RoboCount™ 2020 - A Robotic Non-Destructive Waste Assay System – 19331

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ABSTRACT

A robotic system for non-destructive assay (NDA) of radioactive waste – RoboCount™ 2020[ab] – has been designed, manufactured, and a prototype delivered to a customer.

RoboCount™ 2020 is based on an industrial 6-axis articulating robot platform, combined with a dedicated waste package platform and a high-resolution HPGe gamma spectrometer. The system enables measurement of waste packages including drums (100-l, 200-l, 400-l), crates (up to 1200 x 800 x 800 mm), 1 m^3 flexible intermediate bulk containers (FIBC), and others. Assay type can be freely defined, ranging from currently accepted protocols such as segmented gamma scan (SGS) or integral gamma scan (IGS) to new protocols developed for specific non-cylindrical waste packages, e.g., measurement of FIBCs from all four sides and the top. As a result of the robotic hardware flexibility, reconfiguration of the system for a new task is a matter of software changes only. In addition, while primarily geared towards waste characterization, the system can be configured for free release (clearance) by installing a second detector and field-of-view shielding.

The prototype is currently in operation at a NPP site in Europe where it is used for D&D waste characterization in crates and FIBCs. Additional features beyond the basic functionality have been implemented such as an automatic lead collimator change based on measured HPGe detector dead time and an automatic liquid nitrogen refill, performed by the robot via a docking station at predefined time intervals. (Use of electrically cooled HPGe detectors is also possible.)

INTRODUCTION

NDA is routinely used by radioactive waste producers, intermediate and final storage facilities, and regulatory authorities. So much so that commercial NDA systems are now widely available. However, they are typically limited to a single waste package size and assay type, e.g., segmented gamma scanners for characterization of 200-l drums. Any changes in waste package size and assay type require either a new NDA system or a re-engineering of an existing one. The cost of the commercial NDA systems tends to be commensurate with their single-purpose machine characteristic as does the delivery time. RoboCount™ 2020 mitigates all of the above shortcomings while simultaneously introducing novel features.

The idea to replace a single-purpose NDA system with one based on an industrial robot might not be fundamentally new but to the best of our knowledge, no comparable unit is currently commercially available and/or in operation.

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[a] RoboCount™ 2020 is a registered trademark of DuAl GmbH
[b] Patent pending, application A 60236/2018

SYSTEM DESCRIPTION

Building an NDA system around an industrial robot offers several advantages compared to the single-purpose machine approach. They include

- compatibility with any waste package type and size limited only by robot working area;
- ability to perform any assay type, following existing or novel measurement protocols;
- ability to perform additional automated operations;
- lower cost and shorter delivery time compared to single-purpose units;
- adaptability to changing operational requirements;
- high reliability and low maintenance.

RoboCount™ 2020 consists of a robot carrying a gamma spectrometer, a waste package platform, auxiliary systems, and control PC, see Fig.1.

