iQS-01 InCounter Quantification System for Non-Destructive Assay: Report on Testing Procedures and Results for Device Performance and Holdup Quantification Model

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Abstract:

The InCounter Quantification System and the associated iQS-01 software package are designed to support characterization of nuclear materials retained in process equipment associated with nuclear deactivation and decommissioning (D&D) processes at gaseous diffusion plants. The InCounter is designed to perform automated measurements inside process piping, resulting in a more efficient and reproducible estimate of process holdup. Each InCounter features a thallium doped sodium iodide scintillation (NaI(Tl)) gamma detector, a LIDAR sensor for surface mapping, and a video camera for visual inspection. This combination of sensors allows the user to make a better-informed decision regarding the nature and disposition of holdup deposits. The output from multiple sensors also allows the user to better understand variables that may cause biases in measurement results.

Several testing procedures were developed to assess the performance of the InCounter to initial design specifications. These testing procedures included verifying device physical capabilities for performance limits and positional accuracy, measurement quality and subsequent analysis algorithms for mass quantification and Total Measurement Uncertainty (TMU), and software reliability in accordance with the Nuclear Quality Assurance (NQA-1) Software Quality Assurance (SQA) regime. The InCounter underwent testing at various points in development at multiple facilities in the United States. This included testing at the Oak Ridge National Laboratory (ORNL) Safeguards Lab to evaluate initial detector characteristics, at the Portsmouth Gaseous Diffusion Plant (PORTS) to assess physical characteristics, at the Paducah Gaseous Diffusion Plant (PGDP) using uranium surrogate sources for measurement quality and analysis accuracy, and in-house at the Innovative Solutions Unlimited, LLC corporate facility to assess full integration testing.

Keywords: Non-Destructive Assay; Robotics; Gamma Detection; Non-Proliferation; Holdup.

1. Introduction

The iQS project is a design effort to produce a customizable platform for measurement acquisition and data tracking in regulated environments. The core software suite allows for a variety of endpoint sensors to be connected to an autonomous device that is controlled by pre-defined and scripted software routines. The current offering for such devices is the InCounter, an internal-to-pipe traveling robot that features an NaI(Tl) gamma detector, a light detection, imaging and ranging (LIDAR) sensor, and a camera as its sensor platform. The software system tracks and manipulates the resultant signals from these sensors from acquisition through final reports, thereby streamlining the analysis process and avoiding transcription errors [1].

From the beginning of the InCounter design process, various testing procedures were performed to ensure the software and hardware components satisfy defined quality assurance requirements. The objective of the different tests varied depending on the current status of the design. Subsequent testing protocols were developed based on the results of previous tests modifications made to the InCounter design.

A system capabilities description and design narrative are provided first to describe the baseline test requirements. Then, as a precursor to formal testing, exploratory measurements made at Oak Ridge National Laboratory (ORNL) are described.

The first formal test of InCounter capabilities was performed with the assistance of the Portsmouth Gaseous Diffusion Plant (PORTS) during the beta stage of design. The physical characteristics of the InCounter were tested at PORTS. Subsequent verification and validation (V&V) testing of version 1.0 of the combined hardware and software system was performed at inSolves main office. After ensuring proper functioning to requirements, the U-235 quantification model accuracy was tested using uranium standards at the Paducah Gaseous Diffusion Plant (PGDP) using version v1.1-beta of the system. Each set of testing is described sequentially to explain how each builds upon the successes and lessons learned of the previous testing.

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Figure 1: The InCounter cart resting on a stand. From right to left, the camera, lights, LIDAR, detector and surrounding detector housing, and cart chassis.

2. Design Inspiration

The iQS project has its roots in brainstorming improvements to the Ortec Holdup Measurement System 4 (HMS4) in 2014 after it was recognized that the design of small detection hardware would be sub-optimal for characterizing holdup deposits of low-enriched uranium. Initial InCounter designs focused mainly on hardware improvements with some exploration of a modified version of the Generalized-Geometry Holdup (GGH) method. The current form of the project began in 2016 after studying the D&D projects at gaseous diffusion plants in both Portsmouth, OH, USA and Paducah, KY, USA.

