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Characterisation of the gamma measurement station of the JRC Waste Characterisation System

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Executive Summary

The European Commission is committed to protect the general public and the environment from undue radiological hazards. It has therefore developed a Decommissioning & Waste Management (D&WM) Programme for all nuclear sites of the Joint Research Centre (JRC). In JRC Ispra, the Nuclear Decommissioning Unit (NDU) of the Nuclear Safety and Security Directorate is in charge of activities of decommissioning and waste management to get the JRC Ispra site to the green field.

In JRC Ispra, there are several ongoing projects for the preparation of the decommissioning of several nuclear facilities such as nuclear research reactor, charged particles accelerator, nuclear waste storage etc. In addition to well established activities of decommissioning, NDU is also offering open access to the scientists to use its facilities in theirs R&D projects to face the future challenges of the nuclear decommissioning and waste management which is foresee to grow rapidly.

This report is a deliverable of one the mentioned R&D projects which aim of enhancing non-destructive assay techniques and application of imaging techniques such as tomography for nuclear decommissioning and waste management activities. This report describes one of a large facility designed for the characterisation of low and intermediate nuclear waste. This facility is called Waste Characterisation System (in short WCS). WCS was commissioned at the end of 2007 by the A.N Technology Ltd. (UK), i.e. ANTECH, operated for many years then interrupted for few years until the managerial decision was taken to refurbish it and put it in operation. The main parts of WCS are the two measurements stations for waste drums based on gamma spectrometry and neutrons. The gamma station operates two characterisation protocols, the segmented and tomographic scanning while the neutron station is based on passive and active neutron interrogations.

This report describes WCS, provides the mean features of the facility with respect to the nuclear decommissioning and waste management. Results of measurement campaigns of calibrations drums are reported and show promising perspectives to the validation of the facility regarding nuclear regulation authorities.

1 Introduction

This report describes the design and the characteristics of the Waste Characterisation System (in short WCS) at JRC Ispra. The Decommissioning and Waste Management (D&WM) programme started in 1999 is managed by the JRC G.9 directorate of Nuclear Decommissioning Unit of the JRC Ispra. The JRC's Decommissioning and Waste Management Programme is aimed at the progressive elimination of the Centre's Historical Liabilities, i.e. those nuclear R&D facilities and radioactive waste management installations that have no future role in supporting the mission of the JRC. It main objectives are to decommission the shut-down nuclear facilities (research reactors, nuclear and radiochemical labs, waste management facilities), and to manage the resulting waste together with the old waste. The Waste Characterisation System was commissioned at the end of 2007 by the A.N Technology Ltd. (UK), i.e. ANTECH, for the measurement of fission products, uranium and plutonium in the waste arising from a vast form of waste in the past as well in the future from the nuclear activities still on-going at the JRC Ispra site.

The WCS was designed to analyse 220 and 440 litre drums and to produce assays that include surface dose rate measurement, Tomography Gamma-ray Scanning (TSGS), Segmented Gamma-ray Scanning (SGS) and active and passive neutron assay.

In this context the MetroDECOM II WPks3 under the (ITSP) project. It has the aim to characterize the two measurement stations for up to 400 litre waste containers constructed in Area 40 on the JRC Ispra site. It has the target to validate a new waste characterization system for LLW and ILW. This work package also includes the non-destructive measurement of fissile materials. Measurement campaigns on both real and simulated waste containers will be carried out and the performance of the systems will be characterize in terms of detection limits, accuracy, measurement time.

2 JRC Ispra Decommissioning & Waste Management programme

The shut-down nuclear installations in the past have produced waste in different forms: liquid, solid and gaseous. In addition, the nuclear fuel cycle yielded nuclear materials which need to be taken care of.

The programme is highly dependent on the Italian regulatory framework, in particular for the licensing of the decommissioning activities. As JRC-Ispra radioactive waste will have to be disposed in a national centralised repository (not existing yet in Italy), JRC agreed on appropriate management criteria for such waste, in order to condition it in an adequate form. The Ispra D&WM Programme includes the management of radioactive waste and nuclear materials coming from past research activities (so-called “historical liabilities”) as well as the decommissioning of operational nuclear installations and of the waste management infrastructure (so-called “future liabilities”).

The current programme will require dismantling the following nuclear installations:

- ESSOR and Ispra-1 reactors, shut down in 1983 and 1973, respectively.
- LCSR – "Laboratorio Caldo Studi e Ricerche": a series of hot cells used for a variety of studies, progressively shut down in the 1990s.
- STRRL – "Stazione Trattamento e Raccolta Rifiuti Liquidi Radioattivi": the old liquid effluent treatment plant which has been recently replaced by a modern facility (STEL).
- FARO – Fuel Assemblies (melting) Release Oven, functioning as a light-water reactor severe accidents testing facility, shut down in 1999.
- RCHL – Radiochemistry Laboratory, used for radio-analytical chemistry support to other JRC activities and radiobiology research, progressively shut down in the 1990s.

The JRC-Ispra DWM programme has five main objectives [Ref. (1)]:

1. Keeping obsolete installations safe in accordance with the safety standards in force
2. Constructing or improving of waste characterisation, treatment, conditioning and interim storage installations
3. Recovering, treating and reconditioning existing waste
4. Conditioning nuclear materials with a view to their storage on-site or their transfer to third parties
5. Decommissioning of obsolete installations and managing the resulting waste

The programme will be concluded when the Ispra site will be brought to the “green field” status. A condition reached after the decommissioning process where building and land are released free of any radiological constraint with an estimated completion on 2030.

In particular the 2nd DW&M programme activity, supra mentioned, is supported by the R&D group from G.II.7 Nuclear Safety and Security Unit directorate that in the context of MetroDECOM II WPk3 has been working on the validation of a waste characterisation system for low and intermediate level radioactive waste.

