International Perspective on the Application of Non-Destructive Assay Technology Platforms for Sentencing and Disposal of Radioactive Waste - 12113

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ABSTRACT

Over the past decade, major technology improvements have been introduced in the field of Non-Destructive Assay (NDA) for the management and disposal of radioactive waste in compliance with an evolving regulatory structure. For example in the United States, various NDA technologies have been successfully developed to meet the stringent characterization requirements of the Department of Energy. The use of this instrumentation, combined with the compliant operational processes and expertise levels that have emerged in parallel, have enabled over 75,000 m^3 (or in excess of 145,000 containers) of contact and remote handled transuranic (TRU) waste to be sentenced to date to the Waste Isolation Pilot Plant from 10 different consignor sites. Many of these techniques have applicability that transcends national borders and can be used for common characterization challenges in waste sentencing and disposal on an international basis. Applicable waste streams could include LLW, ILW, TRU and HLW. There are specific design aspects of assay equipment that must be tailored to meet the applicable regulatory requirements for detection and quantification of a set of nuclides of interest to a prescribed limit of detection and measurement uncertainty. Each host nation will have specific challenges in the form of matrix types and processes, availability of historical information, needs for portable versus fixed instruments and the requirement to measure all containers versus assay of a representative sample. Furthermore, the practice of load management (combining smaller packages into a larger package designed to meet the overall waste acceptance criteria for the bulk container) may not have universal acceptability. An evaluation has been performed on a sample of the most successful technologies that have recently emerged to understand their applicability in other countries. Two types of instrumentation 'suite' are considered for measurements on drums and larger boxes / crates: (i) High Efficiency Neutron Coincidence counting combined with gamma isotopic analysis (e.g. the SuperHENC), and (ii) Portable NDA using neutron slab counters and far field high resolution gamma spectroscopy. Target countries (outside the United States) for these applications are: China, Japan, UK, Sweden and Canada. Specific challenges in each country are addressed and the applicability of the technologies as "universal platforms" is considered.

INTRODUCTION

Non-Destructive Assay (NDA) system designers face several challenges in solving both technical and regulatory issues for compliant characterization of radioactive waste. Many issues are country specific (e.g. relating to detection limits, sorting thresholds, container throughput etc.) whereas many others are technical challenges with global scope that can benefit from common solutions.

Many of the challenges faced will be familiar to NDA experts across the world. One of the most difficult problems to solve is to achieve low detection limits in the presence of high backgrounds. At some facilities the background is dominated by local conditions and nearby sources of radioactivity (container storage, operational facilities and legacy buildings). Often, the majority of background can be from cosmic ray sources due to high elevation and, therefore, can be a problem unique to countries with high altitude facilities.

Supply and demand for raw materials tends to be a global phenomenon that dictates and restricts usage of certain materials of limited resource (for example He-3 used in neutron detection has recently become a resource issue).

Contamination from interfering sources is also a common problem. Most countries have adopted broadly similar technologies in their nuclear fuel cycles. So, for example the presence of fission products in spent nuclear fuel debris restricts the ability to measure low energy gamma-rays and limits the characterization techniques that may be applied for quantification of special nuclear materials in this type of waste stream.

Environmental regulations for characterization may vary between countries. For example some countries legislate for assay of every single container whereas others may require only measurement of a representative sample of containers in order to verify waste profiles against consignor records. Safeguards regulations are also applied on a cross-border basis and as such many technical requirements share a common basis when facilities are subject to materials control and accountability.

Each country tends to adopt its own standards for container sizes for shipping and storage of waste. However, the most commonly encountered vessel, the 200 liter drum, is found in almost all countries. Wherever possible, facilities should attempt to perform characterization using the smallest possible container size before repacking or overpacking the waste. The 200 liter drum represents a good trade-off in terms of size, throughput and measurement accuracy.

The movement of radioactive sources between countries can be subject to prohibitively complex requirements. For this reason “no-source” methods for assay and calibration are highly desirable. Monte Carlo methods are widely used to characterize detectors and systems although good practice dictates that all mathematical methods should be benchmarked to known radioactive standards.

Many solutions that have been developed recently are common for many different international scenarios. These include:

- Summation of data to provide an integrated measurement for bulk waste shipments.
- Plutonium and uranium isotopic characterization methods. These are universally applicable as the materials fall into well defined categories (for example military grade plutonium, depleted uranium, commercial grade enriched uranium).
- Use of ‘fingerprints’ or ’acceptable knowledge’ to classify non-measureable nuclides by scaling to measured signals.
- Use of matrix correction methods. The most robust methods for matrix correction are independent of waste streams and based on real-time measured parameters.
- Recently developed detectors and electronics. The use of universal “plug-and-play” architecture (USB connectivity and common Windows software) greatly enhances international compatibility.