The initially chosen measurement targets for the hardware system were long, straight pipes of varying sizes. Although holdup is more common at valves, elbows, expansion joints, or other uneven surfaces, these targets were chosen as the simplest measurement geometry to traverse with robotics and as the most applicable measurement need for the InCounter design, due to the fact that thin-film deposits for long sections of straight pipe can dominate the process holdup inventory given the large amount of surface area relative to that of the valves, elbows and expansion joints. Furthermore, although the reduction in overall measurement uncertainty has not been determined, improvements are expected because the deposit distribution can be observed and a more direct measurement can be performed without having to make corrections for the wall of the pipe. Each pipe is to be measured for ^{235}U holdup, typically in the form of UO_2F_2 attached to walls or within components [2]. An initial prototype system was designed to travel on rails external to the pipe (see Figure 2). However, this design was modified into the InCounter to permit in-pipe travel to simplify the engineering design of the InCounter system and improve the quality of the measurement.

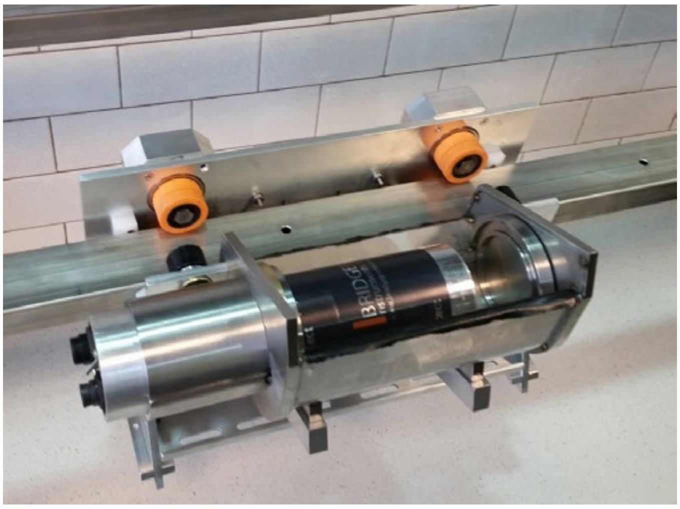

Figure 2: The GammaTrak: an early concept of external measurement system that became a precursor to the InCounter. It travelled on tracks and featured a rotating detector shield for field-of-view modifications.

Concurrent with the InCounter hardware development was the initial design of the software for controlling the data stream associated with acquisition, analysis, data package review, and management approval. Existing data processing methods included steps of handwritten transcription in the field and potentially weeks to months for generation and approval of the final data package. It was recognized that a networked, computer-centric data pathway would vastly speed up the process while also including automatic error checking. In addition, this allowed the custom developed ^{235}U mass quantification algorithms to be integrated directly into the data pipeline.

2.1 Generalized-Geometry Holdup

The procedure for mathematically determining the ^{235}U mass for a process deposit from the associated gamma spectrum has typically used the Generalized-Geometry Holdup (GGH) method. GGH models the deposit as a point, line, or area source. It relies on experimentally determined calibration data to provide a conversion coefficient from gamma peak counts to mass of the associated isotope [2].

It was noted that several aspects of the GGH method could be improved, including inverse-squared distance assumptions and source angulation during calibration [3]. In addition, correction factors for material attenuation do not necessarily account for thickness changes at an angle to the target [4].

When the focus of the iQS project became the internal measurement of pipes via the InCounter, a new model was necessary. The two-dimensional (2-D) geometries offered by GGH in the form of points, lines, and areas with finite width corrections, or a combination thereof with varying distances along the same detector axis, were not sufficient for three-dimensional (3-D) representation of material within the pipe. The new modelling method borrowed from GGH's basis of utilizing experimental responses to a standard to calibrate the instrument, but was expanded to applicable cylindrical geometries [4][5].