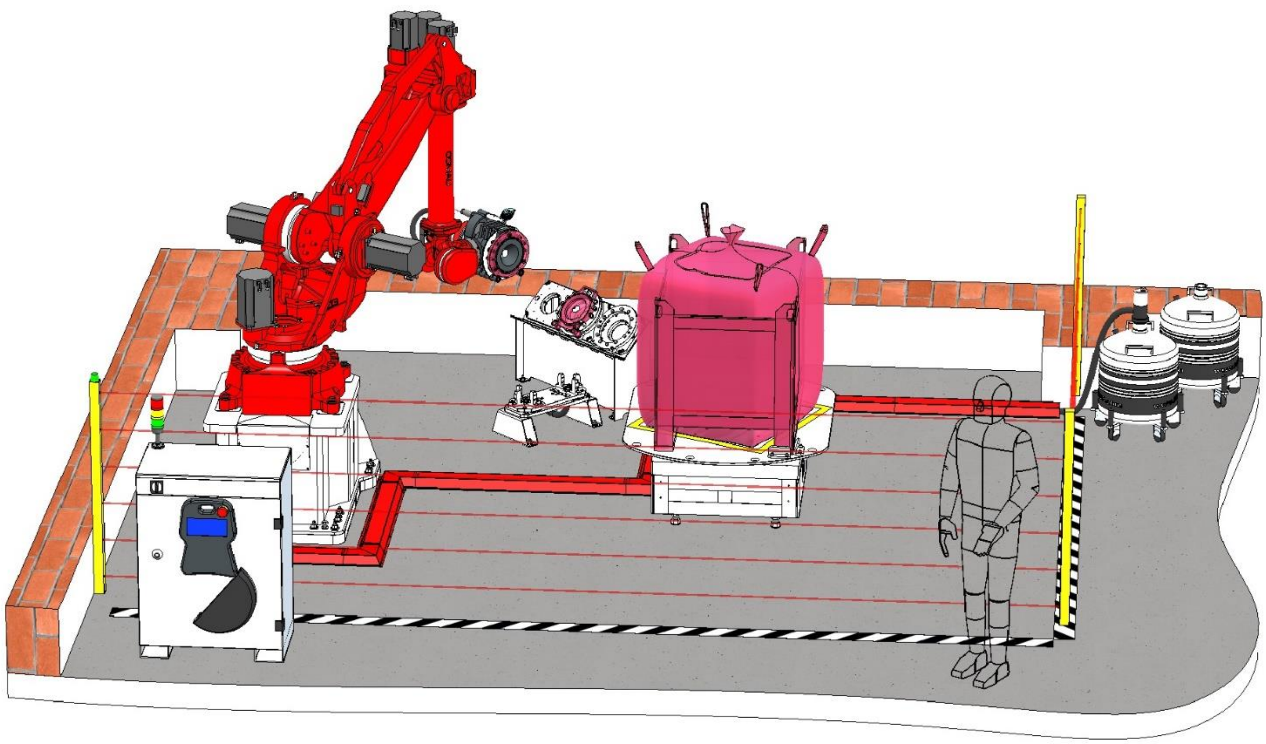

Fig. 1 RoboCount™ 2020 System Overview

RoboCount™ 2020 enables measurement of waste packages including drums (100-l, 200-l, 400-l), crates (up to 1200 x 800 x 800 mm), 1 m^3 FIBCs, and others. Assay type can be freely defined, ranging from currently accepted protocols such as segmented gamma scan (SGS) or integral gamma scan (IGS) to new protocols developed for specific non-cylindrical waste packages, e.g., as is the case with the current unit, measurement of FIBCs on all four sides' axes and crates on the four axes of longer side vertical halves.

The typical measurement sequence starts with placing the waste package on the platform while both the robot and the platform are in their freely definable home positions. In the user application, one of the pre-defined waste package types and measurement protocols is selected. Additional parameters, such as data acquisition time, max. detector dead time, *etc.*, can be adjusted if default values are not suitable. The measurement can then be started. The platform turns and the robot moves to the bar code reading position and the bar code reader is activated. At the same time, the weight of the waste package is determined. The platform and robot then synchronously move and pause in measurement positions while the gamma spectrometer acquires data. After completing all measurements, the platform and robot return to the home position and the waste package can be unloaded. The user application displays both measurement progress and its results and creates spectrum and report files. The spectra can be re-analyzed off line and/or the results made available to a supervisory application.

Robot

RoboCount™ 2020 is based on a Comau SpA industrial 6-axis articulating robot model NJ-220-2.7. The key robot technical specifications are shown in TABLE I.

TABLE I. Comau NJ-220-2.7 Technical Specifications

Specification	Value
Number of axes	6
Maximum wrist payload (kg)	220
Additional load on forearm (kg)	50
Maximum horizontal reach (mm)	2701
Repeatability (mm)	0.08
Tool coupling flange	ISO 9409 - 1 - A 160
Robot weight (kg)	1220
Protection class	IP65 / IP67

The maximum wrist payload of 220 kg is significantly higher than the mass of the spectrometer it is carrying. This is intentional because higher payload corresponds to a larger working area (see Fig.2), enables the use of additional detector shielding and/or additional detectors as needed, and minimizes both wear and maintenance. Even if operated at maximum load, the wear and maintenance are expected to be minimal since the robot performs a few relatively leisurely motions during a typical assay compared to hundreds of high-speed cycles per day in manufacturing operations it was primarily designed for.

