

## **DESIGN AND OPERATION OF THE COMBINED TECHNOLOGY AUTOMATED WASTE CHARACTERISATION SYSTEM**

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### **ABSTRACT**

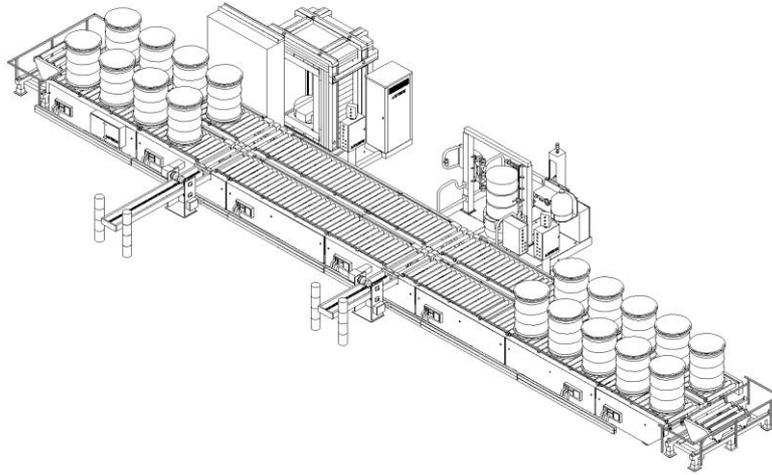
This paper describes the design and operation of the Combined Technology Automated Waste Characterisation System (CTA-WCS) at JRC Ispra. The WCS was designed for the measurement of fission products and uranium and plutonium containing waste arising from nuclear fuel and nuclear materials processing and reactor operations. The WCS covers a range of activity including Low and Intermediate Level Waste (LLW and ILW). The system is designed to measure the waste in 200 and 400 (440) litre drums with a maximum drum weight of 1500 kg. Gamma-ray measurements of radio-nuclide content are performed by a gamma ray measurement station which functions as either a Segmented Gamma Scanner (SGS) or Tomographic Gamma Scanner (TGS). Either of these two techniques may be employed to perform the functions of drum screening, non-destructive examination (NDE) and, where appropriate, final drum assay. Coupled to the gamma ray station is a surface dose-rate measurement station, which employs 6-shielded Geiger-Muller detectors. Active and passive neutron measurements are performed by an advanced, graphite lined Differential Die-away (DDA) system, which comprises the neutron measurement station. The DDA performs conventional passive neutron totals and coincidence counting and active DDA total neutron counting. Data analysis is based on the use of a range of matrix calibrations, some determined by Monte Carlo analysis. Linking the gamma ray and neutron measurement stations is an automated roller conveyor with a 20 drum buffer capability and a weight measurement station. Drums are identified by bar code reading technology. Once loaded, the system performs automatic assay of up to 20 drums and then returns the drums to the buffer position on the conveyor. The WCS is now in routine operation. Results will be presented from the period of one year Pilot Operation during which the system was optimized and waste drums were measured.

### **INTRODUCTION**

The Combined Technology Automated Waste Characterisation System (WCS) is implemented at the Joint Research Centre (JRC) Ispra, Italy, which is operated by the European Commission. This paper describes the operating characteristics and the operation of the system during a pilot period of operation following the completion of commissioning. Details of the WCS have been described elsewhere [1-3].

In order to adequately characterise and quantify radioactive waste generated at the JRC Ispra over a period of some 50 years, the WCS incorporates several different measurement technologies. These include drum weight measurement, surface dose-rate measurement, gamma-ray measurements of radionuclide inventory, and neutron measurements to quantify plutonium and uranium in the waste. The WCS is designed

to measure waste in both 220 and 440 litre drums. The 440 litre drums may weigh up to a maximum of 1500 kilograms. The drums may contain a variety of matrices including waste, which may be homogenous, heterogeneous, hard and soft. Decommissioning and legacy waste from nuclear fuel processing may also be present.



