FINAL STATUS SURVEY REPORT
BUILDING 101 EXTERIOR

MALLINCKRODT, INC.
COLUMBIUM- TANTULUM PROJECT- PHASE 1

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C-T PROJECT – PHASE I

FINAL STATUS SURVEY REPORT

Building 101 Exterior

Survey Units 101NESW and 101R1 – R6

Revision 0

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1. INTRODUCTION

1.1. PURPOSE

1.1.1. This Final Status Survey Report (FSSR) is being submitted by Mallinckrodt, Inc. to the U.S. Nuclear Regulatory Commission (NRC) for the exterior surfaces of Building 101 on the Mallinckrodt St. Louis site. This report is being provided in accordance with the Mallinckrodt C-T Project, Phase I Decommissioning Plan (D Plan). This FSS was performed in accordance with the Field Instruction (FI) CT-FI-008[1] to demonstrate that the established guidelines for unrestricted release have been met. The results of the FSS are presented in this FSSR as justification for release of this survey unit from License STB-401 for unrestricted use.

1.2. HISTORICAL BACKGROUND

1.2.1. From 1942 to 1961 Mallinckrodt was involved in radiological activities outside of the scope of this report which terminated in 1977. Mallinckrodt's facilities have either been released from the applicable license or are being remediated by the US Army Corps of Engineers in the affected areas. License STB-401 was issued to Mallinckrodt in 1961 by the Atomic Energy Commission (AEC), later the Nuclear Regulatory Commission (NRC), to allow extraction of columbium and tantalum

[1] CT-FI-008, *Final Status Survey Plan, Building 101 Exterior Surfaces.*

(C-T) from natural ores and tin slag, since the ores and byproducts of processing contain uranium and thorium isotopes. Mallinckrodt has not performed C-T extraction since 1987. On July 12, 1993, NRC amended License STB-401 to possession-only for D&D and license termination.

2. Scope of Final Status Survey

2.1. Definition and Classification of Survey Unit

2.1.1. The exterior walls of Building 101 have been designated as a single survey unit, SU-101NESW, and the roof of Building 101 has been designated as six survey units, SU-101R1 – SU-101R6. SU-101NESW has been classified Class 3. Although the roof was initially Class 3 as a single survey unit, it has been segmented into 6 survey units each of which was then classified as Class 2 based upon evaluation of the data.

2.1.2. Table 2.1 below contains the description provided in Appendix A of the D Plan for the areas referenced by this FSSR.

Table 2.1[2]
Survey Area Descriptions

Area	Survey Unit	Location / Surface
11	101NESW, 101R1-101R6	Former Gas Heaters/Roof Equipment: Additional AC units installed after CT operations ceased.
12	101NESW	Incinerator Pad Area
13	101NESW	Incinerator Unit/Equipment
14	101NESW	External Walls: Painted once since CT operations ceased. One coat of paint over original paint.
15	101R1-101R6	Roof and Decking: Roof membrane and portions of insulation replaced 10/94. Original metal roof decking.

2.1.3. A summary report for the survey units listing all the surfaces and fixed apparatus assigned to each survey unit is presented in Appendix 1. Because like items of installed apparatus appear in, or extend over, more than one survey unit, all such items are associated with SU-101 NESW and measurements taken on these items will be considered together. A drawing of the survey units showing the location of key fixed apparatus items is presented in Appendix 2, Figures 2.1 through 2.5.

[2] Appendix A of D Plan.

2.2. IDENTIFICATION OF THE RADIOLOGICAL CONTAMINANTS

2.2.1. The radionuclides on the St. Louis site under license STB-401 are the uranium and thorium series. Both series are assumed to be in radioactive equilibrium and to exist in a uranium-to-thorium ratio of two to one.[3]

2.3. REFERENCE BACKGROUND LEVELS

2.3.1. When the initial characterization (CH) surveys were performed from 1992 through 1996, beta backgrounds were determined for several matrices. Where additional background measurements were required for the FSS, they were taken on unaffected surfaces nearby or offsite. Where no background data exist for a given matrix, a value of zero was used.

2.3.2. All background levels were determined by taking direct readings on the specified matrix on unaffected surfaces using the same methods and type equipment as were used for the FSS. Available background data for the contaminants of interest in the survey units are presented in Table 2.2.

Table 2.2
Background Reference Data

Matrix	Mean ($dpm_p/100cm^2$)[4]	Standard Deviation ($dpm_p/100cm^2$)
Concrete	35.4	20.1
Concrete Block	96.1	21.7
Metal	24.0	15.7

2.3.3. Gamma background. The background value used for NaI gamma scans and gamma direct measurements on the roof was the ambient background recorded in each area before the surveys were performed. This was 3,500 cpm for all scans. For direct measurements, this value was 4,229 cpm for SU-101R1 – SU-101R3, 3,999 cpm for SU-101R4 – SU-101R5, and 3,937 cpm for SU-101R6.

2.4. RELEASE CRITERIA

2.4.1. Table 2.3 displays the Derived Concentration Guideline (DCGLw) for measurements on building surfaces and fixed equipment. This value is the primary release criterion from the D Plan and is applied net of background to building surfaces such as roofs. It also applies to items of installed apparatus such as vents, air handlers, and piping.

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[3] Mallinckrodt C-T Project D Plan Appendix D.

[4] $Dpm_p/100\ cm^2$ refers to the disintegrations per minute per 100 cm^2 for the combined nuclide series.

2.4.2. To limit the dose from residual materials as much as possible an Administrative Release Guideline (ARG)[5] was developed and was used during the FSS as if it were the DCGLw with certain exceptions.[6]

Table 2.3
Building Surface and Installed Apparatus Release Criteria

Criterion	(dpm_p /100 cm^2)
DCGLw	13,000
ARG	2,600

2.4.3. Elevated Measurements Criterion (EMC).

2.4.3.1. Because the units surveyed in this FSS were Class 2 and 3, all measurements are required to be less than the DCGLw. Therefore, the EMC criteria do not apply to this FSS.

2.5. SURVEY INSTRUMENTS

2.5.1. The instrumentation utilized to generate FSS data was maintained, calibrated, and tested according to the requirements of the D Plan. All procedures, responsibilities, and schedules for calibrating and testing equipment have been documented.

2.5.2. Maintenance information and use limitations provided in the vendor documentation of the instruments used during this FSS were adhered to. Measuring and analyzing equipment were tested and calibrated before initial use and were recalibrated periodically and whenever previous calibrations were invalidated. Field and laboratory equipment specifically used for obtaining final radiological survey data were calibrated based on standards traceable to NIST. Minimum frequencies for calibrating equipment have been established and documented.

2.5.3. Measuring equipment were tested at least once on each day the equipment was used for FSS. Test results were recorded in tabular or graphic form and compared to predetermined, acceptable performance ranges. Equipment not conforming to the performance criteria was promptly removed from service and any data gathered in the interim evaluated for quality until the deficiencies were resolved.

2.5.4. All calibration and source check records were completed, reviewed, signed-off and retained in accordance with the Mallinckrodt Quality Assurance Program. Copies of the original Calibration Sheets for the instruments used in this FSS are provided in Appendix 3.

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[5] NEXTEP Tech Memo 0211, *Recommendation for an Administrative Release Guideline for the Mallinckrodt C-T Project,* A.H. Thatcher, CHP.

[6] *Final Status Survey Design Guide (Phase I)*, Section 3.2, covers the rules governing use of the ARG.

2.5.5. L2221/AB-100 – The primary instrument used for the detection of surface radioactivity was the AB-100 scintillation detector configured for beta detection. The AB-100 detector houses a ZnS/BC-408 organic scintillator and is paired with the Ludlum 2221 scaler/ratemeter for fixed and scan surveys. The window of the AB-100 was modified to increase the thickness of the mylar to 7-9 mg/cm^2 for the purpose of alpha attenuation[7]. The detector window was unshielded (open) for a time period during counting at each sample location, and shielded (closed) for the same time period at the same location[8]. The difference in the two readings is attributable to beta emissions above 80 KeV in energy.[9] The sensitivity of the AB-100 was derived from experiments by Lucas and Colyott which were reported in Attachment 3 to the D Plan.[10] The actual instruments used were calibrated and normalized to the reference instrument tested by Lucas and Colyott as prescribed in CT-QA-6.1[11] .

2.5.6. L2241-2/AB-100 – The AB-100 detector mentioned above paired with the Ludlum 2241-2 scaler/ratemeter was used in the same way for direct and/or scan beta measurements.

2.5.7. L43-89 – The Ludlum 43-89 scintillation detector is a newer design that is functionally and physically equivalent to the AB-100. It has a slightly lower efficiency as a rule, and it may be paired with the same ratemeters and scalers.

2.5.8. L3030 – The Ludlum Model 3030 alpha/beta scaler houses ZnS(Ag) and plastic scintillators and was used to count removable contamination collected on paper swipes. Smear papers were counted in the laboratory and results were reported in βpm/100 cm^2. Removable contamination measurements were not compared with the release criteria for purposes of releasing the survey unit, but only to confirm that the removable fraction was less than 20% of the DCGLw.

2.5.9. L2221/3x3NaI - When beta measurements could not be taken, the 3"x3" Sodium Iodide (NaI) detector was used. This instrument was calibrated off site and no modification or normalization (as was required for the AB-100) was performed.

2.6. LOWER LIMIT OF DETECTION

2.6.1. The terminology adopted to reflect the measurement (detection) capability of an instrument is the "Lower Limit of Detection" (LLD) or the "Minimum Detectable Activity" (MDA). It refers to the intrinsic detection capability of the entire

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[7] As specified in Appendix D of the D Plan. Measurements taken with only the mylar covering the probe were "open window" measurements.

