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Subject: YNPS Technical Report – Use of Gamma Spectrum Analysis to Evaluate Bulk Materials for Compliance with License Termination Criteria

This letter provides a copy of a technical report in support of the LTP for the Yankee Nuclear Power Station (YNPS) and has been prepared as required by Section 5.6.1.3 of the LTP. The specific technical report provided for your review is as follows:

(1) YA-REPT-00-022-04, "Use of Gamma Spectrum Analysis to Evaluate Bulk Materials for Compliance with License Termination Criteria"

This report supplements Section 5.6.1.4 of the LTP and describes Yankee's use of ISOCS gamma spectroscopy as a component of the Final Status Survey (FSS) program with respect to bulk materials generated during decommissioning demolition. The document purpose is to provide 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 and technically qualify the detector system for the in situ assay.

Use of the detector system is expected in early January 2005. If you have any questions, or desire additional information, please contact us.

Sincerely,

YANKEE ATOMIC ELECTRIC COMPANY

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Principal Licensing Engineer

NMSS01

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

YA-REPT-00-022-04

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

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

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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 designed to evaluate bulk materials in large containers with respect to concentration-based radioactivity (pCi/g). The associated detector characterization and software has been successfully used in several applications throughout the industry over the past decade. This Technical Basis Document describes Yankee Atomic's use of ISOCS© gamma spectroscopy as a component of the Final Status Survey (FSS) program with respect to bulk materials generated during decommissioning demolition. To that end, 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. However, the primary focus of this document is to technically qualify the detector system used for the *in situ* assay. Although data enclosed may be specific to a particular material stream, the data presented represents an example of the system's capabilities.

Prior to the re-use of bulk materials on-site as backfill, a three-stage process is applied to address unique attributes presented by different material streams (e.g. concrete, asphalt, soil, etc.). The first stage involves an 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. The second stage, also implemented prior to demolition, entails a specific survey and sampling campaign which concludes in an ALARA evaluation to assess if either further decontamination or regulated disposal is warranted. This ALARA review is administered under the Final Status Survey (FSS) program. Reviews of pre-demolition survey data also provides an upper bound for potential localized areas of elevated activity in the matrix.

After the first two stages have been completed, the candidate material will be demolished and loaded into containers (e.g. roll-offs, dump trucks, etc.) for *in situ* gamma spectroscopy using a high purity germanium system in order to determine the ratio to the applicable DCGLs for the material disposition decision. This third stage is also administered under the FSS program. A specific Survey Plan is developed for each unique bulk material to be assayed. The Survey Plan provides a mechanism to communicate and document the material's density, the container(s) to be used during assay, and derived acceptance criteria to account for hard-to-detect nuclides. This information is employed to develop the system's calibration efficiencies, radionuclide libraries and acceptance criteria.

The assay system's sensitivity to geometric variations from the parameters input to the efficiency calibration model has been evaluated. The primary variable that determines the system's sensitivity is truck placement within the detector array. This document demonstrates that truck placement variations within 12-inches of the prescribed position result in less than a 10% change on the efficiency values. Additionally, it has been determined that variations in fill-height have almost no impact on calibration values, however it was noted that the efficiency values radically increase as the fill-height is reduced to less than 20 inches, thus yielding a system over-response.

Application of this technology allows for efficiently monitoring of large volumes of bulk material while providing effective sampling density.

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. As an example, for the Reactor Support Structure (RSS), previous surveys taken prior to surface remediation 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, if any. Additional material samples were also taken and analyzed to 1) provide for isotopic distribution of surface materials scanned, and 2) determine hard-to-detect isotopic concentrations both at the surface and in depth of the concrete structure. With the data generated from the 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. Once it was determined that segregation was not necessary, average isotopic concentrations were then estimated. These estimates were then used in accordance with section 4.3.2, "Survey Unit-Specific ALARA Evaluations," of the License Termination Plan.

In a similar fashion, potentially contaminated soil from remediation, below ground structures removal, and underground piping excavations 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 resultant rubble will be randomly loaded into containers for *in situ* gamma spectrum assay. Likewise, bulk asphalt and soil materials will be randomly loaded into containers for assay. The sensitivity and configuration of the assay system will average out any local variations in radionuclide concentrations.

2.2.3 Survey Plan and Nuclide Assessment

For each unique material stream, a survey plan will be prepared in accordance with procedure DP-8856, "Preparation Of Survey Plans." Survey plans will be used to document material densities and container attributes for use during subsequent efficiency calibrations in addition to specifying concentration-based decision levels and required MDA values. In accordance with the License Termination Plan, 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. Survey plans will ultimately serve as a documentation mechanism to envelop the entire assay process including preliminary evaluations, counting efficiency calibrations and gamma spectrum analysis reports 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. During the technician assignment process, consideration has been given toward selecting personnel who can work with limited supervision, pay close attention to detail, and monitor system performance. Pre-operational technician-oriented 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 for 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 used includes Co-60, Cs-137 and Am-241, providing an energy range correlating to the nuclides expected to the 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. During energy calibration, FWHM (Full Width at Half Maximum) values are determined for each gamma ray peak and a calibration curve generated for each of these parameters. These calibration curves define expected peak shape versus peak energy, as well as energy versus channel number.

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.

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 count 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 count 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 yield demonstrate that typical MDA values will be 10%-25% below the anticipated decision levels over a 600-

second count time. If necessary, count times will be extended for containers that are less than completely full. In fact, to ensure that required MDA values are met, the NDA-2000 software will be set up so as to automatically extend count times until MDA values, as specified in the nuclide library, are achieved.

As containers of concrete are loaded, the actual weight will be determined prior to assay for a representative number of containers. These actual weight values will be used by the analysis routines. Once an average effective density is determined, a standard density will be applied to all analyses. Adjustments will be made to efficiency calibrations as necessary. A periodic surveillance will be conducted to monitor the effective density of the bulk materials. If necessary, the "standard" effective density will be adjusted, including re-generation of the ISOCS© efficiency files. Should a standardized effective density be unattainable, a determined conservative density may be applied to during all analyses.