2.1 Waste Characterisation System

As already mentioned above, one of the aims of MetroDECOM II, WPk3's task is to characterize the newly refurbished gamma-ray measurement station in terms of characteristic parameters for measurement of standard 220-litre waste drums LLW and ILW. The measurement sequences and the analysis method will be described in this report. The measurement campaign will make use of simulated waste matrices and both radioactive and nuclear sealed sources of well-known content in order to determine reliable performance values in preparation for the measurement campaign using real LLW and ILW packages in Task 3.3.

Besides due to the presence of fissile materials in the waste it is required to estimate the alpha content of the waste item, as well as the fissile material content of the waste has to be reporting to nuclear safeguards authorities. This task intends to investigate the performance of an active/passive neutron measurement station that can be achieved in an industrial-size system for producing declarations of fissile material content in standard waste containers.

Those tasks are described and performed respectively by the characterisation of the two stations: TGS/SGS station and Passive/Active Neutron station.

The Waste Characterisation System (i.e. WCS) was commissioned in order to measure fission products and plutonium containing waste of 200 and 400 litre drums with a maximum drum weight of 1500 kg. It consists of a Gamma-ray Station (see Figure 1 and Figure 2) and an Active/Passive Neutron Station. Those stations will be described in details later in the appropriate sub-sections. The WCS layout consists (see Figure 2) of an automated conveyor to measure a maximum of 20 drums in 24h unattended. The tandem conveyor system has on the front a weight station (see Figure 1 the drum in the front at the measurement position) and a Bar-code scanning unit that identify the drum from a specific batch selected by the operator. Then the drum move automatically in the conveyor (the right one on the Figure 1 while the left conveyor buffer is to hold the remaining drums to be measure in the batch). After that through the conditions set by the operator at the Measurement Control Computer (MCC) the drum can move automatically to one or both of the measurements stations: the forward Gamma-ray station and the backward Neutron Station.

In front of each measurement systems two loading beams are in place in order to load the single drum inside the Gamma-ray or the Neutron Station in automatic or manual mode (see Figure 2).

The Facility Control Computer is linked to the automation of the system and communicates with the MCC and the Programmable Logic Controller (PLC), which control the roller conveyor through a set of laser positioning system on the conveyor. Then each measurement stations as a dedicated PC (under WinXP®) to control the status of the measurement as well dedicated software to analyse the acquired data and produce a measurement report from a ANTECH fixed template.

Figure 1: The JRC Ispra Waste Characterization System (WCS) showing the tandem conveyor with the gamma measurement station in the foreground and the neutron measurement station towards the far end of the conveyor. (Source: JRC, 2019).

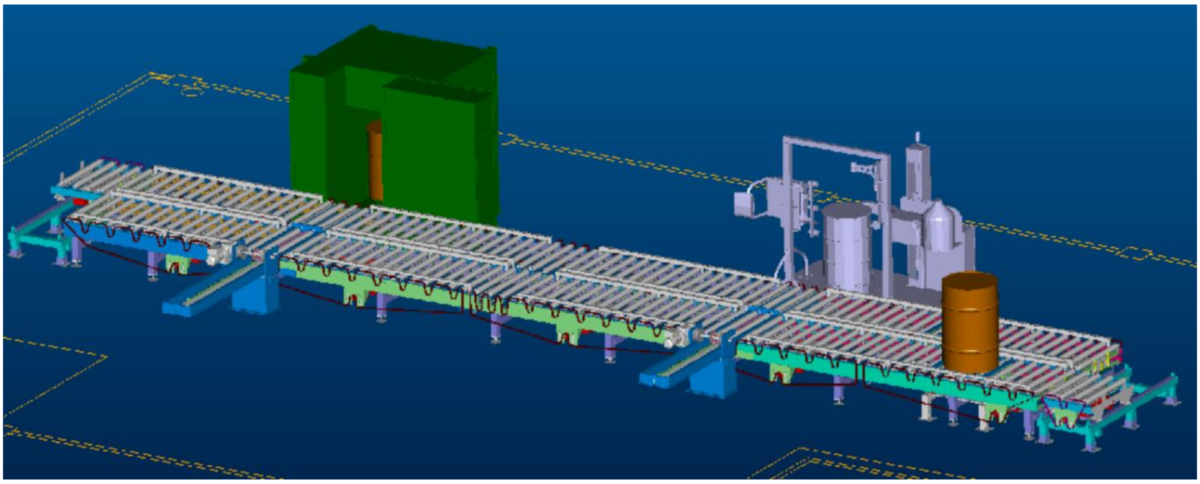

Figure 2: Waste Characterisation System layout (Source: JRC, 2019).

2.1.1 Gamma Station

The Gamma-ray station has the function, when the drums are loaded into the Gamma–ray station to measure the drum content in one of both of the two analysis mode: Tomography Gamma Scanner (TGS) or Segmented Gamma Scanner (SGS). The operator is able to choose one of the two through a set of input controlled by the MCC that it is linked to the individual measurement instrument computers. In the report the acronym TSGS (Tomography Segmented Gamma Scanning) will be used in order to indicate a procedure that include both of the two scanning mode SGS/TGS without the necessity to differentiate them.

The Gamma measurement station (see Figure 3) is able to perform three different measurement functions: surface dose rate, segmented gamma-ray scanning and tomography gamma-ray scanning. The surface dose rate is achieved by employing 6 Geiger Muller counter detectors around the drum. Three measure the dose on the side, one the dose above and another dose below. The last GM detector is positioned to measure the dose at a distance of 1 m from the drum surface.