[8] The "closed window" reading was taken with a 1/8" soft Aluminum plate covering the face of the detector. It is sufficient to exclude β rays from the U and Th series.

[9] Internal Conversion Electrons (ICE) will also be included in this number but are a second order effect and may be ignored.

[10] *Energy Dependent Calibrations for the Bicron Model AB-100 Beta Ray Survey Probe*, A. Lucas, CHP and L. Colyott, Ph.D., submitted as Attachment 3 to the Mallinckrodt Phase I Decommissioning Plan.

[11] CT-QA-6.1 - *Calibration and Control of Measuring and Survey Equipment.*

measurement process. The LLD, or MDA, is the lowest level of radioactivity that will yield a net count, above system blank, that will be detected with at least 95% probability with no greater than a 5% probability of falsely concluding that a blank observation represents a real signal. It is desirable to express the MDA as minimum detectable areal density (MDAD) or minimum detectable concentration (MDC) in units comparable to a regulatory limit with which a measurement may be compared. For a more detailed discussion regarding LLD and equations involved in calculation of LLD, refer to CT-QA-6.1.[12]

2.6.2. The LLD requirements for the FSS have been developed in accordance with MARSSIM[13] Chapter 4 guidelines. They are contained in the Design Guide and are listed in Table 2.4. Since gamma survey measurements on the roof were known to exceed the ARG, the $DCGL_W$ was used to calculate the MDC and thresholds for all gamma measurements.

Table 2.4
MDC Requirements

Measurement Type	MDC Requirement
Direct Beta	50% of ARG
Class 3 Beta Scans	ARG
Direct Gamma	50% of $DCGL_W$
Class 2 Gamma Scans	$DCGL_W$

2.6.3. The MDCs for the instruments used in the FSS were calculated according to Appendix D of the D Plan. A comparison of the MDCs calculated for the AB-100 and the 3" x 3" NaI gamma detector with the requirements is provided in Table 2.5. Details of the MDC calculations are presented in NEXTEP Tech Memo 0230.[14]

[12] CT-QA-6.1, Ibid.
[13] NUREG 1575, *Multi Agency Radiation Survey and Site Investigation Manual.*
[14] NEXTEP Tech Memo 0230, *Technical Basis Document for Mallinckrodt Final Status Surveys,* A.H. Thatcher, CHP (included with FSSR 235 Roof).

Table 2.5
Minimum Detectable Concentration (MDC) Comparison[15]

Measurement	Units	Calculated MDC	Required MDC
BETA DIRECT	$dpm_p/100\ cm^2$	100	1,300
BETA SCAN	$dpm_p/100\ cm^2$	760	2,600
GAMMA DIRECT	$dpm_p/100\ cm^2$	423	6,500
GAMMA SCAN	$dpm_p/100\ cm^2$	830	13,000

2.7. ACTION THRESHOLDS

2.7.1. Action thresholds based upon the release criteria were calculated for each type of instrument used in this FSS. The action threshold for beta scans is derived in NEXTEP Tech Memo 0230.[16]

2.7.2. Since any residual contamination on the roof of Building 101 was expected to be under a new layer of roofing material, only gamma measurements were used to survey the roof. The action thresholds for both direct and scan measurements were calculated using equations presented in NEXTEP Tech Memo 0230[17] and gamma conversion factors, F_g, from NEXTEP Tech Memo 0229 which is included as Appendix 6.[18] Both calculations are based upon the $DCGL_W$ since survey measurements exceeding the ARG were known to exist on the roof.

2.7.3. The calculation for the direct gamma action threshold is given by Equation 1.

Equation 1

$$T_{inv} = DCGL_W * F_g = (13{,}000)\ (0.75) = 9{,}750\ cpm$$

Where:

T_{inv} = The investigation threshold.

F_g = The direct gamma conversion factor for a roof with no gravel covering.

2.7.4. The calculation for the gamma scan action threshold is given by Equation 2.

Equation 2

$$T_{inv} = DCGL_W * F_g * \sqrt{p} = (13{,}000)(0.64)\left(\sqrt{0.5}\right) = 5{,}880$$

Where:

F_g = The gamma conversion factor for scans over a roof with no gravel covering.

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[15] All Values given are net of background. Gamma values reflect a roof surface with no gravel.
[16] NEXTEP Tech Memo 0230, ibid.
[17] NEXTEP Tech Memo 0230, ibid.
[18] NEXTEP Tech Memo 0229, *MCNP Gamma Modeling of Mallinckrodt Roof Surfaces*, N. Zhang.

p = surveyor efficiency

2.7.5. A summary of the action thresholds calculated for this FSS is presented in Table 2.6.

Table 2.6
Action Thresholds[19]

Measurement Type	Class 2 Action Threshold (cpm)
Beta Scan	2,000
Gamma Direct	9,750
Gamma Scan	5,880

2.8. INSTRUMENT SENSITIVITY, BACKSCATTER AND PAINT ATTENUATION

2.8.1. Beta direct measurements taken in the field were converted to $dpm_p/100\ cm^2$ of the parent nuclide series in accordance with Section 9 of the Design Guide using the following equation:

Equation 3

$$AD = \frac{Co - Cc}{PAF * S_i * S_b(m) * t}$$

Where:

AD	=	Areal Density in $dpm_p/100\ cm^2$ for the parent nuclides
Co	=	Counts measured in the open window configuration
Cc	=	Counts measured in the closed window configuration
PAF	=	Paint attenuation factor derived from the number of coats of paint applied to the surface since C-T operations ceased.
S_i	=	Normalized Instrument sensitivity without backscatter.
$S_b(m)$	=	Backscatter factor (a function of matrix)
t	=	Integration time in minutes.

2.8.2. Justification and calculations for separation of backscatter (as a function of the matrix) and instrument sensitivity were presented in NEXTEP Tech Memo 0215.[20] Reference backscatter coefficients for several matrices were generated

[19] The Class 3 action threshold is always equal to the greater of the T_{BK} or the MDC of the instrument used. T_{BK} is defined for each matrix as mean background plus two standard deviations (2σ) as described in Section 3.5.4.

[20] NEXTEP Tech Memo 0215, *Separation of Backscatter & Derivation of Instrument Sensitivity*, A.H. Thatcher CHP, (Included with FSSR 2501).

using an MCNP model and are described in NEXTEP Tech Memo 0213.[21] These coefficients were stored in the Matrix table in the Database and were used in the calculations according to the matrix upon which the measurement was taken.

3. SURVEY METHODS

3.1. SURVEY PROCEDURES

3.1.1. The FSS conformed to the procedures and plans listed in Table 3.1. The primary guidance for the FSS is contained in the Design Guide and the FI.

Table 3.1

Survey Procedures and Documents
CT Decommissioning Plan (Phase I)
CT Decommissioning Project, Final Status Survey Design Guide (Phase I)
CT-FI-008, Final Status Survey Guide for Survey Units 101NESW and 101R1-101R6
CT-QA-6.1: Calibration and Operation of Measuring and Survey Equipment
CT-RP-66: Operation of Scalers, Rate Meters, and Contamination Detectors
CT-RP-39: Performance of Radiation and Contamination Surveys
CT-RP-40: Survey Documentation and Review

3.1.2. All FSS data recorded in the field was submitted to the Quality Assurance Manager (or designee) for processing and review. The data collection forms and annotated drawings were signed by the technician taking the data and reviewed by the Radiation Protection, Health & Safety (RPHS) Manager (or designee) overseeing the survey. After data entry and review, QA approved the data sheets and filed them with the permanent Mallinckrodt records. The QA checklist[22] developed for quality verification of FSS data was used as a guide to data verification.

3.1.3. All the data generated by the surveys were entered into the C-T Radiation Database (RDB) and analyzed as outlined in Section 4.4 of the D Plan.

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[21] NEXTEP Tech Memo 0213, *Beta Backscatter Factors for Several Materials at the Mallinckrodt Site,* N. Zhang and D. Wilson, (Included with FSSR 2501).

[22] NEXTEP Tech Memo 0206, *QA Data Verification for MI CT Final Status Survey Data,* B. Anderson, (Included with FSSR 2501).

3.2. SURVEY MEASUREMENTS

3.2.1. Beta Measurements:

3.2.1.1. *Direct* – A systematic grid of direct beta measurements was obtained on the wall surfaces as described in the FI. Bias measurements were taken on building surfaces and fixed apparatus at locations determined by the surveyor in an effort to fully characterize the fixed apparatus.

3.2.1.2. *Scans* - Beta scans were performed using the same instruments used for the direct beta measurements. Beta Scans were performed on the wall surfaces. Scans were performed at a scan rate of less than one detector width per second with a probe height less than one inch from the surface being scanned.

3.2.2. Gamma Measurements:

3.2.2.1. *Direct* - Because the roof of Building 101 had been replaced, it was not possible to detect residual contaminants beneath the surface with beta detectors. Instead, a 3"x3" Sodium Iodide (NaI) gamma detector was used in both the direct and scan modes to survey the roof in SU-101R1 – SU-101R6. For direct measurements the detector was placed on the roof surface and counts were taken for one minute. (No gravel layer is present on the roof of Building 101.)

3.2.2.2. *Scans* - Gamma Scans were performed in straight lines 5 cm above the surface of the roof in SU-101R1 – SU-101R6 with each scan line separated from the next by 1 meter. The scan rate did not exceed 1 ft/s.

3.2.3. Removable Contamination Measurements:

3.2.3.1. *Swipes* - Removable contamination samples were collected at 100% of all regular grid locations. The swipes were counted in the laboratory and recorded in the database. Sampling of removable contamination was performed to confirm the assumption, used in derivation of the DCGLw, that the removable fraction measures less than 20% of the DCGLw[23].