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 and comparison to efficiencies associated with the geometry to be used during assay operations.

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 yields a characterization file that represents the detector's efficiency response to incident photons at various angles and energies. This characterization file is applied during efficiency determinations via the ISOCS© software. The eight detectors in the Truck Monitor's array were selected as an ensemble to 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 of all eight detectors was compared in an effort to identify a single detector which would approximate or represent 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 recalculate new ISOCS© 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.

Additional verification testing of the ISOCS© efficiency modeling is planned involving a container (roll-off) of non-impacted soil. This test will address distributed K-40 activity reported by the ISOCS© multi-detector array as compared to composite samples assayed with the HPGe system in the on-site Chemistry Lab.

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. As previously discussed, the system will be operated by qualified senior-level Radiation Protection Technicians. Operation of the assay system, as well as routine QC activities and assay reports, will be reviewed on a daily basis 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 (inspection of the K-40 peak, etc.), and the identification of all unidentified peaks before a disposition is applied to a load of material. Engineering reviews of all assay results will also be proceduralized.

A daily 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, notably count times. As previously discussed, each survey plan will specify MDA values to be met during 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 vary as the supply fluctuates. Because these levels are not consistent, the background subtract feature of the Canberra software will not be applied during spectrum analysis routines.

Assay reports will be designed to clearly flag results above decision levels. Each (licensed) nuclide identified by the assay will be compared to a derived activity concentration "limits" and a sum-of-fractions calculation will be applied to determine the disposition of the material assayed. As previously discussed, the derived "limits" will address hard-to-detect nuclides which may be present.

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.

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.

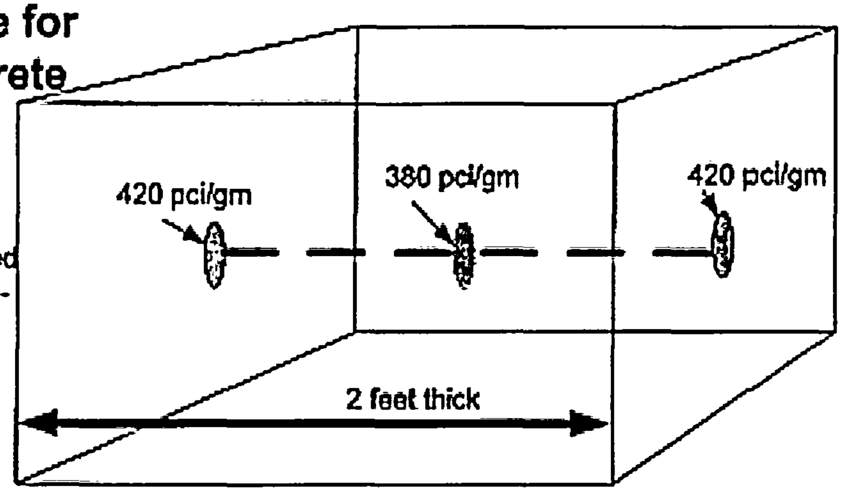
Qualification of the system to ascertain the influences of geometry imprecision indicates that practical variations will not invalidate assay results. This, coupled with prescribed sample attributes, procedurally defined data review and routine quality control activities provides assurance that the system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

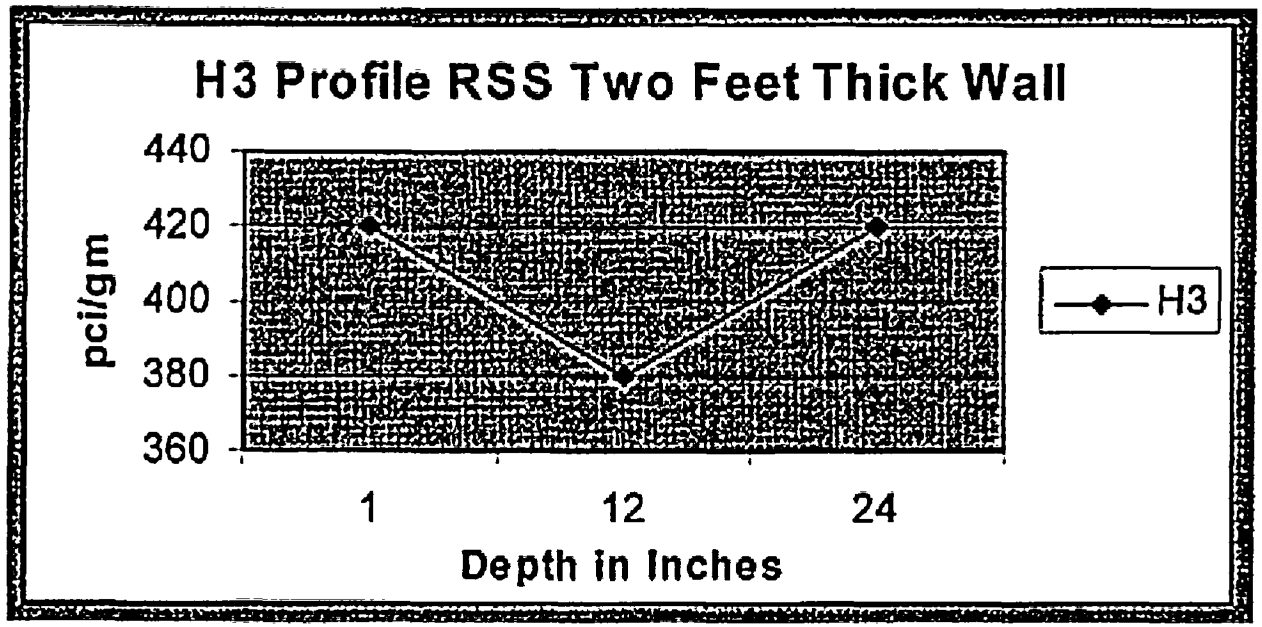
Attachment 1 (Page 1 of 3)
Reactor Support Structure Tritium Profile