Figure 3: Pictorial view of the Gamma-ray station from different point of view. On the left from the beam loader and on the right from the acquisition electronic chain side. (Source: JRC, 2019)

The principle components of the TSGS are (see Figure 4):

1. A plinth with levelling and fixing points;
2. A pillar with vertical scan slide that supports the HPGe detector and the Dewar and an arm that holds the 152Eu transmission source;
3. Liquid nitrogen Dewar;
4. The rotating table on horizontal slides that receives the drum, takes it to its measuring positions, for Dose Rate and TGS, and provides the horizontal and rotation motions for the scan process;
5. The shielded 152Eu source support;
6. The transmission source holder with sh9utter.
7. A drum support to allow drum loading with beams (220L/400l drums resting on pucks);
8. A facility electric interface wiring cubicle;
9. A control cabinet housing motor drives etc.

Those components are the same used either for the TGS or for the SGS mode.

At the beginning of the loading operation from the beam loading station the operator has to decide which mode is going to use for the measurement and he will need also to choose the correct type of tungsten collimator in front of the detector (see Figure 4): Square or diamond shape. The diamond shape it is used for the TGS mode whiles the square shape for the SGS mode (i.e. one for a 220L drum and another one for 400l). The tungsten collimators are inserted in a lead shielding around the Ge crystal.

The electronic Gamma-ray chain consisted of the following:

1. A GEM serie High-Purity germanium (HPGe) coaxial detector system with a crystal size of 65.8 x 72.3 mm size. Relative efficiency 50% (on 137Cs) and FWHM 0.855keV (122 keV 57Co gamma line);

2. A ORTEC DSPEC50® Digital Signal Processing Gamma Spectrometer with Ethernet/USB connectivity to the PC Master Scan system (16k ADC Conversion Gain, List mode, single MCA and high count rate applications capabilities);

3. An ORTEC 419 Precision Pulser Generator that generates an electronic pulse at 1974.5 keV for energy stabilization and dead time correction;

4. Optical Ethernet connectivity to the FCC.

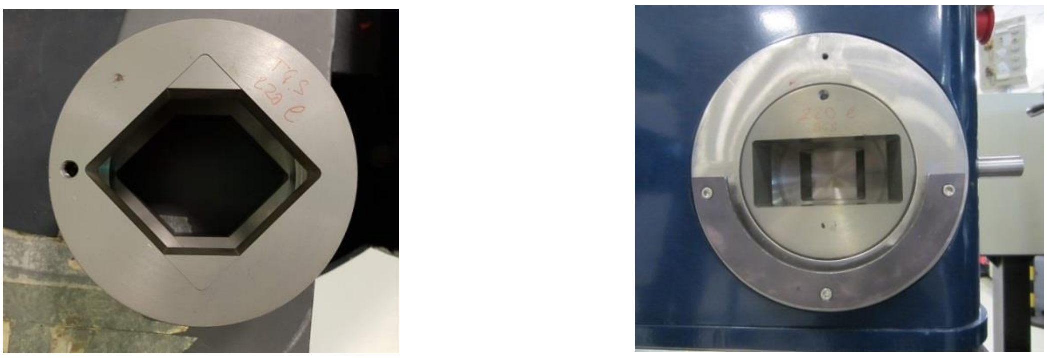

Figure 4: On the left the tungsten diamond shape collimator for the TSG mode and on the right the tungsten square shape collimator for the SGS mode inserted in the lead shielding surrounding the Ge crystal (Source: JRC, 2019)

In the following picture is possible to identify the different electronic components of the Gamma-ray electronic chain as well their position on the moving arm of the TSGS (see Figure 5).

Figure 5: The gamma-ray electronic chain at the Gamma station. From the top to the bottom: the digital pulser, the DSPEC50 digital multichannel analyser and on the back side of the tungsten collimator the HPGe detector (red arrows). Also showing the supporting arm (yellow arrow) (Source: JRC, 2019).

From now on the system will operate in different mode in relation to the operator choice: SGS or mode. The SGS and TGS share common electronic and mechanical components but they require different setting parameters from the operator that it will be describe in the following sections.

2.1.1.1 *Segmented Gamma Scanning*

The Segmented Gamma Scanning (SGS) system will use a square tungsten/shield collimator in front of the HPGe and a sequence of transmission and emission spectra stored. To perform this measurement is assumed to have a uniform distribution of the materials in the drum (i.e. homogenous matrix).

The transmission source, as explained before (see Figure 3), consisted of 152Eu source of about 1 GBq in a lead shielding holder on the same horizontal axis of the HPGe detector at about 418 mm distance. A shutter will also control the opening and closing of the transmission source shutter.

A typical measurement in SGS will consist of a transmission measurement in the open position (at the top of the drum in an open shutter transmission condition). Then the drum will start to rotate around is vertical axis and a set of segmented vertical scanning (i.e. typical 16 segments of 100 s grab time) will be registered by the gamma spectrometry acquisition system (MAESTRO Ortec®) in emission mode. At which the transmission shutter is closed to prevent influence from the transmission source. At the same time at each of 16 segmented vertical emission scans will be associate a transmission scan in order to take in account of transmission coefficient for the tested matrix drum. As it is showed in Figure 6 the Master Scan program will show during the measurement the sequence of the steps in progress and the remaining time of one measurement drum scan in relation to the initial setting of the operator (i.e. grab time and number of layers).