3.3. MEASUREMENT LOCATIONS

3.3.1. Statistical Grid Data Points

3.3.1.1. The *Visual Sample Plan*© (VSP)[24] software was used to develop a MARSSIM grid for all seven survey units. The minimum number of points required and their spacing were calculated in accordance with the statistical guidance given in MARSSIM Sections 5.5.2.2 and 5.5.2.5.

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[23] Section 3.3 of the C-T Design Guide.

[24] NEXTEP Tech Memo 0008, *Verification and Validation of Applicable Portions of VSP Software, A.* H. Thatcher, CHP.

3.3.1.2. VSP uses Data Quality Objective (DQO) input values to calculate the number of measurement points, N, required to satisfy MARSSIM statistical guidance. A summary of all the input parameters used with VSP for this Report is presented in Table 3.2.

Table 3.2
VSP Inputs for Building 101 Exterior

DQO	Units	Walls	Roof
Type I error rate		5%	5%
Type II error rate		5%	5%
Width of Gray Region	$dpm_p/100cm^2$	200	200
Level (ARG)	$dpm_p/100cm^2$	2,600	13,000
Estimated Std Deviation	$dpm_p/100cm^2$	200	200

3.3.1.3. The minimum number of grid measurements for all survey units was 24. Up to 20% excess was used in survey planning to account for inaccessible or unusable locations. The actual number of grid points surveyed in each of the survey units is presented in Table 3.3.

Table 3.3
Grid points Recorded by Survey Unit

Survey Unit	Class	N
SU-101NESW	3	29
SU-101R1	2	26
SU-101R2	2	26
SU-101R3	2	26
SU-101R4	2	26
SU-101R5	2	26
SU-101R6	2	26

3.3.2. Bias Measurement Locations

3.3.2.1. Bias direct measurements (gamma on SU-101R1-101R6 surfaces, beta on SU-101NESW surfaces, and beta on fixed apparatus) were taken at the discretion of the HP technician performing the survey.

3.3.2.2. Bias surveys were also taken at hot spot locations identified by scans as directed in the Hot Spot Protocol[25].

3.4. REFERENCE COORDINATE SYSTEM

3.4.1. A unified reference system was prescribed for the location of all data points taken on all building surfaces and on the surface of installed apparatus. A description of the reference coordinate system is provided below.

3.4.2. A data point's unique location is specified by a combination of the following data elements: building, room, surface ID, X, and Y. The surface ID refers to the four walls, floor, ceiling and roof as shown in Table 3.4. X and Y are distances from the origin measured as shown in the table. An example of X and Y axes for floors and walls is presented in Appendix 2, Figure 3.1.

Table 3.4
Coordinate System Locators

Location	Identifier	X	Y
North Wall	N	Feet right from leftmost edge of the wall surface	Feet up from floor or the lowest point in the room
South Wall	S		
East Wall	E		
West Wall	W		
Floor	F	Feet east from western most edge of the surface	Feet North of southernmost edge
Ceiling	C		
Roof	R		

3.4.3. The surface ID for a roof applies only in the case when measurements are being made on the exterior surface of a building. In this unique case the "room" assigned has the special number "999."

3.4.4. Systematic grid data points which fell on external surfaces of installed apparatus were located with the primary coordinate system. The ID code of the apparatus was recorded in the remarks. For example: Let Q2 be identified as a large air conditioning unit located on the roof. Any systematic grid measurement points for the roof surface which landed on the air conditioner would have been identified using the X and Y coordinates from the southwest corner of the roof. "Q2 – A/C unit" would be noted in the remarks. The surface ID would be "R".

3.4.5. All bias data points taken on installed apparatus were numbered and located on the drawings provided. This number was recorded as the X coordinate on the data sheet and amplifying information was entered in the remarks section.

3.5. DATA EVALUATION

[25] CT-FI-004, *Final Status Survey Guide for Survey Unit 2504.*

3.5.1. All of the direct, swipe and scan data were entered into the C-T Radiation Database (RDB) for easy access and analysis. The direct beta measurements are the primary means for documenting the survey unit and justifying its release. Therefore, a special report was programmed to perform all the tests specified in Section 4.4.8 of the D Plan and to provide a clear report of the results for evaluation. The calculations in this report have been validated and verified as described in NEXTEP Tech Memo 0231[26].

3.5.2. The purpose of the screening software is to compare each direct beta reading taken in the survey unit with specified threshold levels, to apply the statistical tests called for in MARSSIM when appropriate, and to present the results in a clear and useful manner so that an analyst can accurately assess the action to be taken or declare that the survey unit meets the requirements for release.

3.5.3. Some of the screening tests apply to each record in the survey unit and failure of one data point results in failure of the survey unit. Other tests do not apply to each survey record but generate a single PASS/FAIL verdict for the entire data set. The tests are described in the following paragraphs[27]. An abbreviated summary of these tests is presented in Table 3.5.

3.5.4. *Background Screen.*

3.5.4.1. For each MATRIX code in the database, calculate the mean background reading, its standard deviation, and its minimum value. Calculate and store the Background Threshold, T_{bk}, with its matrix code according to the following equation:

Equation 4

$$T_{bk}(m) = \overline{BK}(m) + 2 * \sigma_{bk}(m)$$

3.5.4.2. T_{bk} is equal to the mean of the background readings $\left(\overline{BK}\right)$ for a given matrix plus two times its standard deviation (2σ).

3.5.4.3. Compare each data point in the filtered survey unit with T_{bk}. If the survey reading > T_{bk} the data point fails the test. One data point failure implies failure of the background screen test for the survey unit.

3.5.5. *Min/Max Test.*

3.5.5.1. Find the maximum direct survey result, in $dpm_p/100cm^2$, for the survey data set.

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[26] NEXTEP Tech Memo 0231, *Validation and Verification of the C-T Database Analysis Report,* B. Anderson, (included with FSSR 2501).

[27] A more detailed explanation is provided in the Design Guide.

3.5.5.2. Find the minimum background reading among all the background data points having MATRIX codes that match those in the data set.

3.5.5.3. If the difference between these two values is greater than DCGLw the MIN/MAX test fails for the survey unit.

3.5.6. *DCGLw Screen.*

3.5.6.1. For each matrix code calculate and store a DCGLw Threshold (T_d). T_d is calculated by adding the value of DCGLw to T_{bk}.

Equation 5

$$T_d(m) = T_{bk} + DCGLw$$

3.5.6.2. Compare each data point in the survey unit with T_d. If the survey reading > T_d the data point fails the test. One data point failure implies failure of the DCGLw screen test for the survey unit.

3.5.7. *EMC Screen.*

3.5.7.1. For each matrix code calculate and store an EMC Threshold (T_e). T_e is calculated by adding the value of EMC to T_{bk}. The EMC value selected is normally dependent upon the area involved. However, if no specific area was known, the EMC was normally set to the a priori $DCGL_{EMC}$.

3.5.7.2. Compare each data point in the filtered survey unit with T_e. If the survey reading > T_e the data point fails the test. One data point failure implies failure of the EMC test for the survey unit.

3.5.8. *DCGL Average Test.*

3.5.8.1. For each matrix material in the survey unit, calculate the mean activity density, (in $dpm_p/100cm^2$), in the survey data set. Subtract from this value, the mean value of background activity for the same matrix. If the remainder is greater than DCGLw for any matrix in the survey unit, the test fails.

Equation 6

$$\overline{AD} - \overline{BK} > DCGLw$$

3.5.9. *Statistical Tests.*

3.5.9.1. The statistical tests prescribed by MARSSIM operate only on the data points of MEASUREMENT TYPE = RG (Regular Grid). The program narrows the filter to include only these points before proceeding.

3.5.9.2. The Wilcoxon Rank Sum Test[28] is applicable to survey units with measurements on a single matrix type or on matrices with similar background characteristics. Where more than one matrix was present, the Sign Test for Paired Data[29] was used.

3.5.10. The output of the Threshold Comparison Test Report (TCTR) was used for analysis of the data and the results are presented in Appendix 4. The TCTR is divided into eight sections which are briefly described in the following paragraphs to assist the unfamiliar reader.

3.5.10.1. General: date, survey unit number, class, and grid information.

3.5.10.2. Survey Unit Table: building surface included, affected fixed apparatus, and total surface area of the survey unit.

3.5.10.3. Initialization Data: On startup of the analysis report program, the analyst must tell the program which parameters to use while running the tests described in this section. The *Initialization Data* section of the report output displays the options that were chosen for the run. The measurement types listed are those chosen by the analyst to be included in the report. The date range chosen is also listed. The default value is "All Dates". Values for DCGLw (ARG) and $DCGL_{EMC}$ are also specified at the start of the run and are listed in this section. If remediated data points are included in the run, it will be noted in this section. Normally they will be excluded.

3.5.10.4. Survey Unit Test Status: Lists Pass/Fail status of all tests and gives a high level summary of key activity levels in the SU.

3.5.10.5. Points that failed tests: Lists all points that failed each specified threshold test (EMC, DCGL, and Background).

3.5.10.6. Points that passed all the tests: This includes the remainder of all the points in the data set. These data points have passed all the tests.

3.5.10.7. Summary of background data used in the calculations. This table includes the matrix materials included in the survey and the thresholds calculated for each of the tests discussed in this section.

3.5.10.8. Statistical Test Results: This page lists the results of the Sign Test for Paired Data or the Wilcoxon Rank Sum test, whichever is selected. If the Test Status line reads Pass then the survey unit passes the Sign Test for Paired Data. The Data Summary section lists the number of background points and the number of survey points used from the data set. If the operator selects the option to show all data, a table of all data points used in the test is printed out.

[28] Described in Appendix I of MARSSIM.
[29] Described in NEXTEP Tech Memo 0231, Ibid.