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

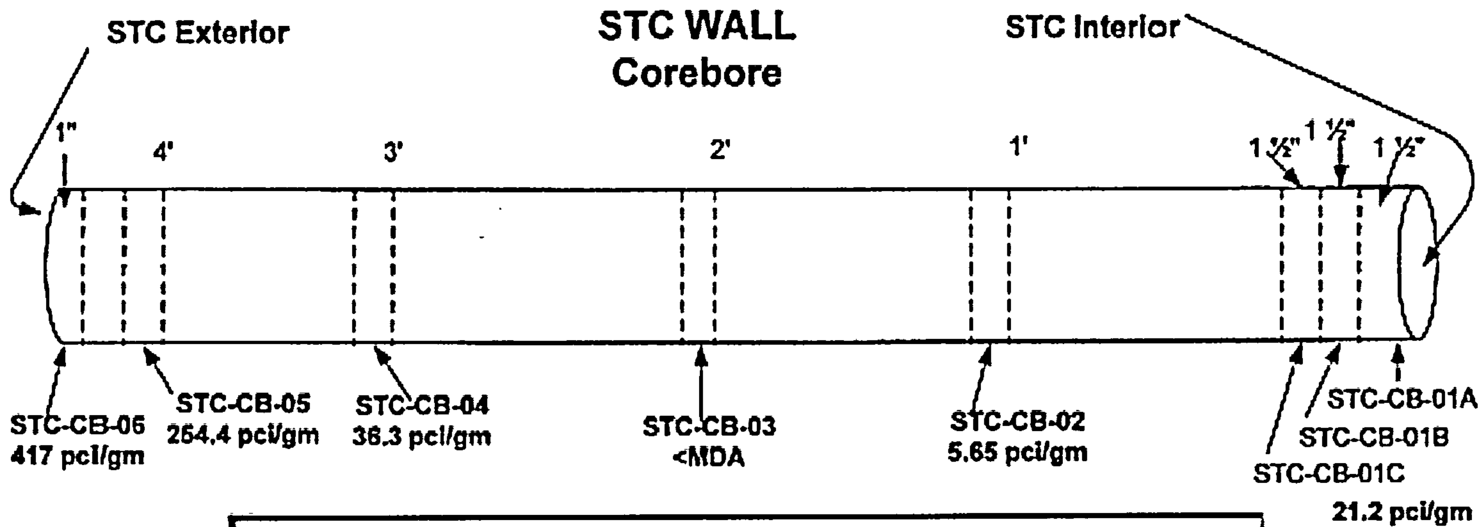
Center concentrations were an average of surface and one foot corebore results

