The Role of Piece Monitors for the Assay of Plutonium Waste in Alpha Plant Decommissioning Operations – 8425

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ABSTRACT

Plutonium contaminated (TRU) wastes arising during decommissioning and waste retrievals operations at a UK reprocessing facility include small process items, strippable coatings, size-reduced pieces of glove box and metal pipes, etc. These waste materials are generally assayed in a 'Piece Monitor' employing neutron coincidence counting and gamma assay technologies. The major function of the TRU D® Piece Monitor is to provide an accurate assay of the TRU content of waste pieces/packages, primarily for nuclear safety purposes. The Piece Monitor follows each waste measurement by calculating the cumulative plutonium content of a waste drum as it is filled with this waste, allowing maximum filling of the drum whilst ensuring it remains within fissile content limits.

TRU Piece Monitors are deployed at the interface between clean-air (C2) and the active decommissioning (C5) areas by attaching them to the wall of removable modular containment structures (MCSs). In the C5 area, the plant operator uses a variety of cold-cutting processes to size-reduce plant equipment and then places waste items in the monitor chamber for assay, prior to placing the waste in a 200 litre drum. The 're-entrant bulge' design of the assay chamber provides access from the active operations side, whilst the detection equipment remains in the C2 area. This ensures that the Piece Monitor equipment does not become contaminated and remains readily accessible for maintenance or repair. Piece monitors measure and report the plutonium content of each waste item immediately prior to placing in the waste drum, and provides a continuous 'tally' of the drum content. Warnings are shown when a drum is close to exceeding its allowable plutonium content and the waste drum can therefore be changed when either physically full or nearing its nuclear safety limits.

INTRODUCTION

The TRU-D® Piece Monitor is a safety related non-destructive assay instrument for the characterization of TRU waste, arising from the decommissioning of redundant alpha plants or from operating alpha plants. The TRU waste is generally solid waste containing a few mg to 500g Pu. The Piece Monitor's main function is to provide an accurate assay of the Pu content, and other radionuclides, of waste pieces/packages prior to drum filling for primarily criticality safety control, but also to aid efficiency of drum filling and accountancy purposes. The filled drum may then require a second confirmatory assay before consignment to waste stores depending on the safety case.

The Piece Monitor is just one solution for the management/assay of TRU waste. Every waste management project presents its own unique set of characteristics and problems, many of which require a radiometric assay employing gamma or neutron assay. The type of instrument will vary enormously depending on the format and nature of waste and other factors such as regulatory and economic issues.

ALPHA PLANT DECOMMISSIONING STRATEGY

The processing of plutonium and uranium is carried out in a series of process vessels and gloveboxes generally linked by tunnels and conveyors. In recent years the overall decommissioning strategy implemented for these plutonium facilities has been to decontaminate and to progressively remove waste, first from within the process gloveboxes and other vessels, then to remove the gloveboxes and vessels themselves and finally to identify and remove any contaminated areas of the cell floors and walls. This strategy leaves the structure of the building ready for refurbishment or demolition (Fig. 1.).

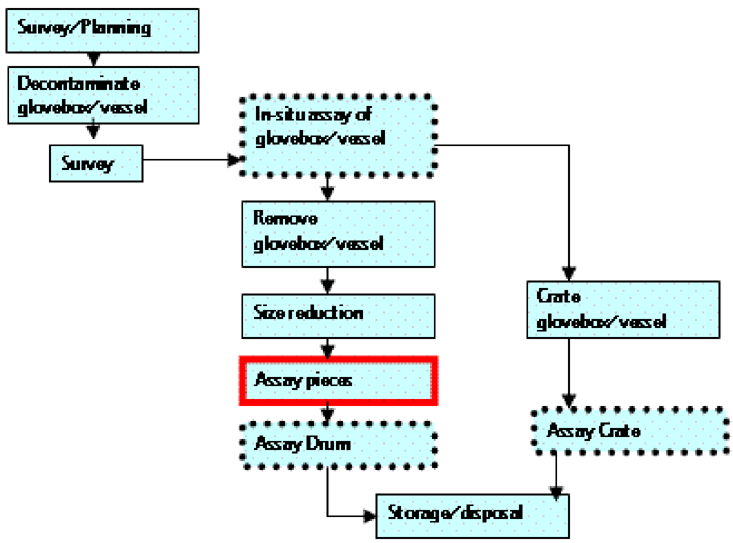

Fig. 1. Decommissioning Strategy for Alpha Plants

The decommissioning of alpha plant relies on the following criteria for basic criticality prevention:
Fissile Mass limitation, Safe Geometry and Limited introduction of moderators