Widespread use of consistent software platforms is an example of an area where sites from various countries can collaborate and share resources. Examples include PC-FRAM (Pu and U isotopic measurements), INCC (Neutron Coincidence and Multiplicity Counting), ORTEC ISOTOPIC and Canberra ISOCS for in-situ gamma spectroscopy. The use of standard software platforms provides several advantages in ensuring data quality. Users can share analysis parameters, database files and settings. In addition, facilities can adopt consistent approaches allowing easy regulatory monitoring and acceptance.

BEST MEASUREMENT PRACTICES

A universal truism is that “early characterization pays”. Sites who characterize their waste at the point of generation can assay in small well defined packages with good operational records. The benefit is achieving a low total measurement uncertainty and hence saving money in the long run when it comes to transport and disposal of the waste. On the other hand if waste is poorly tracked and mixed in uncategorized temporary storage, then high uncertainties often result as many independent error components are added together to account for multiple unknown.

For example, consider the measurement of Pu bearing waste that arises from mixed processes (say military and commercial). The practice of segregating waste into drum streams that are isotopically pure can be a huge benefit to a measurement process that relies on neutron assay. The active or passive neutron signal tends to be dominated by a single key nuclide be it Pu-239 or Pu-240. When the waste has well known isotopic composition the characterization can proceed with a simple HPGe measurement to verify the isotopics (e.g. by reference to a ratio of key gamma emissions). The total plutonium content and total alpha content of the waste may then be calculated with the only source of uncertainty arising from the neutron measurement.

By contrast where isotopics are unknown the analyst is faced with a very difficult task of performing high resolution gamma spectroscopic analysis on a waste container with assorted debris materials and possible isotopic heterogeneity. Despite recent advances in the capabilities of software such as PC-FRAM and MGA for measuring isotopic composition in difficult conditions, these codes will only work well on large well defined samples. Low quantities and heterogeneous contents can lead to large sources of uncertainty in the isotopic measurement and in many cases the results can be at best ambiguous and at worst meaningless.

Site Requirements: Safety and Cost

Another clear pattern to have emerged in the last decade is the dominance of “simple and robust” NDA methods over the complex methods. Portable instrumentation is highly desired by waste management personnel. The most frequently demanded characteristics of an assay solution are that it should be simple to set up and operate, have minimal points of failure and low maintenance requirements. In particular by using intelligent software many sites are moving away from the need to hire and train an extensive team of expert data analysts to process individual container results.

Sites are also looking to minimize long term operational costs and maximize safety, for example by opting for non liquid nitrogen based cooling for HPGe detectors. The new generation of electro-mechanical coolers has brought forth advances in reliability and stability and it is now practical to perform cost-effective field gamma spectroscopy without the need for liquid nitrogen.

Many sites prefer methods that eliminate the need to deploy interrogating radiation sources such as neutron generators and high activity radioactive sources. Thus passive neutron coincidence counting may often be preferred over active neutron methods such as differential die-away for measurement of plutonium waste. In some countries the use of radioactive sources can cause problems particularly in view of import and export regulations where nations have a concern for the long term disposition of radioactive materials. Thus many manufacturers will now offer a "no source" calibration of their detectors using a mathematical model (such as Monte Carlo methods) to calibrate with rather than a radioactive source.

There is an increasing tendency among many facilities to opt for technically simple, pragmatic and robust methods for characterization in preference to more complex methods. For example in the US there is now widespread adaptation of use of dose-to-curie methods for characterization of remote-handled waste. In particular for waste forms with good operational records, a simple dose rate (or total gamma count) can yield an adequate quantification of transuranic materials without the need to perform a complex neutron based measurement.

Certification Processes

As yet no international consensus standards have been developed to address certification of existing and new instrumentation. Methods used to certify, verify and validate performance should be standardized to enable portability of new technologies from country to country without have to "reinvent the wheel". This will be particularly beneficial in smaller countries and developing nations that lack national scientific and academic resources needed to develop their own certification processes independently.

One example of a successful national program for system certification is the US DOE's Performance Demonstration Program (PDP) Plan [1, 2]. Radiological characterization data are required prior to the transport and acceptance of transuranic (TRU) waste at WIPP. The PDP Plan for NDA of waste in drums and boxes provides an independent and objective means to test the capability and performance of diverse systems. Blind tests are performed on all certified systems on an annual basis. An independent review team arranges for surrogate matrix-filled containers with radiological material (known to the review team but not to the system operators) to be assayed. The reviewers assess results from all systems and provide a scoring report based on the accuracy and precision of declared results. Systems that fail the predefined acceptance criteria are removed from service until the cause of failure has been addressed.