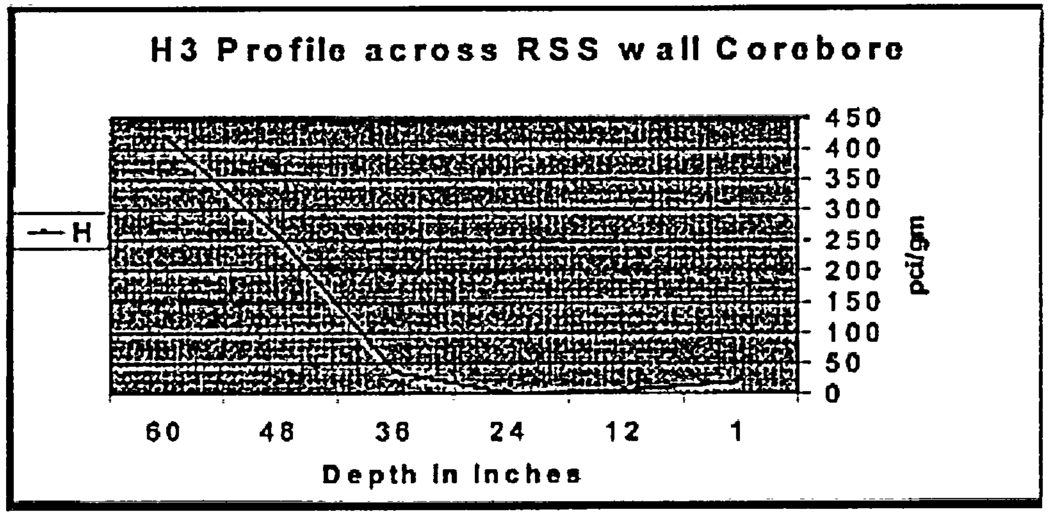


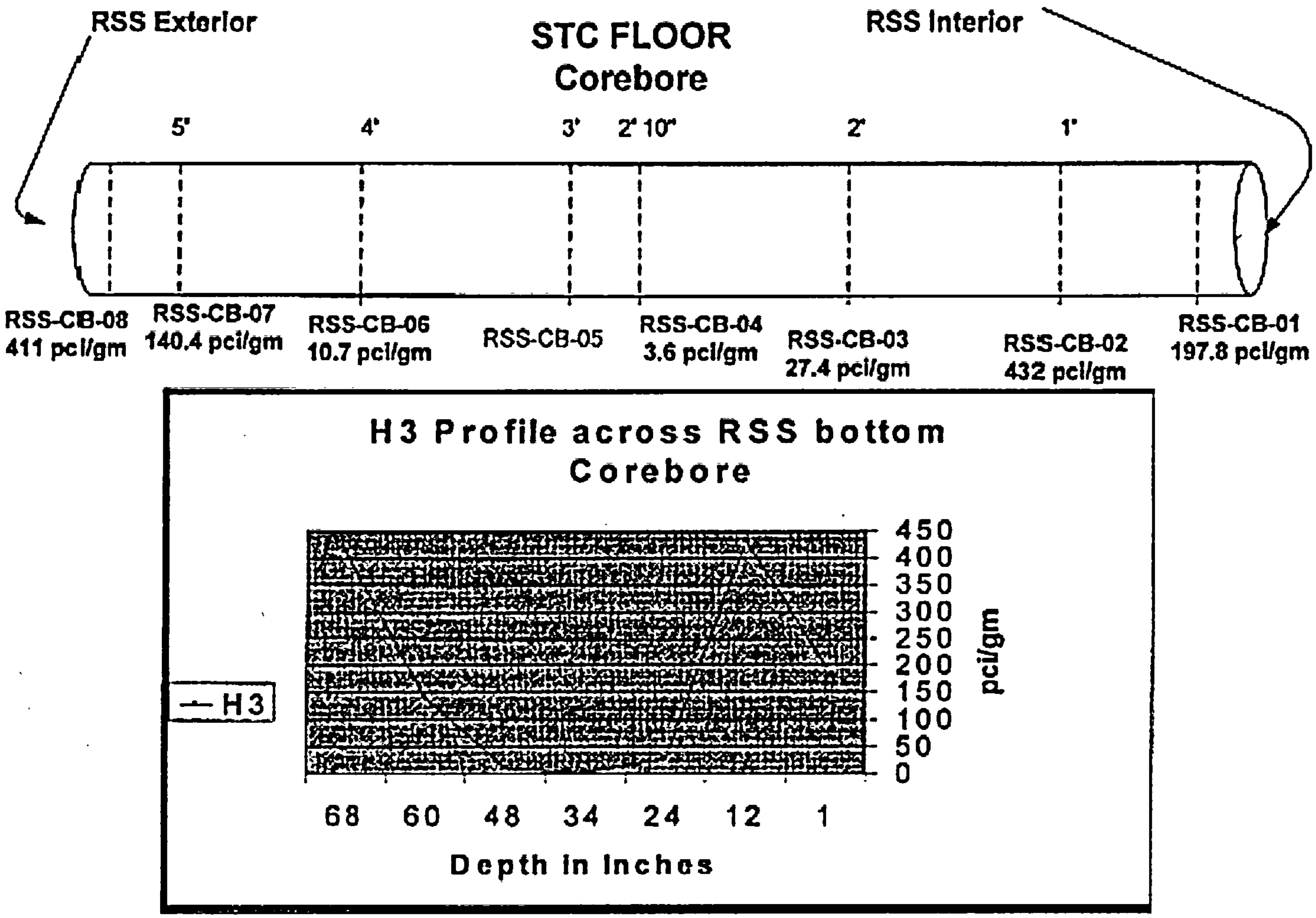


Attachment 1 (Page 2 of 3)

Reactor Support Structure Tritium Profile



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STC FLOOR
Corebore
RSS Interior
5'
4'
3'
2' 10"
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1'
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RSS-CB-07
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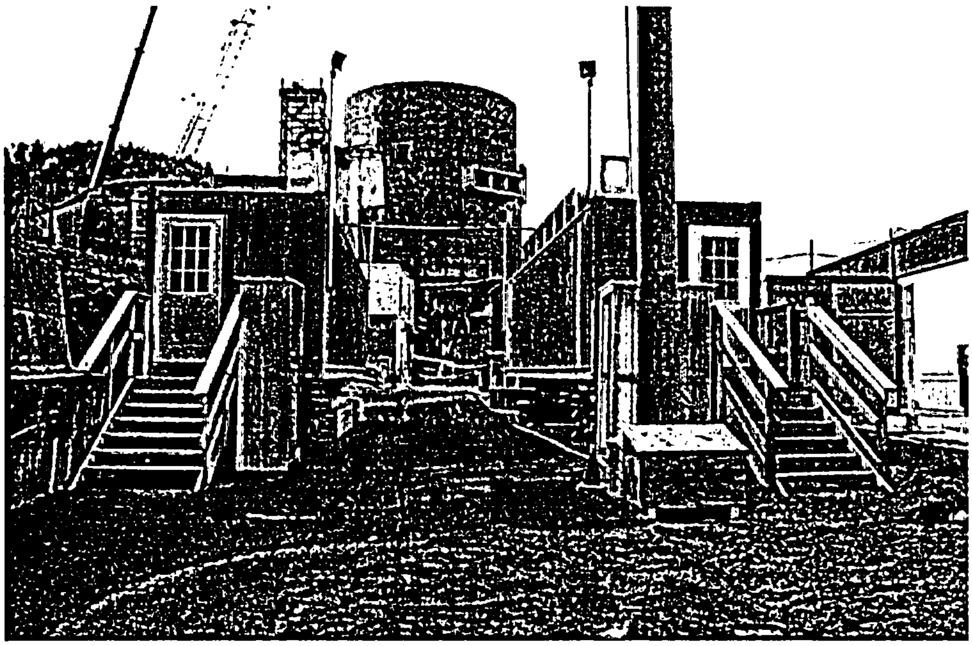
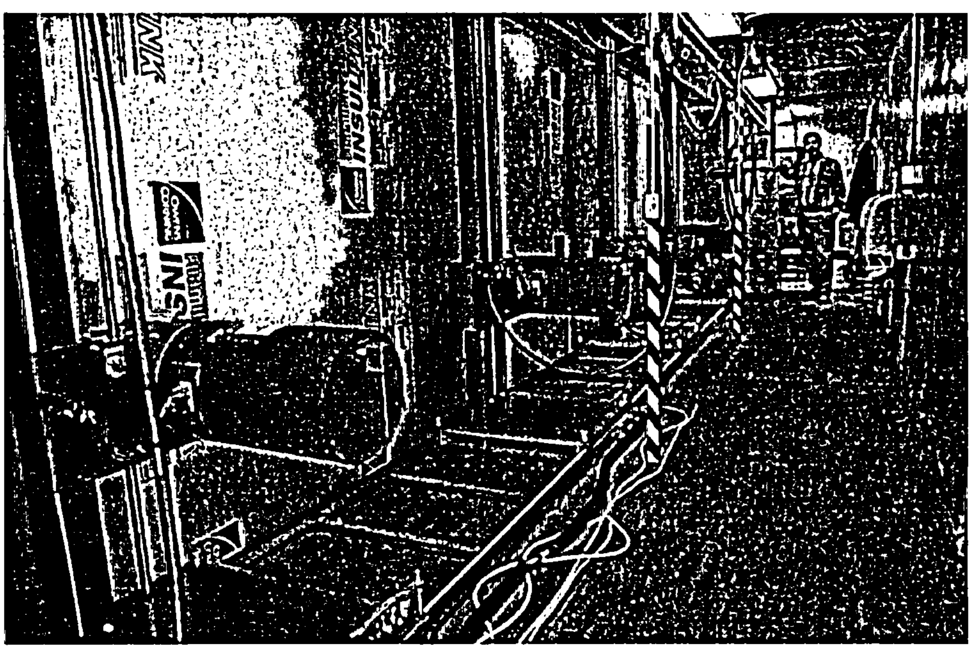
RSS-CB-02
432 pci/gm
RSS-CB-01
197.8 pci/gm
H3 Profile across RSS bottom
Corebore
H3
450
400
350
300
250
200
150
100
50
0
pci/gm
68
60
48
34
24
12
1
Depth in Inches