There are three methods of criticality prevention used during decommissioning:

- Demonstrate using verified operational records, that there is insufficient fissile material for criticality based on a mass balance including errors.
- Measure the residual fissile material using passive neutron coincidence counting to demonstrate that the residual mass is less than the nuclear safety case limits.
- Ensure that each item is removed from the plant in a geometrically safe manner. The Piece Monitor forms a vital part of this strategy, monitoring the size reduced packages before they are exported in drums from the decommissioning area.

DEPLOYMENT OF PIECE MONITORS

In the decommissioning of a typical alpha plant, TRU D® Piece Monitors are deployed at the interface between clean-air (C2) and the active decommissioning (C5) areas by attaching them to the wall of removable modular containment structures (MCSs). The MCS contains a steel "Top Hat" which extends through the wall into the C2 area. The Piece Monitor is then constructed around this structure. The 'Top Hat' design of the assay chamber provides access from the active operations side, whilst the detection equipment remains in the C2 area. This ensures that the Piece Monitor equipment does not become contaminated and remains readily accessible for maintenance or repair. The design also means that a Piece Monitor can be easily redeployed to another decommissioning area at a later stage.

In the C5 area, the plant operator uses a variety of cold-cutting processes to size-reduce plant equipment and then places waste items on to a tray which is then loaded into the monitor chamber for assay. The Piece Monitor measures and reports the plutonium content of each waste item immediately prior to placing in the waste drum, and provides a continuous 'tally' of the drum content. Warnings are shown when a drum is close to exceeding its allowable plutonium content and the waste drum can therefore be changed when either physically full or nearing its nuclear safety limits.

The monitor uses a short assay time (typically 5 minutes) in order to maximise the throughput and efficiency of the size reduction and drum packing operations. Total measurement errors of less than 15% are usually obtained for Pu masses of the order of a few grams.

An accurate and automated assay and drum totalling system has a number of advantages over other methods of monitoring the drum filling process:

- Using a Piece Monitor prior to drum filling there is minimal risk of filling beyond the drum safety limits.
- Separating the piece assay from the drum filling port means that any sized drum can be filled.
- The automated nature of the measurement and drum totalling reduces operator calculation/transcription errors in the assay or totalling of the drum contents.