2.2 Quality System for Non-Destructive Assay

At the PORTS and PGDP sites, NDA measurement quality is ensured by the Quality System for Non-Destructive Assay Characterization (QSNDA) program document. QSNDA provides requirements for qualification of new instruments and the acquisition of new measurement data, such as requirements for duplicate measurements and control check frequency [6].

The iQS system is designed to support the stringency of calibration and measurement quality required under QSNDA. Several of the requirements of QSNDA resulted in the definitions found in the iQS system requirements document [7].

3. iQS-01 Project and InCounter Descriptions

3.1 InCounter Quantification System

The InCounter is designed directly to its intended measurement environment: the inside of long, straight pipes. This measurement environment was considered in the chassis design, sensor selection and placement, and the contamination control features.

Movement of the InCounter is accomplished via connected drive wheels at the front of the cart that have large, angled tires to improve traction by increasing contact against the potentially irregular contours of the pipe. Position tracking is handled by an interior encoder system attached to the free-spinning back wheels. The back wheels are designed with very thin wheels to provide a consistent contact point that allows for positional calibration [1].

Within the chassis, motors are located in the front compartment beneath the detector housing. The computing and power systems are located in the rear compartment. Power is provided by a hot-swappable lithium ion battery commonly used for hand-held power tools [1].

3.1.1 Sensors

The InCounter features three sensors: a NaI(Tl) gamma detector with a 5-cm. by 5-cm. crystal, a camera with associated lighting, and a LIDAR sensor. The sensor array is positioned along the axis of the pipe, allowing easier modeling of deposits using radial symmetry [1].

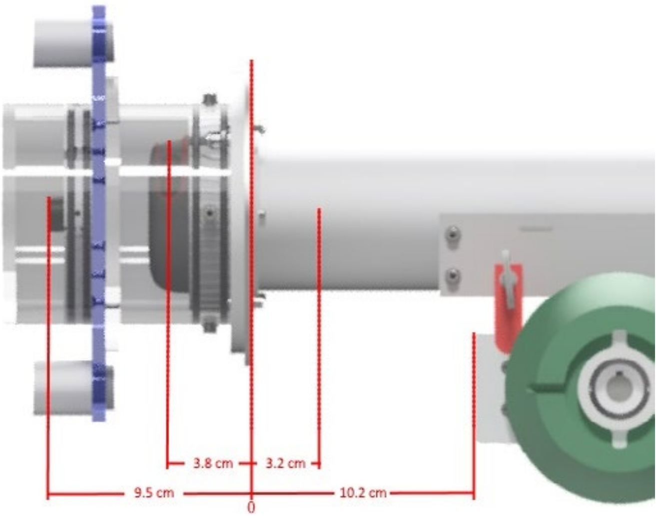

Figure 3: Sensor locations relative to a physical zero location. From left to right: camera, LIDAR, center of detector crystal, and the front of the cart.

Concurrent gamma detector is the key component of the InCounter system and features a field-of-view (FOV) of approximately 15 cm in front of and 15 cm behind the center of the NaI crystal. The detector is not collimated, but the chassis of the cart is designed to accommodate the addition of collimation if needed. Due to the absence of collimation, the detector response decreases with distance, which is accounted for in the detector calibration procedure. The detector exclusively provides input to the mass quantification algorithms discussed in section 3.2.1 [5].

The LIDAR sensor and camera provide the ability to perform visual inspection of the measured deposits and of internal pipe condition. The LIDAR sensor rotates along the pipe axis, providing a 2-D "slice" of the surface. Many of these slices can be combined into a point cloud representing the interior physical contour of the pipe. Due to limitations in the precision of LIDAR measurements, the point cloud data is not used for quantification analyses, but it does serve as a visual aid to operators and analysts for determination of future measurement plans and the application of the correct model selected for quantification [1].