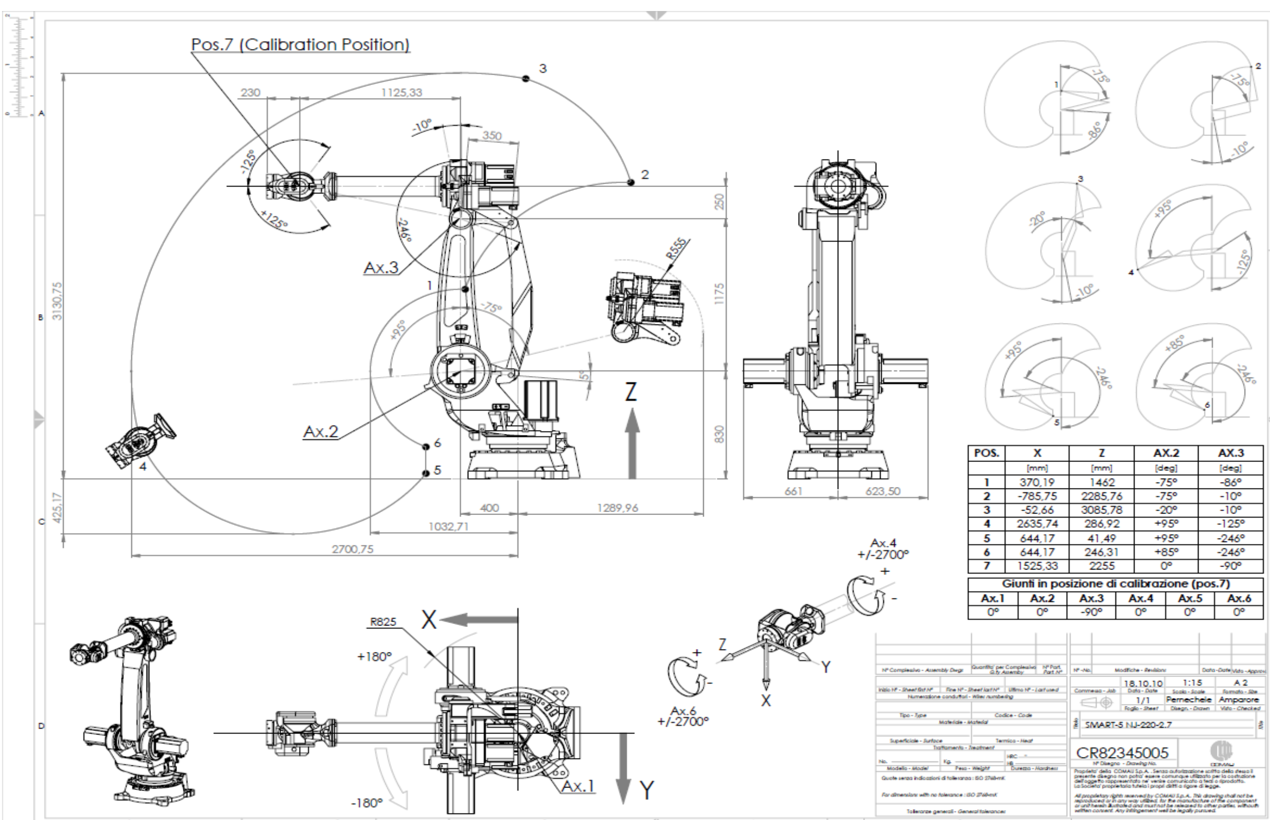

Fig. 2 Robot Working Areas

The robot features a C5G control unit with a TP5 teach pendant. All robot motions can be performed manually from the teach pendant which is also used for robot programming.

The robot is mounted on a custom massive steel pedestal which increases its effective maximum horizontal reach.