Table 3.5
Threshold Screening Tests

Test	Test Criteria for PASS
Min/Max	Difference between minimum background measurement and maximum survey value less than DCGLw
Background	All samples must be less than the background threshold[a]
$DCGL_w$	All samples must be no more than $DCGL_w$ + the background threshold
$DCGL_{avg}$	The average of all net survey values must be less than $DCGL_w$
EMC	All samples must be less than $DCGL_{EMC}$ + the background threshold
Sign Test for Paired Data	The Sign Test for Paired Data is described in detail in NUREG 1505[30]
Wilcoxon Rank Sum Test	This statistical test is described in detail in MARSSIM, Appendix I.

[a] The background threshold is equal to the mean background value plus twice σ_{BK}.

3.5.11. Provided all additional considerations such as scan data, swipes, sampling of removable contamination or sludge from traps, etc. indicate that the survey unit meet the release criteria, the release of the survey unit can be determined from the test report according to Table 3.6.

Table 3.6
Requirements for SU Release[31]

Test	Class 1	Class 2	Class 3
Min/Max	not required[a]	not required[a]	PASS
Background	not required	not required	PASS
$DCGL_w$	not required	PASS	PASS
$DCGL_{avg}$	PASS	PASS	PASS
EMC	PASS	PASS	PASS
Sign Test for Paired Data	PASS	PASS	PASS

[a] Class 1 or 2 survey units which pass Min/Max may be released without further consideration.

[30] NUREG 1505, *A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys.*

[31] See MARSSIM, Chapter 8, Table 8.2

4. FSS RESULTS AND DISCUSSION

4.1. CHARACTERIZATION DATA

4.1.1. The characterization data taken in these survey units from 1992 to 1996 was very limited. Since the data on file in the characterization report were all taken with an HP-210 instrument they cannot be normalized to the AB-100 calibration standards and therefore are not included in the data set.

4.2. SURVEY UNIT 101NESW

4.2.1. Direct Beta Measurements on Building Surfaces

4.2.1.1. SU-101NESW was surveyed in June and July 2003. Seventy-three direct beta measurements were taken on the wall surfaces. 54 of these were included in the systematic grid. A diagram showing the survey unit layout with beta measurements is presented in Appendix 2, Figure 4.1.

4.2.1.2. A summary of the direct measurement results is presented in Table 4.1 and shows that the maximum activity measured, net of background, was 577 $dpm_p/100cm^2$. The average net value for the survey unit was 200 $dpm_p/100cm^2$.

Table 4.1
SU-101NESW Direct Measurements Summary

Matrix	Points	Avg Net Activity ($dpm_p/100cm^2$)	Max Net Activity ($dpm_p/100cm^2$)
Concrete	52	175.8	419.2
Concrete Block	17	334.5	576.6
Metal	4	-59.5	-35.0

4.2.2. Direct Beta Measurements on Installed Apparatus

4.2.2.1. All 17 items of installed apparatus assigned to SU-101NESW (listed in Appendix 1) were surveyed by direct beta measurements. A summary of the measurements taken is provided in Table 4.2 sorted by matrix. The net values observed ranged from -29 to 167 $dpm_p/100cm^2$. All values were less than 7% of the ARG. The data confirm that no significant residual radioactivity was measured on the 17 items of installed apparatus in SU-101NESW.

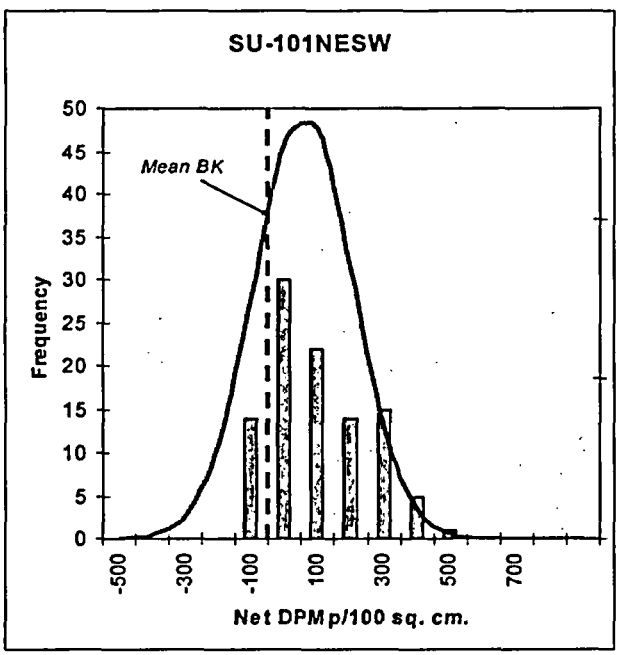
Table 4.2
SU-101NESW Fixed Equipment Direct Measurements Summary

Matrix	Points	Avg Net Activity ($dpm_p/100cm^2$)	Max Net Activity ($dpm_p/100cm^2$)
Concrete	5	69.0	132.6
Metal	19	28.0	167.1
Other	4	84.6	122.7

4.2.3. Direct Beta Measurement Distribution and Threshold Tests

4.2.3.1. A histogram of all the beta direct net activity values found in SU-101NESW is provided in Figure 4.1. The distribution appears to have a single mode with the majority of the data centered at approximately 100 $dpm_p/100cm^2$. This is consistent with a normal distribution of background radioactivity.

4.2.3.2. The normal curve for all direct beta measurements in SU-101NESW was plotted using the normdist function in MS Excel. This function takes the mean and standard deviation of the dataset and calculates the value of the associated normal curve for the values entered. As the graph shows, all of the survey data fell within the lateral limits of the normal distribution associated with the survey dataset. This indicates a high likelihood that the survey data belong to a single background distribution as expected of a Class 3 survey unit.



Histogram of Net Direct Beta Measurements
Figure 4.1

4.2.3.3. All the direct measurements in the survey unit were analyzed using the Threshold Comparison Test Report (TCTR) and the results are presented in Appendix 4 for SU-101NESW. The TCTR report contains a complete listing of all the beta direct measurements taken in the Final Status Survey within SU-101NESW sorted by activity. The summary pages indicate that all tests described in the D Plan passed except for the background test.

4.2.3.4. Because the survey unit failed the background test, further analysis was performed in accordance with the FI and the Analyst Guide[32]. A normal curve was created for the data (as described in paragraph 4.2.3.2) and is presented in figure 4.1. The graph shows that all the survey data fell within the lateral limits of the normal distribution associated with the dataset. This indicates a high likelihood that the survey data belong to a single background distribution as expected of a Class 3 survey unit.

4.2.3.5. A comparison of test results and requirements for release of the survey unit is presented in Table 4.3.

Table 4.3
Requirements for SU Release

Test	Class 3	SU-101NESW
Min/Max	PASS	P
Background	PASS	F
$DCGL_w$	PASS	P
$DCGL_{avg}$	PASS	P
EMC	PASS	P
SignTest	PASS	P

4.2.3.6. Although the survey unit failed the background test, further analysis showed that all of the survey data most likely belong to a single background distribution. The small displacement of the mean net value above zero (see figure 4.1) may be explained by differences between the standard background dataset and the actual local background existing at the survey site. Therefore, within the scope of this survey, SU-101NESW meets all the release criteria for a Class 3 Survey Unit.

4.2.4. Measurements of removable contamination

4.2.4.1. Swipes were taken at each location where a direct grid measurement was performed. Swipes were also taken at some bias measurement locations. The results of the measurements are presented in Table 4.4.

[32] *Analyst Guide, Mallinckrodt C-T Decommissioning Project*, A.H. Thatcher, CHP.

Table 4.4
SU-101NESW Removable Contamination Summary

Surface	Points	Avg Net Beta ($\beta pm/100cm^2$)	Max Net Beta ($\beta pm/100cm^2$)	Avg Net Activity[a] ($dpm_p/100cm^2$)	Max Net Activity ($dpm_p/100cm^2$)
E	15	9.9	50.0	2.1	10.4
N	14	16.3	38.0	3.4	7.9
S	15	6.2	50.0	1.3	10.4
W	29	22.0	56.0	4.6	11.7

[a] Activity was converted to $dpm_p/100\ cm^2$ from $\beta pm/100\ cm^2$ using an approximate figure of 4.8 betas per disintegration.

4.2.4.2. The results show that removable contamination averages near zero $dpm_p/100cm^2$ and varies between –5.8 and +11.7 $dpm_p/100cm^2$. The data confirm that virtually no removable contamination is present within SU-101NESW.

4.2.5. Beta Scan Measurements

4.2.5.1. Beta scans were performed on about 15% of the wall surfaces. A summary of the areas scanned is presented in Table 4.5. Drawings of the areas scanned on the north and west walls are presented in figures 4.2 and 4.3 of Appendix 2.

Table 4.5
SU-101 NESW Scan Areas

Surface	Areas covered
N	West End
E	South End North End
S	Center Area East End
W	North End Incineration Area Center to South End

4.2.5.2. The scan threshold used for these surveys was 2,000 cpm (net of background) which corresponds to the ARG of 2,600 $dpm_p/100cm^2$.

4.2.5.3. All scans performed on the wall surfaces were taken on concrete block. The average background value used for analysis of the concrete block raw data was obtained from the open window, direct beta readings (in cpm) taken in the survey unit. This value was 348 cpm. The average of all open window survey readings taken on concrete block in the background data set was 412 cpm.

4.2.5.4. During the surveys the maximum and average gross count rates were recorded for each area scanned. The beta scan data are summarized for SU-101NESW and presented in Table 4.6.

Table 4.6
SU-101NESW Scan Measurements Summary

Matrix	Areas	Maximum (cpm)	Average (cpm)	Max Net (cpm)	Avg Net (cpm)
Concrete Block	8	550	397	203	49

4.2.5.5. The maximum net scan value of 203 cpm is well below the scan threshold of 2000 cpm. No beta scan data were observed in SU-101NESW above the scan threshold.