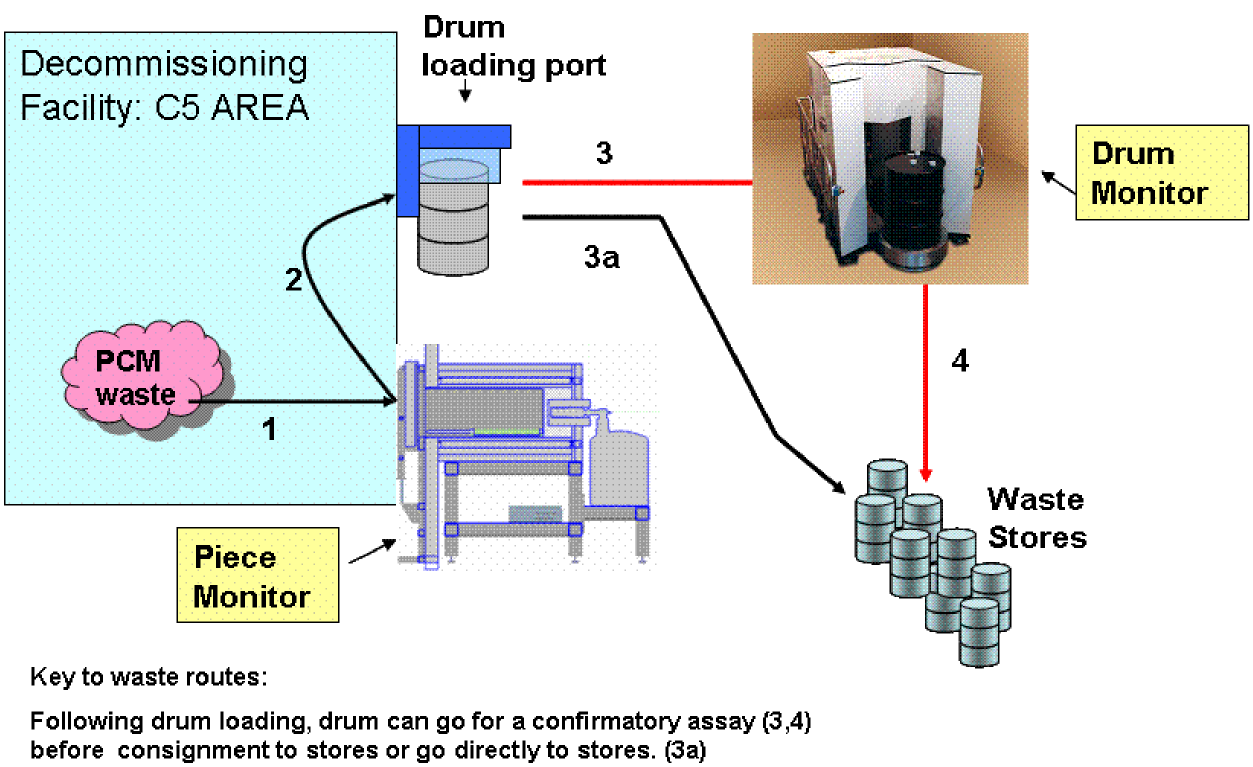

Fig. 2. Assay & Disposal route of PCM waste in the Decommissioning of Alpha plants

Seven Piece Monitors have been deployed within alpha facilities and continue to be used extensively for decommissioning operations within those buildings (Fig.3.). These systems have been successfully monitoring a range of materials from cut up sections of glovebox, metal pipes, process vessels, through to cut up sections of drums, concrete, soil, plus other waste generated during the decommissioning programme work itself including scaffolding poles, PVC tenting and PVC suits.

Fig. 3. TRU-D® Piece Monitors operational in alpha plants

The rigour of the calibration and reliability of the systems are such that safety cases can allow drums assayed by the piece monitors to be consigned directly to Interim Storage without confirmatory assay by a Drum monitor.

TRU-D® PIECE MONITOR ASSAY & ANALYSIS TECHNIQUES

PNCC Measurement Principles

The BIL Solutions TRU-D® Piece Monitor system comprises a high efficiency neutron measurement chamber utilising passive neutron coincidence counting (PNCC) technology to determine the plutonium-Pu-240 effective mass (Pu-240eff) of waste items and size-reduced waste pieces. The PNCC technique is the internationally accepted method for PCM assay [1] and ideally suited to the accurate measurement of Pu contamination on both high and low density wastes - unlike alternative gamma measurement based assay techniques that are adversely affected by the attenuating nature of metallic wastes.

Passive neutron coincidence counting systems exploit the fact that neutrons from spontaneous or induced fission are emitted essentially simultaneously. Thus measurements of particular nuclear materials can be made in the presence of ambient or (α, n) background sources. The output of the method is usually given in units of Pu-240eff: the mass of Pu-240 that would give the same signal as observed from the sample. For this reason PNCC is most effective when the isotopic composition is known or can be measured. PNCC is often used in combination with HRGS for Pu assay

HRGS Measurement Principles

The PNCC assay measurement result is combined with plutonium isotopic composition data from a simultaneous high resolution gamma spectroscopy (HRGS) measurement. HRGS systems detect the penetrating gamma emissions coming from an object of interest. The technique makes use of the unique fingerprint of discrete gamma energy lines emitted by each isotope to enable isotope specific measurements to be made. The plutonium isotopic composition is quantified using the internationally recognised MGA code [2]. This code has been successfully implemented in other PCM assay systems.

The instrument will provide the isotopic proportions of Plutonium in the range 2% Pu-240 to 30% Pu-240, representing typical low burn-up to high burn-up material. However on a single measurement by measurement basis the entire waste contents of the chamber will be assumed to be of a single isotopic composition. Whenever there is insufficient gamma signal, is available to determine a sufficiently precise Pu isotopic composition from the particular waste piece, or MGA fails to provide a reasonable answer, then stored ‘default’ isotopic data will be used to interpret the PNCC data. This default value will commonly be used where there is little or no plutonium contamination on the waste piece.