Gamma Spectrometer

The spectrometer is a Canberra Industries, Inc., unit featuring a single GC2020 high-purity germanium (HPGe) detector, 7 l BigMAC liquid nitrogen cryostat with a 5 day holding time, and a DSA-LX multi-channel analyzer with digital signal processing. The detector end cap is placed in a 5 cm thick cylindrical modular lead shield. The standard manually exchangeable collimator set (90^o or 30^o conical opening) has been modified for automatic collimator change, see Auxiliary Systems. Since the current unit is primarily geared towards waste characterization, one HPGe detector is sufficient. However, for free release (clearance) or to increase material throughput, the system can be re-configured by installing a second HPGe detector and, optionally, field-of-view shielding.

Waste Package Platform

The waste package platform is an optional system component. However, it significantly expands the system functionality providing waste package weighing and positioning (rotation). The rotation motion is seamlessly integrated into the robot control architecture as a seventh axis. The integrated balance has a maximum load of 2500 ± 1 kg.

Auxiliary Systems

Additional features beyond the basic spectrometry functionality have been implemented such as a bar code reader, automatic collimator change, and automatic liquid nitrogen refill.

A Sick AG CLV620-2000 bar code reader is attached to the detector shield and is configured to read bar codes from pre-determined positions on the waste packages. If bar code placement is not reproducible, reading during rotation and/or robot movement can be implemented.

Waste packages containing high activities could cause the HPGe detector incoming count rate to exceed the maximum throughput of the spectrometry chain, leading to increased detector dead time and, thus, inaccurate results. A pre-measurement of the waste package is performed with a 90^o opening collimator. If the detector dead time preset is exceed, the robot will select the narrower 30^o collimator and perform a full measurement. The unused collimator is stored in a tray (Fig. 3) which, together with the bayonet mounting mechanism, are designed for mechanical operation without the need for electrical or pneumatic elements. The number and type of additional collimators could be increased if needed.

The system also features an automatic liquid nitrogen refill, performed by the robot via a docking station (Fig. 3) at predefined time intervals. The detector and docking station feature special cryogenic male and female couplings, respectively. The fill and vent coupling of the detector are connected to the inlet and outlet of the HPGe detector Dewar, respectively. The fill coupling of the docking station is connected to a 35 l supply Dewar via a Norhof #900 micro-dosing pump, providing a ~25 day effective holding time. The vent coupling of the docking station exhausts into the atmosphere through a Pt resistance sensor connected to the pump. Flow of liquid nitrogen is interrupted as soon as the sensor detects the switch from gaseous to liquid nitrogen. Larger supply Dewars could be used to further extend the effective holding time, *e.g.*, ~75 days with a 100 l supply Dewar. (Use of electrically cooled HPGe detectors, eliminating liquid nitrogen entirely, is also possible.)