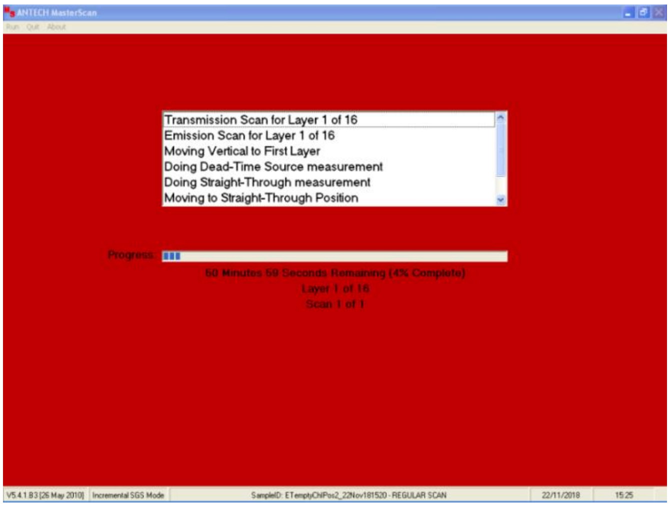

Figure 6: Master Scan control system during the SGS measurement (Source: JRC, 2019).

Then the system transfers the data to the Master Analysis and creates a total sum of the 16 emission spectra with the corresponding transmission coefficient for the specified drum matrix. It also calculates the radio-nuclide content and then the activity of the drum for the selected radio-nuclides. The data are then transferred to the Master Analysis that is responsible for the setting up of the parameters (Correction factor that taking in account the detector efficiency, the energy calibration and the transmission coefficient) and to generate a final data analysis report (see Figure 7).

As you can see from the data analysis report (see Figure 7) is possible to extract the total activity to any specific radioisotopes that are inserted in the material type submenu of the Master Analysis program. In the material type are defined all essential physics characteristics of the radioisotope energy peaks (ROI) to be analysed in the drum (i.e. energy peak, lifetime, branching ratio).

ANTECH

MasterAnalysis Software V4.1.10.B13 [02 July 2010]

Data Analysis Report

Machine Name:	WCS-DTGS	**Assay Type:**	SGS_TCO220_1.04
Container ID:	ETemptyChlPos1_22Nov181	**Lump Correction:**	No
Seal No.:	Not Enabled	**Number of Grabs:**	1
Acquisition Date/Time:	22/11/2018 14:20:00	**Grab Time:**	100000
Analysis Date/Time:	22/11/2018 15:38:11	**Number of Layers:**	16
Operator:	SecurityDisabled	**Gross Weight:**	52.00 kg
Container Type:	SGS_220_16	**Tare Weight:**	45.51 kg
Material Type:	LIB02	**Net Weight:**	6.49 kg
		One Pass:	False

Pre-Analysis Comment:
No Comments Entered

Post-Analysis Comment:
No Comments Entered

Energy Line (keV)	SGS#	Calibration Correction Factor	Dead Time Correction Factor	Bias Correction Factor	Reported Bq
Am241 - 99	-3.49	1.736E+006	1.00	1.00	-6.065E+006 +/- 3.219E+005
U238 - 114	0.63	3.492E+006	1.00	1.00	2.193E+006 +/- 1.280E+006
Pu241 - 149	-1.60	1.750E+008	1.00	1.00	-2.795E+008 +/- 4.889E+007
U235 - 186	1.54	7.178E+002	1.00	1.00	1.107E+003 +/- 2.610E+002
Ba133 - 356	0.20	1.220E+003	1.00	1.00	2.487E+002 +/- 3.448E+002
Pu239 - 414	-0.43	6.016E+007	1.00	1.00	-2.577E+007 +/- 1.501E+007
Eu152 - 444	-0.85	2.991E+004	1.00	1.00	-2.547E+004 +/- 2.982E+003
Sb125 - 463	-0.10	9.328E+003	1.00	1.00	-9.730E+002 +/- 2.486E+003
Cs134 - 605	-0.98	9.570E+002	1.00	1.00	-9.362E+002 +/- 1.289E+002
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cs137 - 662	145.26	1.203E+003	1.00	1.00	1.748E+005 +/- 2.640E+003
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nb95 - 766	-0.50	1.177E+003	1.00	1.00	-5.926E+002 +/- 1.182E+002
Cs134 - 796	-0.30	1.424E+003	1.00	1.00	-4.277E+002 +/- 1.051E+002
Nb94 - 871	0.04	1.217E+003	1.00	1.00	4.592E+001 +/- 1.223E+002
Eu154 - 1005	-0.02	7.660E+003	1.00	1.00	-1.792E+002 +/- 5.960E+002
Co60 - 1173	-0.09	1.517E+003	1.00	1.00	-1.430E+002 +/- 1.222E+002
Eu154 - 1274	-0.10	4.630E+003	1.00	1.00	-4.751E+002 +/- 2.836E+002
Co60 - 1333	-0.02	1.582E+003	1.00	1.00	-3.596E+001 +/- 8.872E+001

Figure 7: Example report produced by master analysis using a known 137cs radioactive source with a 220l TCO drum. (Source: JRC, 2019)

Calibration standards are pre or user defined by using the Calibration Standards screen accessible from the main menu in Master Scan program. If a calibration standard is not defined is possible to create a new one through the Master Scan menu (i.e. for a specific number of radioisotopes is possible to insert the mass and the energy of interest, ROI). Also from the Master Scan is possible to define the drum to be measured (e.g. 220L drum), its weight and the number of vertical layers to split the drum (e.g. 52 kg and 16 layers).

During the 2018 year and beginning of 2019 the JRC research team with the support of the Bouygues Construction Services Nucléaires was able to solve some IT issues as well some mechanical complication with sensors on the conveyor, updated the digital multichannel analyser and the gamma spectrometry software.

