Use Of Gamma Spectrum Analysis To Evaluate Bulk Materials For Compliance With License Termination Criteria

YA-REPT-01-022-04

Approvals	**(Print & Sign Name)**	
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Rev. 1

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TABLE OF CONTENTS

Attachments

1.0 EXECUTIVE SUMMARY

The Yankee Rowe decommissioning project is expected to produce significant quantities of debris, some of which may contain detectable radioactivity. Three general types of materials identified are concrete, soil, and asphalt. It is anticipated that much of these materials will not require disposal at a licensed disposal facility, but instead could be used as backfill and grading material for final site closure. The benefits of this reuse strategy are to: 1) eliminate environmental and societal impacts and risks associated with transportation to disposal facilities, 2) minimize impact on limited waste disposal resources and, 3) reduce decommissioning costs.

The decision-making process regarding the re-use of decommissioning debris as backfill is supported by the use of *in situ* gamma spectroscopy. A multi-detector (HPGe) array, referred to as the Truck Monitor, has been configured which employs the ISOCS© (*In situ* Object Counting System) efficiency calibration software developed by Canberra Industries. This system has been successfully employed to assay bulk materials at both commercial and Department of Energy facilities, including at the Big Rock Point decommissioning project.

2.0 REPORT

2.1 Introduction

The ISOCS© gamma spectrum assay system is capable of assaying bulk materials in large containers to yield concentration-based radioactivity. The unique detector characterization and associated software has been successfully employed in several applications throughout the industry over the past decade. This Technical Report describes Yankee Atomic's use of ISOCS© gamma spectroscopy as a component of the Final Status Survey (FSS) program as well as supporting decommissioning activities outside the scope of the FSS Program. With respect to the FSS Program, this document provides an overview of the various aspects of a multi-tier evaluation process leading up to the *in situ* gamma spectrum assay of bulk demolition materials. A secondary goal of this document is to technically qualify the assay system. Although data enclosed may be specific to a particular material stream, the data presented represents an example of the system's capabilities.

Prior to re-use of bulk materials as backfill, the radiological characteristics of the different material streams are evaluated. This evaluation includes a historical assessment of the material stream, including the nature of potential contamination and its radionuclide distribution. Included in the historical assessment are reviews of previous post-operational characterization surveys and associated decontamination activities. Reviews of pre-demolition survey data also provides an upper bound for potential localized areas of elevated activity in the matrix.

Material streams subjected to the FSS Program for on-site re-use will be have an ALARA evaluation performed to assess if either further decontamination or regulated disposal is warranted. This ALARA review is administered under the FSS program. An ALARA evaluation will not be performed for material streams associated with unconditional release activities.

A Survey Plan, or other form of documentation, per the FSS or Radiaition Protection (RP) program, will be used to define and derive acceptance criteria to account for applicable nuclides. This information is employed to develop the calibration efficiencies, radionuclide libraries and apply acceptance criteria. The candidate material will be sized as necessary and loaded into containers (e.g. roll-offs, dump trucks, etc.). Assay results associated with Final Status Surveys are compared to the applicable acceptance criteria (e.g. DCGLs) to determine the material's disposition.

The system's sensitivity to geometry-related variations has been evaluated. The primary variable that influences the system's sensitivity is container placement within the detector array. This document demonstrates that container placement variations within 12-inches of the prescribed position result in less than a 10% influence on the efficiency values. Additionally, it has been determined that variations in a container's fill-height between 45-100% have almost no impact on efficiency values. Below 45% it was noted that the efficiency values radically increase. These variations tend introduce a conservative bias so as to over-report activity concentrations.

Therefore, it is concluded that application of this technology supports efficient monitoring of large volumes of bulk material.

2.2 DISCUSSION

2.2.1 Pre-Demolition Surveys and ALARA Review

For each material stream, a historical data review will provide the information required to document decommissioning ALARA decisions and establish surrogate DCGL values for use with the bulk material gamma spectroscopy system. With respect to the Reactor Support Structure (RSS) for example, pre-remediation surveys had characterized the distribution and levels of gamma-emitting radioactivity in the concrete structure. Based on these surveys, extensive surfaces remediation of the RSS was performed in the late 1990s.

Subsequently, sufficient fixed surface contamination scan surveys were recently performed to estimate the remaining surface activity on the structure and determine "hot" spot limitations based on guidance provided by NUREG-5849. Subsequently, material samples were collected and analyzed. These sample results provided an isotopic distribution for the surface activity as well as a characterization of the hard-to-detect isotopic concentrations at various depths within the concrete structure. Using data generated from yet additionally recent scans and samples, an estimate of the total isotopic activity remaining in the RSS was determined. Areas of elevated activity, including potential hot spots, were compared to DCGL limits and assessed against potential demolition techniques for possible segregation. Average isotopic concentrations were then estimated. These estimates will be used in accordance with section 4.3.2, "Survey Unit-Specific ALARA Evaluations," of the License Termination Plan.

In a similar fashion, potentially contaminated soils will be evaluated before being subjected to *in situ* gamma spectroscopy prior to re-use as backfill. For surface soils and during excavations for sub-surface soil, scan surveys will be performed to identify potential hot spots that should be considered for licensed disposal. Due to the nature of soil remediation, it is anticipated that a generic ALARA evaluation will be utilized.

2.2.2 Bulk Material Configuration and Activity Distribution

For each of the re-use material streams, the demolition process will result in random dispersal of any radioactivity throughout the volume. For concrete, the structures will be broken apart, most reinforcing metal removed, and the rubble will be randomly loaded into containers for *in situ* gamma spectrum assay. The assay system will average local variations in radionuclide concentrations over the mass of the sample.

2.2.3 Survey Plan and Nuclide Assessment

For each unique material stream, either an FSS or RP survey plan will be prepared or acceptance criteria will be otherwise documented and communicated. Survey plans will be used to specify concentration-based decision levels and required MDA values. As applicable per the FSS or RP Program, gamma isotopic surrogate decision levels will be developed for each material stream based on gamma isotopic ratios to hard-to-detect radionuclides identified or assumed for the material stream. Either survey plans or specifically prepared guidance documents will administer the assay process for each material stream.

As an example, the survey plan for concrete rubble from the RSS will contain a summary of pre-demolition characterization activities. The isotopic data collected from the RSS has been reviewed in order to assess the potential disposition of this material on-site. Surface activity levels were determined via scan surveys of concrete surfaces. Volumetric (activity at depth) and isotopic mix were determined by analysis of core bores sent for outside laboratory analysis.

The core bores taken to date indicated that all concrete surfaces of the RSS not covered by metal during operation exhibit tritium contamination levels in the top 1 inch layer of 400+ pCi/gram and up to 250+ pCi/gram at 1 foot depth. Due to tritium infusion from two sides of the 24-inch thick walls, average tritium concentrations in the thinner walls were estimated to be 400 pCi/gram. An overview of these results is presented in Attachment 1.

As the results of lab analyses of core samples from the RSS were reviewed, it was noted that there is no correlation between the tritium and other isotopes and that the tritium activity was uniformly distributed. Because of this condition, the average tritium concentration across the RSS was determined. This average concentration will then be compared to tritium's DCGL and the tritium DCGL fraction determined to be used for the entire RSS structure.

A decision level for one of the gamma-emitting nuclides (most likely cesium 137) will be developed to account for non-tritium hard-to-detect isotopes. The ratios of all radionuclide concentrations (greater than their critical levels) to their respective DCGLs will be summed. If this value, considering the applied average tritium concentration, is less than unity, the material may be qualified for on-site fill. Unidentified peaks will require manual identification to ensure that all licensed radioactive materials are included in comparisons against applicable decision levels.

Material control (isolation) provisions of the FSS program will be implemented as a natural byproduct of the survey plan's implementation. A process will be used to track the origin and disposition of each load of bulk material assayed. This process will communicate the source and description of the bulk material to the Truck Monitor operators as well as communicating disposition to the truck drivers. Management controls will be implemented concerning the staging of bulk materials after assay to ensure that material that is not suitable for on-site reuse is not commingled with acceptable materials.

2.2.4 Qualifications and Training

Radiological Engineers responsible for the set-up, calibration, and operation of the ISOCS© equipment have received specific training tailored to the nature of involvement. Several 32-hour courses have been presented to members of the Radiological Engineering staff by Canberra Industries. This training addressed energy calibration of the gamma spectrum equipment, development of geometric models using the ISOCS© software, and operation of the multi-detector production environment (NDA-2000 software). Training for Radiological Engineers also includes system-specific and operationally-specific materials. Technical consultation is available from the manufacturer to assist in pre-operational training, system set-up, and to ensure that all data and measurement quality operational objectives are achieved.

The system will be operated by senior-level Radiation Protection Technicians. Pre-operational technician training will address the following:

- Basic principles of gamma spectroscopy
- Assay system design and software features
- An overview of ISOCS© efficiency modeling
- Operation and maintenance of the multi-detector system
- The License Termination Plan
- The application of DCGLs to assay results
- The system's integration into the Final Site Survey program.

Additionally, a qualification-card style sign-off list is maintained for each technician to account for on-the-job (OJT) training activities. Subsequent to the completion of qualification requirements, technicians will be under the oversight of both their supervision and a Radiological Engineer specifically assigned overall responsibility for the operation of the Truck Monitor.

Training records for the Radiological Engineers and Senior Technicians will be maintained in the FSS training record files. Qualification "cards" specific to the Truck Monitor will be included with these records.

2.2.5 Quality Assurance

Quality Assurance requirements are addressed by procedure AP-8852, "Final Status Survey Quality Assurance Project Plan (QAPP)." Included in this document is guidance for routine detector QC performance checks, data review and validation techniques, and periodic surveillances and assessments. Operational activities will be controlled by approved implementing procedures. These procedures will direct activities associated with instrument calibrations, system operation, QC functions, data review, and record keeping requirements.

