.

Once the calibration efforts were complete, a factory acceptance test was performed on each system prior to shipping to the SRS. A summary of the major performance results is given in the tables below. Table I gives the BSGS detection levels for a uniform source/matrix combination in a SLB-2 container of 2000 kg (~0.3 $kg.\ell^{-1}$). The results are based on a 1-hour count time. For a single localized source in the least sensitive part of this container the MDA is ~0.5 grams ^{239}Pu, which is equivalent to 16 nCi/g.

Table I. BSGS detection levels for a uniform source/matrix in a SLB-2 container of 2000 kg (~0.3 g/cc). Results are based on a 1-hour count time.

Nuclide	Concentration	Equivalent Mass
^{137}Cs	0.05 pCi/g	
^{235}U	0.14 pCi/g	125 mg
^{238}Pu	10 nCi/g	1 mg
^{239}Pu	2 nCi/g	60 mg

Table II gives the BNAS detection levels for a non-interfering matrix in a SLB-2 container of 1000 kg. The results are based on a 1-hour count time.

Table II. BNAS detection levels for a non-interfering matrix in a SLB-2 container of 1000 kg. Results are based on a 1-hour count time.

Source type	Coincidence mode	Totals Counting (go/no-go screening)	
$^{240}Pu_{eff}$	4.6 mg	Assuming PuO_2	Assuming Metallic Pu
Weapons-grade Pu total	69 mg (6 nCi/g)	22 mg (2 nCi/g)	40 mg (3 nCi/g)
Heat-source Pu total	2.1 mg (29 nCi/g)	0.2 mg (3 nCi/g)	1 mg (16 nCi/g)

CONCLUSIONS

The Integrated Crate Interrogation System (ICIS) has been built, factory performance tested, and delivered for use at the Savannah River Site. The system is designed to assay transuranic waste in large containers, and to this end comprises the Box Segmented Gamma Scanner (BSGS), a high resolution gamma system, and the Box Neutron Assay System (BNAS), a passive neutron counting system. Results from both systems are combined using a multi-modality approach to obtain the best results towards meeting the WIPP waste acceptance criteria.

While based on existing best practices, the ICIS required augmentation of several analysis techniques in order to successfully assay waste containers on a scale previously unexplored. In addition the expansive scope and complexity of the calibration efforts required innovative solutions. The ICIS has been performance tested on site, and awaits the commencement of the certification stage which involves a finalization of the calibration parameters and TMU analysis, and a demonstration of compliance with the WIPP waste acceptance criteria. Reports on the calibrations and novel features are expected shortly, and reports on operational data are expected in the near future when the system enters service.

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