Attachment 2
Detector Enclosure Facility





Attachment 3

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

The enclosure's wall surface in front of the detector's field of view is constructed of steel and Styrofoam. Accounting for the corrugation pattern of the steel sidewall material, an adjustment was made to derive an effective thickness. Since each enclosure has a slightly different corrugation pattern, the more conservative correction value of 1.19 (verses 1.05) was applied, yielding an effective thickness for the steel walls of 0.189 cm. The density for each of these materials was empirically determined. 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:

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

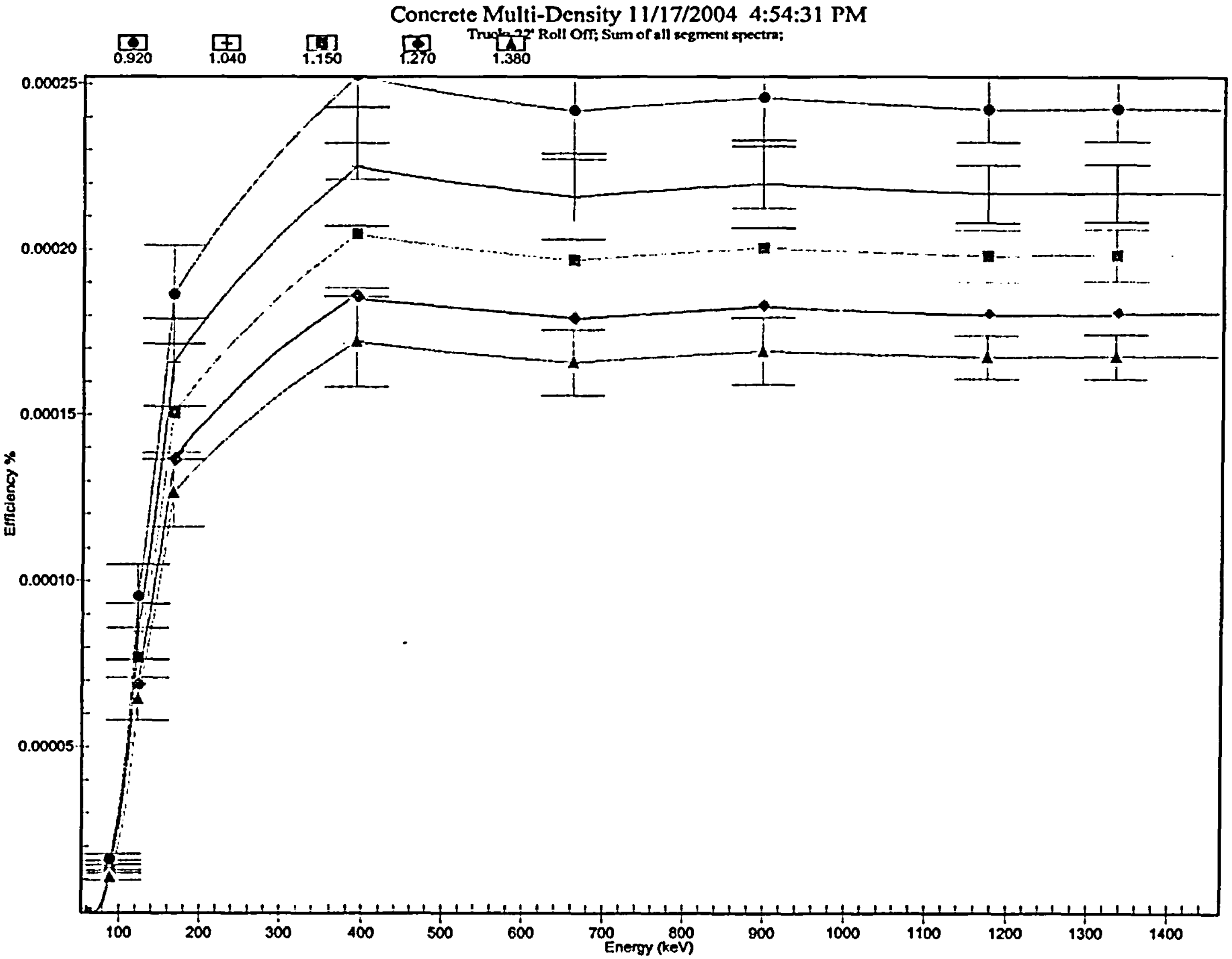
The material weighting factors are the mass fractions of each of the two layers that make up the "sandwich", where 'i' = iron and 'j' = Styrofoam.