Additionally, quality assurance is inherently implemented during pre-operational activities. Quality control measures have been applied by Canberra Industries during system fabrication, software development and detector characterization. Independent on-site verification testing of ISOCS© efficiency models using sources of known activity has been performed. Site QA personnel have been involved during training and procedure development (and approval) to ensure that all programmatic activities are adequately defined.

A readiness review by experienced and independent personnel will be performed before the system is declared operational. After the system is operational, surveillances will be periodically performed by site Quality Assurance personnel to verify procedure compliance and implementation.

2.2.6 Assay System Description and Configuration

A system of eight 40% coaxial HPGe detectors with a resolution of 2 keV at 1332 keV, supplied by Canberra Industries, was designed so as to achieve environmental LLDs in a reasonable time period. Each detector is housed in a 2-inch thick lead collimator with a 90-degree viewing angle. Canberra's DSA-1000 MCA is used to drive each detector. Each MCA is set up for 8192 channels over a range of 2000 keV. Canberra's NDA-2000 software enables spectra from multiple detectors to be combined (summed) and processed as a single measurement result. This provision decreases Lower Limit of Detection (LLD) values while significantly increasing sample coverage.

The original concept provided for assaying containers up to 40 feet long. As the project matured, it became evident that containers used to handle the bulk materials would be closer to 20 feet long. Subsequently, the primary configuration of the detection system consists of a six-detector array, where two of the remaining eight detectors will either act as spares or be available should containers substantially longer than 20 feet be used. Since the lead time to procure an HPGe detector is upwards of three months, having detectors available as spares is a valuable consideration with regard to the project schedule and cost impacts should a detector be rendered out of service.

The facility constructed for the detection system is referred to as the Truck Monitor, and includes an office space for operating the system. Two separate enclosures house four detectors each and are situated 12' apart so as to flank a container (e.g. roll-off, dump truck, etc.) during an assay. The detectors are mounted on towers and tracks to provide for vertical and horizontal adjustments. The physical adjustment range is between 5½' to 11' above the pavement over a 28' length. The detector enclosures are climate controlled to minimize environmental influences on amplifier gain shifts. Photographs of the facility are in Attachment 2.

2.2.7 Energy Calibration

A mixed-gamma NIST traceable source is used for energy calibration. The source includes Co-60, Cs-137 and Am-241, providing an energy range correlating to the nuclides expected to be present in the materials to be assayed. The specific peaks referenced during energy calibrations are 59.5, 662, and 1332.5 keV.

The energy calibration process is governed by an approved procedure and is in accordance with the Genie-2000 software users manual. Energy calibration activities include adjusting the system amplifier gain(s) for approximately 0.25 keV per channel. At the conclusion of the energy calibration process, the centorid channel for each gamma ray peak (listed above) is verified. Additionally, the Full Width at Half Max (FWHM) value at 1332 keV is compared to the factory specification and verified to be within acceptable limits.

2.2.8 ISOCS© Efficiency Calibration

Efficiency calibration curves are generated using Canberra's ISOCS© (*In Situ* Object Counting System) software. This software, in conjunction with a specific characterization of each detector, allows efficiencies to be mathematically determined. This calibration method is especially useful and necessary for large geometries where construction of large calibration sources is not practical.

The ISOCS© calibration process requires the development of an input data (geometry) file. This file contains all parameters associated with the (*in situ*) geometry including detector characterization data, collimator dimensions, shields and attenuators present (enclosure walls, etc.), physical attributes and dimensions of the container, configuration of the source material as well as relative detector position(s) with respect to the container. The range of the material's effective (packing) density will be estimated and appropriate multi-density efficiency calibration curves will be developed. These curves allow the software to interpolate a correct density-based efficiency value for each assay based on the actual sample weights and volumes input at the time of the assay.

To address the enclosure's wall with respect to the geometry, the effective density of the wall was determined for input into the geometry file. The density was empirically determined via weighing a sample of the steel wall in the Yankee Rowe lab. Applying this weight to the volumetric dimensions of the sample, the density was determined. The corrugation pattern was addressed by adjusting the thickness of the steel by the amount of additional material introduced by the corrugation. The effective density was determined by summing the attenuation factors for each material. Finally, the mass fractions of the enclosure wall's constituent compounds were determined. Details regarding this determination are presented in Attachment 3. These factors were applied in the software's Material Editor to define a unique material representing the enclosure's sidewalls, which is subsequently applied in the ISOCS© geometry files.

From the geometry file, efficiency data points and curves are generated for distinct energies. The ISOCS© software enables efficiency curves to be applied to analyses of summed spectra for multiple detectors. Analysis of the summed spectra significantly increases sensitivity to total activity. Additionally, the multi-density feature of the Canberra software allows efficiency curves to be established to address a range of potential densities. Subsequently, as assays are performed and the truer density becomes known, software can interpolate the appropriate efficiency value during the analysis process, avoiding the re-generation of efficiency calibrations as the material density varies (within a specified range).

As a starting point, geometry files were prepared for concrete rubble to address a range of densities most likely to be encountered. Based on Turbine Building concrete previously packaged into inter-modal containers, a density of 72 lbs/ft^3 (1.15 g/cc) is the anticipated density for concrete rubble from the RSS. A tolerance value was applied to address a potential density range from 0.92 to 1.38 g/cc at ±10% and ±20% intervals. The resultant five "point" multi-density curve was developed. Efficiency curves for the six-detector array configuration are presented in Attachment 4.

Applying the above ISOCS efficiency calibration, a 600-second count was performed applying the parameters for a standard roll-off container full of concrete debris (density = 1.15 g/cc) to estimate minimum detectable activity (MDA) concentrations. This 600-second assay yielded MDA values of 0.39 pCi/g (Co-60), 0.34 pCi/g (Cs-137), and 0.20 pCi/g (Eu-

152). A second 600-second assay was performed to address a container half loaded with concrete debris. The resultant MDA values for the half-full container were 0.86 pCi/g (Co-60), 0.73 pCi/g (Cs-137), and 0.41 pCi/g (Eu-152). As expected, outside of varying count times, the container fill level (sample volume) has the most significant influence on MDA values. The above scenarios demonstrate that typical MDA values will be 10%-25% below the anticipated decision levels over a 600-second count time. To ensure that required MDA values are met, the software will automatically extend count times until MDA values, as specified in the nuclide library, are achieved.

As containers of material are loaded, the actual weight will be determined. These weights, as well as the container's fill-height (volume) will be input into the assay software. If a default density can be derived based on a statistical evaluation, then a default density may be applied to all similar analyses in lieu of weighing each container. When default densities are employed, a periodic surveillance will be conducted verify the applicability of the default density. If necessary, the default density will either be appropriately adjusted or discontinued. Adjustments will be made to efficiency calibrations if the observed densities are significantly beyond the initially estimated density range addressed by the efficiency calibrations.

2.2.9 Geometric Sensitivity Analysis

Evaluations have been performed to qualify the sensitivity of the six-detector array to geometric variables such as container alignment between the detectors and variances in the amount of material (fill level) in the container. These evaluations involve comparing efficiency values from a variety of geometries.

The specific geometric variables evaluated included: 1) longitudinal variations in the position of the truck/container between the assay trailers (i.e., end-to-end alignment), 2) lateral variations (i.e., side-to-side alignment), and 3) variable fill levels of waste material/debris in the assay container. ISOCS© calibrations were used to model the same input parameters as the actual calibration files, except for the varied longitudinal position, lateral position, or fill level as shown on the graphs.

Variations in efficiency due to longitudinal (forward-backward) positioning were evaluated. Efficiencies were determined for off-set container positions in three-inch increments, up to 12 inches. This evaluation indicated that system error due to forward-backward placement is less than 10%. Since it is expected that the alignment of the container in this axis could reasonably be routinely controlled to within approximately

6 inches, this variable will not produce significant error. The results of this evaluation are presented in Attachment 5.

A similar evaluation was performed for lateral (left-right) variations in the position of a truck/container between the system's trailers. For lateral off-sets, the relative response for a single detector position varies by a greater degree (up to 30%) than for longitudinal variations. This is expected since lateral variations move the container (source) away from or closer to the detectors in a direct way. However, when all detectors are evaluated as a system (summed), it was noted that the relative efficiency actually increases (up to +5%) as a container's position approached 12 inches off-center. This is attributed to the fact that efficiency gains exceed efficiency losses with respect to the source-to-detector distance. Therefore, lateral alignment does not negatively impact assay results. These comparisons are presented in Attachment 6.

An evaluation specific to vertical positioning of the container is not practical since this dimension should not vary significantly short of a truck having a flat tire. However, to address this variable, an evaluation of the effect of partially filled containers was also performed. Fill levels from a full container down to 14" (in 6 inch increments) were evaluated. Attachment 7 illustrates the calculated efficiencies for various fill levels. The effect of fill level was negligible down to about 20 inches, however the calculated efficiency value notably increased at 14 inches. This increase is due to the detector's view of the top surface of the material in the container, increasing the amount of material in the detector's field of view not impacted by self-attenuation.

The potential errors of an imprecisely positioned truck/container are considered adequate for the application. The sum detector response, which is the most important measurement performed by the system, was found to be minimally affected (<10%) over the potential range of misalignments (±12 inches) expected during routine assays. Similarly, response variations due to possible container fill levels were also found to be within acceptable limits. Other than a minimally filled container (< 20 inches), which is not expected, the variation of efficiency values observed in the modeled geometries were nearly negligible with regard to container fill level. Efficiency values actually increase significantly when a container's fill-level drops below 20 inches.