**Figure 1. Combined Technology Automated Waste Characterisation System**



**Figure 2. Photograph of the JRC Ispra Waste Characterization System (WCS) showing the tandem conveyor with the gamma measurement station in the foreground and the active/passive differential die-away based neutron measurement station towards the far end of the conveyor.**

The WCS is an automated system designed for unattended operation. It is designed to measure a maximum of 20 drums in a 24 hours period without operator supervision. The layout and configuration of the WCS is illustrated in the concept drawing, Figure 1, which shows the tandem conveyor system, the gamma measurement station with a drum in the measurement position, and the neutron measurement station with the chamber door open. Figure 2 is a photograph of the WCS in current operation at JRC Ispra.

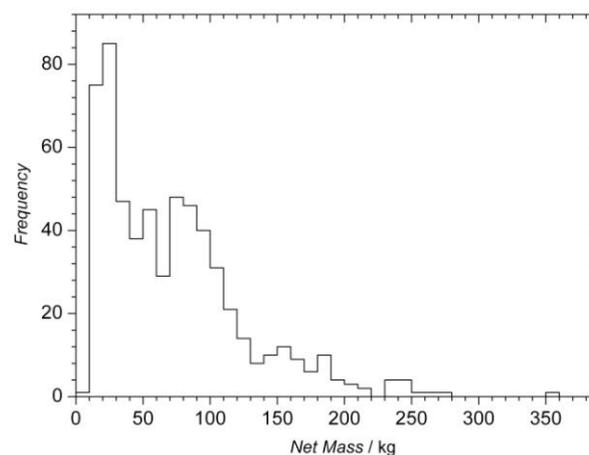
## PLANT AUTOMATION

The WCS constitutes a distributed control system with a Facility Control Computer (FCC) controlling automatic operation. The Measurement Control Computer (MCC) controls the measurement process, which takes place at the individual measurement stations. The FCC communicates directly with a Programmable Logic Controller (PLC), which controls the roller conveyor. All system interlocks and the emergency stop system is implement through the PLC. Ethernet and Fieldbus technology is used to implement internal communication between the individual components of the overall system.

Drums are loaded onto the WCS conveyor in a semi-automatic manner from the Drum Transfer System (DTS). The WCS can be operated in either automatic or manual mode. Prior to the commencement of automatic measurements the operator sets up a measurement task through the MCC. The measurement of up to a maximum of 20 drums per batch can then take place automatically. In manual mode, the operator can control each step of the measurement process. Prior to starting the measurement sequence, the operator establishes a measurement task, which directs which drums are to be measured by the different measurement stations.

## DRUM WEIGHT MEASUREMENT

The WCS is fitted with an accurate load cell, which is used to determine drum weight. The data from the load cell is recorded as part of the drum data and used in characterising the drum matrix. Each drum is weighed before dose-rate, gamma or neutron measurements are performed. Figure 3 is a frequency distribution of the drum net mass in kg for a range of drums with different matrices including Technological Combustible, Metal and Cement. Note that a majority of drums have a density of  $0.5 \text{ g.cm}^{-3}$  or less.



**Figure 3. Frequency distribution graph of the Net Mass in kg of the drums measured during WCS pilot operation. No distinction has been made between the different matrices (Technological Combustible, Metal, Cement).**

## DOSE-RATE MEASUREMENTS

The gamma-ray measurement station incorporates three different measurement functions as shown in Figure 4. The first of these is surface dose-rate measurement. The second and third measurement functions are performed by a Tomographic Gamma Scanner (TGS), which operates in either SGS or TGS mode. Surface dose-rate data is recorded for each drum passing through the WCS. A total of 6 Geiger-Muller (GM) detectors are positioned around the drum. Three measure the dose of the side, one measures the dose above and another the dose below. A final GM detector is positioned to measure the dose at a distance of 1 metre from the drum surface.



Figure 4. This is a photograph of the Gamma Station showing the dose-rate measurement position in the foreground and the TGS-SGS to the rear.

The maximum dose-rate is determined for each drum and a frequency distribution of maximum dose-rates measured at a distance of 5 cm from the drum surface is plotted in Figure 5 below.