This type of program is preferable to a generic "system-based" certification process. Certifying systems by genre or manufacturer can lead to many potential problems. Operating personnel and sites can easily be overly complacent in their approach to complex analytical problems and can treat systems as "black boxes". The generic method may itself be accurate but if the system is set up with inaccurate calibration, is poorly maintained, or the software is used inappropriately without rigorous (daily) measurement control procedures in place, there is still scope for undeclared error in the measurement. An annual program can identify such problems and can yield confidence for the regulator and customer.

Data Quality Checks

There is widespread consensus on the need for quality checking. At a minimum sites should deploy quality checks on a daily basis comprising standardization checks (with a source wherever possible) and background (no source) checks. Extended QC programs can include the requirement for periodic checks on long term stability of the system efficiency and efficacy of matrix correction methods. For example the US DOE mandates [3] that Waste Isolation Pilot Plant (WIPP) certified instruments are checked on a once-per-week basis with a known source using a set of interfering matrices that encompass the range of waste matrix to be assayed. The results of these checks are summarized and reported semi-annually.

Peer Review Process

A critical component of an accurate NDA program is the peer review process. The purpose of peer review is to identify and, where possible, correct reported results that may affect data quality due to conditions outside the bounds of the calibration assumptions. Possible conditions, if any, are identified and appropriate remedial action steps may be initiated (e.g. re-analyse or re-measure). The procedure includes initial Data Quality review by the NDA Technical Specialist or Operator and an Independent Review once the data analysis is completed.

An initial review of the measurement data is carried out by the operator to ensure that the data quality is satisfactory. This includes spectral quality checks of the assay data and the daily check source data. These checks include spectral resolution, detector efficiency and energy calibration stability. For example, acquisition dead time is reviewed to ensure that it is consistent with the observed count rates and peak shapes.

An independent review is performed on each measurement. In this process a statistical assessment is performed on all data analysis results produced from field measurements. All technical documentation created for supporting NDA activities are reviewed. This may include a walk-through of technical documents, quality control, and spectral analysis performed on a measured item. If during the analysis process, the electronic media is determined to be bad or erroneous results are generated from known data, it shall be considered a statistical failure or if the quality control is outside the guidelines established for a given detector it may be considered out-of-control. In the event a statistical failure occurs, an independent analyst may analyze the data for failure confirmation. If confirmation is obtained, the data is omitted and re-measurement of the item should be considered. During the measurement process, the NDA team must maintain all measurement equipment both quantitatively and qualitatively within the bounds of control. Once the Independent Review process is completed, the results are then processed for reporting.

Training Requirements

Training is another critical component of a successful measurement protocol. All staff involved in NDA (i.e., technical analysis, data review, operating assay equipment etc.) must be, at a minimum, trained and qualified in accordance with ASTM C-1490-04 [4] which stipulates the minimum education levels, training and experience necessary for the team members.

Standardizing Measurement Techniques

In some areas there is still an absence of clear consensus on the standard assay methods to be used to solve what are essentially common problems. In particular, for high resolution gamma spectroscopy of drums, several competing methods have been developed including segmented gamma scanning (SGS), tomography gamma scanning (TGS) and far-field (FF).

The general rule of thumb here is the sites should simplify their processes as much as possible in particular where characterization is driven by geological disposal requirements and thus the purpose of the measurement is not driven by the need to characterize individual drums as accurately as possible but rather by the need to characterize the disposed waste on a repository element basis which may comprise large groups of containers. Thus, where possible, sites should look to deploy the simplest and most robust method in preference to more complex techniques as long as the safety of the shipping and handling process is not compromised.

For example where facilities have diverse streams of heterogeneous waste with multiple container sizes, the far-field method has many advantages over the SGS method in terms of throughput, maintainability and lifetime project cost. This benefit can many times outweigh the slight technical advantages bestowed by use of more complex methods such as SGS and TGS.

PORTABLE ASSAY METHODS

There is a growing need for on-site non-destructive assay (NDA) characterization activities in order to streamline the packaging and sentencing of radioactive waste in a cost effective manner. Portable and hand-held devices, particularly high purity germanium (HPGe) systems, are now widely deployed for this purpose benefiting from recent improvement in rugged digital electronics and battery operated detectors. The process of waste stream screening and segregation is nevertheless, a non-trivial exercise requiring expert knowledge and rigorous procedures to ensure data quality requirements are maintained in challenging environments.

Portable far-field High Resolution Gamma Spectroscopy (HRGS) assay is usually performed using a High Purity Germanium (HPGe) detector, a DigiDART™ multi-channel analyzer, and a laptop computer. The system is deployed using a suitable universal cart such as the PSC TechniCART™; figure 1 shows a typical arrangement.