3.1.2 Atmosphere

The chemical reactions that give rise to the typical UO_2F_2 deposit also release hydrofluoric acid (HF) as a byproduct, which can build up in the internal volume of the pipes and result in a corrosive atmosphere. In an effort to protect the more delicate sensor and computing hardware, the InCounter is designed to be resistant to HF.

The chassis and detector housing are made of aluminum to ensure low weight and resist corrosion without significantly attenuating the detector. The gamma ray transmission rate through the aluminum housing is approximately 95% at the 185 keV gamma ray of ^{235}U. Fasteners are made of stainless steel [1].

Seams between the chassis plates are sealed with a corrosion resistant caulk. The tires of the InCounter are a custom blend material and are 3-D printed [1]. The material was subject to hydrofluoric acid bath testing without losing integrity or corroding.

3.2 iQS-01 Software Backbone

The iQS software suite serves two purposes: to provide control for the InCounter or other hardware endpoint and to serve as the data pipeline. It is split into different programs: a control server within the InCounter that handles wireless networking, sensor interfacing, and low-level InCounter control functions; a control application allowing an operator to run the InCounter; and the Workbench, which allows an analyst to review data, run analyses, generate reports, and access administrative features of the suite [1].

Control of the InCounter can be done manually, but usually relies on a custom scripting language that grants the unit autonomy during data collection. This script can control movement and sensor acquisition and respond conditionally based on sensor input. Meanwhile, all data is sent to a central database in real-time, allowing operators and analysts to review data within seconds of collection [8].

3.2.1 Mass Quantification Methodology

Analyses are run within the Workbench, either on analyst command or automatically upon data collection. The mass quantification takes the results of the detector response calibration and the measured gamma spectra to return an estimate of the mass of ^{235}U in the pipe (units: g ^{235}U per foot (30.5 cm) pipe) [5].

The method begins with the detector response calibration. A small, mixed gamma source set consisting of exempt quantities of ^{133}Ba, ^{57}Co, ^{60}Co, and ^{137}Cs is moved around the internal surface of a test pipe. Spectra are collected for a sample of source locations within the pipe, spaced evenly around the circumference by angle and along the axis of the pipe by distance. The detector crystal is taken as the origin in these measurements, and on-axis measurements are taken over a few meters on each side of the detector to establish FOV boundaries and detector response. This calibration varies by the internal radius of the pipe, which depends on the construction standards. On each spectral peak, Gaussian fits are applied, and the counts in each peak are compared to the decay corrected source assays to determine a total efficiency of detection at that energy and location, including both detector and geometric efficiencies. High order (4th degree or higher) polynomial fits are applied to the total efficiencies as a function of energy. Polynomials were chosen after exploring several options including exponential and power functions. Although polynomials do not permit extrapolation, the energy range of interest is well bounded by the calibration peaks. These efficiency curve fits are used to interpolate the 186 keV peak efficiency needed to calculate the ^{235}U mass from the InCounter measurement [5].

On initial run of quantification for a set of measurements, default models of the physical deposit shape are created by the software. This default model assumes a thin film of holdup material over the entire interior surface of the pipe. Using a thin-film assumption, self-attenuation is not included in this first calculation, allowing for rapid calculation for a large number of measurements. After expert review of measurements of interest, custom models can be defined by an analyst to account for different distributions and thicknesses of deposit. Models are digitally represented as collections of voxels in cylindrical coordinates having a set thickness and spanning finite lengths of θ around the pipe circumference and z along the pipe axis. Each voxel corresponds to the location of a calibration response point with the associated efficiency curve. Self-attenuation of the deposit and attenuation of the cart chassis are included in the evaluation of each voxel's expected response to the detector, which are all combined to return a single quantification coefficient for the model [4].

Similar to GGH, the quantification coefficient is multiplied by the result of the peak analysis of ^{235}U - in this case, the Gaussian fitting of the 186 keV peak - to return total estimated mass.