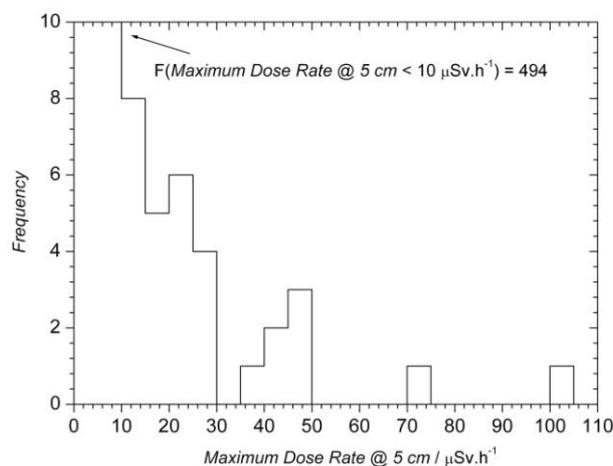


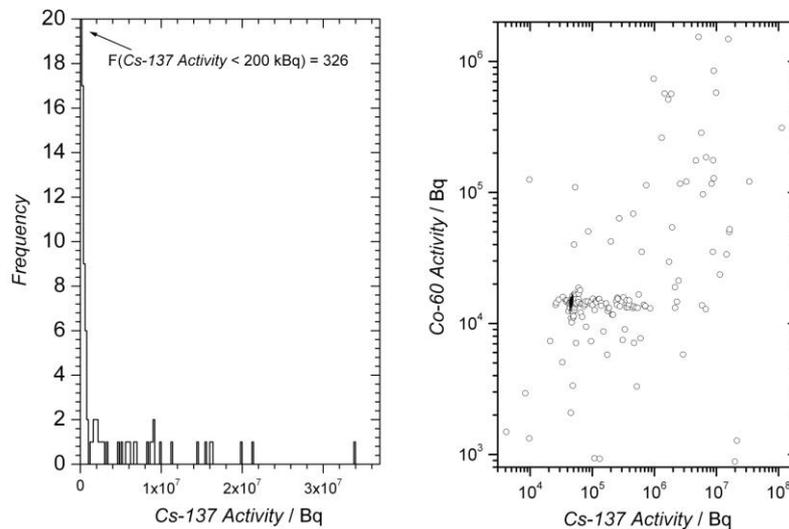
Figure 5. Frequency distribution graph of the Maximum Dose Rate in  $\mu\text{Sv.h}^{-1}$  of the drums measured during WCS pilot operation. The dose rate is measured at a fixed distance of 5 cm from the surface of the drum.

## GAMMA-RAY MEASUREMENTS

Gamma-ray measurements of waste drums are performed either by Segmented Gamma Scanning (SGS) or by Tomographic Gamma Scanning (TGS). The TGS measurement is used less frequently, for investigating difficult heterogeneous drums for which SGS measurements are likely to result in large errors. To date, most measurements have been conducted using the SGS so this paper will be concerned with that technology. The SGS measures the drum in segments (or vertical layers), typically 16.

All measurements are conducted in two-pass mode with separate emission and transmission measurements. The transmission measurement is applied to determine the average density per segment. This information is used to provide an attenuation correction for the emission measurement for each segment. In the process of the transmission measurement the transmission source shutter is opened to expose the transmission source. The transmission source employs an Eu-152 gamma ray source, which had an initial activity of 30 mCi (1.1 GBq).

For the emission measurement, the transmission source shutter is closed and the HPGe detector acquires a gamma-ray spectrum for each segment or layer of the drum. From the spectrum obtained for each segment the radionuclide content of the segment is determined based on a calibration. Figure 6 displays a frequency histogram of measured Cs-137 activity in Bq for drum measurements performed during pilot operation and a logarithmic plot of the Cs-137 activity as a function of Co-60 activity for each drum. As expected very few of the drums measured in the pilot phase of operation have a high gamma ray activity.