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

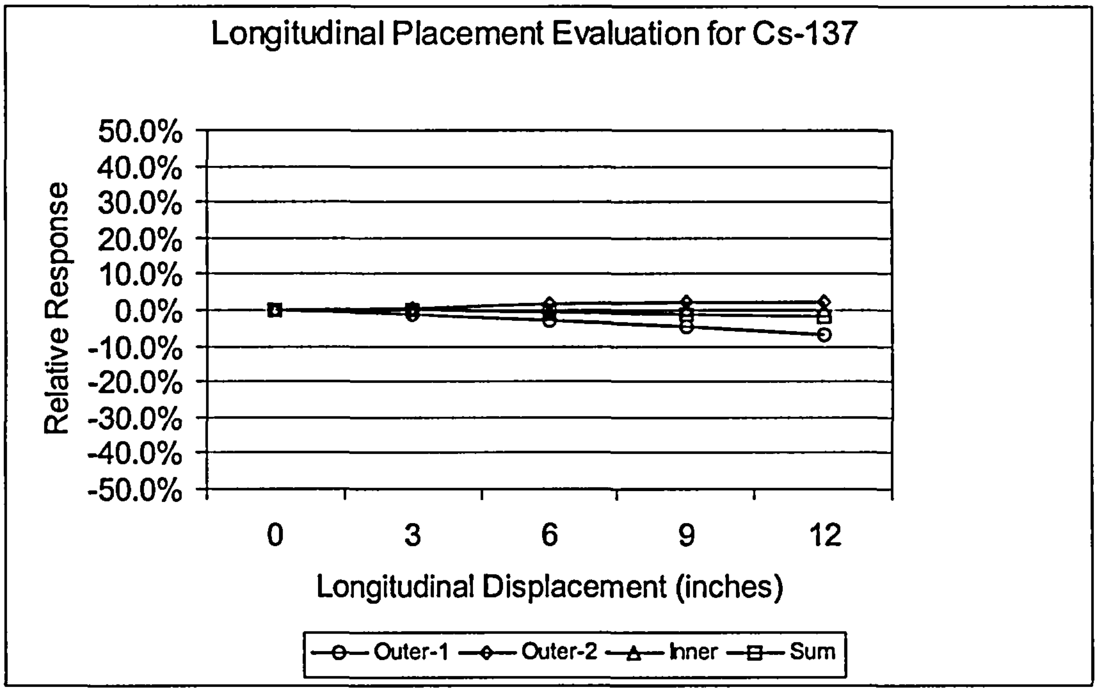
Therefore the wall's effective composition is 93.2% steel and 6.8% Styrofoam. The software's material editor has "stock" materials, two of which are carbon steel and Styrofoam. Each of these has a pre-defined chemical composition. During the process of defining a unique material, the (mass-based) percentage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