Data Analysis

Combining PNCC and HRGS isotopic composition data allows the quantification of total plutonium content for the measured waste item. The Piece Monitor will provide both "best estimate" and "nuclear safety" plutonium mass estimates. The best estimate value is used for material accountancy purposes and represents the most likely plutonium mass value associated with each item. The Nuclear safety value is calculated from the "best estimate" value with the addition of an uncertainty value that captures both systematic and statistical errors, (as defined in the UK NPL Good Practice Guide [3]), this value is used for "Criticality Control" to ensure that the plutonium content has not been underestimated.

The TRU-D® Piece Monitor also keeps a running total (or 'tally') for all waste pieces assigned to the current PCM waste drum. This requires the operator to open a drum "account" when a new drum is ready to be filled. The instrument will then assign all measurement results to that account until the operator closes the drum account due to its waste fill status or indicated plutonium content. If inclusion of the next measured piece would result in the drum content exceeding the Criticality Control plutonium mass limit then a warning will be given. When the current drum account is closed, the system prints out a drum summary, including the individual waste piece plutonium mass values, and the overall total content of the drum. The system therefore provides data for both materials accountancy and nuclear safety of drum filling operations to fully meet the needs of the defined Safety Functions.

System Calibration

The calibration methodology used on the system can vary significantly with the application and the decommissioning strategy.

For certain applications, the calibration will be based upon the worst case waste materials. Each measurement will assume this pessimistic calibration case in order to ensure that the nuclear safety mass is not underestimated. Such calibrations are primarily used when the filled drum will be consigned direct to interim storage and is not subject to further assay.

Alternatively where the waste items can be clearly segregated the system can employ multiple calibrations. Prior to the start of a waste item measurement the operator will select the appropriate waste type. The Piece Monitor will implement the correct calibration factors for this waste to ensure an accurate measurement. As a minimum this will include calibrations for 'soft waste' (plastics, wood, etc), which can have a significant effect on the measured neutron signal and 'hard wastes' (metals, rubble etc) which do not significantly affect the neutron signal. The selected waste type will be recorded with other measurement data.

A third calibration is also supported using a "flux probe" methodology to automatically select the most appropriate correction for the waste item. By including additional unmoderated He-3 neutron detectors (called flux probes) horizontally along and recessed into the corners of the measurement chamber, the observed ratio between the ratio of the count rate in the flux probes to that of the moderated detectors can be used to determine a empirical correction. The observed neutron coincidence count rate is then corrected for matrix effects caused by the presence of moderating material within the piece.

Mechanical Details of the Measurement Chamber

The BIL Solutions TRU-D® Piece Monitor system consists of a robust PNCC measurement chamber fabricated as a cuboid from high density polythene and containing an array of 12 embedded He-3 thermal neutron detectors. Within the measurement chamber these 5cm diameter He-3 neutron detectors are be mounted horizontally in a polythene moderator assembly. These detectors each have an active length that ensures good measurement precision and geometric accuracy. The detectors are arranged in a regular array with 3 per side in order to achieve a uniform response throughout the measurement chamber.

The measurement chamber is horizontally oriented so that it readily fits over a modular containment bulge (referred to here as the 'top-hat') from the C5 size-reduction area. The 'top-hat' is constructed from stainless steel and is designed to:

- Mate with the C5 area boundary wall.
- Maintain containment of the C5 area at its mechanical interfaces
- Fully support and accommodate waste pieces during both loading operations and measurement.
- Close the C5 end of the assay chamber during measurements.

The polythene moderator assembly is divided into two separate layers, an inner layer and an outer layer separated by a thin (0.5mm thick) sheet of cadmium. The detectors are embedded in the inner polythene layer. As the Piece Monitor may be used in areas having a significant ambient neutron background the outer polythene layer and intermediate cadmium sheet provide an effective neutron background shield. An outer cladding of stainless steel protects the internal polythene construction from damage and aids cleaning or decontamination of the instrument following completion of operations. Criticality control requirements for the Piece Monitor chamber are met by the inclusion of a second 0.5mm thick cadmium layer between the inner moderator assembly and the 'top hat' assembly. This layer effectively decouples the thermal and epithermal neutron fluxes between the measured waste item and all polythene in the chamber construction.