2.2.10 Validation and Verification

The ISOCS© efficiency calibration software developed by Canberra Industries allows efficiency values to be mathematically derived as a function of energy over a wide variety of geometric and source activity distributions. Canberra has performed comprehensive Validation and

Verification (V&V) testing which included Internal Consistency and Validation Tests. These tests verify that the ISOCS© software processes input geometry parameters as intended and correctly calculates associated efficiencies in a consistent manner. Geometries tested included point sources, rectangular volumes (boxes), circular planes (open land areas), cylinders, pipes, spheres, and miscellaneous lab containers (beakers, etc.). Results from each of the tested geometries were consistent, generally within 1% of each other.

Canberra's validation testing also compared efficiency values calculated by the ISOCS© software to those empirically determined using actual radioactive source distributions. This testing addressed field, laboratory, and collimated geometric categories. Ratios of averaged ISOCS© results to empirically determined efficiency values were within 10%. A copy of Canberra's ISOCS© V&V documentation is maintained with other manuals supplied by Canberra.

In addition to the software V&V, each ISOCS© detector was specifically characterized by Canberra. The results of this characterization are written to a unique characterization file that represents the detector's efficiency response to incident photons at various angles and energies. This characterization file is then applied during ISOCS© efficiency calibrations. The eight detectors in the Truck Monitor's array were selected as an ensemble so that all of the detectors would have very similar efficiency responses, particularly for energies greater than 100 keV. To demonstrate the similarity of the efficiency responses for geometries typical to the use of the Truck Monitor, the characterization data for all eight detectors was compared to identify a single detector that would best approximate the response of the other detectors in the system. The use of a representative detector's characterization simplifies the efficiency calibration process and allows the flexibility of swapping detectors, if necessary, without having to perform new ISOCS© calibration efficiencies for each detector. This use of one detector has a negligible effect on the accuracy of the system, since the reported activity is based on the sum of the spectrum from all (six) detectors in the array. It was determined that detector serial number 09047828 represents the average response. Comparing this detector to each of the other detectors in the system, it is noted that the expected error introduced by this approximation is no more than 5% for energies above 300 keV. Details concerning this comparison are presented in Attachment 8.

Field testing was performed to verify ISOCS© efficiency calibrations using a source with known activity. This testing involved the use of a 6.56 μCi Co-60 point source positioned equi-distance between two detectors (approximately 84 inches) at 0° off-center from the detector. An ISOCS©

model was created to represent the source's geometry. Associated efficiency files were applied to each spectra after background subtraction. Assay results compared favorably (within 10%) for individual detectors and are presented in Attachment 9. When the summed average was compared to the true activity of the source, the deviation was less than 2% for both the six-detector array as well as the eight-detector array. Since the assay results will be based on the summed spectrum, this 2% error is considered the error associated with the efficiency calibration. This test verifies the performance of the ISOCS© model and supports the practice of applying the same characterization file (for detector S/N 09047828) to each detector in the system.

An additional verification test was conducted to address volumetrically distributed radioactive material. This test compared the K-40 results of an *in situ* assay of bulk soil to both laboratory analyses of the same soil material as well as 15 individual soil samples previously collected from a wide variety of locations over the site.

The bulk soil "sample" consisted of approximately 21,000 pounds of soil assayed in a 690 ft^3 inter-modal container. The container was visually estimated to be 40% filled yielding an estimated volume of 276 ft^3. Using this data, a density of 1.22 g/cc was calculated. Following the bulk assay using the ISOCS detectors, four 1-liter samples of the same soil were collected. Each 1-liter container was packed and compressed to 100% full and weighed. From these weights, density values were determined. Results comparisons are presented in Table 1 below.

SAMPLE	AVERAGE RESULT (pCi/g)	ACTIVITY RANGE (pCi/g)	AVERAGE DENSITY (g/cc)
Bulk in situ assay (21,100 lbs)	18.1 [1]	N/A	1.22 [1]
One-liter samples of bulk soil	13.7	13.5 – 14.1	2.3
Site-wide (historical) samples	14.1	8.4 – 20	NOT EVALUATED
1 – Not an averaged value.			

Table 1, Volumetric Activity Comparisions

The data in Table 1 suggests that the ISOCS detector system reports activity approximately 28% higher than the laboratory analyses. Two systematic errors may account for these differences: 1) underestimation of the volume in the inter-modal container; and 2) the resultant density in the 1-liter samples is greater than the soil calibration standard (1.8 g/cc) used in laboratory. Considering these possible errors, the difference in results appear to be within expected variances, as discussed below.

First, with respect to large containers for bulk assays, it is estimated that a relative error of up to 20% may be experienced when visually estimating sample volume for use in density determinations. Based on this assumption, the volume of the 690 ft^3 inter-modal, assumed to be (truly) 40% filled, could range from 220 ft^3 to 331 ft^3. Applying the actual bulk sample's mass (21,000 pounds) to this volume range yields a bounded density range from 63.4 lbs/ft^3 to 95.4 lbs/ft^3 (1.02 g/cc to 1.52 g/cc). Because sample mass is fixed and well known, this translates to a potential over-estimation of up to 25% and a potential under-estimation of up to 16%.

Secondly, samples processed by the on-site laboratory may also exhibit density-related errors. In this scenario, density errors are introduced by the manual (over) packing of the soil into the 1-liter container, biasing density values high. The soil calibration standard used by the laboratory has a density of 1.8 g/cc, which is lower than the density of the soil samples analyzed for this comparison. With a higher density, the reported activities would be expected to be lower than the actual value considering the additional attenuation of the photons in the sample matrix. This additional attenuation is not accounted for in the analysis performed.

Based on the results reported by the on-site laboratory, it appears that the bulk *in situ* assay results may tend to be conservatively biased high. Considering systemic variations, the results comparisons for this validation exercise demonstrate an acceptable agreement between the in situ assay of the bulk material and the sample results obtained via the on-site laboratory. In conclusion, efficiency calibrations developed with the ISOCS software for determining activity concentrations in bulk material are valid.

2.2.11 System Operation

Operation and maintenance of the assay system is under the guidance and direction of specifically assigned Radiological Engineers. Assigned engineers are responsible for all aspects of the system's configuration, set-up, and calibration, including ISOCS© efficiency modeling. Qualified senior Radiation Protection Technicians may operate the system. Operational oversight of the assay system, as well as routine QC activities and assay reports, will performed by an assigned Radiological Engineer.

The system's operational procedure will reference the survey plan procedure to ensure that appropriate decision levels are applied to assay results. Additionally, the operational procedure will provide guidance for daily QC source checks, performance monitoring for each assay result (K-40 peak centroid, etc.), and resolution of all unidentified peaks before a disposition is applied to a load of material. Reviews of assay results will be proceduralized.

A QC source check will be performed each day prior to use. These results will be plotted on a control chart with established limits for performance. The sources used for daily QC activities will be those provided by Canberra, which contain Na-22 and Eu-155. These nuclides provide energies that span the range of expected gamma-emitters present in the materials to be assayed.

Background QC checks will be routinely performed to verify that background levels in the vicinity of the assay system are not significant so as to impact results. As previously discussed, MDA values will be specified and documented prior to assays. Counting software will be configured to automatically extend pre-set count times so as to achieve these prescribed MDA concentrations. The current location of the instrument calibration facility (and its sources) and the storage facility for protective clothing introduces small amounts of Co-60 and Cs-137 to the spectrum. While the use of the calibration sources can be controlled and limited so as to not influence assay results, the levels of activity due to the stored protective clothing can vary. If it is determined that the nominal background is statistically stable, then the background subtract feature may be enabled. To support the use of background subtraction, daily QC activities will include a surveillance of the nominal background levels to insure that background subtraction does not yield under-reported activity concentrations.

Assay reports will be designed to clearly identify results above decision levels. Each (licensed) nuclide identified by the assay will be compared to a derived activity concentration "limit". Sum-of-fraction calculations may be applied to determine the disposition of the material assayed. As previously discussed, the derived "limit" will account for hard-to-detect nuclides.

Regarding the use of the Truck Monitor to support unconditional release survey activities, the detection system will not involve nuclide identification. Instead, an evaluation of aggregate materials will be made with respect to the nominal background activity. To achieve this objective, system responses will be output in terms of gross counts per second. To support this objective, QC activities will need to include daily background surveillances. Monitoring results of aggregate materials will be statistically compared to a mean background value. The mean background value and associated standard deviation will be derived from actual background data. System responses within ±3 sigma of the mean value of the established background shall be considered as acceptable for unconditional release. Indications of elevated activity above the nominal background levels (i.e. greater than ±3 sigma) will be factored into subsequent evaluations prior releasing the material.

2.3 Conclusions/Recommendations

Interfacing the application of the ISOCS© gamma spectrum assay technique with the demolition process is an effective methodology to evaluate materials with respect to concentration-based radioactivity (pCi/g) for comparison to applicable DCGLs or other concentration-based criteria.