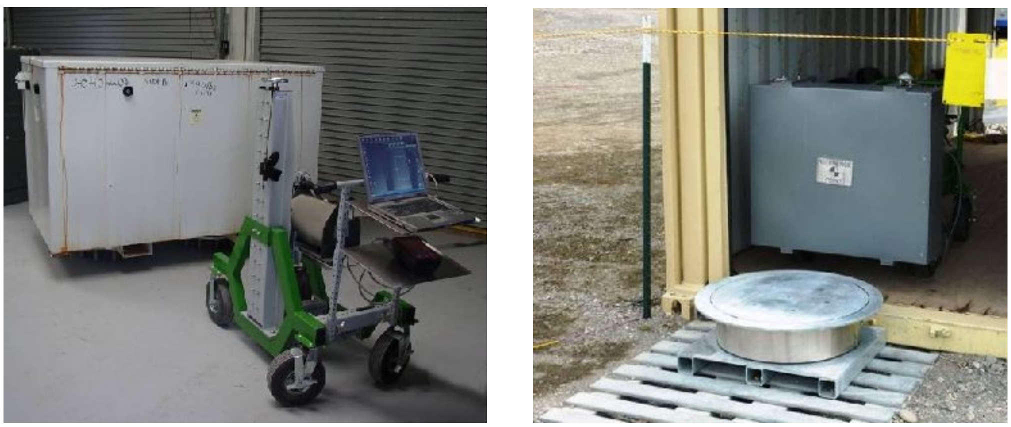

Fig 1 Portable NDA Equipment:
TechniCART™ (Left) and Neutron Slab Counter (Right)

The TechniCART™ is engineered for adaptability and flexibility to support up to 250 kg of detection & measurement equipment including heavy collimators. The HPGe can be accurately positioned up to 243 cm above the ground. The system allows for rapid reconfiguration including adjusting slide mechanism and a variable tilt adjustment. Flat free wheels permit movement through warehouse, dirt and gravel type terrain. This type of multi-use platform is ideal for portable NDA because it is lightweight, rugged and ergonomically efficient.

Hand-held Sodium Iodide (NaI) detectors may also be used to supplement the HPGe measurements in locating hot spots. Extensive evaluation of the assay requirements presented at DOE complex sites has determined that this is the most effective means to attain a quantitative assay suitable for the in-situ characterization.

In addition, portable neutron slab monitors (See Figure 1) are used for assays where gamma measurements are not suitable. The total neutron count is correlated to the primary neutron emitter after (alpha,n) emissions are corrected for from a knowledge of the chemical and isotopic composition of the waste (the latter may be measured by HRGS).

Importance of Measurement Procedures

After the portable NDA equipment has been set up on site, the measurement campaign usually begins with a set of one or more background measurements. In accordance with ANSI N15.36-1994 [5], the system is tested for proper operation before and after use in its operating environment. This is accomplished with a measurement of a Quality Control (QC) source. Three parameters are tracked to determine the HRGS system's functionality: peak centroid, peak Full Width at Half Maximum (FWHM) and peak net area.

QC tracking software is used to monitor the functionality of the system. Control Charts are often generated to provide long term tracking information that allows the analyst to rapidly diagnose systematic trends in system performance (e.g. slow degradation in detector resolution) and take early preventive action as appropriate.

Hot-Spot Scanning

The usual procedure for identifying 'hot-spots' (for large container assay) is to use a 3"x3" NaI Detector. Firstly, the operator will determine the gamma background of the measurement area by acquiring data in different directions around or near the item to be scanned. The item is then scanned by pointing the detector toward the item and moving the detector across all surface areas at a speed of about 10 cm/s with the detector as close to the surface as possible. For large boxes, the operator uses the "multi-point" scan method using up to 18 points on a box type container to detect gamma-ray anomalies or hotspots to assist with modeling.

Data Analysis

Nuclide quantification and sample modeling corrections may be performed using software such as ORTEC ISOTOPIC. This provides a practical solution to a wide range of gamma-ray measurement problems encountered in site characterization including the measurement of large boxes and drums. ISOTOPIC has been developed from work done originally at several US DOE sites in the analysis of thousands of fissile waste containers [6]. The analysis engine includes methods developed at the US Energy Measurements Laboratory to measure wide-area contamination of soils and surfaces.

A semi-empirical approach to efficiency calibration is used. ISOTOPIC provides a number of standard geometry "templates" from which a specific measurement template may be developed. This primary calibration, which can be traced to a certified standard, for any detector, is extrapolated or modelled to match the physical situation of the sample.