4. Oak Ridge National Lab Testing – Detector performance

The Oak Ridge National Lab (ORNL) has several uranium standards in its Safeguards Lab that were key to establishing the basis of detector reliability on the InCounter (see Table 1 on next page). When testing at ORNL, the InCounter was in a v1.0-beta design, and the iQS software was still in active, pre-v1.0-alpha development. The purpose of this testing was to verify detector performance and compare uranium standards to mixed source sets, as well as run initial tests of the mass quantification algorithms that were updated in later versions of the system.

Source No.	^{235}U Weight Percent	Total Mass ^{235}U (g)
1	0.3166 ± 0.0002	0.52
2	0.7119 ± 0.0005	1.2
3	1.9420 ± 0.0014	3.28
4	2.9492 ± 0.0021	4.99
5	4.4623 ± 0.0032	7.54
6	20.107 ± 0.020	39.12 ± 0.04
7	52.488 ± 0.042	101.81 ± 0.10
8	93.1703 ± 0.0052	181.12 ± 0.12

Table 1: Sources used as standards during ORNL testing. All numbers provided by Safeguards Lab source certificates.

The sources listed in Table 1 come from two sets: SRM 969 for low assay sources, and CRM 146 for the 20% and greater assay sources. Specifically included are SRM 969-031 (1), SRM 969-071 (2), SRM 969-194 (3), SRM 969-295 (4), SRM 969-446 (5), CRM 146 – NBL 0021 (6), CRM 146 – NBL 0022 (7), and CRM 146 – NBL 0023 (8).

4.1 Mixed Source Qualification

The mixed source set used to calibrate the NaI(Tl) scintillation detector was chosen to allow easy licensing and location flexibility for calibration procedures. In addition, by utilizing a fitted efficiency curve, other isotopes besides ^{235}U can be measured. The challenge is in qualifying exempt quantity, non-uranium sources for use in a uranium measurement system. Measurements were taken of ^{235}U standards at varying enrichments, and efficiencies of each measurement were compared to the evaluated efficiency generated by fitting the efficiencies of the mixed gamma source: see Figure 4, in which measured efficiencies as red dots are compared to the expected efficiency for a specified energy represented by the blue line. All uranium sources from both SRM 969 and CRM 146 were used to conduct the comparison. Although the SRM 969 sources are similar to enrichment ranges expected for field measurements using the InCounter system, both sets provide a full enrichment range.

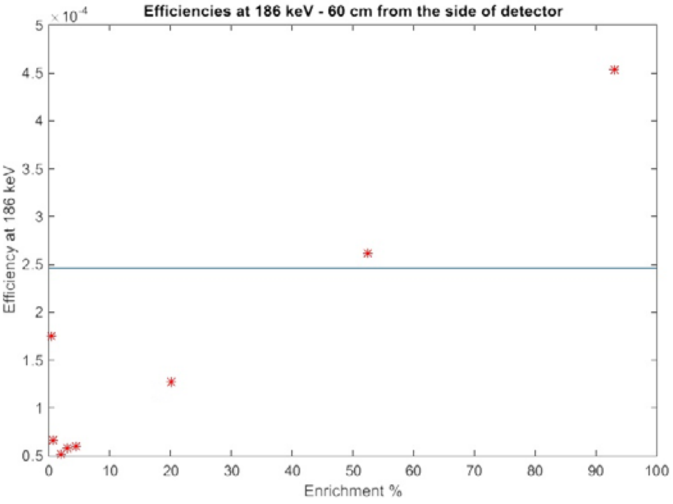

Figure 4: Total efficiencies of uranium standards as a function of enrichment. The blue line represents the value calculated using the mixed source set.