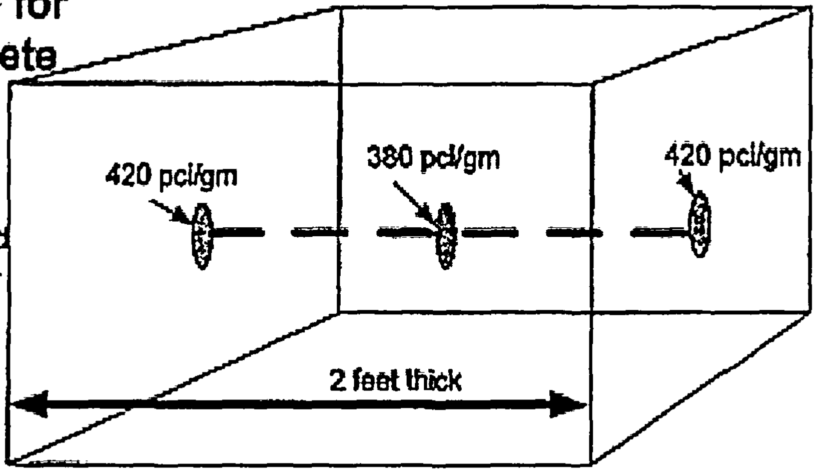
The material handling process inherently provides for the random distribution of the "sample" material and potential radioactivity. While it is acknowledged that the system's efficiency decreases for materials positioned toward the center of the container, almost 15% of the material is within six inches of the container's outer wall, where efficiency values are highest. Applying this consideration to a typical roll-off container of material, the outer six-inches of material alone constitutes an equivalent of over 2000 one-liter samples of material. This effective sample density (1 part in 7) far exceeds any industry-standard protocol.

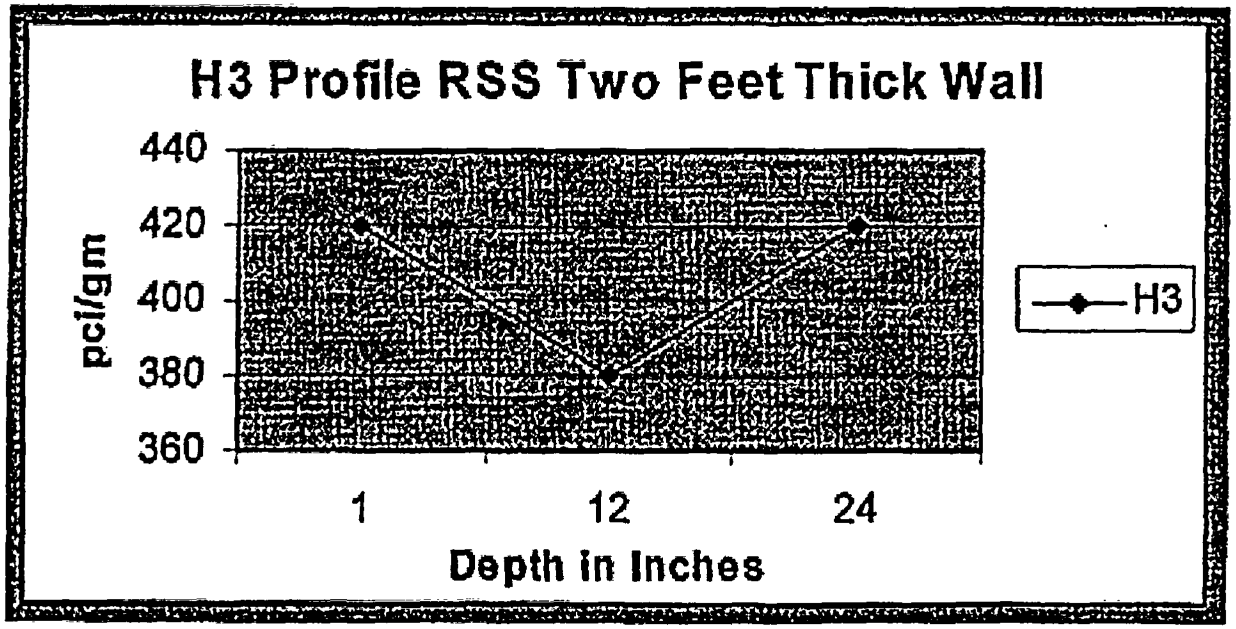
Qualification of the system to ascertain the influences of geometry imprecision indicates that practical variations will not invalidate assay results. This, coupled with prescribed sample attributes, procedurally defined data review and routine quality control activities provides assurance that the system can be implemented as conceptualized and is technically capable of meeting all of the design and operational objectives of the system.

Projected Tritium Profile for a Two Foot Thick Concrete Slab

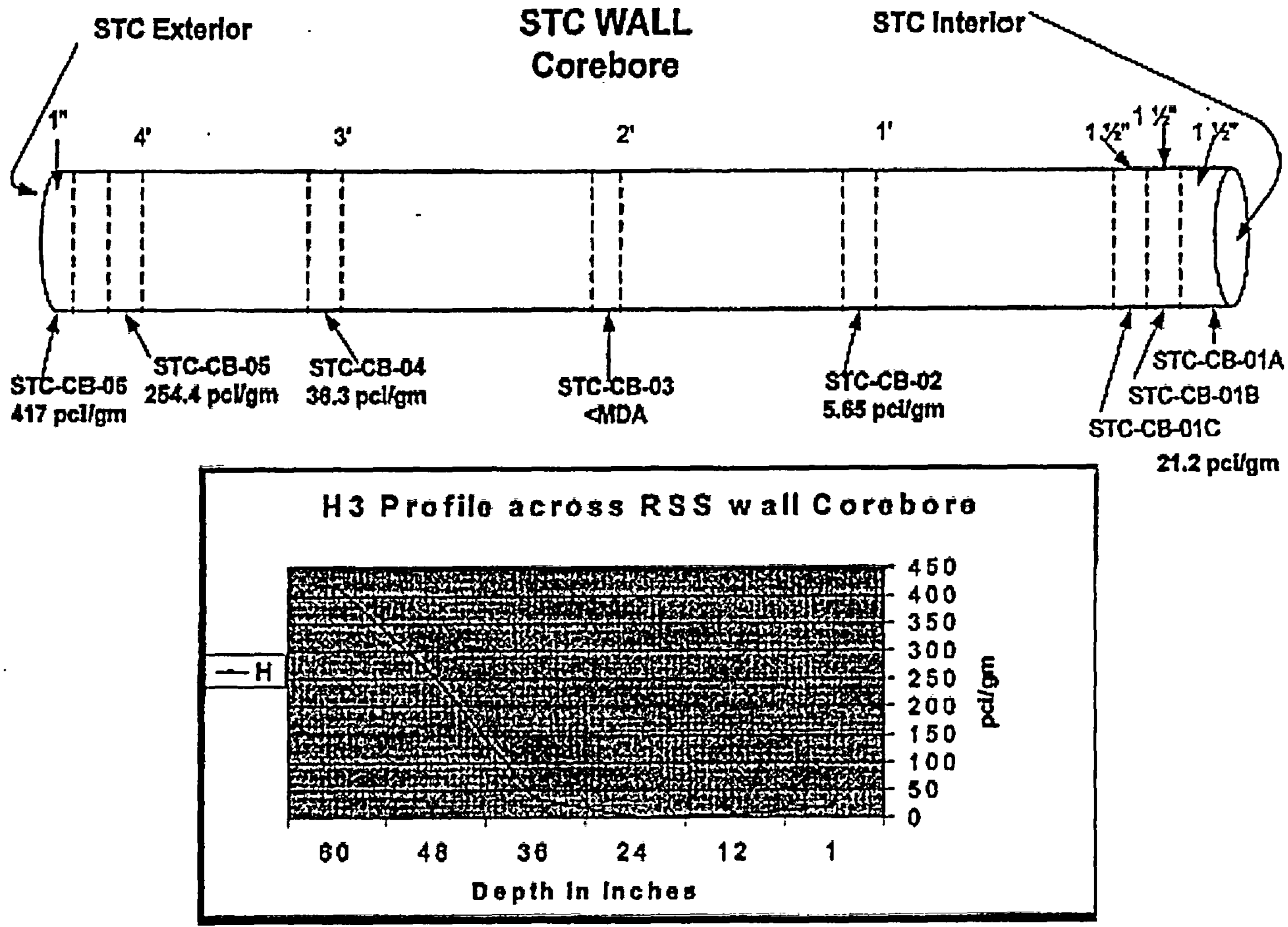
Surface concentrations were determined by an average of RSS-CB-08, RSS-CB-02, and STC-CB-06