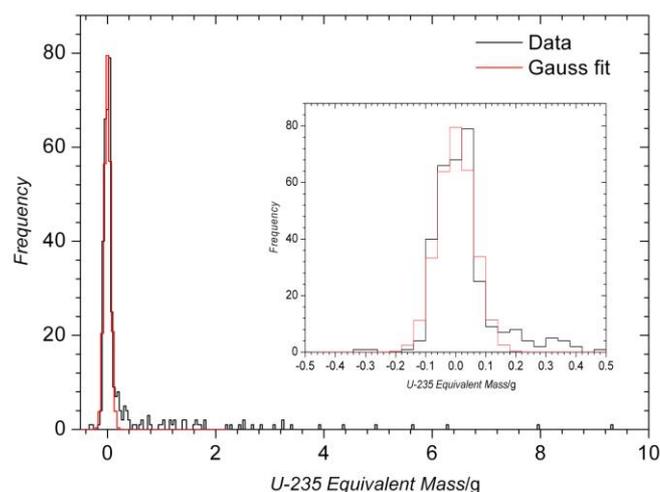
**Figure 6. Left: Frequency distribution graph of the Cs-137 Activity (Bq) for the drums measured during WCS pilot operation. One drum with an exceptional high content of 1.1E+8 Bq is not included in the graph. Of the 349 reported SGS measurements 326 of these have an activity below 200 kBq. Right: Graph showing both the Co-60 and Cs-137 activities.**

## NEUTRON MEASUREMENTS

Both active and passive neutron measurements are made using the WCS. Neutron measurements are reserved for those drums where plutonium or uranium are suspected or known to be present. If, for a particular waste stream, neutron measurements are unnecessary then the neutron measurement station may be bypassed according to the measurement task set up in the MCC before the measurement batch is started. In passive counting mode, the neutron station operates as a conventional Passive Neutron Coincidence counter employing neutron correlation [4] for measuring plutonium using neutron pairs and neutron total count rates. By counting the correlated neutrons arising from the spontaneous fission of the even numbered plutonium isotopes, the Pu-240eff is determined. By combining the Pu-240eff mass with the plutonium isotopic ratio information obtained from gamma ray measurements or using default values the total plutonium mass is determined.

In active neutron counting mode, the neutron station operates as a Differential Die-away (DDA) system. In conventional DDA totals counting mode, pulses of neutrons are used to interrogate the waste drum, which is placed in the chamber of the neutron station. A neutron generator is used to generate 14 MeV neutrons that are slowed down or moderated in the chamber graphite lining. The combination of neutron generator and graphite lining provides a source of thermal neutrons that induce fission in the U-235 and Pu-239 that may be present in the waste drum positioned in the measurement chamber. Fast neutrons, which arise from induced fission, are measured by cadmium shielded and polyethylene moderated He-3 detector packages that surround the measurement chamber. These same detector packages are used to count the fast neutrons that arise from spontaneous fission in the even numbered isotopes of plutonium during passive neutron measurements.

Figure 7 shows the frequency distribution of U-235 equivalent mass measured during the active neutron interrogation of technical combustible waste drums.



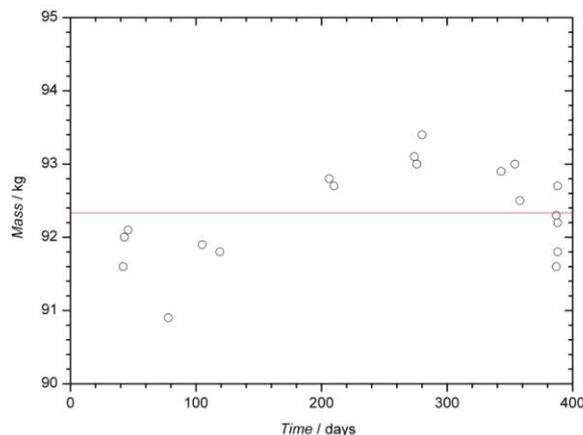
**Figure 7. Frequency distribution of U-235 Equivalent Mass (g) for active neutron measurements of technical combustible drums.**

From a historical knowledge of the waste at JRC Ispra we know that a considerable fraction of the drums contains little or no fissile material and only activation products. When these drums are interrogated in the Active Neutron DDA the measured signal will be equal or very close to that of the active background of the calibration drum with the same matrix. There will be a minor difference between the measured net signal of the real waste drums and the calibration drum of the same matrix, because of variations in fill factor, density or hydrogen content. Due to the relatively large number of variables one can assume a Gaussian shape to the distribution.