Minimum Detectable Activity (MDA) is calculated for each isotope. Unknown peaks are identified in the report file so that any nuclide not already found in the analysis library will be available to the analyst. The library can then be changed to include these nuclides. Activities, , or MDAs of a particular nuclide from multiple measurements of an item may be reported as weighted averages. The weighting is user definable by the analyst.

It is good practice for the data analyst to inspect the measurement for potential sources of bias such as due to matrix composition and density. The energy dependency in the activity is calculated at the various photo-peak energies in order to determine if a bias exists due to the matrix composition or the matrix density. If the reported activity constantly increases or decreases with energy then the inaccuracy is most likely attributed to the matrix density. If however, the variation in the reported activity has a more complex form then this is an indication of either self-absorption in a lump of the radionuclide being analyzed or deviations between the assumed and actual matrix composition. Careful data review is essential to remove this and other sources of bias in the model used to analyze the measurements.

Benefits: Screening and Segregation

Portable NDA equipment can quickly categorize and segregate bulk containers (drums, crates etc.) into waste streams defined at various boundary levels (based on its radioactive hazard) in order to meet disposal regulations and consignor waste acceptance criteria. Typically for LLW / TRU sorting this boundary is at 100 alpha nanoCuries per gram of waste (3700 Bq/g). Early screening and segregation of waste with portable NDA equipment allows the site operator to efficiently sentence and repackage the waste. Thus the throughput of containers to any downstream high sensitivity assay units (e.g. systems using passive or active neutron) can be more effectively controlled and managed. Repackaging of the waste at this stage can also ensure dose uptake minimization and reduce transportation and storage costs.

PORTABLE NDA EXPERIENCE

The following case histories provide valuable experience and lessons learned at sites in North America where many different waste streams and isotopic mixtures have been encountered.

Portsmouth Gaseous Diffusion Plant (PORTS)

NDA services have been performed at PORTS since 2005. The portable assay systems have measured thousands of items including drums, boxes, cans, bottles and HEPA filters. Uranium is the main element of interest for these measurements but all radionuclides detected are reported. Many of the waste items assayed at PORTS have been disposed of at Nevada Test Site (NTS) using this characterization data.

Los Alamos National Laboratory (LANL)

Portable far-field HRGS HPGe assay systems have been deployed at most technical areas at LANL to measure a wide variety of items including drums, boxes, cans, bottles, HEPA filters and glove boxes [7]. A wide range of radionuclides are encountered routinely from the measured items at LANL, including but not limited to Pu-239, Pu-238, Pu-240, Pu-241, Am-241, Am-243, Cf-249, Cm-243, Eu-152, Eu-154, U-235 and U-238. Since 2005, the portable NDA program set up at LANL has assisted in the measurement of thousands of items and continues to be part of the gamma spectroscopy group. The assay results are primarily used for transuranic (TRU) low-level (LL) sorting with many of the waste items having been disposed of at NTS.

Hanford

Portable far-field HRGS HPGe assay systems have been utilised at Hanford's 100 and 300 areas to characterize a wide variety of items including glove boxes, HEPA filters, pipe arrays, ducts and tanks. Innovative characterization techniques have been used to overcome significant challenges including remote characterization of the highly contaminated building 324 B-cell, and in-situ characterization of the building 327 dry fuel storage carrousel. These assay results are primarily used to guide and optimize D&D activities on the Hanford site.

Advanced Mixed Waste Treatment Facility (AMWTP) – at Idaho National Laboratory

The Advanced Mixed Waste Treatment Facility in Idaho processes transuranic (TRU) waste for shipment to WIPP. At AMWTP, various fixed and portable measurement instruments have been used to solve challenging measurement problems including assay of sludge, soil, high activity waste, depleted and enriched uranium, heat source and weapons grade plutonium, fission products, activation products, transuranics and other more exotic nuclides. Characterization has been performed of LLW, lead lined drums and remote handled waste using both historical data and field NDA measurements [8].

SUPERHENC

The SuperHENC system combines a high efficiency neutron assay with a high resolution gamma spectroscopy system in a single trailer for assay of drums and Standard Waste Boxes (SWBs) up to a maximum envelope of 138.4 cm wide by 94.0 cm high by 180.3 cm long.

The SuperHENC has, to date, been deployed at five locations in the United States Department of Energy (DOE) complex. Table I summarizes the deployment and WIPP certification history.