Then it has performed a complete set of gamma measurements on all available 5 different matrixes in order to characterize the SGS system and the used parameters. The following standard matrixes have been used for a drum:

1. Empty
2. Technological waste, combustible (TCO)
3. Technological waste, non- combustible (TCO)
4. Metallic (MET)
5. Cement (CEM)

The JRC research team performed a series of measurements with different sources (i.e. 137Cs and 60Co) and all the 5 different matrixes have been used. The used standard 220L drum has been characterized by using radioactive sources in 7 different channels and for each at three different vertical positions (i.e. top, middle and bottom) on the drum (see Figure 8) in order to verify the position dependence vs. measured activity.

Figure 8: Standard 220l drum for SGS using a Cs-137 source in each of the 7 different channels (Source: JRC, 2019).

Following is the table representing the extracted activity data from the Master Analysis program (grab time = 100sec for each layer). In particular this data represent the activity variation of only a 137Cs source in the 16 layers positioned at the middle height in the Channel A in 220L drum. The superimposed histogram in the Table 1 shows the position consistency activity with the actual setup.

Somma di Activity	Etichette di colonna			
Etichette di riga	Co60 - 1173	Co60 - 1333	Cs137 - 662	Totale complessivo
Layer 1	69.019	78.471	402.373	549.863
Layer 2	169.67	283.575	579.772	1033.017
Layer 3	442.969	199.793	746.576	1389.338
Layer 4	563.103	591.927	1167.671	2322.701
Layer 5	1825.555	2193.296	8983.39	13002.241
Layer 6	5494.099	4806.499	24856.303	35156.901
Layer 7	9026.781	8106.362	42741.876	59875.019
Layer 8	10048.46	9752.414	50554.766	70355.640
Layer 9	8903.538	8625.729	42716.338	60245.605
Layer 10	6338.532	5477.916	27994.931	39811.379
Layer 11	2477.708	2139.641	7771.401	12388.750
Layer 12	659.153	813.687	1358.021	2830.861
Layer 13	470.752	289.12	512.252	1272.124
Layer 14	199.644	213.023	313.085	725.752
Layer 15	208.793	297.323	592.351	1098.467
Layer 16	287.786	206.754	353.995	848.535
Totale complessivo	47185.562	44075.53	211645.101	302906.193

Figure 1: Measured activity of a 137Cs radioactive source from the Master Analysis data extraction in relation to the 16 scanned layers in a TCO 220l drum (Source: JRC, 2019).

All the 7 channels have been showed an activity consistency in the vertical position plus a minus one layer (each layer is ~ 5 cm) for a 137Cs and 60Co sources. Extra investigation will be conducted on the extreme positions, top and bottom where the higher vertical differences in comparison to the actual source position have been found for a 137Cs source.

The JRC research team has also investigated the measured activity of a 137Cs source in the three vertical positions (i.e. top, middle and bottom) in different matrix drums. Following is an example of a 220L empty drum where the 137Cs source was positioned respectively in the top, middle and bottom vertical position (±1 cm). It is evident a huge discrepancy between the calculated value of

2.56+E05 Bq and the measured value in the three positions (i.e. respectively 2.35+E05, 2.68+E05 and 1.20+E05) for all channels. The closest value is obtained only in the middle vertical position and in the central "A" channel. In the plot (see Figure 9) are represented with a red, dash blue and dash light blue lines respectively the calculated activity, the negative variation of 10% and the one -20 % from the calculated 137Cs activity. The actual condition that create a >50 % underestimation of the 137Cs activity is some condition has been further investigate in different matrix calibration drums and the analysis is in progress.

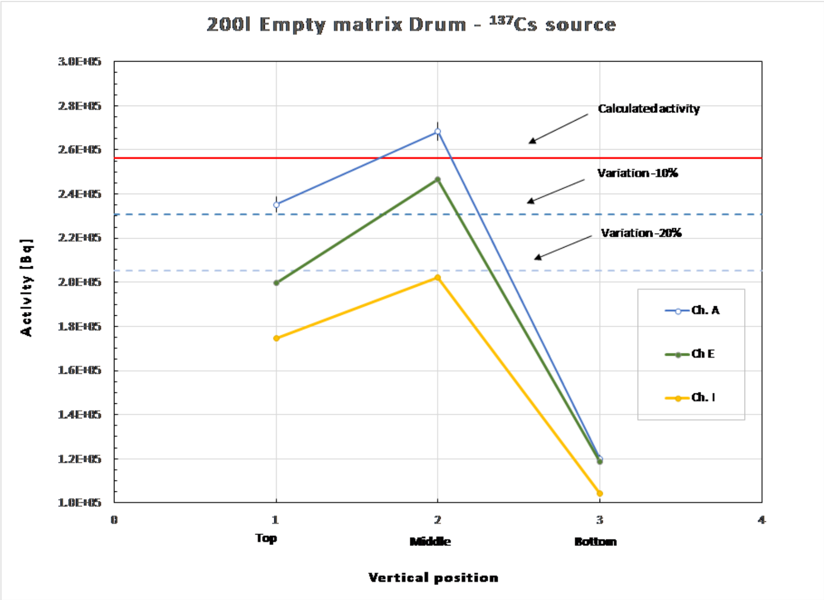

Figure 9: 137Cs activity variation vs. the vertical position in an empty matrix drum of 220l (Source: JRC, 2019).