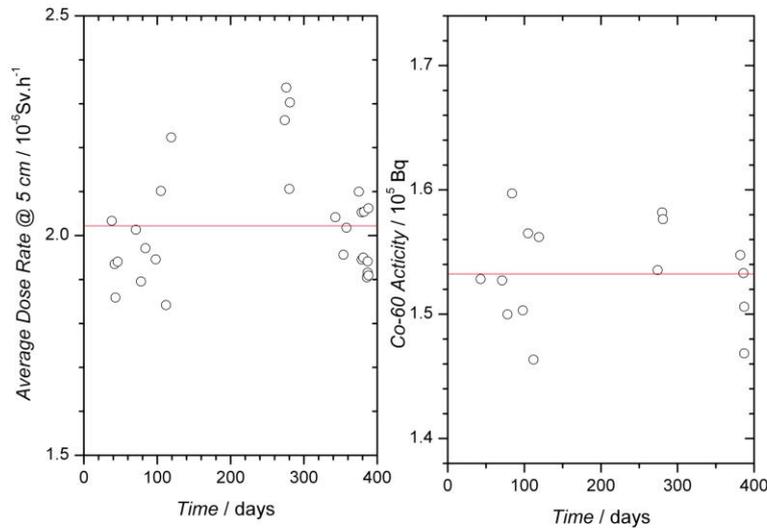
By subtracting the constant signal corresponding to the calibration drum, for instance with a technological combustible matrix, but without fissile material, the resulting Gaussian distribution is centred around zero as can be seen in Figure 7. The width of the Gaussian depends on counting statistics as well as the variations in the drum matrix (we assume that all the drums coinciding with the Gaussian do not contain fissile material). The frequency distribution of the measured drums is asymmetric: the frequency corresponding to the positive U-235 equivalent mass is larger than that of the negative side, revealing a limited number of drums with a small content of fissile material.

## QUALITY ASSURANCE MEASUREMENTS USING A STANDARD QUALITY CONTROL TEST DRUM

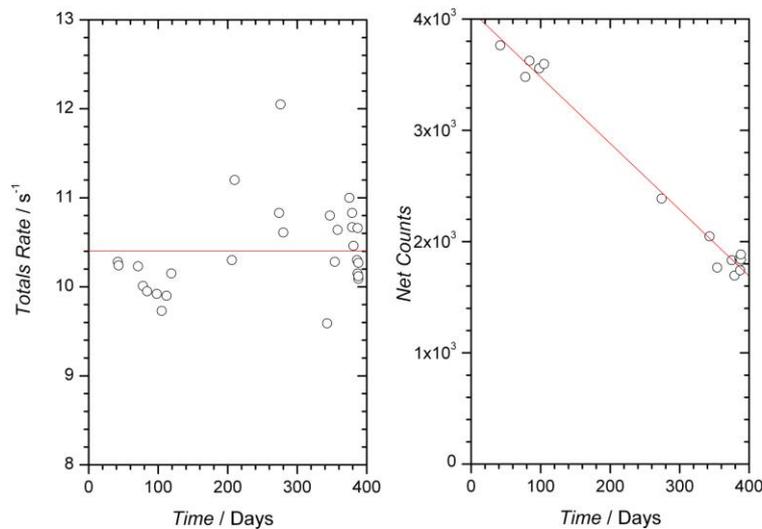
In order to confirm correct operation of the WCS and to validate the measurement data obtained for each batch of drums a Quality Control (QC) test drum is normally included in each batch. The QC test drum contains a calibrated gamma-ray source and a calibrated californium spontaneous fission neutron source. The QC test drum may be placed anywhere in the sequence of drums to be processed and is measured by the system as if it were a standard waste drum. Only at the time of data analysis is the drum identified by the WCS as the QC test drum by means of its unique barcode. The measured data is then subject to a comparison with stored reference values. Using the QC test drum measurements, control charts for the operation of each of the measurement stations can be maintained. The measured data for the drums in the batch is validated if successful measurements of the test drum have been performed.