Center concentrations were an average of surface and one foot corebore results

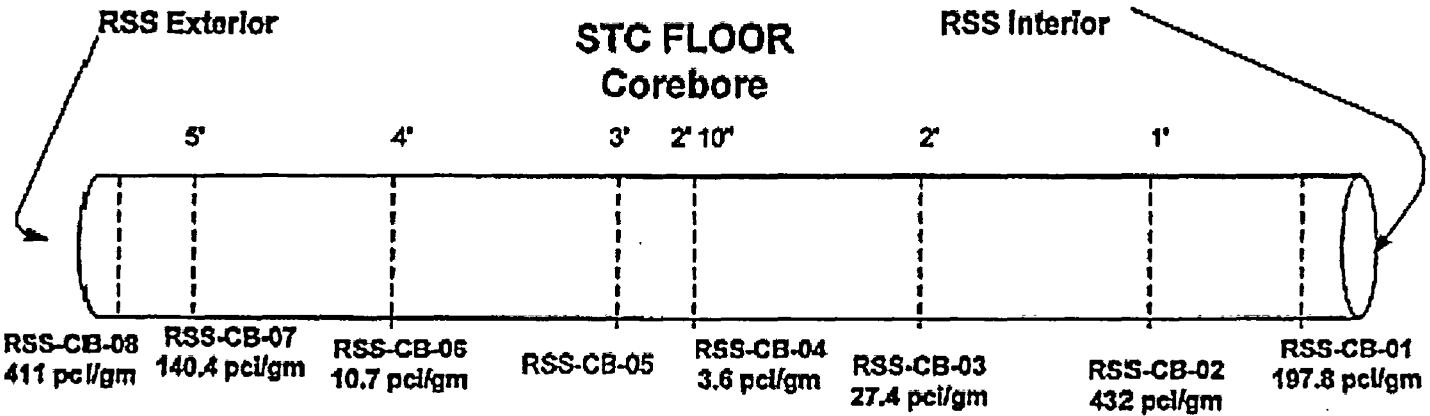


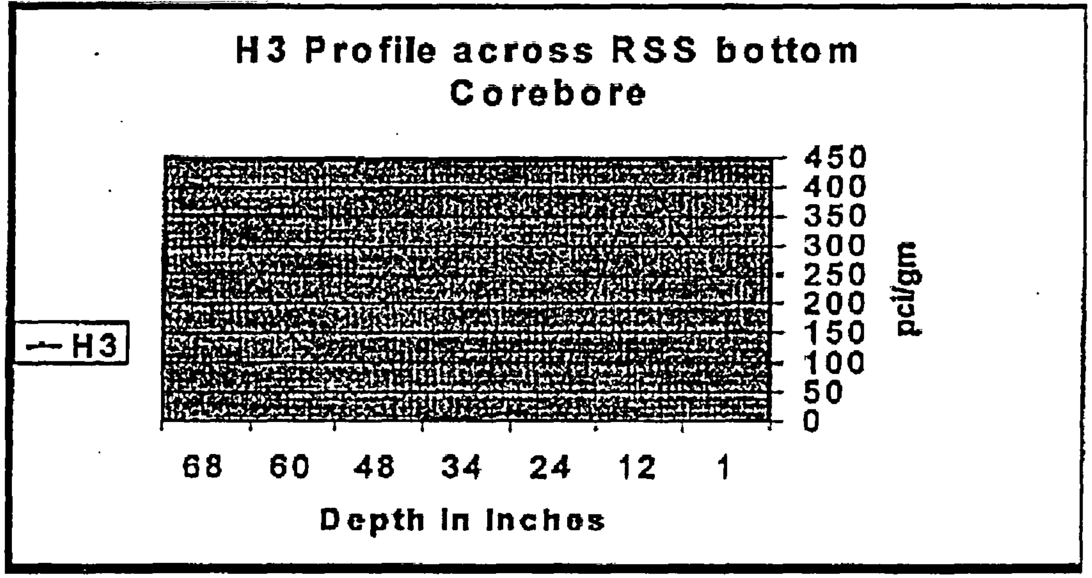


Attachment 1 (Page 2 of 3)
Reactor Support Structure Tritium Profile

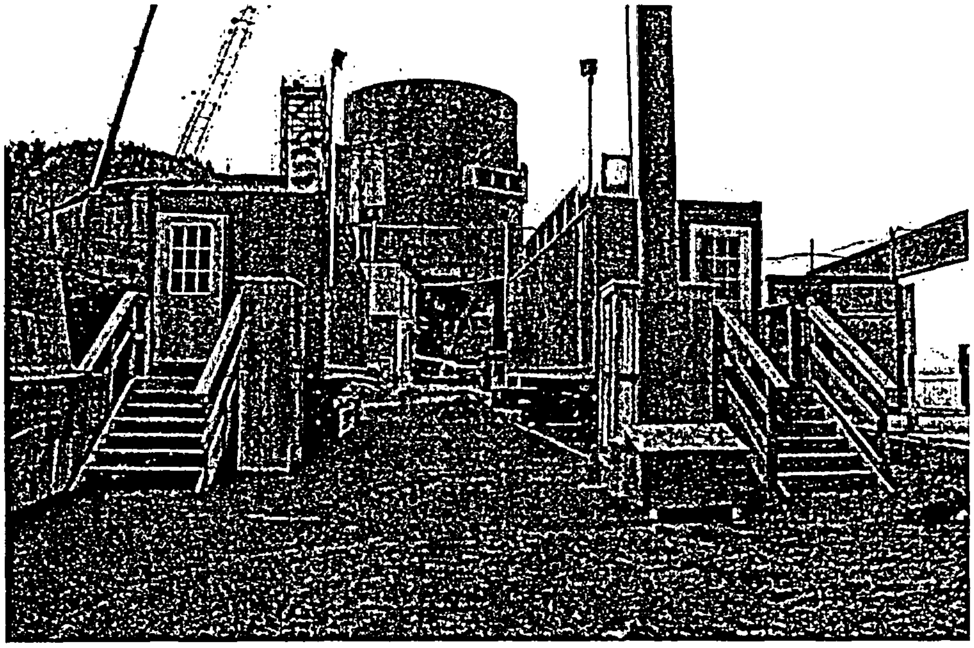


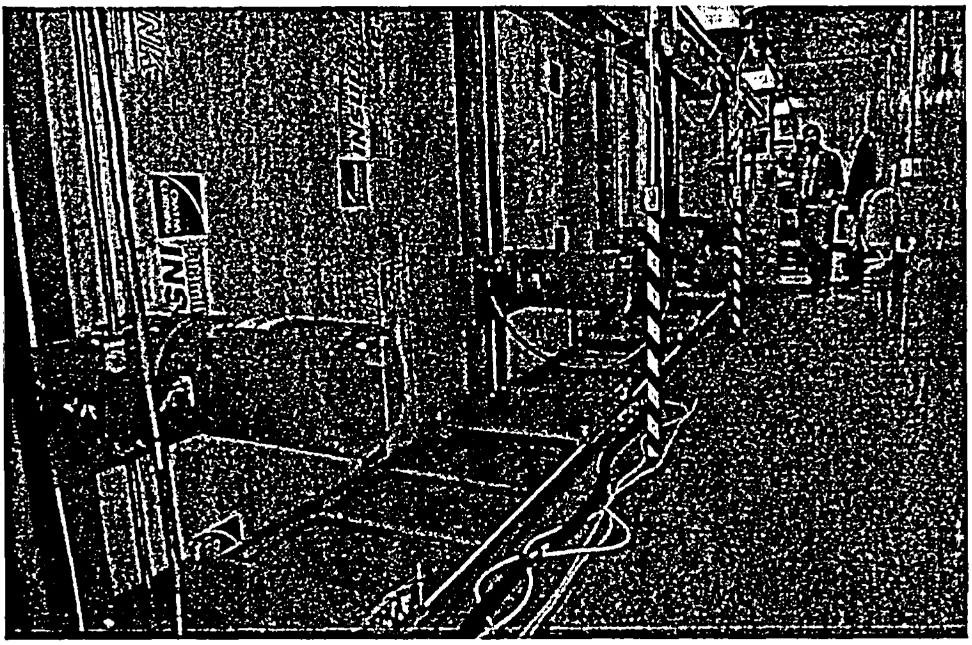
Attachment 1 (Page 3 of 3)
Reactor Support Structure Tritium Profile





Attachment 2
Detector Enclosure Facility





Attachment 3

Effective Density Determination Of Detector Enclosure Walls For Use in ISOCS© Geometry Models

The wall surfaces in the detector's field of view are constructed of corrugated steel and Styrofoam. To account for the additional material associated with the corrugation, a correction factor of 1.09 was derived. Application of this factor yielded an effective thickness for the steel wall of 0.189 cm. The thickness of the Styrofoam was easily measured. The density for each of these materials was empirically determined in the on-site chemistry lab. Resultant physical attributes are presented below:

MATERIAL	THICKNESS (cm)	DENSITY (g/cc)
Steel	0.189	8.30
Styrofoam	3.81	0.03

The summed "effective" thickness = 0.189 + 3.81 = 3.999 cm (1.57 inches)

The attenuation factors for enclosure wall's two-layer "sandwich" is expressed as:

$$e^{\frac{\mu}{\rho}\rho x_{\,steel} + \frac{\mu}{\rho}\rho x_{\,styrofoam}}$$

The effective density for the two layers can be expressed as follows:

$$\frac{\sum \rho\, x}{\sum x} = \frac{(.03)(3.81)+(8.3)(0.189)}{0.189+3.81} = \frac{(0.1143)+(1.5687)}{3.999} = 0.4209$$

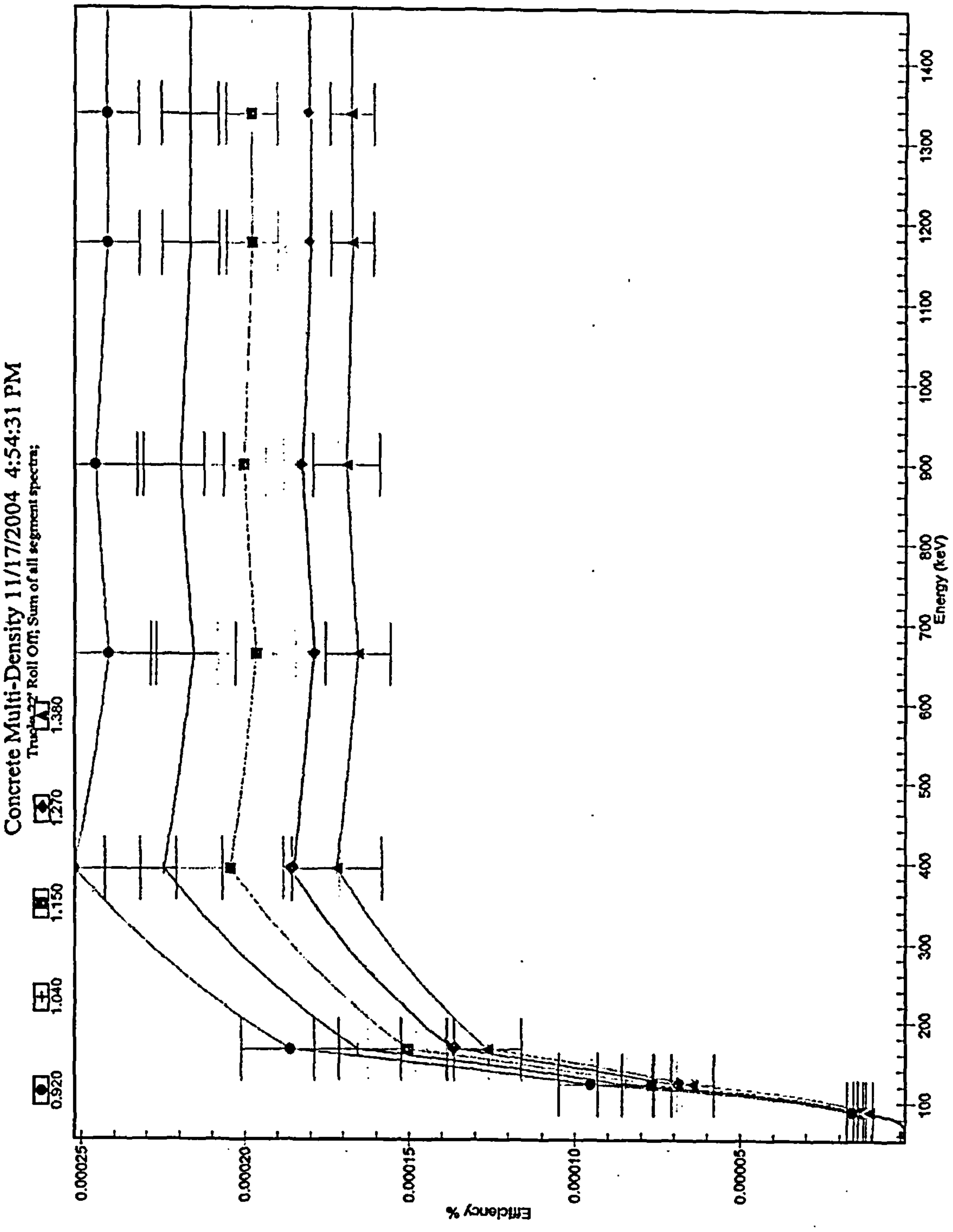
The material weighting factors are the mass fractions of each of the two layers that make up the "sandwich", where 'i' = iron and 'j' = Styrofoam.