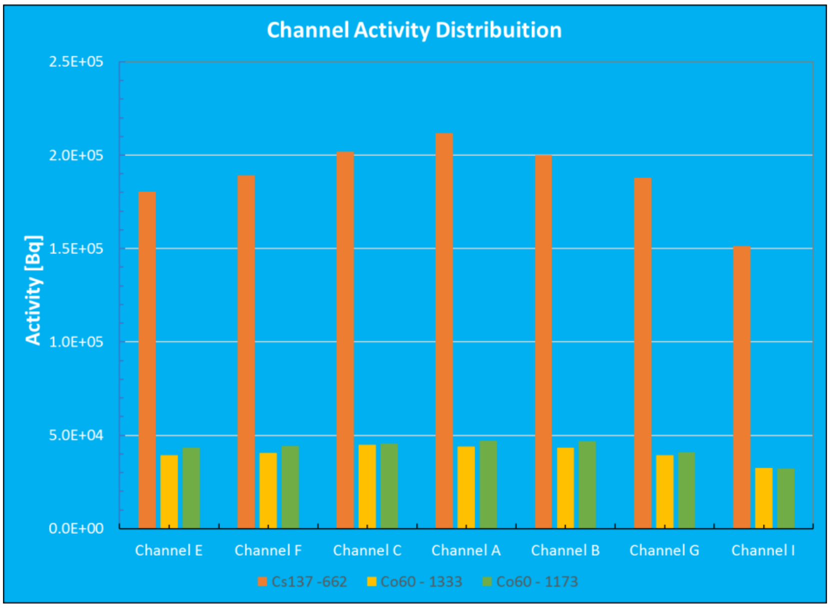

Figure 10: Activity distribution of 137Cs and 60Co sources in relation to the channel positions (Source: JRC, 2019).

The SGS has been also used to characterize a CBNM standard of Pu61 in the central channel at a middle height and in an empty modified calibration matrix drum (see Figure 11Figure 11). The drum had an aluminium structure to be able to insert the CBNM type samples available at the JRC Ispra. The holder is constituted by 4 channels distribute as in the following picture and by a 'carrot', a hollow Al cylinder, that contain the CBNM standard at three possible different vertical positions. As the following gamma spectra showed, it was possible to identify the 241Pu radioisotopes from his gamma line (208.0 keV) and the 241Am gamma line (59.5 keV). In this way the presence of Pu will be possible be identified also from the Gamma Station and then verified is content with the Neutron Station.

Figure 11: Aluminum carrot holder of different sides for PU CBNM standard sources in aluminum structure with 4 different channels (on the left picture). The 'carrot', a hollow aluminum cylinder, is able to position the CBNM standards a three different height (on the right picture) (Source: JRC, 2019).

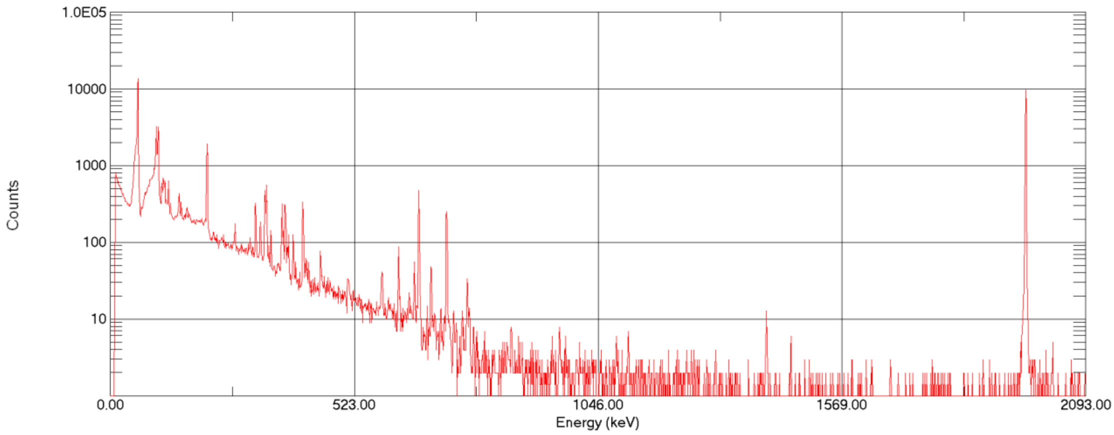

Figure 12: Gamma-ray spectra of a CBNM Pu61 standard in an empty matrix 220l drum for 528s with visible the 241Pu gamma line (208.0 keV) and the 241Am gamma line (59.5 keV) (Source: JRC, 2019).

2.1.1.2 Tomography Gamma Scanning

The TSGS extends the range of gamma-ray measurement technology as it is able to correctly determine the radionuclide inventory in heterogeneous matrices. The TGS has the capability to generate images of the distribution of both absorbers and radionuclides within drums.

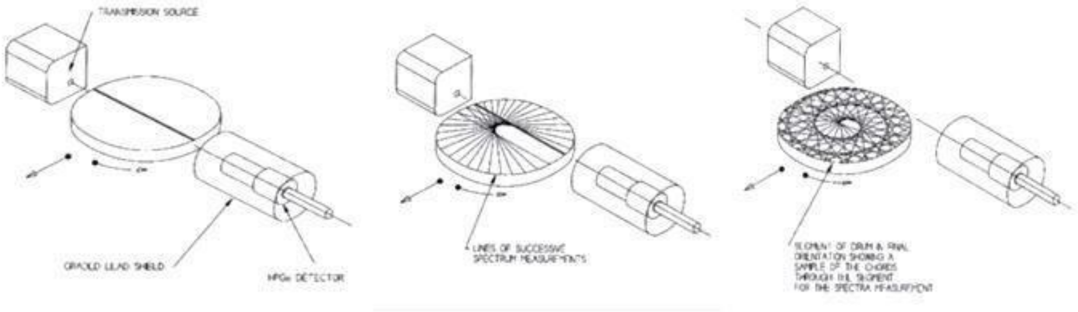

Figure 13: Schematic representation of the movement in TGS mode. The HPGe detector and the transmission source are in line while the drum will rotate on the bench. On the second picture each sector represents a single measurement and the bench is moving horizontally respect to the detector-transmission source axis. On the last picture a complete round and a back-forth movement is able to produce a complete tomography layer image (Source: JRC, 2019).