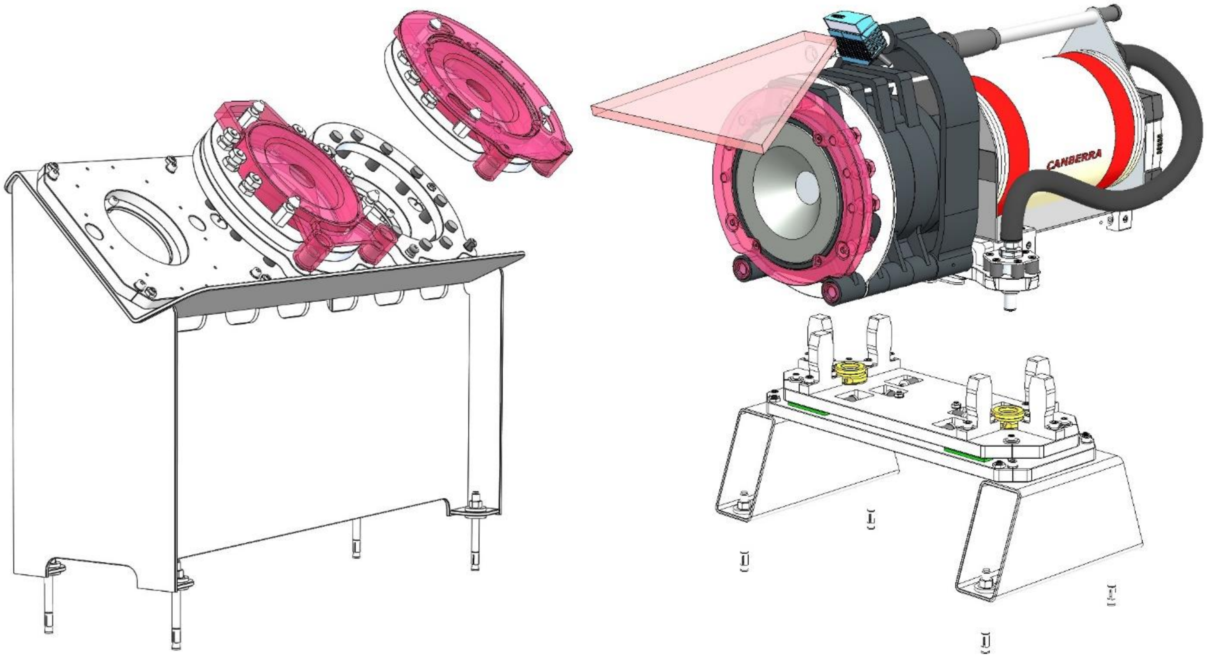

Fig. 3 Collimator tray (left), liquid nitrogen docking station (right)

Software

The control PC, connected to the C5G control unit by an IEEE 802.3 cable, runs the user application developed specifically for RoboCount™ 2020. The application communicates with the robot, the waste package platform balance, the bar code reader, and the gamma spectrometer. It also provides a GUI for system setup and operation. For gamma spectrometer data acquisition and analysis, the application integrates the Canberra Industries, Inc., Genie™ 2000[c] software suite. Genie™ 2000 can also be used independently, *e.g.*, for calibration and data re-analysis. The user application architecture is such that other commercially available gamma spectrometry hardware and software can be integrated.

Safety

Personnel safety is of utmost importance in industrial settings involving heavy automated machinery such as an industrial robot. In addition to standard emergency stop buttons on both the control unit and the teach pendant, the perimeter of the system working area is protected by a Sick AG C4000 light barrier.

DISCUSSION

Measurement Geometry

The system is currently set up for measurement of crates (1200 x 800 x 800 mm) and FIBCs (870 x 870 x 1000 mm). Rotation of these non-cylindrical waste packages during measurement, normally employed to minimize the effects of matrix density and/or activity inhomogeneity, is not useful in this case since the measurement efficiency changes with the relative position of the waste package and the detector. Therefore, a different approach was selected to achieve the same goal – measurement in several efficiency-equivalent geometries. The individual spectra acquired can be summed and the sum spectrum evaluated. As an added benefit, individual spectra can be evaluated separately and the differences in activities so obtained used as a measure of matrix density and/or activity inhomogeneity. (Selecting efficiency-equivalent geometries is convenient but not necessary. If need be, other geometries can be selected, *e.g.*, measurement from the top, and the corresponding spectra evaluated using appropriate efficiencies.)

[c] Genie™ 2000 is a trademark of Canberra Industries, Inc.

In the case of the crate, see Fig. 4, four measurements are performed with the detector axis normal to the long side of the crate at ½ its height and at ¼ and ¾ of its length, respectively. The detector end cap to crate side distance is 30 cm with the 90° collimator and 120 cm with the 30° collimator, respectively. The filling grade is assumed to be 100% with lower actual values taken into account in the course of data analysis.