$$\frac{x_i\rho_i}{x_i\rho_i + x_j\rho_j} = \frac{(0.189)(8.30)}{(0.189)(8.30)+(3.81)(0.03)} = 0.932$$

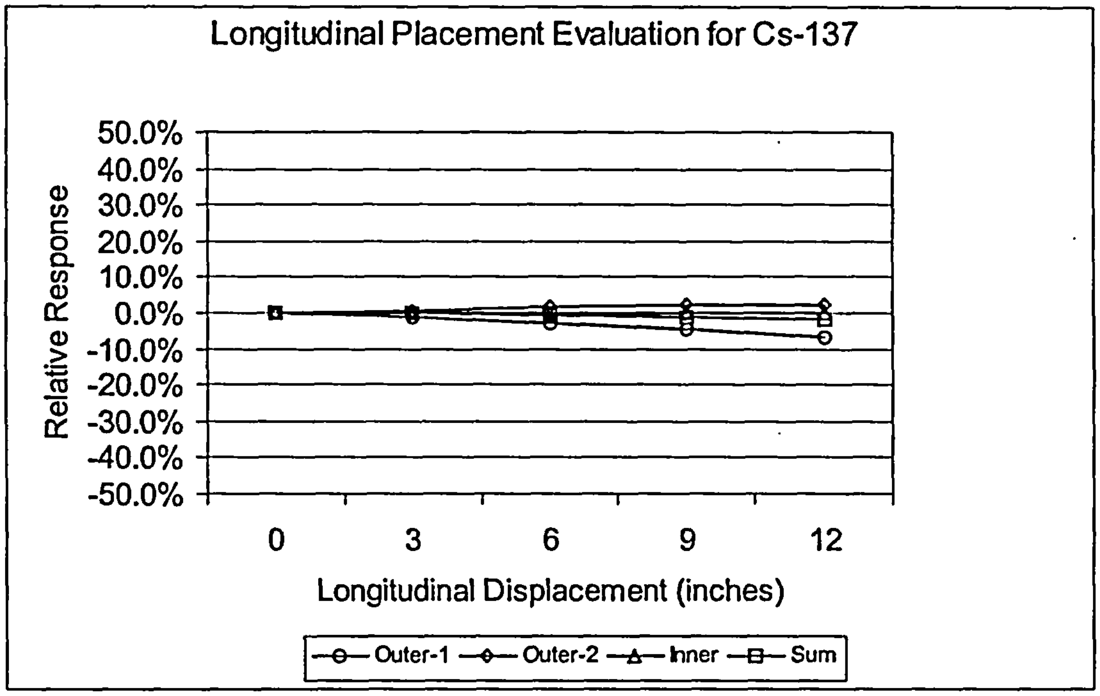
Therefore the wall's effective composition is 93.2% steel and 6.8% Styrofoam. The software's material editor has "stock" materials, two of which are carbon steel and Styrofoam. Each of these has a pre-defined chemical composition. During the process of defining a unique material, the (mass-based) percentage of each component is specified.