Table I. SuperHENC Deployment Sites

Site	Purpose	Waste Streams	WIPP Certification
Rocky Flats Environmental Technology Site (RFETS)	Waste Characterization	Heterogeneous debris waste in SWBs	January 2001
Hanford WRAP and Hanford PFP	Waste characterization and safeguards	Debris waste in SWBs	June 2005
Idaho National Laboratory (INL).	Waste Characterization	100-gallon drums of compacted waste (pucks), SWBs with sludge, debris waste	February 2007
Los Alamos National Laboratory (LANL)	Waste Characterization	Drums and SWBs of debris waste.	January 2010

SuperHENC Description

The SuperHENC is a passive neutron counter combined with high resolution gamma spectrometer. The neutron counter consists of arrays of He-3 detectors embedded in all six sides of the neutron counting chamber thus providing a high efficiency 4π neutron detector. The gamma spectrometer consists of a single High Purity Germanium (HPGe) detector and a turntable to allow viewing different sides of the SWB. The turntable also serves as a scale for weighing the SWB during the gamma measurement.

The neutron assay chamber utilizes a six-sided arrangement of polyethylene moderated He-3 detectors. The detectors are filled to ten atmospheres pressure and have various active lengths. The exterior of the neutron chamber is clad with eight inches of polyethylene to shield against exterior neutron sources. Passive neutron coincidence counting and multiplicity techniques [9] are used to quantify the Pu-240 effective mass content of the waste container.

SuperHENC measures the Pu-240e content using passive neutron coincidence counting and calculates the total plutonium content using either Acceptable Knowledge (AK) or direct gamma measurement for the plutonium isotopic mass fractions and other radionuclides present.

The neutron counter uses the Add-A-Source (AAS) method [10] for matrix correction and normalization. The AAS is a Cf-252 source attached to a Teleflex™ cable that travels under the neutron assay chamber, stopping at six pre-selected positions. When not in use, the source is retracted from the chamber and stored in a polyethylene pig. The INCC software calculates the measured response to the AAS, compares this to a reference count and calculates the matrix correction factor. The normalization is a simple and quick check on the empty neutron chamber counting efficiency compared to a reference initial source measurement.

The neutron system runs under a derivative of the Los Alamos National Laboratory (LANL) General Purpose Neutron Coincidence Counting (INCC) software [11]. Using the gamma spectrum, relative Pu isotopic and other nuclide fractions are determined which then are folded using PC-FRAM [12] with the neutron data to produce a final radioassay report.

SuperHENC at RFETS

At Rocky Flats, the SuperHENC needed to comply with WIPP and RFETS Nuclear Material Control and Accountability (MC&A) performance requirements for accuracy and precision [13]. The system was operated at RFETS for four years and was a key component in the shipment of over 4,000 SWBs to WIPP. Certification of SuperHENC was a significant technical achievement given the relevant data quality objectives that were originally developed for drums [14].

SuperHENC at Hanford

Several new challenges were faced with the systems that were built for deployment at Hanford. The original RFETS system was calibrated for segregated waste streams such that metals, plastics, wet combustibles and dry combustibles were separated by “Item Description Code” prior to assay. Furthermore, the RFETS mission of handling only Weapons Grade Pu enabled the original SuperHENC to benefit from the use of known Pu isotopics.

One system (SHENCA) was deployed at the Waste Receiving and Processing (WRAP) facility to measure TRU heterogeneous debris waste for sentencing to WIPP. A second system (SHENCB) was deployed at the Plutonium Finishing Plant (PFP) in support of the site’s Materials Control and Accountability (MC&A) program. These systems are depicted in Figure 2.

Fig 2. Hanford SuperHENC system

Operations at Hanford (and most other DOE sites) generate non-segregated waste streams, with a wide diversity of Pu isotopics. Consequently, the Hanford SuperHENCs were required to deal with the challenges presented by un-segregated waste matrices and also perform a real-time determination of isotopic grade for each box. The challenge was made more demanding as Hanford customer required that the system must be capable of Lower Limit of Detection (LLD) at an alpha activity less than 60 nCi/g (2220 Bq/g).

The system's software and calibration method were modified to meet these new requirements. Performance was rigorously tested and validated against the WIPP Waste Acceptance Criteria (WAC) [15]. These modifications together with the mobile platform make the SuperHENC far more robust to handle diverse waste streams and allow for rapid redeployment.

SuperHENC at Idaho

Following the closure of the RFETS site, Pajarito Scientific Corporation (PSC) refurbished the original SuperHENC for deployment at Idaho National Laboratory (INL) for assay of 100-gallon drums containing compacted 55-gallon waste drums (pucks), SWBs containing drums of sludge and SWBs containing debris waste. Original certification for the SuperHENC system was issued in February 2007. Soon thereafter, the Environmental Protection Agency (EPA) added Tier 1 approval to the SuperHENC's impressive list of credentials.