4.3. SU-101R1 – SU-101R6

4.3.1. The original roof of SU-101R1 – SU-101R6 affected by C-T operations has been covered with new roofing material. Therefore, beta detection methods are not adequate to characterize the survey unit and gamma methods were employed instead.

4.3.2. Direct Gamma Measurements

4.3.2.1. A total of one hundred and seventy six direct gamma measurements were taken on the roof of SU-101R1 – SU-101R6. One hundred and fifty six of these were included in the systematic grid, with each survey unit containing 26 grid measurements. A diagram of the roof layout with the gamma measurements taken in the survey unit is presented in Appendix 2, Figure 4.4.

4.3.2.2. Gamma direct measurements were converted to $dpm_p/100cm^2$ using a conversion factor calculated for ½ inch asphalt binder overlaying the contamination as described in NEXTEP Tech Memo 0229 (Appendix 6)[33]. The conversion factor was 0.75 $cpm/dpm_p/100\ cm^2$.

4.3.2.3. A summary of the direct measurement results for SU-101R1 – SU-101R6 is presented in Table 4.7 and shows that the maximum activity measured, net of background, was 7,536 $dpm_p/100cm^2$. The averages ranged from 83 to 2823 $dpm_p/cm100^2$. A complete listing of all the direct gamma measurements taken on the roof is presented in Appendix 5.

[33] NEXTEP Tech Memo 0229, ibid.

Table 4.7
SU-101R1 – SU-101R6 Direct Gamma Measurements Summary

Survey Unit	Points	Avg Net Activity ($dpm_p/100cm^2$)	Max Net Activity ($dpm_p/100cm^2$)
101R1	31	2823	6828
101R2	26	928	3240
101R3	31	597	7536
101R4	31	609	4144
101R5	31	83	3740
101R6	26	1322	3640

4.3.2.4. Since all the direct gamma measurements were less than the $DCGL_W$, the data set must automatically pass the $DCGL_W$, $DCGL_{AVG}$, and EMC tests and the Sign Test for Paired Data. A comparison of the maximum gross survey reading (9,589 cpm) in Appendix 5 with the minimum background reading (3,937 cpm) shows that the survey unit also passed the Min/Max test. A comparison of test results and requirements for release of SU-101R1 – SU-101R6 is presented in Table 4.8.

Table 4.8
Requirements for SU Release

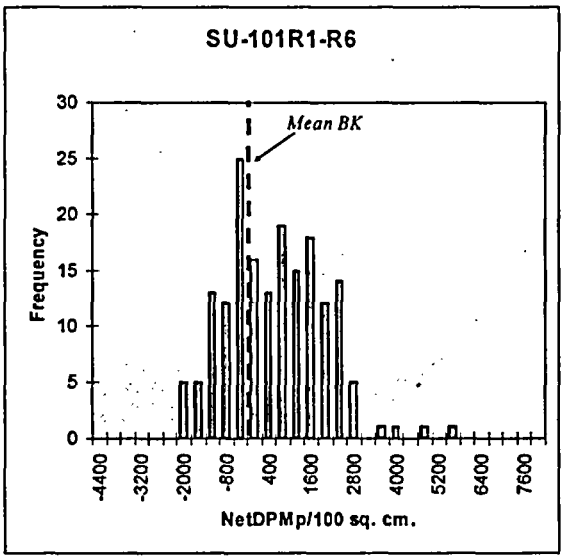
Test	Class 2	SU-101R1-6
Min/Max	not required[a]	P
Background	not required	N/A
$DCGL_w$	PASS	P
$DCGL_{avg}$	PASS	P
EMC	PASS	P
Sign Test for Paired Data	PASS	P

[a] Class 1 or 2 survey units which pass Min/Max may be released without further consideration.

4.3.2.5. The direct gamma measurements show that SU-101R1 – SU-101R6 passed all the tests required for release of a Class 2 survey unit.

4.3.3. Direct Gamma Measurement Distribution and Threshold Tests

4.3.3.1. A Histogram of all the gamma direct net activity values found in SU-101R1 – SU-101R6 is provided in Figure 4.2. The distribution appears to represent background with some residual activity just above the background but well below the $DCGL_W$.



Histogram of Net Direct Gamma Measurements
Figure 4.2

4.3.4. Measurements of Removable Contamination

4.3.4.1. Even though the roofing material on Building 101 is considered to be post – CT operations, removable contamination measurements were taken on the new roof surface at all of the locations where a direct grid or bias measurement was performed. The results of these measurements are presented in Table 4.9. The results show that removable contamination in SU-101R1 – SU-101R6 ranges between –4 and +15 $dpm_p/100cm^2$ and averages between 4.1 $dpm_p/100cm^2$ and 6.1 $dpm_p/100cm^2$. No significant removable contamination is present in SU-101R1 – SU-101R6.

Table 4.9
SU-101R1 – SU-101R6 Removable Contamination Summary

Survey Unit	Surface	Points	Avg Net Beta ($\beta pm/100cm^2$)	Max Net Beta ($\beta pm/100cm^2$)	Avg Net Activity[a] ($dpm_p/100cm^2$)	Max Net Activity ($dpm_p/100cm^2$)
101R1	R	31	19.9	53.0	4.1	11.0
101R2	R	26	29.4	72.0	6.1	15.0
101R3	R	31	27.5	66.0	5.7	13.8
101R4	R	31	23.7	63.0	4.9	13.1
101R5	R	31	24.5	69.0	5.1	14.4
101R6	R	26	21.1	63.0	4.4	13.1

[a] Activity was converted to $dpm_p/100\ cm^2$ from $\beta pm/100\ cm^2$ using an approximate figure of 4.8 betas per disintegration.

4.3.5. Installed Apparatus

4.3.5.1. The installed apparatus on the roof surface were included in the survey of SU-101NESW.

4.3.6. Gamma Scan Measurements

4.3.6.1. Gamma scans were performed on a total of about 75% of SU-101R1 – SU-101R6. At least 65% of each survey unit was scanned. A diagram of the areas surveyed is presented in Appendix 2, Figure 4.5.

4.3.6.2. The scan threshold used for these surveys was 5,880 cpm (net of background) as listed in Table 2.6.

4.3.6.3. The average background value used for analysis of the raw data was 3,500 cpm as described in paragraph 2.3.

4.3.6.4. During the surveys the maximum and average gross count rates were recorded for each area scanned. The gamma scan data for SU-101R1 – SU-101R6 are summarized and presented in Table 4.10.

Table 4.10
SU-101R1-6 Scan Measurements Summary

Survey Unit	Areas	Max Net (cpm)	Avg Net (cpm)
101R1	2	1,500	0
101R2	2	1,000	-500
101R3	2	2,500	500
101R4	2	1,500	0
101R5	2	2,500	0
101R6	2	2,500	500

4.3.6.5. The maximum net scan value recorded (2,500 cpm) was well below the gamma scan threshold presented in Table 2.6 (5,880 cpm). No gamma scan data observed in any of the roof survey units exceeded the scan threshold.

5. CONCLUSIONS

5.1. BUILDING 101 EXTERNAL WALLS

5.1.1. SU-101NESW passed all the tests described in the D Plan except Background. (Par. 4.2.3.3)

5.1.2. Although SU-101NESW failed the background test, further analysis showed that all of the survey data most likely belong to a single background distribution. (Par. 4.2.3.6)

5.1.3. No residual radioactivity was measured above 7% of the ARG on the items of installed apparatus in SU-101NESW. (Par. 4.2.2.1)

5.1.4. Virtually no removable contamination is present within SU-101NESW. (Par. 4.2.4.2)

5.1.5. No beta scan data were observed in SU-101NESW above the scan threshold of 2,000 cpm. (Par. 4.2.5.5)

5.1.6. SU-101NESW meets all the requirements of the D Plan and MARSSIM for unconditional release.

5.2. BUILDING 101 ROOF

5.2.1. SU-101R1 – SU-101R6 passed all the tests described in the D Plan which are required for release of a Class 2 survey unit. (Par. 4.3.2.5)

5.2.2. No significant removable contamination was measured in SU-101R1 – SU-101R6. (Par. 4.3.4.1)

5.2.3. No gamma scan data were observed in SU-101R1 – SU-101R6 that exceeded the gamma scan threshold. (Par. 4.3.6.5)

5.2.4. SU-101R1 – SU-101R6 meet all the requirements of the D Plan for unconditional release.

6. RECOMMENDATIONS

6.1. SU-101NESW should be released from the license.

6.2. All six roof survey units should be released from the license.

Appendix 1
Building Survey Unit Listing for
Building 101 Exterior

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101NESW					***Class:*** 3
Room 999					
N	242.67	23	5,581	1.0	
S	242.67	27	6,089	1.0	
E	242.67	23	5,581	1.0	
W	242.67	23	5,581	1.0	
Q1				0.0	5'X5' ventilation stack
Q2				0.0	6" roof drain
Q3				0.0	roof drain inside of chase
Q4				0.0	18" stack
Q5				0.0	6" stack
Q6				0.0	4" stack
Q7				0.0	3" stack
Q8				0.0	8" stack
Q9				0.0	exhaust vent
Q10				0.0	A.C. unit
Q11				0.0	fire sprinkler
Q12				0.0	vent
Q13				0.0	Incinerator Mounting Brackets (W Wall)
Q14				0.0	ladder
Q15				0.0	weather station
Q16				0.0	metal flashing
Q17				0.0	wall stack extending above roof
Summary for Room 999 (21 detail records)					*22,833* Sq. Feet
TOTAL for Survey Unit 101NESW					*22,833* Sq. Feet

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101R1					***Class:*** 2
Room 999R1					
R	242.7	41	9,951	0.0	Southernmost Section of Roof (All Coords to Roof zero)
Summary for Room 999R1 (1 detail record)				*9,951* **Sq. Feet**	
TOTAL for Survey Unit 101R1				*9,951* Sq. Feet	

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101R2					***Class:*** 2
Room 999R2					
R	242.7	41	9,951	0.0	Coordinates to Roof Zero.
Summary for Room 999R2 (1 detail record)				*9,951* **Sq. Feet**	
TOTAL for Survey Unit 101R2				*9,951* Sq. Feet	

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101R3					***Class:*** 2
Room 999R3					
R	242.7	41	9,951	0.0	Coordinates to Roof Zero.
Summary for Room 999R3 (1 detail record)				*9,951* **Sq. Feet**	
TOTAL for Survey Unit 101R3				*9,951* Sq. Feet	

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101R4					***Class:*** 2
Room 999R4					
R	242.7	41	9,951	0.0	Coordinates to Roof Zero.
Summary for Room 999R4 (1 detail record)				*9,951* **Sq. Feet**	
TOTAL for Survey Unit 101R4				*9,951* Sq. Feet	

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*

SurveyUnitID: 101R5 ***Class:*** 2

Room 999R5

R	242.7	41	9,951	0.0	Coordinates to Roof Zero.