FEATURES OF THE NEW TRU D® PIECE MONITOR

Recently a new piece monitor system has been designed and commissioned allowing the proven techniques of the existing piece monitors to be upgraded to incorporate the latest in HRGS and Neutron Counting technologies. This system builds on the successful TRU-D® Piece Monitors, but is enhanced including improved piece loading/unloading, and an optimal counting time technique.

Improved Measurements Technologies

The neutron counting electronics employed on the system are the BIL proprietary Neutron Timestamping System[4]. This counting technology was developed to permit high speed processing of the neutron detector pulses, utilising a amplifier attached to each detector connected via local detector hubs to a time stamping PC. This system reduces the normal cable heavy architecture with a simple fibre optic ring transmitting the detector pulses to an acquisition PC. The normal coincidence counting cards are replaced with a software based multiplicity counting system allowing flexibility in data acquisition and storage. In the TRU-D® Piece Monitor a full neutron multiplicity acquisition is performed and stored allowing detailed re-analysis of the measurement data if required.

The simultaneous plutonium isotopic composition measurement of waste pieces are carried out using a fully integrated, germanium gamma detector (HPGe). This detector is positioned on a support framework at the end of the Piece Monitor chamber. The HPGe detector head will be located within a lead shield and collimator that ensures minimum gamma background interference while maintaining the measured waste item inside the chamber within its 'field of view'. A copper/cadmium filter is included to ensure successful operation of the detector in waste item contact dose-rates of up to 100mSv/hr (assuming predominantly 60keV gamma radiation from Am-241). This practical arrangement ensures that the periodic filling of the HPGe detector with liquid nitrogen can be easily achieved. Alternatively the recent production of reliable mechanical coolers for HRGS systems has permitted these "Electro cooled" system to be used in such applications. These electrical systems remove the requirement for a regular supply of liquid nitrogen.

The HRGS spectrum is then analysed using MGA in order to determine the plutonium isotopic composition of the waste item. The system can also be configured to identify other isotopes of interest such as U-235. Any waste item which also display a significant signal from this fissile isotope can automatically flagged for additional investigation in order to ensure that the nuclear safety mass based solely on the plutonium content is not underestimated.

Routine standardisation checks of the HRGS system during 'Standby Mode' are carried out using a radionuclide source that is moved by an electrical actuator between positions in the HPGe field-of-view and a shielded location. This is engineered for locations close to the HPGe detector (to minimise source activity) within the clean (C2) area. Standardisation will include detector energy calibration, detector resolution and detector efficiency checks. In addition, this actuator is removable from the assay chamber to allow manual source recovery if needed.

C5 Area 'Top-Hat' and Waste Tray Assembly

Waste for monitoring is placed into the C5 area bulge, or 'top hat' via a hinged and latched chamber door. The position of the TRU-D® Piece Monitor 'top hat' is at a vertical height that minimises the manual handling difficulties of heavy waste items for decommissioning personnel. The BIL Solutions design for the Piece Monitor is an integrated 'top-hat' door assembly that provides a practical loading and unloading arrangement for waste items into and from the assay chamber. To achieve this, the chamber door within the C5 area will be of sturdy construction and hinged along its lower edge. To access the chamber this door will lowered until at 90^{o} to the C5 wall, forming a fully supported, horizontal platform onto which a sliding tray from inside the 'top-hat' can be withdrawn. This sliding tray will support the waste piece and allow easy movement of waste pieces into and out of the 'top hat' (Fig. 4.). With the door opened and the tray pulled out by its handle, the tray height will be approximately 1000mm from floor level, this significantly easing the waste loading and unloading operations for the C5 area operators. A sensor fitted to the 'top-hat' door will monitor the door status during all measurements (e.g. during waste and background measurements) to ensure that the door remains closed at these times.

The standard measurement chamber and BIL Solutions 'top-hat' and waste tray assembly will fully support the waste item during measurement. The internal dimensions of the chamber will be 300mm high x 350mm wide x 500mm long. It should be noted here that the UK directive for manual handling of material recommends an upper limit of 25kg per person. However, the BIL Solutions TRU-D® Piece Monitor 'top-hat' assembly is structurally sturdy and exceed this mass limit to allow for wastes loaded by more than one person.