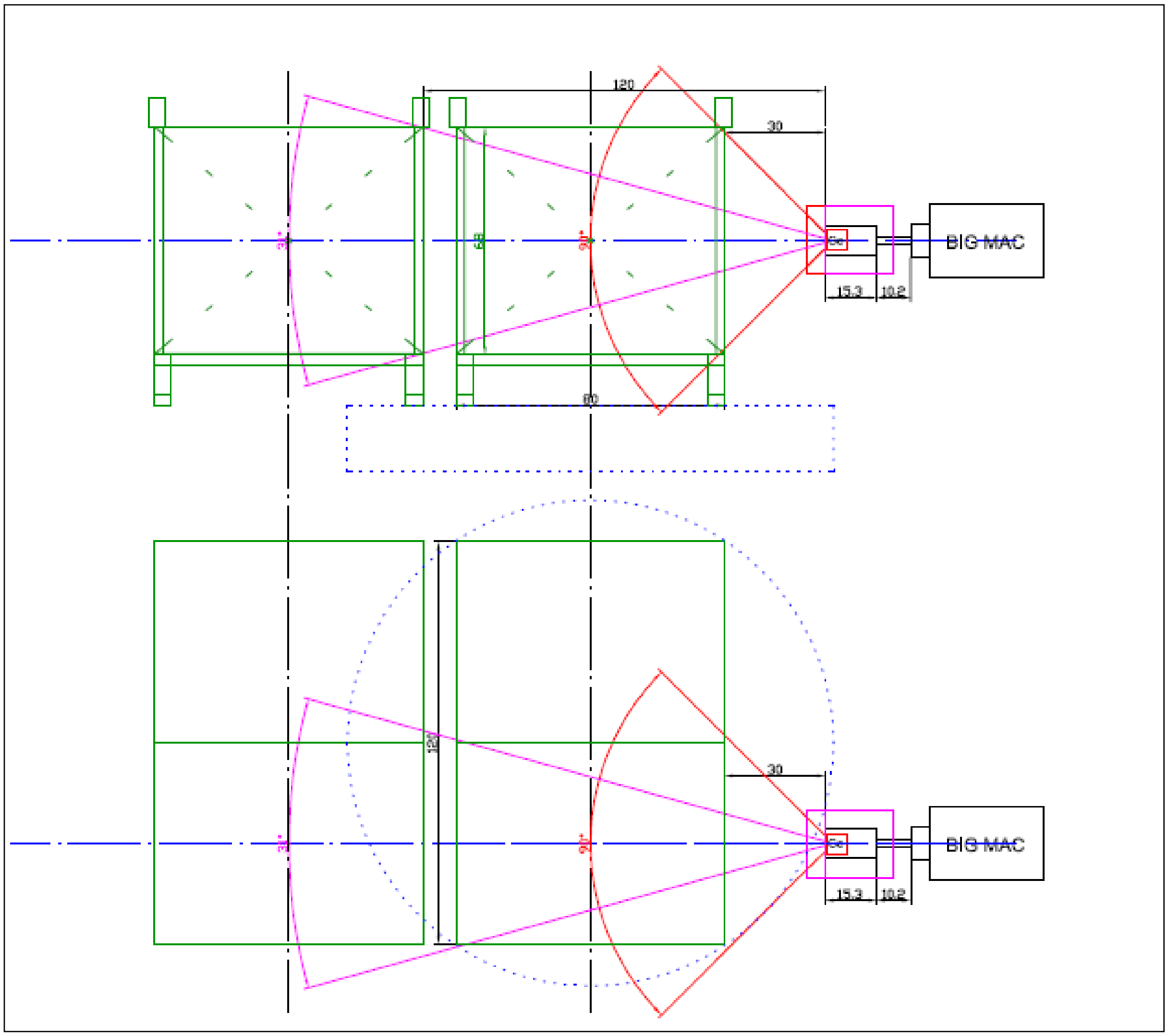

Fig. 4 Measurement Geometry – Crate

In the case of the FIBC, see Fig. 5, four measurements are performed with the detector axis normal to the side of the FIBC at the middle. The detector end cap to crate side distance is 40 cm with the 90° collimator and 160 cm with the 30° collimator, respectively. The filling grade is assumed to be 60% with differing actual values taken into account in the course of data analysis.