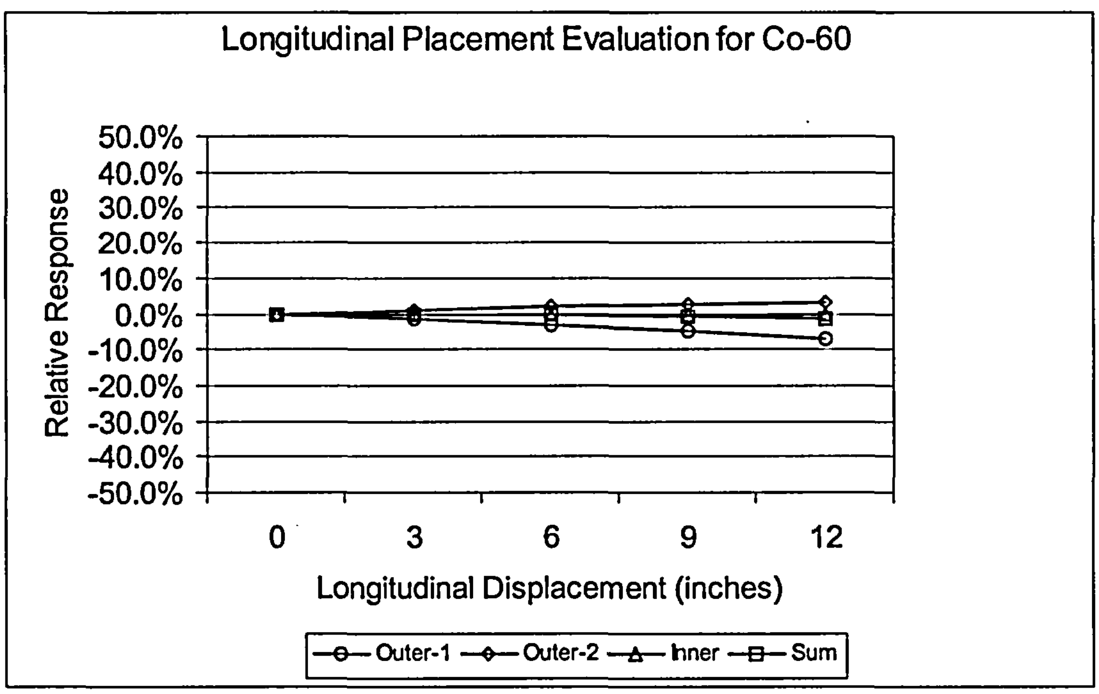
Attachment 4

Efficiency Calibration Curves For Various Densities

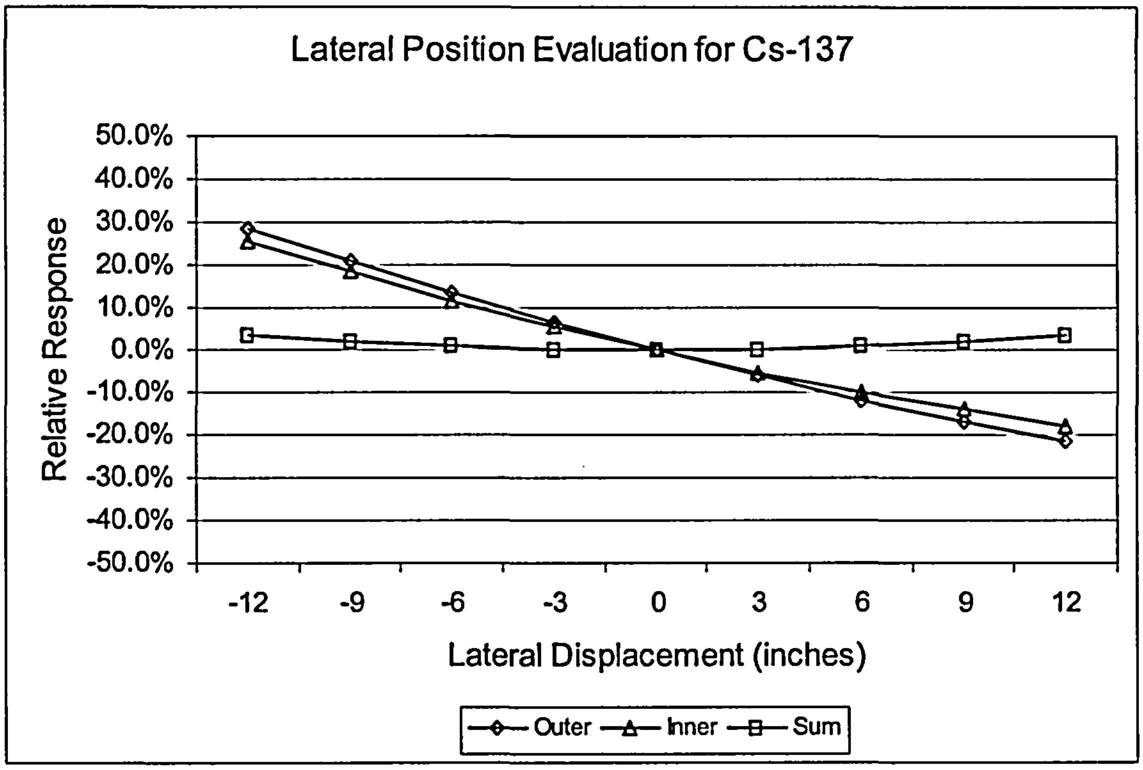


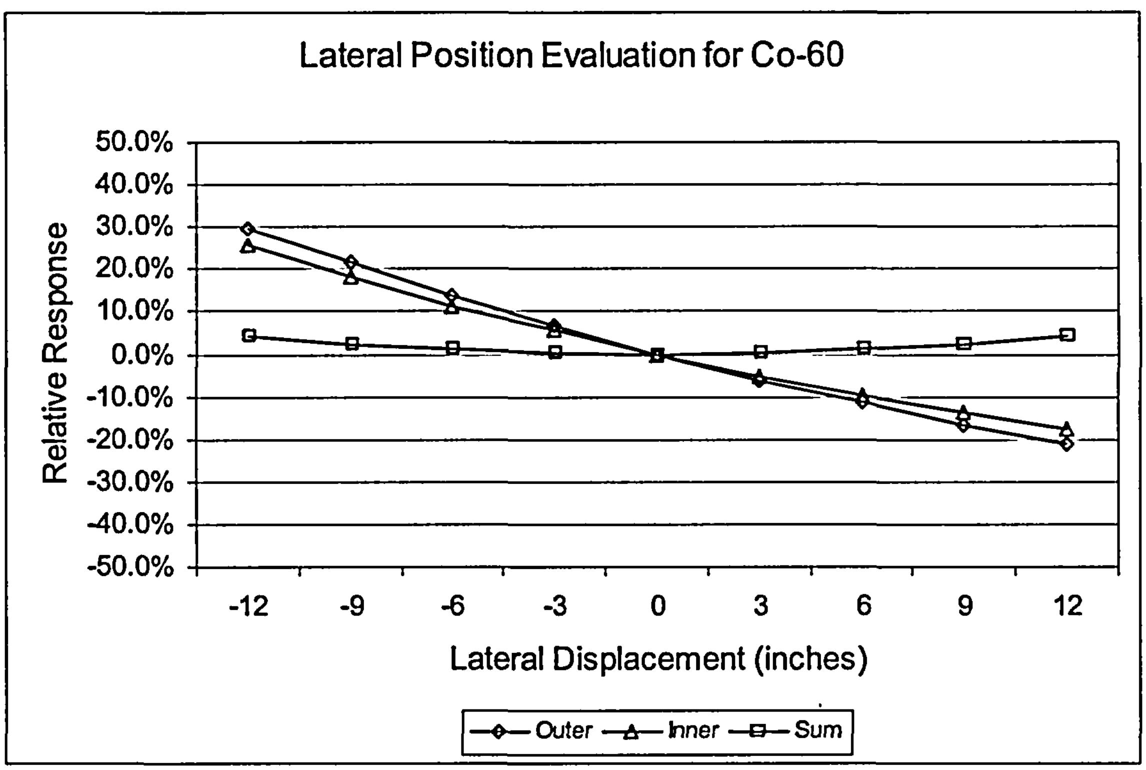
Attachment 5
Evaluation of Longitudinal Variations of Container Placement
With Respect To Efficiency Values
For A Six-Detector Array