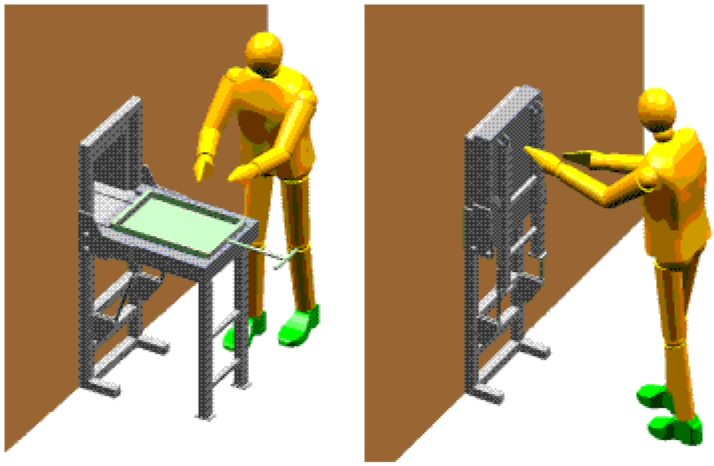

Fig. 4. Movement of waste pieces in the sliding tray (C5 Area)

From the operational experience of existing TRU-D® Piece Monitors the benefits of this chamber size include the following:

1. The manual handling of waste pieces up to these dimensions has been found to be acceptable by decommissioning personnel.
2. Waste pieces up to these dimensions generally provide better loading efficiency for 200 litre PCM drums.
3. The assumption of uniform Pu isotopic composition for the measured piece remains realistic and practical.
4. A compact Piece Monitor is better suited to areas having space limitations and is easier to install than systems designed for larger waste items.
5. Size reduction of waste to the TRU-D® Piece Monitor chamber size has not limited the operations of other Alpha decommissioning operations.

The external dimensions of the monitoring chamber are approximately 1600mm x 750mm with a height of approximately 1500mm. The overall length of the system with the C5 area door closed is approximately 1900mm (this is reduced if an electro cooled HRGS system is used)

The design of the monitoring chamber ensures that redeployment of this part of the Piece Monitor to other areas of is easily and readily achieved by withdrawing the chamber from the top-hat assembly and moving to a new location by pallet truck or fork lift. The top-hat and C5 door assemblies could be redeployed if sufficiently well decontaminated. However, the exposure of these system components to the C5 environment will probably result in a new top-hat and door assembly being fabricated for these follow-on deployments.

Optimal Counting Time

The TRU-D® Piece Monitor system also implements an optimal counting time methodology. Whilst the measurement is performed with a nominal maximum duration, if the required precision is achieved before the full measurement duration has elapsed then the measurement will stop and the result is reported. This methodology will minimises the time taken to perform piece measurements and increases system throughput.

Both the neutron and HRGS spectrum counts employ this methodology, by checking the uncertainty on the measurement result during the acquisition against a target precision. In addition to stopping when the required relative precision is achieved both systems also test the quality of the measurement.

For pieces with high plutonium contents there is little benefit in determining the measurement result to a high statistical precision when the fixed systematic uncertainties associated with the calibration will dominate the total measurement uncertainty. Therefore the Piece Monitor system can be configured to stop the acquisition when some appropriate target precision is achieved.

Similarly if there is little or no plutonium present in the waste there is no benefit in quantifying the low mass precisely if it can be rapidly shown to be under some suitable limit of detection. In such a case the HRGS spectrum will contain too few counts for an accurate MGA result within the maximum measurement duration, therefore acquisition can be stopped and the default value for the isotopic composition used. Similarly, if the uncertainty on the neutron system count rate confirms that the plutonium content cannot exceed the system limit of detection, then a mass result equal to the limit of detection can be quickly reported.

System Performance

The TRU-D® Piece Monitor system builds on the highly successful operational experience of previous Piece Monitors. BIL Solutions Ltd has enhanced performance in a number of key areas. Of particular importance is the utilisation of electronics and plutonium isotopic composition measurement using an HPGe detector and the internationally recognised MGA code. In addition, the Neutron Counting Technology employed provides an EMC compliant system to the industrial standard. The data analysis associated with the Neutron Counting Technology includes segment rejection and filtering algorithms to remove the effects of external influences such as transient background effects.