Figure 4 shows significant deviation from expected in the measurement efficiencies at distance. All efficiencies were calculated accounting for self-attenuation of the source material and attenuation of the canister window. The peak fits for the low enrichment sources had much smaller goodness-of-fit values than those for the high enrichment sources, likely due to the distance of measurement. Uncertainties for the measurements are comparatively larger at lower enrichment due to lower counts, further increased by the propagated fitting uncertainty that also increases with lower counts. The results from this test, however, did indicate that improvements were needed in the efficiency model across all ranges of enrichment. This issue was addressed in the next phase of development.

Preliminary tests of mass calculation were also run using two uranium oxy-fluoride sheet sources that contain 11.108 g ^{235}U and 11.113 g ^{235}U respectively. These sheet sources are made from approximately 93% enriched uranium. The physical dimensions of the sheet sources are 23 cm x 46 cm. The sheets were placed inside a pipe and the InCounter was run past them such that the extent of the sheet source was outside of the FOV of the InCounter's starting and ending positions. Calculated masses are found in Table 2.

Scenario	Calculated mass ^{235}U (g)
1 sheet (11.113 g ^{235}U)	8.99
2 sheets	23.875
2 sheets (2nd Pass)	24.060

Table 2: Results from early test of mass calculation algorithm with ORNL sheet sources.

For the first scenario in Table 2, the difference in the measured versus declared ^{235}U mass for the single sheet measurement indicates that the in-development quantification model calculated a mass value that was biased low. However, runs 2 and 3 show calculated results very close to the expected mass, which is inconsistent with the first run. In the first scenario, a single source sheet was in the bottom of the pipe, while in the two-sheet scenario, one source sheet is at the bottom of the pipe and one is at the top. Images show the top sheet hanging down from the pipe several centimeters, which suggests the measured response was artificially inflated. The conclusion that the quantification was under-estimating is applicable to all three scenarios.

The uranium efficiencies being lower than expected from the mixed source set naturally lead into the consistent underestimation in the quantification algorithm. As the iQS software was still in early development, changes were made to both systems in later software versions. The results of these changes can be seen in Section 7.

5. Portsmouth Testing – Physical Characteristics

With the assistance of quality assurance (QA) engineers from the PORTS site, the physical characteristics of the InCounter were tested. At the time of testing, the InCounter was a final v1.0-beta design and the iQS software was in early v1.0-beta, with some ongoing feature development.

The testing focused on the cart movement and positional tracking accuracy, battery functional limits at different feature loads, lighting limits, and visual inspections of sensor data quality [9].

Figure 5: Setup of the piping for testing of battery. The cart ran until the end of the pipe, then reversed to the point of origin, summing up total distance.

The first testing focused on battery lifetime as a function of operational features. Three scenarios were run: 1) continuous movement at 2.5 cm per second with no data collection, 2) continuous movement at 2.5 cm per second with lights on and data collection enabled on all sensors, and 3) movement punctuated with stops each 30.5 cm for 30 second spectrum acquisition and full data collection during movement. Results of these tests are presented in Table 3 [10].

Scenario	Battery life (hrs. & mins.)	Distance traveled (meters)
1	4:54	301
2	2:44	90
3	2:25	38

Table 3: Battery lifetime and maximum distance traveled as a function of features enabled.

Testing involved visual inspections of the real time data collection, available for viewing in the iQS InCounter Controller application. In addition, manual and scripted control methods were verified for positional accuracy. Results were consistently accurate to within 0.5 mm. of the arbitrarily determined target location, as verified by a traceable tape measure in the bottom of the pipe test stand [10].

Camera illumination was tested at 25%, 50%, 75%, and 100% lighting power at locations 30.5 cm., 61 cm., and 91.5 cm. in front of the InCounter cart. A maximum lighting of 685 lumens was achieved at 100% power at a distance of 30.5 cm. [10], and visual inspection confirmed the estimated maximum illumination distance of approximately 6 ft. [1].

6. In-house Testing – V&V and Integration

The successful testing of InCounter functionality and the completion of the v1.0 of the iQS software led to the administration of the verification and validation suite of the combined system and software quality assurance program. The SQA package was designed under NQA-1 and features the System Requirements Document, the collection of V&V tests, a traceability matrix to ensure V&V test coverage to the requirements, a QSNDA acknowledgement checklist, and a software interfaces chart for the interactions and interdependencies of development tools.