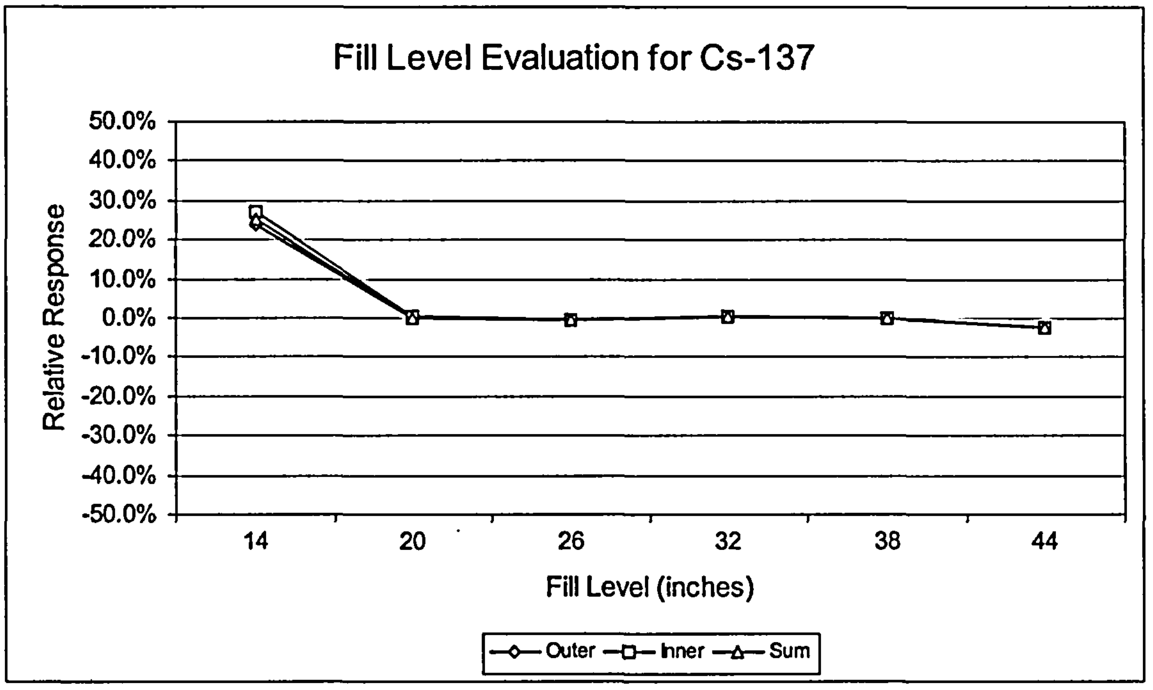
Attachment 6
Evaluation of Lateral Variations of Container Placement
With Respect To Efficiency Values
For A Six-Detector Array

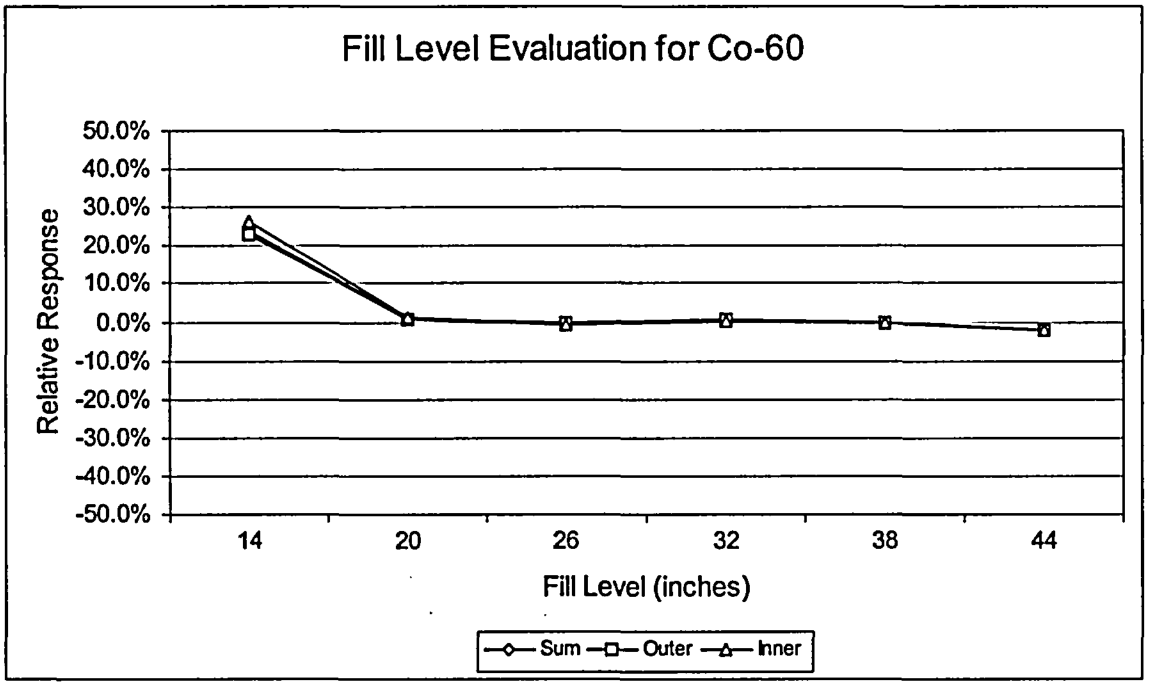




Attachment 7

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	Detector S/N 7813		Detector S/N 7810		Detector S/N 7812		Detector S/N 7809	
(keV)	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	Detector S/N 7829		Detector S/N 7828		Detector S/N 7831		Detector S/N 7824	
(keV)	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.

Attachment 8 (Page 2 of 4)

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 0°	90°	Detector S/N 7810 0°	90°	Detector S/N 7812 0°	90°	Detector S/N 7809 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 0°	90°	Detector S/N 7828 0°	90°	Detector S/N 7831 0°	90°	Detector S/N 7824 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.

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 0°	Detector S/N 7813 90°	Detector S/N 7810 0°	Detector S/N 7810 90°	Detector S/N 7812 0°	Detector S/N 7812 90°	Detector S/N 7809 0°	Detector S/N 7809 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 0°**	**Detector S/N 7829 90°**	**Detector S/N 7828 0°**	**Detector S/N 7828 90°**	**Detector S/N 7831 0°**	**Detector S/N 7831 90°**	**Detector S/N 7824 0°**	**Detector S/N 7824 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 0°	Detector S/N 7813 90°	Detector S/N 7810 0°	Detector S/N 7810 90°	Detector S/N 7812 0°	Detector S/N 7812 90°	Detector S/N 7809 0°	Detector S/N 7809 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 0°**	**Detector S/N 7829 90°**	**Detector S/N 7828 0°**	**Detector S/N 7828 90°**	**Detector S/N 7831 0°**	**Detector S/N 7831 90°**	**Detector S/N 7824 0°**	**Detector S/N 7824 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.

Observed Responses To ISOCS Point Source Efficiency
From Data In Table 9.1