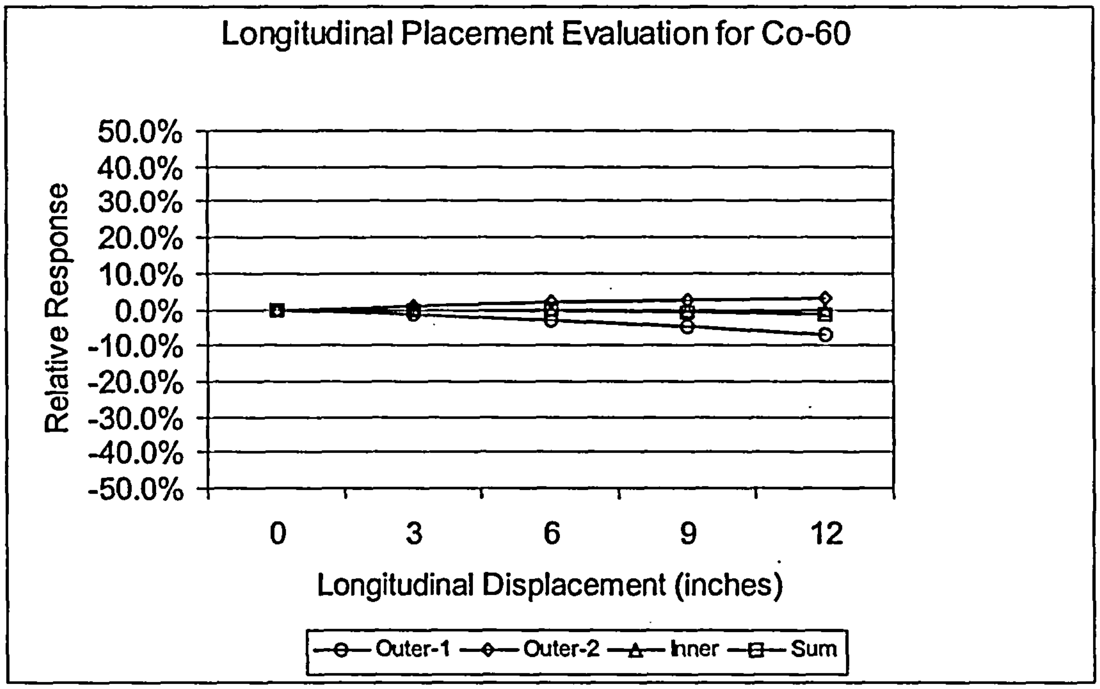
Attachment 4

Efficiency Calibration Curves For Various Densities

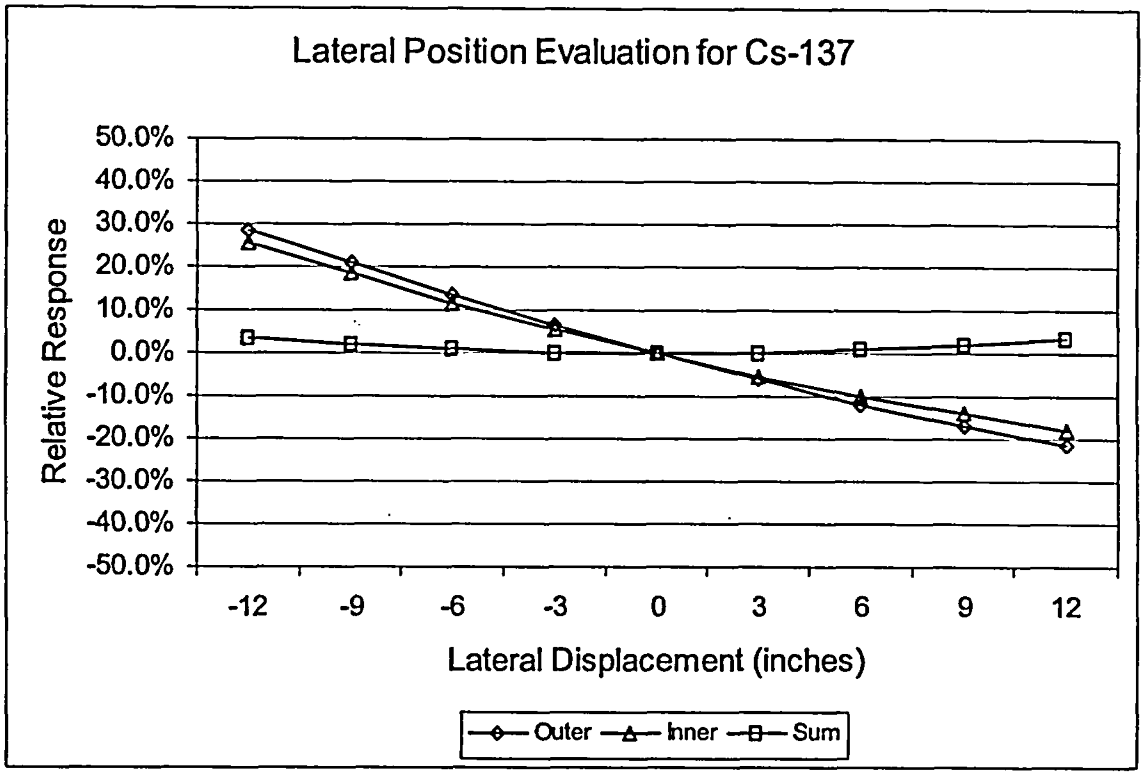


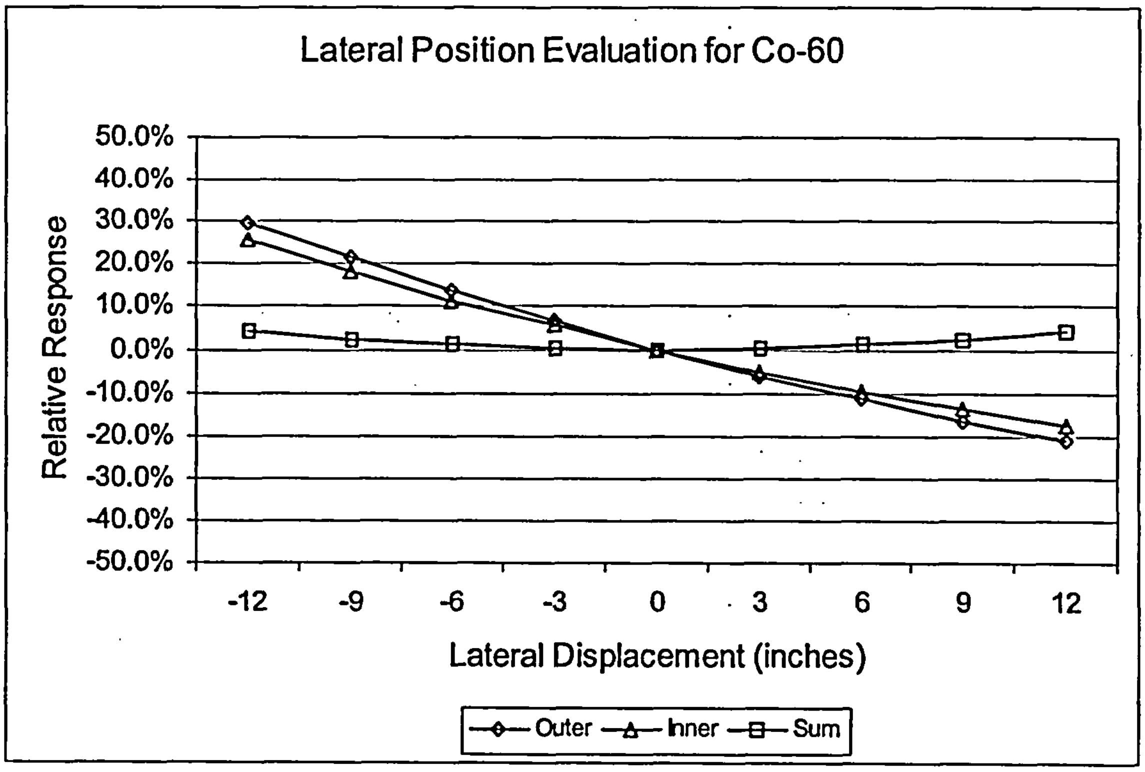
Attachment 5
Evaluation of Longitudinal Variations of Container Placement With Respect To Efficiency Values For A Six-Detector Array



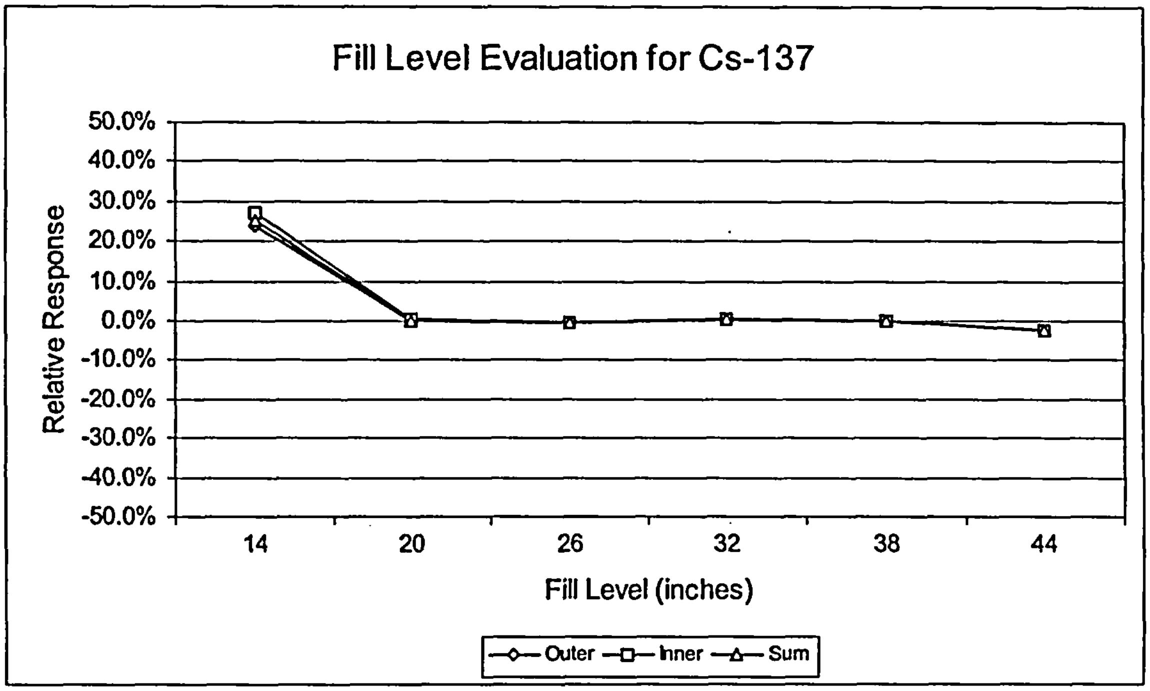


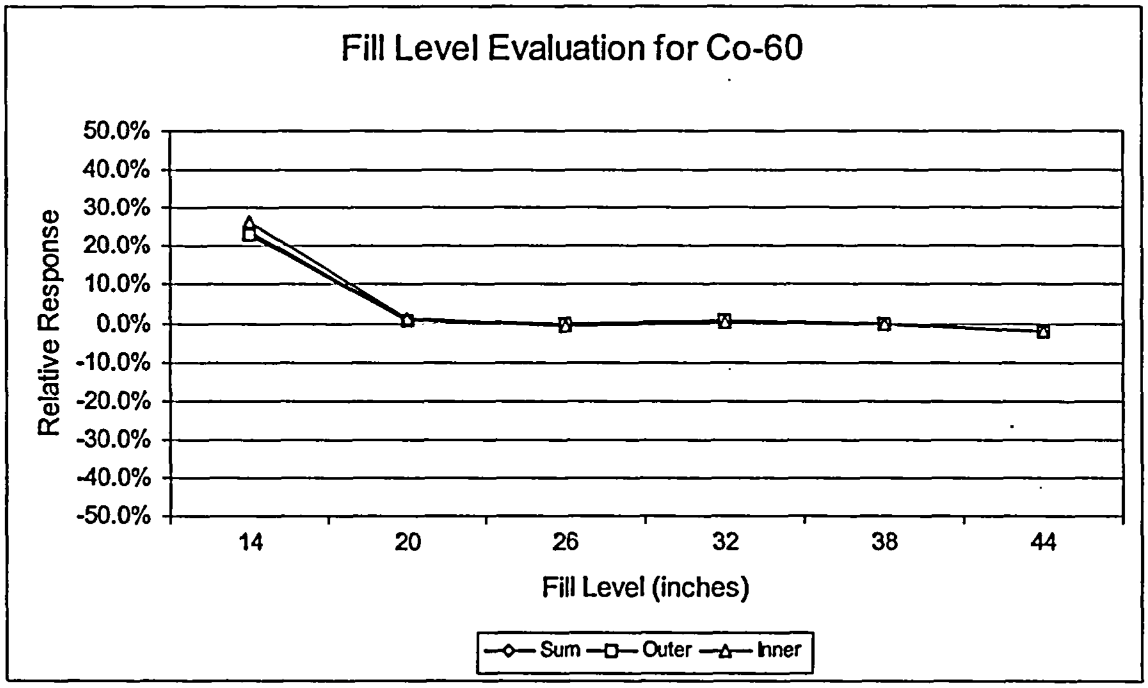
Attachment 6
Evaluation of Lateral Variations of Container Placement With Respect To Efficiency Values For A Six-Detector Array





Attachment 7
Evaluation of Variations In Container Fill Levels With Respect To Efficiency Values For A Six-Detector Array





Attachment 8 (Page 1 of 4)

The Use Of A Single Detector's Characterization to Approximate All Detectors In A Multi-Detector Array

The Truck Monitor includes eight high-purity germanium (HPGe) coaxial detectors, Canberra model GC4020. All eight detectors were selected from the manufacturing line as an ensemble to have very similar efficiency responses, particularly for energies above 100 keV. Each detector was characterized for ISOCS©. To demonstrate the similarity of the efficiency responses for anticipated (*in situ*) geometries, the data from the 0° and the 90° ISOCS© characterization results for each detector serial number are presented in Table 8.1 below. Since the material to be assayed by the Truck Monitor will be positioned in the "forward" (i.e. 0°) position relative to each detector, the 0° response will dominate over the 90° response.