The V&V tests were run manually on each InCounter produced and for each version of the iQS software due to the nature of the integrated hardware-software design where neither functions fully without the other.. InCounter calibration activities are also included within the V&V tests. The iQS v1.0 V&V tests included:

- Test 0: Comprehensive,
- Test 1: Cart Calibration,
- Test 2: Cart Movement and Positioning,
- Test 3: Battery Endurance,
- Test 4: Sensors and Scripting,
- Test 5: Reports and Calibration Certificates,
- Test 6: Cart Inspection Test,
- Test 7: Uranium Data Analysis Test,

where Test 0 is included for compliance with internal SQA requirements [11]. These tests are categorized as end-to-end tests of various features of the system.

Test 7 is of special note due to the lack, at the time of the V&V testing, of comparison to experimentally simulated deposit measurements. As such, the data used for testing was generated from MCNP5 [12] simulations of ideal deposits.

6.1 Deviations from Requirements

One deviation from requirements was found in Test 2: Cart Movement and Positioning, in which the position of the cart as tracked by the iQS software remained constant after repeated back and forth runs but the real position varied irregularly by a few percent of the total distance of the run. This was found to be the consequence of physical modifications made to the position tracking to support movement over rough terrain in which the tracking wheels may not be on the ground at the same time. This issue was deemed to be less of a problem than potentially complete loss of tracking in uneven terrain. Designs to handle both scenarios are currently still in progress.

A further issue was found in the mass quantification algorithms when the input MCNP model was of a thick accumulation of UO_2F_2 in the bottom of the pipe. Test 7 includes three scenarios: 1) a fully uniform distribution of

30 g ^{235}U all the way around the internal surface of the pipe, 2) a uniform distribution of 20 g of ^{235}U in the bottom half of the pipe, and 3) an accumulated pile of 20 g of ^{235}U at the bottom of the pipe. The results of the quantification algorithm from the generated spectra were 33.47 g, 21.27 g, and 41.77 g respectively [11]. A study of the accumulated model revealed invalid assumptions, and a more complex model was devised to use prior knowledge inputs and iteration to remove the need for those assumptions.

Other aspects of the testing showed the v1.0 iQS software and InCounter to be sufficiently ready for version release.

7. Paducah Testing – U-235 Quantification

To make up for the lack of experimental measurements related to Test 7 of the V&V process, experiments to test the quantification algorithms were performed at PGDP using several uranium sources measured with different methods. The InCounter used was release v1.0, and the iQS software was v1.1-alpha, which was undergoing active development. This allowed quick turn-around in case adjustments needed to be made to the quantification algorithms.

At the initiation of the test it was initially determined that positioning issues similar to those identified during the V&V testing had not been resolved. The addition of a ballast to add weight to the rear wheels resolved this issue. The added weights were incorporated into future versions of the InCounter hardware.

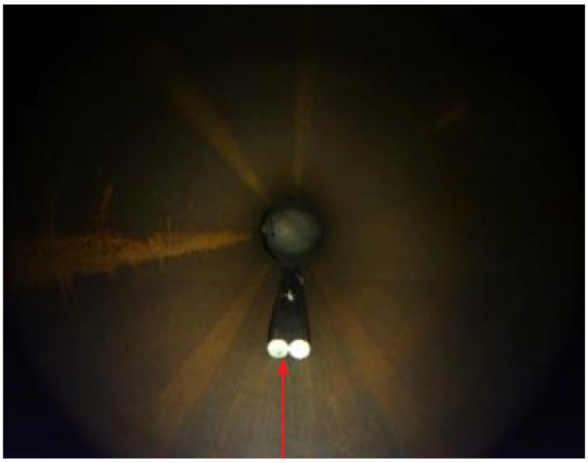

Figure 6: Image of four rod sources inside a capped steel pipe with an internal radius of 15 cm. These images were taken using the onboard camera and lighting.