In TSG mode the system will perform a rotation and a horizontal movement of the drum in the Gamma– transmission source axis. It also will acquire 150 separate spectra while the system will create a helicoidally drum movements (i.e. translation and rotation in Figure 13). In this tomography process after a geometric transformation of the different coordinate system, the Master Analysis will compute a yield distribution of the activity and an attenuation coefficient map in a rectangular grid for each scanned layers. Through the attenuation map the operator is able to visualize the variation of density in regions of the drum. In relation to the collimator size and the voxel resolution the grid map will produce a three-dimensional with a certain pixel resolution. As in the SGS mode, in the TGS the system will perform a two-pass scanning to produce emission data and transmission data for attenuation correction, but voxel by voxel and then segment by segment. The TSG extend the capability of the WCS because it is able to correct the emission data with the attenuation coefficient in a heterogeneous matrix.

Also in the TGS mode the system will perform a dose rate measurement in the same way as in the SGS mode.

It is evident that all the mentioned three methods, dose rate, SGS and TGS measurements, will produce a complete view of the activity distribution per radioisotopes but only the TGS mode will be able to clearly spot an anomaly activity in accurate way on the vertical and horizontal position in a drum. In particular when the matrix is heterogeneous the TGS method will be the only accurate measurement but it will require a longer time of measurement.

2.1.2 Neutron Station

The presence of fissile materials in the waste requires an estimate of the alpha content of the waste item, as well as the fissile material content of the waste to be reporting to nuclear safeguards authorities. This task intends to investigate the performance of an active/passive neutron measurement station that can be achieved in an industrial-size system for producing declarations of fissile material content in standard waste containers.

The Neutron Station is able to perform an Active and passive neutron measurements through an advanced, graphite-lined Differential Die-Away (DDA) system. The DDA is an active and passive neutron measurement device for determining the fissile content of waste drums. In active mode a D-T neutron generator operated at 100 Hz provides the bursts of 14 MeV neutrons that interrogate the drum to determine the 235U and 239Pu content of waste drums by induced fission using total neutron counting. In passive mode, the DDA operates as a conventional passive neutron coincidence counter for measuring plutonium using neutron pairs and neutron total count rates.

2.2 Pilot tomography project

The Pilot Tomography (PilTom) project has the aim to produce an alternative tomography system where the complete control from the user of all parameters will allow all flexibility of the case. This parallel PilTom program will allow the JRC research team to analyse different algebraic algorithm for the extraction of the 3D visualization of the activity of each radioisotope into a drum. PilTom allows more flexibility for experimentation various scanning geometry configurations and for testing different tomography calculations algorithms with respect to the utilisation the large WCS facilities. PilTom is in principle a test bench for any new development prior to any implementation in WCS.

The setup consists of the following (see Figure 14):

1. A HPGe planar electric cool detector 500 mm2 with FWHM (57Co) 550 eV
2. A lead 1cm diameter collimator of effective 15cm thickness for a fan beam configuration
3. A rotary table where the drum is positioned
4. A translational linear guide to move the HPGe detector respect the central axis of the rotary table
5. A Mini-MCA-527 digital signal processing and multichannel analyser
6. A LabVIEW interface to acquire the data and post processing the tomography image
7. A MATLAB or Python script to produce the reconstructed image from the sinograms of all radioisotopes and alternative MATLAB methods to post processing the data
8. The Software is witting in LabVIEW interfaced with C code in the dynamic link library (DLL) for interface with MiniMCA-527 and MATLAB package.

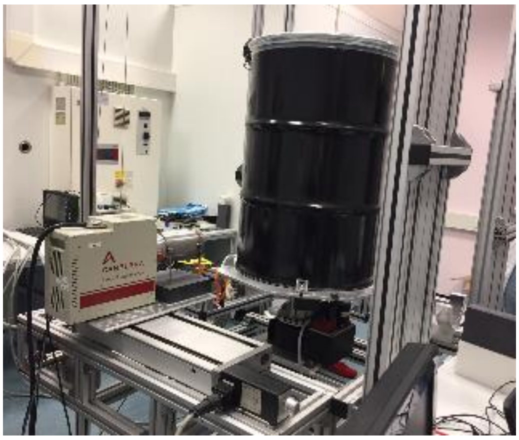
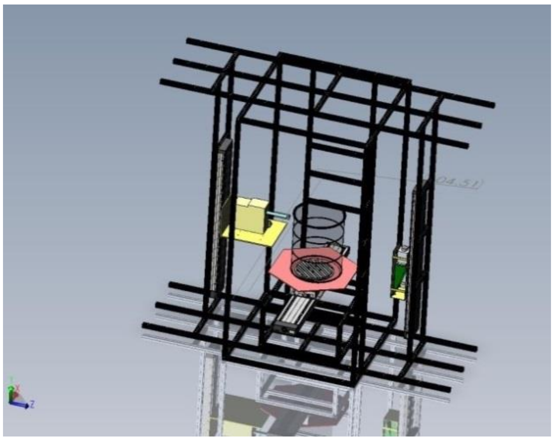

Figure 14: View of the PilTom setup with the HPGe electric cooler detector on the top of the linear motor guide and a 220L drum on top of the rotary table. A CAD representation of the new setup with the 152Eu transmission source (Source: JRC, 2019).

During the last year three major tests has been conducted on the PilTom setup using either 3 or 4 different radioactive sources. The different point sources configurations have been used to test the actual performance of the current system and the algorithm used for the reconstruction. Projection and algebraic techniques have been implemented in MATLAB and in Python 3.7 with the ASTRA toolbox[1] [(2)].