Table 8.1, Detector Characterization Response

Energy (keV)	Detector S/N 7813		Detector S/N 7810		Detector S/N 7812		Detector S/N 7809	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	7.54E-04	7.88E-04	1.01E-03	7.91E-04	1.06E-03	8.92E-04	7.72E-04	7.10E-04
121.8	1.64E-03	1.92E-03	1.83E-03	1.81E-03	1.82E-03	1.86E-03	1.60E-03	1.80E-03
244.6	1.29E-03	1.50E-03	1.37E-03	1.39E-03	1.36E-03	1.44E-03	1.23E-03	1.44E-03
344.3	1.05E-03	1.22E-03	1.08E-03	1.10E-03	1.10E-03	1.16E-03	9.86E-04	1.13E-03
778.9	5.82E-04	6.66E-04	5.77E-04	5.88E-04	5.96E-04	6.29E-04	5.34E-04	6.03E-04
1112.1	4.54E-04	5.21E-04	4.44E-04	4.61E-04	4.67E-04	4.93E-04	4.17E-04	4.66E-04
1408	3.83E-04	4.33E-04	3.70E-04	3.82E-04	3.82E-04	4.11E-04	3.42E-04	3.88E-04
Energy (keV)	Detector S/N 7829		Detector S/N 7828		Detector S/N 7831		Detector S/N 7824	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	8.23E-04	7.68E-04	9.91E-04	9.17E-04	1.00E-03	9.27E-04	1.04E-03	9.61E-04
121.8	1.70E-03	1.86E-03	1.77E-03	1.88E-03	1.75E-03	1.85E-03	1.76E-03	1.95E-03
244.6	1.30E-03	1.46E-03	1.34E-03	1.44E-03	1.32E-03	1.51E-03	1.31E-03	1.50E-03
344.3	1.04E-03	1.17E-03	1.08E-03	1.16E-03	1.07E-03	1.21E-03	1.06E-03	1.21E-03
778.9	5.67E-04	6.28E-04	5.83E-04	6.28E-04	5.85E-04	6.53E-04	5.85E-04	6.51E-04
1112.1	4.44E-04	4.92E-04	4.49E-04	4.86E-04	4.57E-04	5.09E-04	4.51E-04	5.10E-04
1408	3.71E-04	4.08E-04	3.80E-04	4.05E-04	3.81E-04	4.25E-04	3.73E-04	4.21E-04

To provide for clearer inter-comparison, the average response for the eight detectors was calculated and this average was then compared to each detector's observed response. The resultant ratio (deviation) of each detector's response from the average is presented in Table 8.2 below.

The Use Of A Single Detector's Characterization to Approximate All Detectors In A Multi-Detector Array

Table 8.2, Detector Response-To-Average Ratios

Energy (keV)	Detector S/N 7813		Detector S/N 7810		Detector S/N 7812		Detector S/N 7809	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	0.810	0.933	1.085	0.937	1.138	1.057	0.829	0.841
121.8	0.946	1.029	1.056	0.970	1.050	0.997	0.923	0.965
244.6	0.981	1.027	1.042	0.952	1.034	0.986	0.935	0.986
344.3	0.992	1.043	1.021	0.940	1.039	0.991	0.932	0.966
778.9	1.010	1.056	1.002	0.932	1.034	0.997	0.927	0.956
1112.1	1.014	1.058	0.991	0.937	1.043	1.002	0.931	0.947
1408	1.027	1.058	0.993	0.934	1.025	1.005	0.918	0.948

Energy (keV)	Detector S/N 7829		Detector S/N 7828		Detector S/N 7831		Detector S/N 7824	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	0.884	0.910	1.064	1.086	1.074	1.098	1.117	1.138
121.8	0.981	0.997	1.021	1.007	1.009	0.991	1.015	1.045
244.6	0.989	1.000	1.019	0.986	1.004	1.034	0.996	1.027
344.3	0.983	1.000	1.021	0.991	1.011	1.034	1.002	1.034
778.9	0.984	0.996	1.012	0.996	1.015	1.035	1.015	1.032
1112.1	0.991	0.999	1.003	0.987	1.020	1.034	1.007	1.036
1408	0.995	0.997	1.019	0.990	1.022	1.039	1.001	1.029

To simplify the efficiency calibration process for a multi-detector system, is has been a common practice to select one detector which best represents the average response. This makes it possible to swap detector positions, if necessary, without requiring a recalculation of ISOCS© efficiencies for each detector. This practice has a negligible impact on the accuracy of the system since the reported activity is based on the summed (averaged) spectra from all detectors in the system. The detector which best represents the average response would be the one which has the smallest deviation from 1.0. Applying a greater "weight" to the 0° response over the 90° response and inspection Table 8.2 above, the most representative detector is the detector with serial number 7828.

To evaluate the expected error introduced by applying the characterization for detector 7828 to the other detectors in the system, the ratio of each detector's efficiency to that of detector 7828 is presented in Table 8.3 below.

Attachment 8 (Page 3 of 4)

The Use Of A Single Detector's Characterization to Approximate All Detectors In A Multi-Detector Array

Table 8.3, Deviation From Detector 7828

Energy (keV)	Detector S/N 7813		Detector S/N 7810		Detector S/N 7812		Detector S/N 7809	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	0.76	0.86	1.02	0.86	1.07	0.97	0.78	0.77
121.8	0.93	1.02	1.03	0.96	1.03	0.99	0.90	0.96
244.6	0.96	1.04	1.02	0.97	1.01	1.00	0.92	1.00
344.3	0.97	1.05	1.00	0.95	1.02	1.00	0.91	0.97
778.9	1.00	1.06	0.99	0.94	1.02	1.00	0.92	0.96
1112.1	1.01	1.07	0.99	0.95	1.04	1.01	0.93	0.96
1408	1.01	1.07	0.97	0.94	1.01	1.01	0.90	0.96
Energy (keV)	**Detector S/N 7829**		**Detector S/N 7828**		**Detector S/N 7831**		**Detector S/N 7824**	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	0.83	0.84	1.00	1.00	1.01	1.01	1.05	1.05
121.8	0.96	0.99	1.00	1.00	0.99	0.98	0.99	1.04
244.6	0.97	1.01	1.00	1.00	0.99	1.05	0.98	1.04
344.3	0.96	1.01	1.00	1.00	0.99	1.04	0.98	1.04
778.9	0.97	1.00	1.00	1.00	1.00	1.04	1.00	1.04
1112.1	0.99	1.01	1.00	1.00	1.02	1.05	1.00	1.05
1408	0.98	1.01	1.00	1.00	1.00	1.05	0.98	1.04

By inspecting the values presented in Table 8.3 above, it is clear that the expected error introduced by applying the characterization of detector 7828 to all detectors in the system is no more than 10% for energies above 100 keV, and typically less than 5% for energies above 300 keV.

Considering a six-detector array (omitting detectors 7829 & 7831 as reflected in the current configuration), a similar comparison was performed to determine the effect of applying the characterization for detector 7828 to all detectors. By inspecting the values presented in Table 8.4 below, the expected error due to the application of the characterization for detector 7828 to all detectors in a six-detector array is very similar to that for an eight-detector array.

Attachment 8 (Page 4 of 4)

The Use Of A Single Detector's Characterization to Approximate All Detectors In A Multi-Detector Array

Table 8.4, Deviation From Detector 7828 For A Six-Detector Array

Energy (keV)	Detector S/N 7813		Detector S/N 7810		Detector S/N 7812		Detector S/N 7809	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	0.76	0.86	1.02	0.86	1.07	0.97	0.78	0.77
121.8	0.93	1.02	1.03	0.96	1.03	0.99	0.90	0.96
244.6	0.96	1.04	1.02	0.97	1.01	1.00	0.92	1.00
344.3	0.97	1.05	1.00	0.95	1.02	1.00	0.91	0.97
778.9	1.00	1.06	0.99	0.94	1.02	1.00	0.92	0.96
1112.1	1.01	1.07	0.99	0.95	1.04	1.01	0.93	0.96
1408	1.01	1.07	0.97	0.94	1.01	1.01	0.90	0.96
Energy (keV)	**Detector S/N 7829**		Detector S/N 7828		**Detector S/N 7831**		Detector S/N 7824	
	0°	90°	0°	90°	0°	90°	0°	90°
59.5	☒	☒	1.00	1.00	☒	☒	1.05	1.05
121.8	☒	☒	1.00	1.00	☒	☒	0.99	1.04
244.6	☒	☒	1.00	1.00	☒	☒	0.98	1.04
344.3	☒	☒	1.00	1.00	☒	☒	0.98	1.04
778.9	☒	☒	1.00	1.00	☒	☒	1.00	1.04
1112.1	☒	☒	1.00	1.00	☒	☒	1.00	1.05
1408	☒	☒	1.00	1.00	☒	☒	0.98	1.04

Attachment 9

Observed Responses To Point Source Applying "Standard" Detector (Det06, S/N=09047828) Characterization To Each Detector In The Array

Table 9.1, Point Source V&V Results

DETECTOR	OBSERVED RESPONSE (µCi)	PERCENT DEVIATION[1]
DET01 (7809)	6.12	-6.71%
DET02 (7810)	6.84	4.27%
DET03 (7812)	7.03	7.16%
DET04 (7813)	6.76	3.05%
DET05 (7824)	6.26	-4.57%
DET06 (7828)	7.1	8.23%
DET07 (7829)	6.79	3.51%
DET08 (7831)	6.58	0.30%
8-detector average	6.685	1.91%
6-detector average	6.685	1.91%

[1] Decay-corrected Co-60 source activity (µCi) = 6.56µCi

Note that the averaged response exhibited less than a 2% deviation from the source's activity and is identical for both the 6-detector and 8-detector arrays.