- Reported LoD (criticality control measurement) = <1.0g Pu (high burn-up Pu)
- Pu isotopic composition. = via MGA (2% 240Pu to 30% 240Pu)
- Count time = <10 minutes (typically 3 to 5 minutes)
- ‘Accountancy’ and ‘Criticality control’ total Pu mass estimates. Total Pu mass = Pu-238 to Pu-242 inclusive. (90% confidence interval that true Pu mass is below ‘Criticality control’ mass value.)
- Measurement range = LoD to >>500g Pu (high burn-up Pu)
- Operating gamma dose rate range = 0 to 100μSv/hr
- Overall chamber dimensions (footprint) = 160cm (long) x 75cm (wide) x 150cm (high)
- Assay chamber dimensions (internal) = 50cm (long) x 35cm (wide) x 30cm (high)
- Assay chamber weight = 935kg
- Standard two metre cubicle – weight 250kg

CONCLUSIONS

The TRU D® Piece Monitor has been successfully deployed in alpha plant decommissioning operations since 1992 to provide an accurate assay of the TRU content of pieces and packets prior to filling a drum for criticality control. The assay of pieces prior to drum filling means the fissile content of the drum is never exceeded and yet the potential drum fissile capacity can be fully utilised. Two results are reported to the operator: the “Criticality safety Pu mass” for nuclear safety considerations for drum filling drums and the “Accountancy Pu mass +/- total error” for accountancy purposes. The nuclear safety value is calculated as the best estimate plus all significant errors (including geometrical variations in efficiency, counting statistics, etc.).

The Piece Monitor can be used to assay known waste streams or can characterize the isotopic composition of any waste utilising HRGS. A wide range of material including metals, rubble, PVC, etc and off varying shapes and sizes can be measured which demonstrates the versatility of the system to the a wide range of assay challenges commonly found in waste management and decommissioning environments .

REFERENCES

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2. “Multi group Analysis MGA++, The MGA program Plutonium Isotopic Abundance by Gamma-Ray Spectrocopy” Ortec, 2002.
3. P. McCLELLAND, V LEWIS, “Measurement Good Practice Guide No.34 Radiometric Non-Destructive Assay”, National Physical Laboratory, 2003
4. The Neutron Counting technology is covered by International Patent W0 00/67044 and US patent 6912485

Operating plant requirements in such areas as security and emergency preparedness remain in force even when the reactor has been rendered inoperable and permanently defueled. To align staffing and programs with the low risk profile of a defueled reactor, plant owners must submit eight to 12 requests for exemptions and license amendments to the NRC for approval. The approval process normally takes about 12 to 18 months to complete.Â Decommissioning costs include three major components: labor, energy, and the transportation and disposal of waste materials. Specifically, the NRCâ€™s regulatory structure provides decommissioning funding assurance through multiple layers of requirements and limitations by Plutonium contaminated (TRU) wastes arising during decommissioning and waste retrievals operations at a UK reprocessing facility include small process items, strippable coatings, size-reduced pieces of glove box and metal pipes, etc. These waste materials are generally assayed in a 'Piece Monitor' employing neutron coincidence counting and gamma as View. Current institution. Transuranic Waste, Alpha Waste or Intermediate-Level Waste. Transuranic (TRU) waste is defined by DOE waste acceptance criteria (WAC)1 as waste that is contaminated with alpha-emitting transuranium radionuclides with half lives greater than 20 years and concentrations greater than 100 nCi/g (3700 Bq/g) at the time of assay.Â 1. Transuranic waste acceptance criteria for the waste isolation pilot plant (WIPP-WAC).Â To provide the complete information required for characterization of plutonium waste, the primary assay system is mated with a gamma isotopics system to provide the plutonium (and other actinide) isotopic ratios, the uranium enrichments, or, both in the case of measurements of Mixed Oxide Fuel (MOX). Radioactive waste management and dismantling and decommissioning of nuclear facilities are an essential public service whose title rests on the State and whose development is carried out by the Empresa Nacional de Residuos Radiactivos (Enresa). The main principles applicable are the followingÂ In this role, the Ministry defines the policy and strategy in relation to radioactive waste, spent nuclear fuel management and decommissioning of nuclear facilities.Â In the field of nuclear energy, the most relevant Spanish pieces of legislation are the following: â€¢ The Nuclear Energy Act 25/64, adopted in 1964. This law establishes the institutional framework.