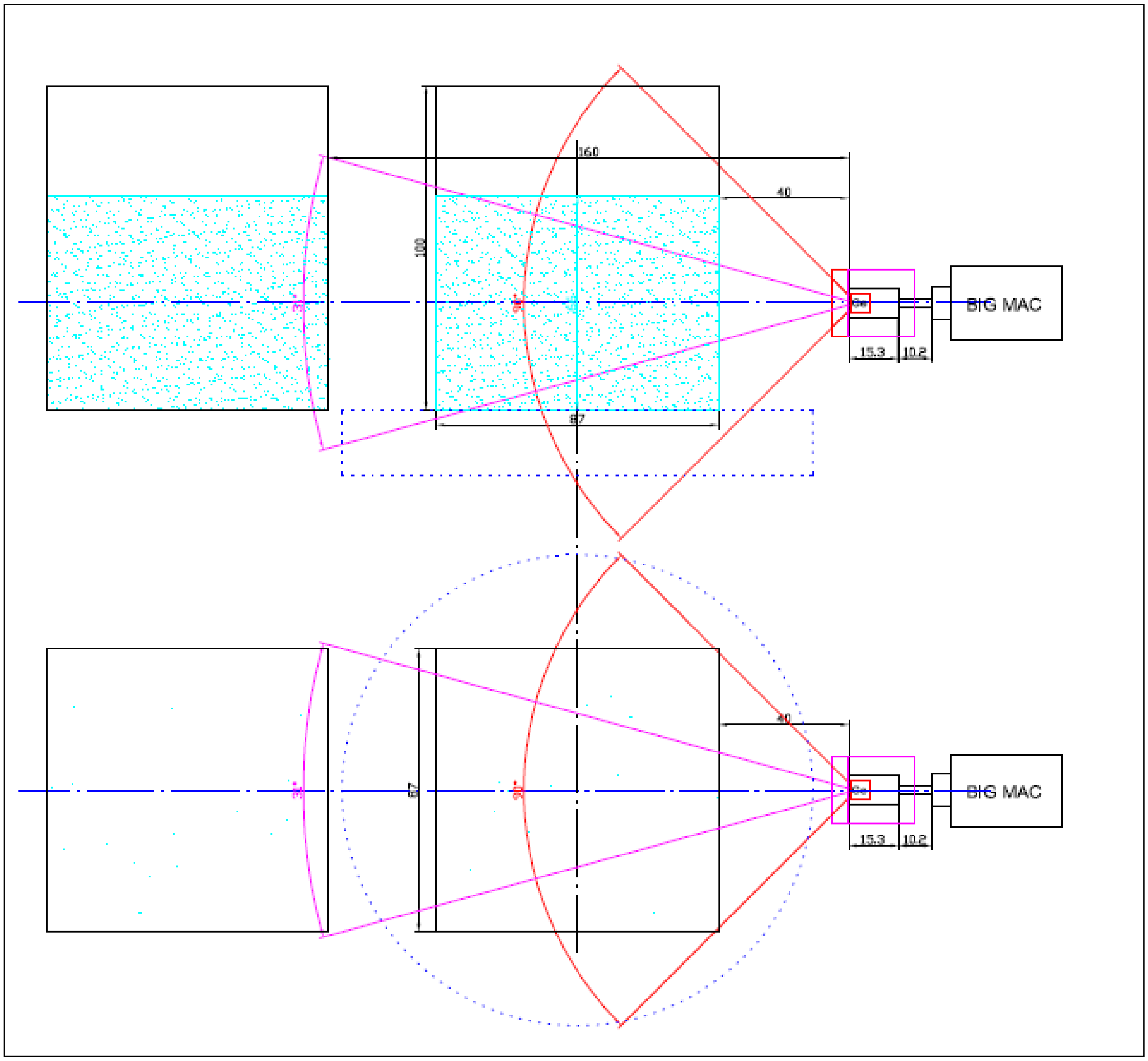

Fig. 5 Measurement Geometry – FIBC

Performance

Performance of NDA systems for radioactive waste can be specified in any number of ways. For clearance, the lower limit of detection (LLD) or, incorrectly, minimum detectable activity (MDA), are typically quoted and compared to applicable regulatory limits. The RoboCount™ 2020 prototype is primarily employed for waste characterization so that the measurable activity range of selected nuclides and the resulting throughput in terms of waste packages assayed per unit of time are more appropriate performance parameters.