**Figure 8. QC chart for the total mass of the QC test drum with technological combustible matrix (including the tare weight of 25.2 kg for the drum and 23.1 kg for the puck on which the 220 litre drums are placed for the movement on the conveyor rollers).**



**Figure 9. QC charts for the technological combustible QC drum with a small Co-60 source. Left: Average Dose Rate at 5 cm from drum surface. Right: Decay-corrected Co-60 activity from SGS.**



**Figure 10. QC charts for the technological combustible QC drum without nuclear sample. Left: Passive Neutron Counting (Passive Background). Right: Active Neutron Counting (Net Counts is equal to Early Gate Counts – Late Gate Counts) (Active Background).**

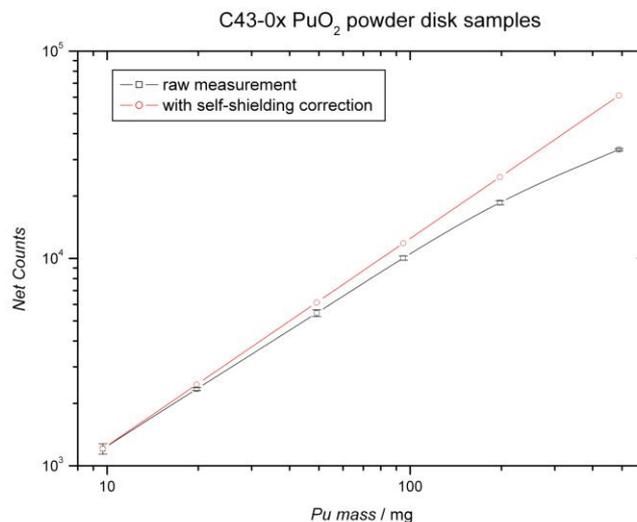
The graphs (Figures 8 to 10) display a sample of data from the technical combustible QC test drum employed over a period of more than a year during the pilot operation phase. There are gaps in the data as other test drums were used for other matrices (such as the metal matrix) and the system was taken out of operation for modification, upgrades and maintenance during the period. The large gap in the QC chart for Active Neutron Counting is related to a short circuit inside an inductor of a pulse forming network, which is part of the neutron generator power electronics. Unfortunately it took 84 days to repair the unit, between diagnosis, preparation of shipping documentation, shipping to the US, repair, return shipping, customs delays, installation and testing. The breakdown of the inductor was probably caused by a combination of a manufacturing defect and the high ambient temperatures in the

facility. In fact the temperature in the facility housing the WCS was not well controlled over period of pilot operation and on various occasions the hall temperature reached 27 °C. This effect has contributed to some of the scatter in the measured mass of the QC test drum data, which can be seen in Figure 8.

It should also be noted that a relatively small Co-60 source with activity of 350 kBq (10 µCi) on 15 November 2003 was used as the check source. At the start of the pilot operation period the source had declined to a value of 153 kBq (4.1 µCi). With hindsight it is clear that the source is too small and is close in value to the background, some of which is coming from the large Eu-152 transmission source (original activity 1.1 GBq or 30 mCi). This explains some of the scatter in the dose-rate measurement and the SGS measurement (Figure 9).

The polyethylene shielding of the neutron measurement chamber reduces the passive neutron background from waste drums located near the neutron detectors (Figure 10). Figure 10 also shows the decline in the output of the D-T neutron generator during the pilot operation period and is consistent with expectations.

Disk PuO<sub>2</sub> standards were measured as part of the validation process for the active neutron DDA. The results are displayed in Figure 11. Because self-shielding effects are significant for these large sources, a Monte Carlo simulation was performed and the linear data corrected for self-shielding is also displayed on the graph.



**Figure 11. Net counts as a function of total Pu mass for PuO<sub>2</sub> disk standards. A Monte Carlo simulation has been used to model the self-shielding effects for these large standards.**

## CONCLUSIONS

The WCS has been shown to perform successfully as a comprehensive automated waste assay tool for the measurement of 200 and 440 litre drummed waste with a wide range of activity and matrix type. Automated and unattended batch runs of up to 20 drums have been successfully demonstrated in a 24 hour period. A significant number of drums have been measured and many repeat measurements have been performed as part of the process of WCS validation. During the pilot operation period a number of modifications and upgrades have been implemented in order to improve

operational efficiency of the measurement components and drum automation process. The WCS has now entered a period of routine operation and plays a significant part in the accelerating process of decommissioning legacy nuclear facilities and processing legacy radioactive waste at the JRC Ispra Site.

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