The relationship between LLD (in terms of g WG Pu) and Minimum Detectable Concentration (MDC) for the Idaho deployment is plotted in Figure 3 for plutonium with 6% Pu-240. The MDC is the parameter of most interest as this is used to evaluate the suitability of the instrument for waste category sorting against regulatory prescribed conditions (MDC is activity per unit mass of waste). LLD reaches its maximum value for the highest matrix mass, whereas MDC reaches its maximum value for the lowest matrix mass.

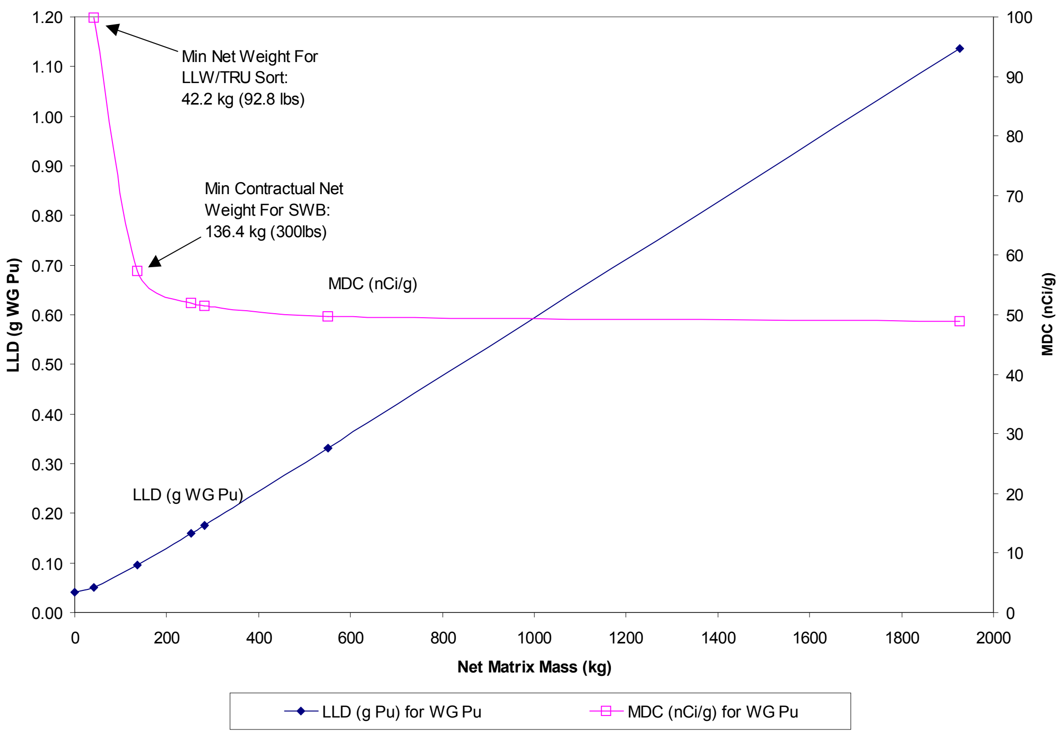

Fig. 3. SuperHENC LLD and MDC plot against net matrix mass at INL

INTERNATIONAL PERSPECTIVES

The definitions of waste boundaries can differ at the international level. Boundaries between low, intermediate and high level waste can depend on the national nuclear priorities. For example in the USA, waste management is divided between commercial and defense programs with separate definitions being applied although broadly the boundaries between surface and geological disposal are in consensus.

Some countries base category divisions on the half-life of the radionuclides of concern, whereas others define their boundary between heat generating and non-heat generating waste forms. An example of various boundaries is shown in Table II.

Table II. International Waste Definitions

<table>
<tr><th>UK</th><th>Some Europe</th><th>US Commercial</th><th>US DOE</th><th>Germany</th></tr>
<tr><td>LLW</td><td>LLW</td><td>LLW Class A</td><td rowspan="2">LLW –
Not HLW or TRU</td><td rowspan="3">Non-Heat Generating</td></tr>
<tr><td rowspan="2">ILW</td><td>SL-ILW $t_{1/2}$<30a</td><td>LLW Class B/C</td></tr>
<tr><td>LL-ILW $t_{1/2}$>30a</td><td>LLW GTCC</td><td>TRU</td></tr>
<tr><td>HLW</td><td>HLW</td><td colspan="2">HLW / SNF</td><td>Heat Generating</td></tr>
</table>

Despite the confusion that exists between boundaries, there is clearly a role for standardized NDA technologies in ensuring safe and compliant characterization of waste in many different countries. Table III demonstrates the common processes that give to the largest quantities of waste in each respective country.