Measurements using uranium sources began with various arrangements of rod sources used to simulate accumulated deposits. The rods were spread throughout 4.6 meters of pipe at lengths of either 20.3 cm or 40.6 cm (two rod-lengths), sometimes side-by-side (see Figure 6). Measurements were made using several predefined scripts:

1. The cart stopping every foot (30.5 cm) for spectrum collection while also recording scanning data during movement.
2. The cart stopping only when a threshold of countrate had been reached, otherwise always recording scanning data during movement.
3. The cart not stopping at all, instead traveling at various speeds while only recording scanning data.

Because the accumulated deposit model for quantification was identified to be non-functional during the v1.0 V&V testing (see Section 6.1), quantification on these sources was not performed. As expected, quantification of an accumulated source using a uniform model returned results significantly smaller than declared, confirming that an appropriate model is required to properly estimate the deposit mass.

The next step in testing was the usage of "mouse-pad" sources, which were wrapped around the pipe and held in place with a small piece of metal tubing (see Figure 6).

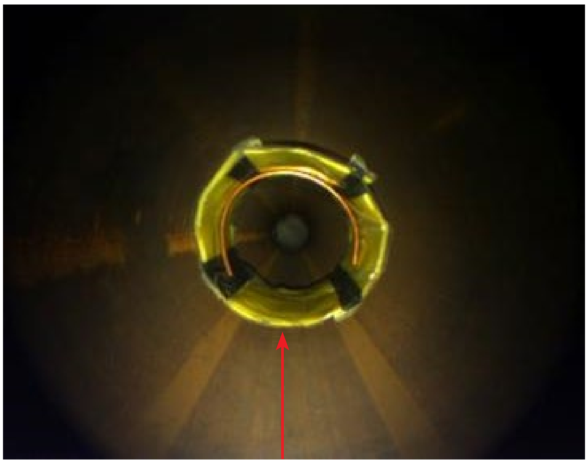

Figure 7: Image of four mouse-pad uranium sources taped to the inner surface of the test pipe with an internal radius of 15 cm.

Assay of mouse-pad sources was estimated at 1.5-2 g ^{235}U per source, with 4 sources being taped together inside the pipe. Multiple runs of the quantification identified masses found in Table 4, which are all within the expected range of the declared values for this source configuration. While this does provide basic confirmation of well-functioning mass quantification, proper testing requires sources of established traceability.

Run Number	Calculated ^{235}U Mass (g)
1	7.29
2	7.12
3	7.53
4	7.58
5	7.41
6	7.43
7	7.53
8	7.21

Table 4: Results of multiple runs for quantification algorithm testing using PGDP mousepad sources.

8. Ongoing and Future Efforts

The v1.1 update to the iQS software is recently completed, and V&V testing is imminent. The updated SQA package has been rewritten to include new features found in v1.1 and any bugs and associated fixes identified from v1.0 testing.

Proper sheet sources of uranium need to be researched further. In all detector testing with uranium sources, the sheet sources have not been traceable standards, while traceable canister or rod sources do not accurately represent deposit shapes.

9. Conclusions

The iQS project, including the InCounter quantification system and the iQS-01 software suite, is designed to improve quality and efficiency of piped holdup measurements. Likewise, its vantage within the pipe also provides a unique, unattenuated view of holdup deposits for gamma measurement and visual inspection. The tests performed show that the InCounter can produce measurements much faster and in a more reproducible fashion than a handheld detection system, and the integrated quantification analyses provide masses of holdup with improved accuracy.

The success of the latest rounds of testing indicates the InCounter and iQS software are ready for a more detailed, formalized qualification and testing program. Once complete, the InCounter should be qualified for incorporation into a facility NDA measurement program that complies with QSNDA.

10. Acknowledgements

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