The activity range was specified by the customer as 10^5 – 10^9 Bq per waste package with ^{60}Co and ^{137}Cs as key nuclides. Peak count rates for these two nuclides were calculated using the Canberra Industries, Inc. ISOCS™ software[d] for two cases – steel scrap in the crate and concrete rubble in the FIBC. The results are shown in TABLE II and TABLE III, respectively.

[d] ISOCS is a trademark of Canberra Industries, Inc.

TABLE II. Crate Measurement Performance

Waste Package	Crate, 1200 x 800 x 800 mm		
Matrix Material	Steel Scrap		
Matrix Density / kg.m^{-3}	1.5		
Geometry	90^o, 30 cm		
Nuclide	^{137}Cs	^{60}Co	
Energy / keV	661.6	1173.2	1332.5
Peak Efficiency	4.51E-6	3.79E-6	3.66E-6
Count Rate @ 10^5 Bq / cps	0.4	0.4	0.4
Counts @ 10^5 Bq in 240 s	92	91	88
Count Rate @ 10^9 Bq / cps	3842	3790	3660
Counts @ 10^9 Bq in 240 s	922 205	909 600	878 400
Geometry	30^o, 120 cm		
Nuclide	^{137}Cs	^{60}Co	
Energy / keV	661.6	1173.2	1332.5
Peak Efficiency	1.77E-7	2.09E-7	2.18E-7
Count Rate @ 10^9 Bq / cps	151	209	218
Counts @ 10^9 Bq in 120 s	18 120	25 080	26 160

TABLE II. FIBC Measurement Performance

Waste Package	FIBC, 870 x 870 x 1000 mm		
Matrix Material	Concrete Rubble		
Matrix Density / kg.m^{-3}	2.0		
Geometry	90^o, 40 cm		
Nuclide	^{137}Cs	^{60}Co	
Energy / keV	661.6	1173.2	1332.5
Peak Efficiency	4.20E-6	3.45E-6	3.32E-6
Count Rate @ 10^5 Bq / cps	0.4	0.3	0.3
Counts @ 10^5 Bq in 240 s	86	83	80
Count Rate @ 10^9 Bq / cps	3578	3450	3320
Counts @ 10^9 Bq in 240 s	858 816	828 000	796 800
Geometry	30^o, 160 cm		
Nuclide	^{137}Cs	^{60}Co	
Energy / keV	661.6	1173.2	1332.5
Peak Efficiency	1.15E-7	1.31E-7	1.35E-7
Count Rate @ 10^9 Bq / cps	98	131	135
Counts @ 10^9 Bq in 120 s	11 760	15 720	16 200

Both crates and FIBCs can be measured in 4 x 60 = 240 s with the 90^o collimator across most of the activity range. For activities approaching the top limit of 10^9 Bq per waste package, the 30^o collimator and the increased detector end cap to waste package distance will lower the integral count rate to below the hardware limit of 100,000 cps and allow the assay time to be cut by half to 4 x 30 = 120 s. The assay time limited throughput is thus 15 to 30 waste packages per hour. The actual throughput, taking loading and unloading into account (estimated 300 s), is 7 to 8 waste packages per hour.

CONCLUSIONS

A robotic system for non-destructive assay (NDA) of radioactive waste has been designed, manufactured, and a prototype delivered to a NPP site in Europe where it is used for D&D waste characterization in crates and FIBCs. The development and testing confirmed the expected advantages of a robotic system over single-purpose NDA units. The system is best suited for operators encountering variable waste packages, needing to apply existing as well as specialized measurement protocols. The industrial robot platform is over-dimensioned, ensuring maintenance-free operation.

The system's capabilities can be extended in several ways. For free release (clearance) operations, a second detector and field-of-view shielding can be installed. If batch operation is desired, the waste package platform can be integrated into an automatic conveyor or, alternatively, a robotic pallet truck / forklift can be used to load and unload the waste packages. A tomographic functionality is made possible by employing a second robot carrying a shielded and collimated transmission source. All of the above developments are being actively pursued.