Table III. Common Waste / Universal Processes

	UK	USA	China	Japan	Canada	Germany	Sweden
Nuclear Power Plants	✓	✓	✓	✓	✓	✓	✓
Commercial Reprocessing	✓		✓	✓			
Weapons program	✓	✓	✓				
Nuclear R&D Labs	✓	✓			✓	✓	

FUTURE CHALLENGES

Passive neutron non-destructive assay systems demand high sensitivity in order to be capable of detecting milligram levels of plutonium for waste characterization applications. Chamber efficiencies greater than 30% are required for neutron coincidence and multiplicity counting systems. Existing systems are based on He-3 proportional counters and require hundreds of liters of this gas. The severe He-3 shortage has created a driver to evaluate alternative detectors in this application.

Non He-3 neutron detection technologies that are currently being considered [16] for assay applications include alternative designs such as the next generation of advanced B-10 lined / high surface area tubes, Li-6F/ZnS(Ag) screens and advance elpasolites such as CLYC scintillators.

Another challenge that designers face is use of alternative neutron sources in response to the expected reductions in future supply of Cf-252. This nuclide is commonly used as a surrogate source to calibrate and test performance of passive neutron coincidence counting systems. The spontaneous fission neutron emissions of Cf-252 are a close approximation to nuclides commonly found in waste including Pu-240.

SUMMARY

Many improvements have recently occurred in the development of reliable and acceptable NDA programs. In the USA many sites have successfully met stringent regulatory requirements. Use of advanced technologies combined with the compliant operational processes and high expertise levels have emerged in parallel. This has enabled over 75,000 m^3 (or in excess of 145,000 containers) of contact and remote handled transuranic (TRU) waste to be disposed to date to a geological repository (the Waste Isolation Pilot Plant) from 10 different consignor sites.

Many of these techniques have applicability on an international basis for waste streams such as LLW, ILW, TRU and HLW. There are specific design aspects of assay equipment that must be tailored to meet the applicable regulatory requirements.

Host nations have specific challenges in terms of matrix types, processes, and availability of historical information and the requirement to measure all containers versus assay of a representative sample. For example, some load management practices (i.e. combining smaller packages into a larger package designed to meet waste acceptance criteria for the bulk container) may not have universal acceptability.

Systems will not attain widespread usage unless they can characterize all required input streams. One of the most common failure routes that has emerged from lessons learned is the ‘un-measurable container’ problem whereby a system is unable to produce a meaningful result when presented with a waste form with contents outside of the design envelope. System designers should therefore build failsafe mechanisms into the design. For example by including a simple dose-rate measurement into a complex neutron assay system, the instrument is able to default to “dose-to-Curie” approach to characterize a high gamma emitting drum.

Elimination of the “orphan” drum problem (i.e. drums that cannot be characterized into one or other waste class definition) is a far more useful capability to the overall waste management program than the ability to provide a small reduction in total measurement uncertainty.

Key features required for assay systems to ensure suitability for worldwide applications are as follows:

(i) **Ease of use.** In particular the system software must be operator friendly, well-tested and validated through appropriate levels of Quality Assurance.

(ii) **Simplicity.** Avoid where possible using overly complex, unproven techniques.

(iii) **Transparency**. Designers should eliminate the "black box" approach with well written system manuals, documentation together with comprehensive training and peer-review programs.

(iv) **Longevity.** Systems should be easy to maintain and trouble-shoot.

(v) **Full Automation.** Sites will benefit from reduced reliance on expert analysts through use of intelligent software and diagnostics,

(vi) **Supplier Support.** Long-term product support through appropriate contractual mechanisms throughout the project lifetime will enable site costs to be reduced.

(vii) **Future-Proofing.** Avoid use of obsolete or costly replacement parts.

(viii) **Source-free.** Avoid need for international import/export of radioactive sources, particularly those that require frequent replenishment.

(ix) **Non-hazardous**. Avoid used of hazardous materials and/or costly consumables.

(x) **Upgradability.** Sites should have the capability to deal with future diverse waste streams.

Two types of assay 'suites' that are capable of meeting these requirements for measurement of drums and larger boxes / crates: (i) Portable NDA using neutron slab counters and far field high resolution gamma spectroscopy and (ii) High Efficiency Neutron Coincidence counting combined with isotopic analysis (e.g. the SuperHENC) often deployed in a mobile platform.

Target countries (outside the United States) for these applications include: China, Japan, UK, Sweden, Germany and Canada. Each nation has its own waste category definitions arising from diversity in nuclear programs including commercial reactors, reprocessing, weapons production and research. The results of this study have demonstrated the versatility and flexibility of the two platforms studies for characterizing a diverse range of matrix materials. Waste forms such as combustibles, plastics, metals, compacted pucks, and sludge have been successfully measured to date in a wide variety of container shapes and sizes.

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