In order to increase the accuracy of the measurement different collimator geometries have been tested to find the best compromise between acquisition time and accuracy (imagine resolution). In the last test (see Figure 15 the bottom picture) it has been used 1.0 cm diameter Pb collimator with horizontal movement of 0.75cm and rotation of 2° angle for a total of over 10 000 acquired files in ~7.7d (i.e. acquisition single spectra time of 60 s). In the mentioned picture is possible to recognize

[1] ASTRA toolbox is a MATLAB and Python toolbox of high-performance GPU primitives for 2D and 3D tomography (http://www.astra-toolbox.com/).

the position of the four sources and estimate their coordinate in relation to the actual experimental setup. For the reconstruction from the 4 sinograms it has been analysed the spectra of the four known sources (i.e. ROIs of 137Cs, 60Co, 57Co and 133Ba) and used the ASTRA toolbox in Python 3.7 to perform a Filtered Back-projection (FBP) algorithm for the 2D data sets.

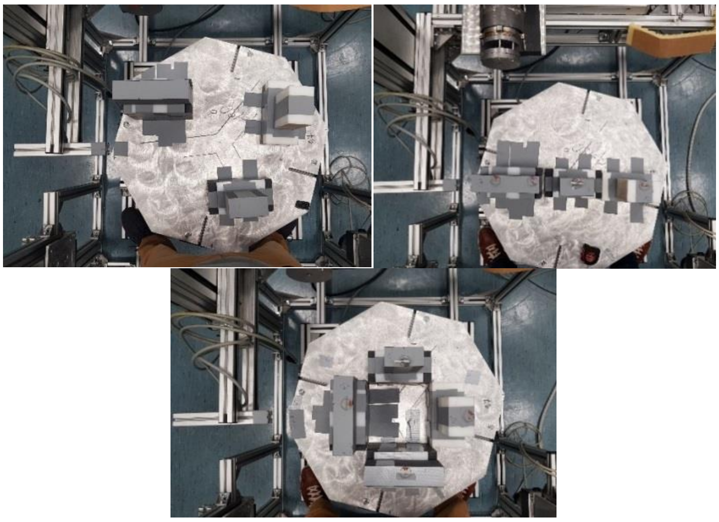

Figure 15: Different point-sources configurations on the rotating table at the same height to the HPGe detector. From the left to the right: (1) Three sources 137Cs, 60Co, 57Co in random positions. (2) Four sources in line 137Cs, 60Co, 57Co and 133Ba and (3) Four sources in square disposition 137Cs, 60Co, 57Co and 133Ba (Source: JRC, 2019).

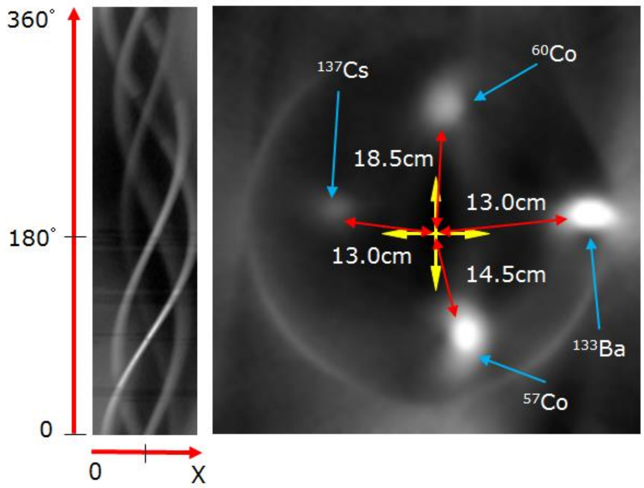

Figure 16: Image reconstruction with the sinograms of four sources on the left and algebrical reconstruction using Python ASTRA toolbox on the right (Source: JRC, 2019

3 Outlook

An extensive work from the JRC research team in order to continue to characterize the analysis process of the SGS is in progress. Even if extensive progress has been reached during these months and a more detailed knowledge of the WCS has been achieved, as some of the data showed, a continued improvement of the quality achievable by the system must to be met. It is necessary to be able to update the software system to the current Windows OS (i.e. Win7 or 10®) and to be able to have an alternative method to acquire all the spectra taken during the SGS mode and not only the summing spectra. Various solutions have been considered to bypass the problem with the actual close ANTECH software/hardware system. A strong effort will be also devolved to the understanding of the TGS system that currently is not operating. The use of the PilTom parallel project will help to achieve this condition.

For the PilTom project a new setup has been developed by CAD software (SOLIDWORKS) to get essentially the introduction of a structure for a 152Eu transmission source in front of the HPGe detector with the use also of two new linear motor guides and a new rotary table. In order to decrease the acquisition time it is planned to insert some CdZnTe detectors in a linear configuration with a tungsten collimator. This will require a new driver code to support a new type of detector and with the possibility to have also to create multiple series of CZT detectors.

It is also planned to update the system to:

- Use a NI-PXI 7975+NI 5261 (FPGA board + 250MHz/14 bits resolution) to extend the acquisition capability of the system.
- For continuous (helicoidally tomography) to couple with an optical system (2 high resolutions camera to measure the position/speed in order to create a table <Ti, Ei, x, z, theta>, where Ti is the time-stamp of the HPGe incoming photon i, Ei is the energy of the incoming photon and x, z, theta are the position of the drums.

It has been planned also to perform a model simulation by MCNP or GEANT4 simulation code in order to optimise the shape of the tungsten collimator and the setup configuration with CZT detectors. Besides, a strong effort will be devoted to the improvement of the Python or MATLAB code analysis for the algebrical reconstruction of the tomography image.

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