Summary for Room 999R5 (1 detail record) *9,951* **Sq. Feet**

TOTAL for Survey Unit 101R5 *9,951* Sq. Feet

Building Survey Unit Listing

SurfaceCode	*Xmax*	*Ymax*	*Area (sq.ft.)*	*Paint (Coats)*	*Description*
SurveyUnitID: 101R6					***Class:*** 2
Room 999R6					
R	242.7	37.7	9,150	0.0	Northernmost section (all coords to roof zero)
Summary for Room 999R6 (1 detail record)					*9,150* Sq. Feet
TOTAL for Survey Unit 101R6					*9,150* Sq. Feet

APPENDIX 2
Figures

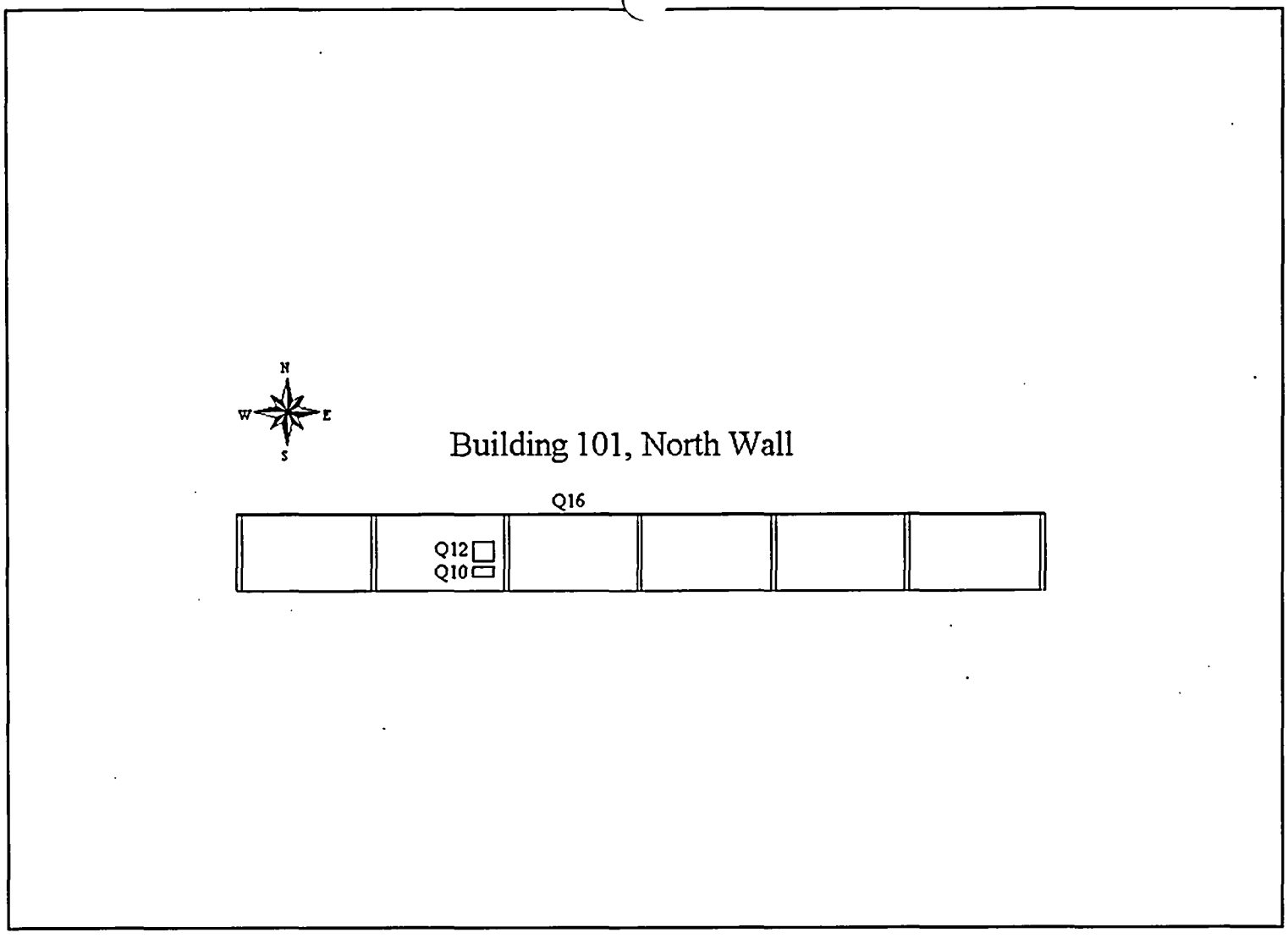


Figure 2.1
SU-101NESW, North Wall

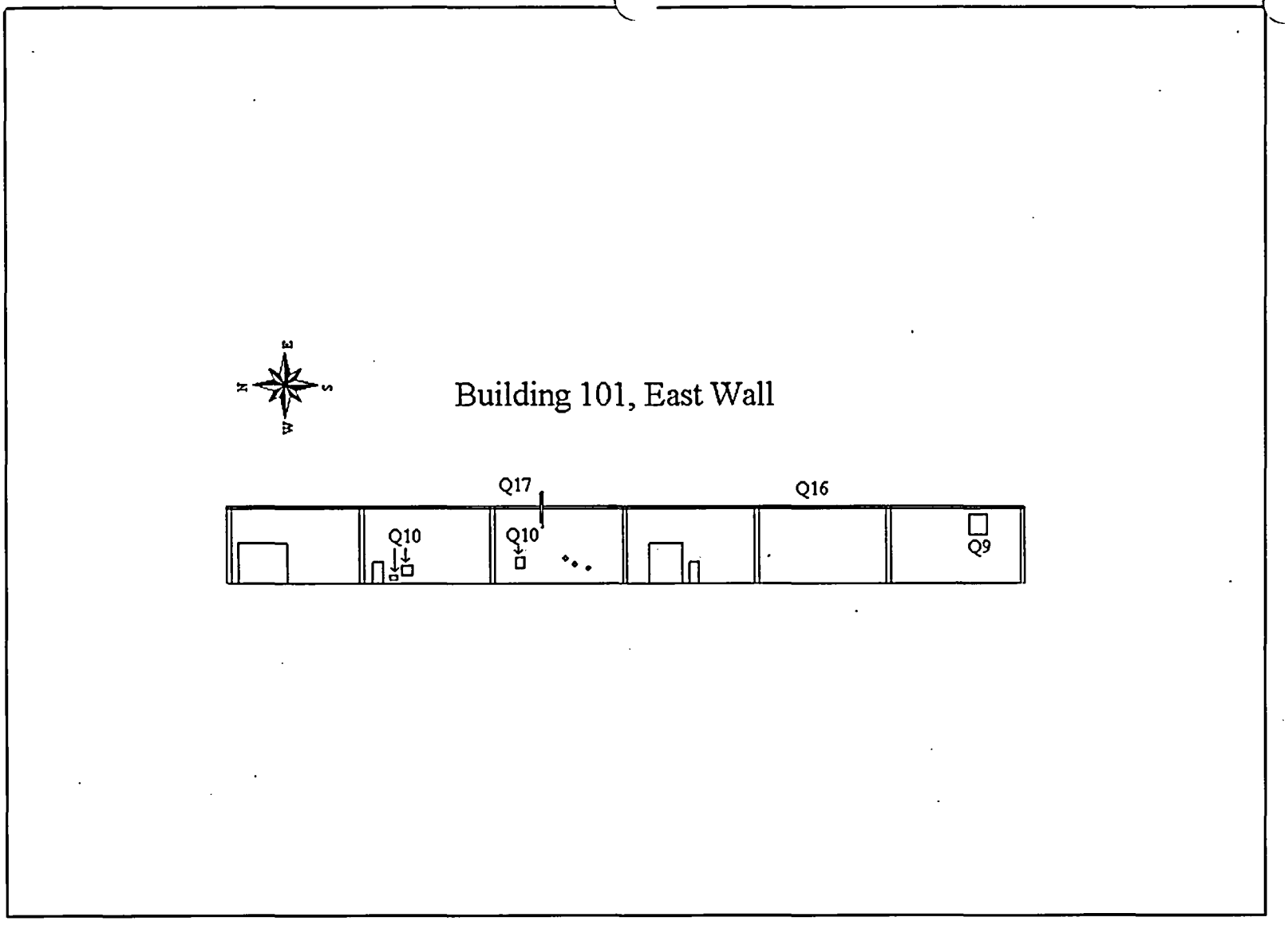


Figure 2.2
SU-101NESW, East Wall

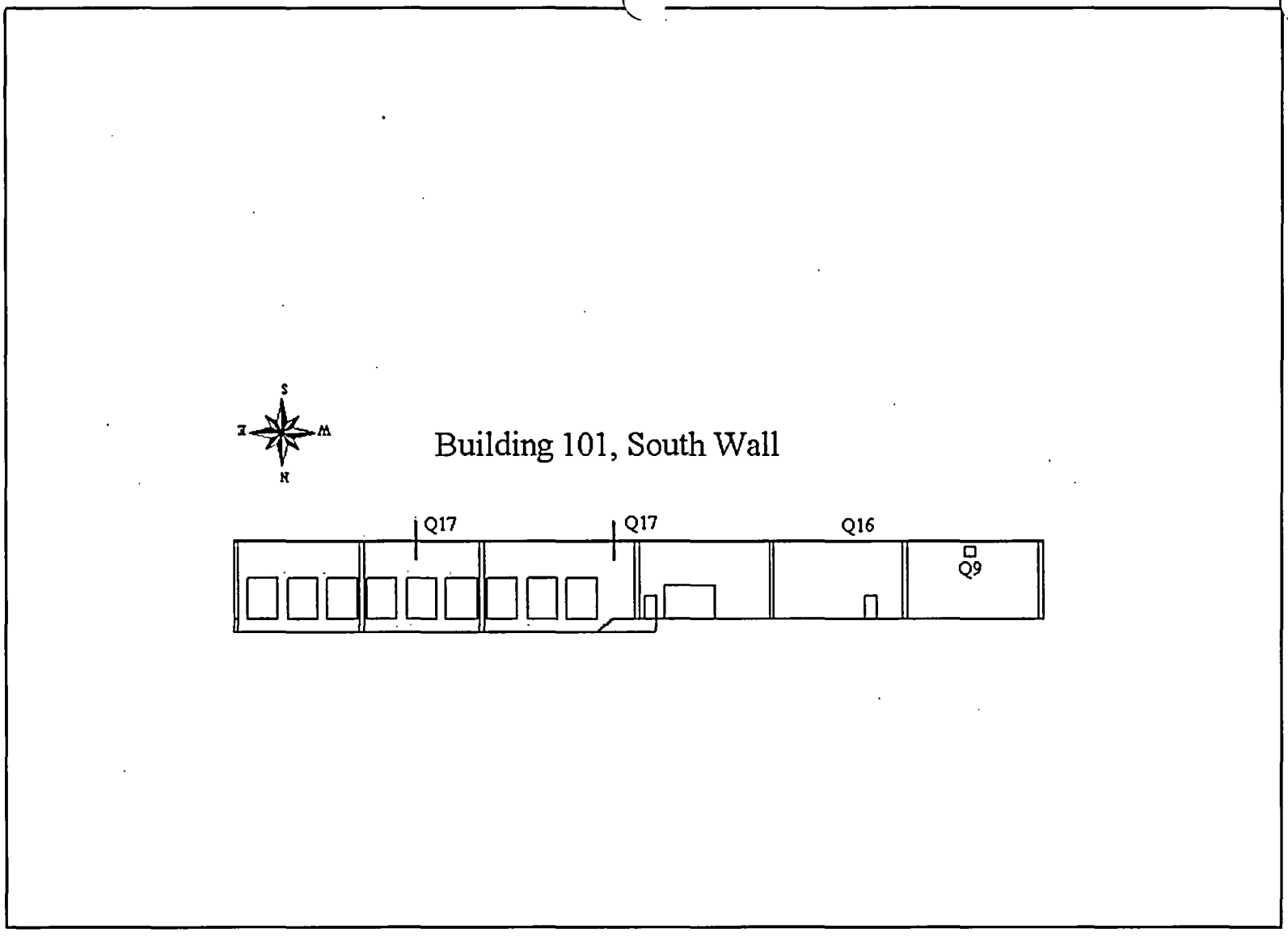


Figure 2.3
SU-101NESW, South Wall

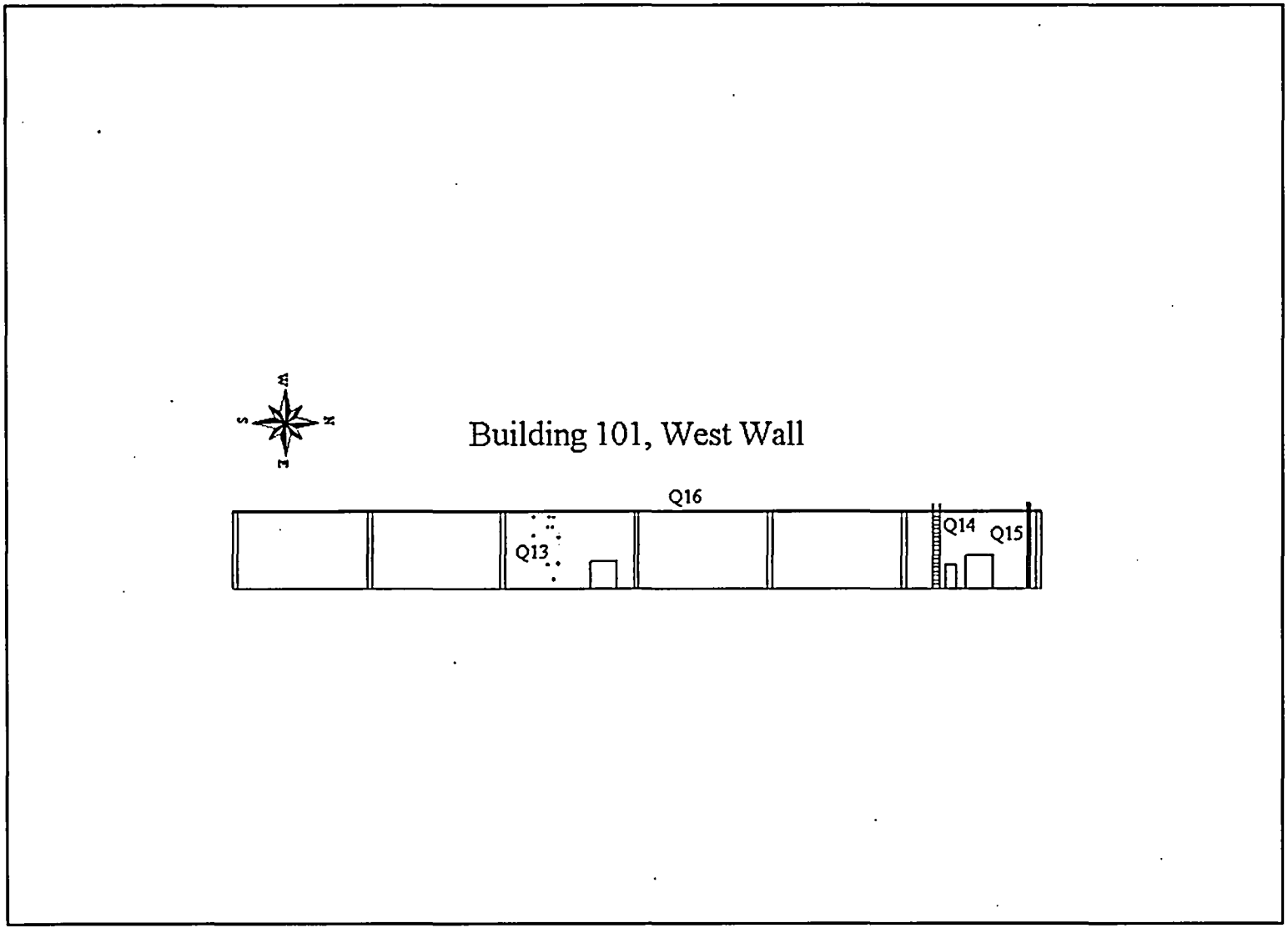


Figure 2.4
SU-101NESW, West Wall

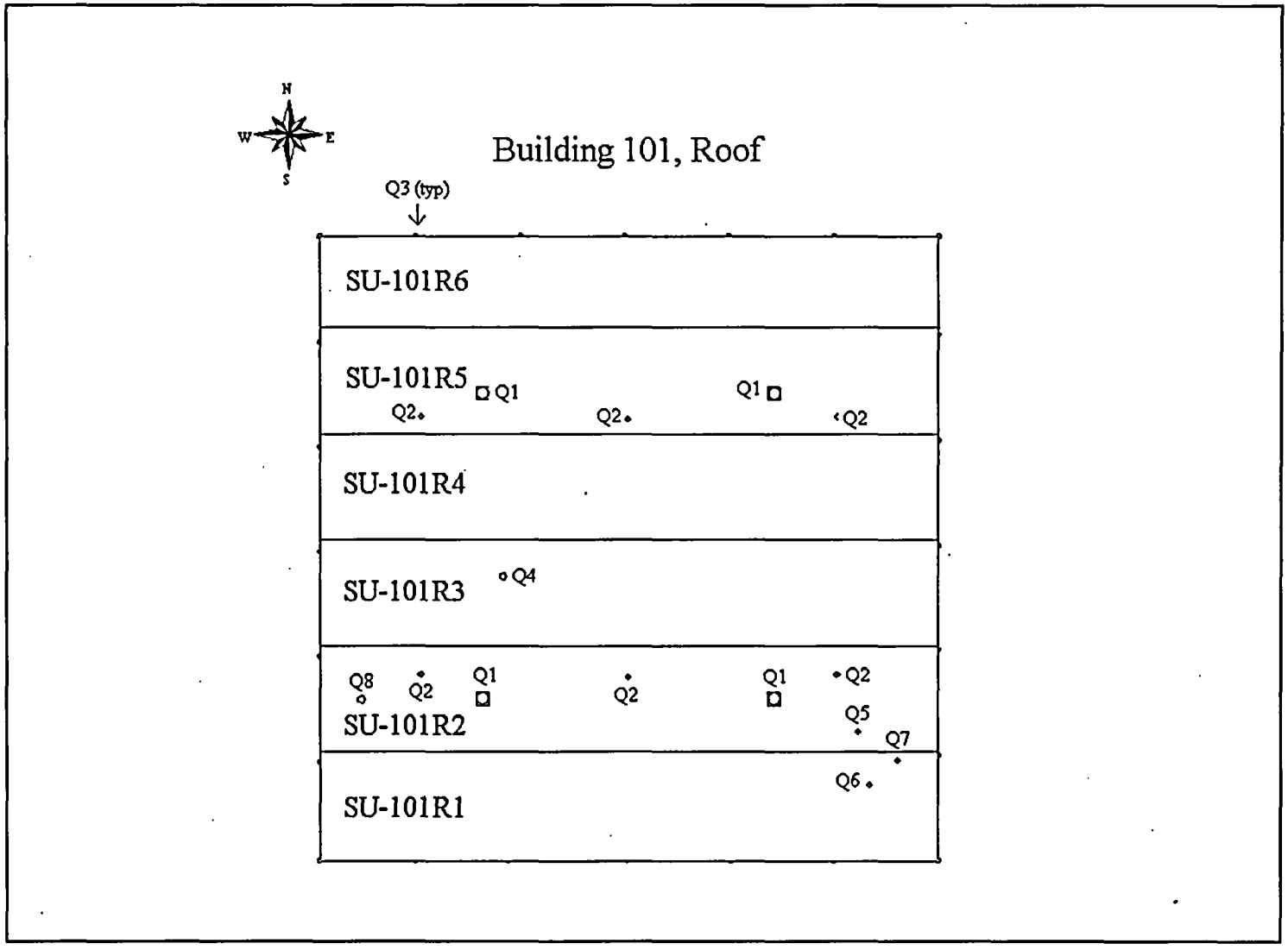
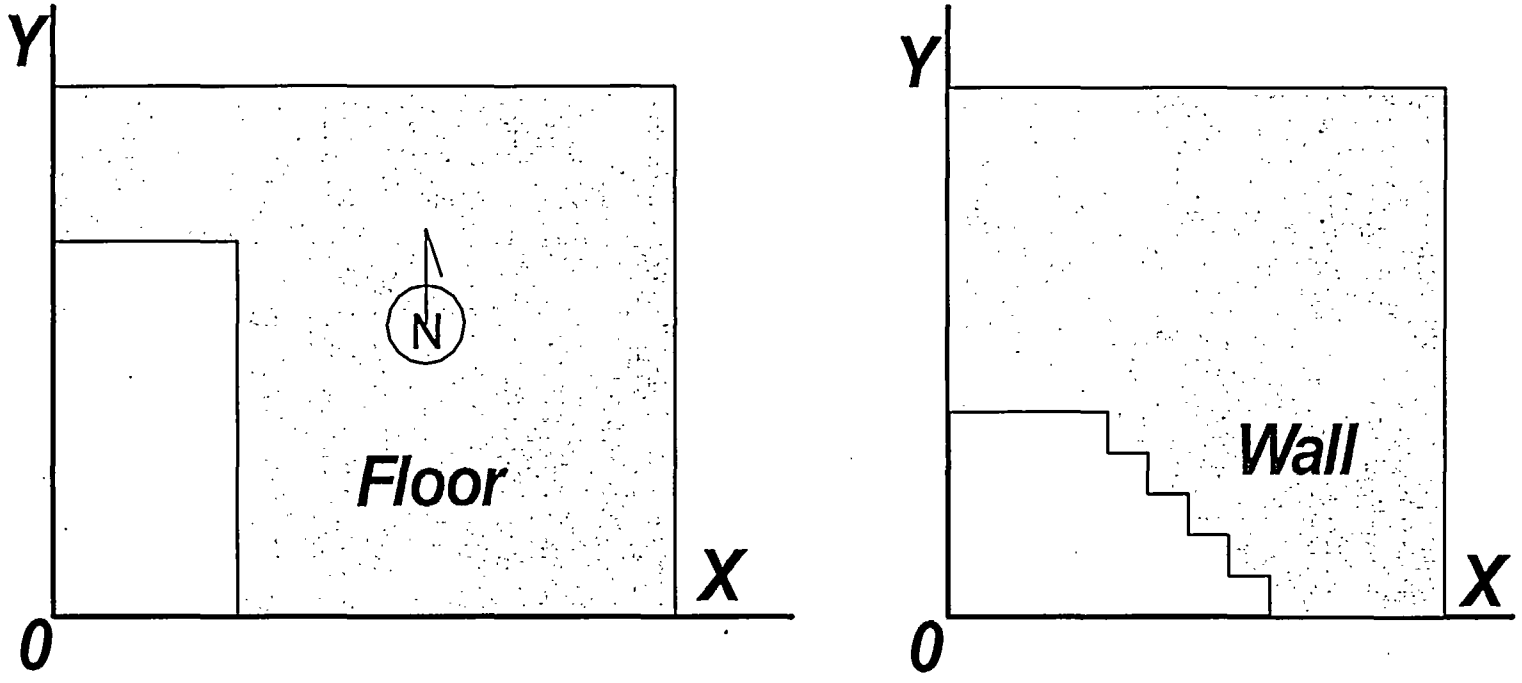
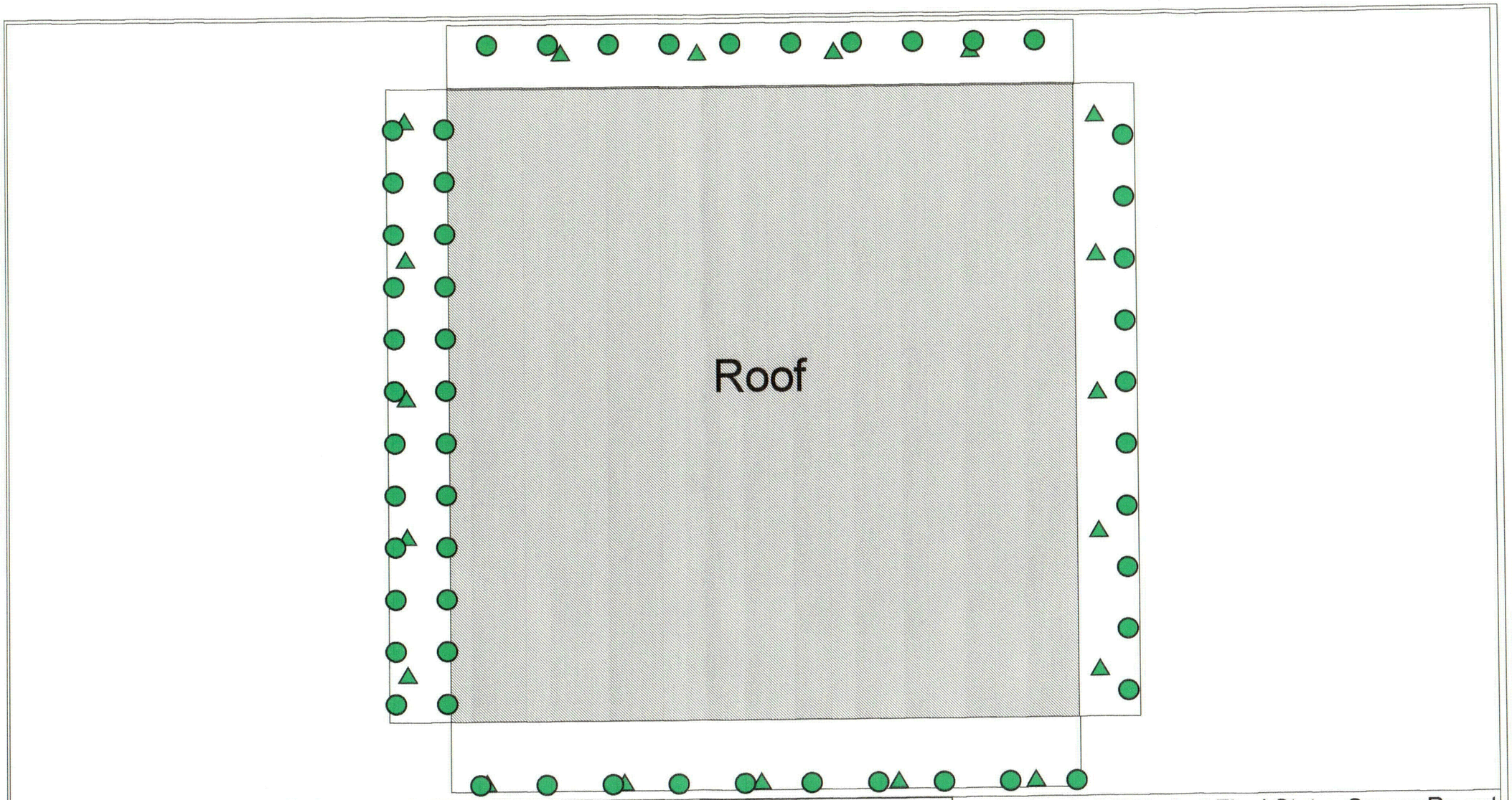


Figure 2.5
SU-101R1 –SU-101R6



Coordinate System

Figure 3.1


Roof
MALLINCKRODT
NEXTEP
ENVIRONMENTAL
Legend
Survey Unit
Not Part of SU
Direct Beta Measurements (dpm$_p$ /100 cm^2)
Grid Bias
Under 2600
2600 or More
N
W
E
S
20 0 20 40 Feet
Mallinckrodt C-T Project Final Status Survey Report
Figure 4.1
Building 101 Exterior Walls
SU-101NESW
Direct Beta Measurements
Drawn by: DCW
Date: 12/16/2003
Building: 101
Revision: 0

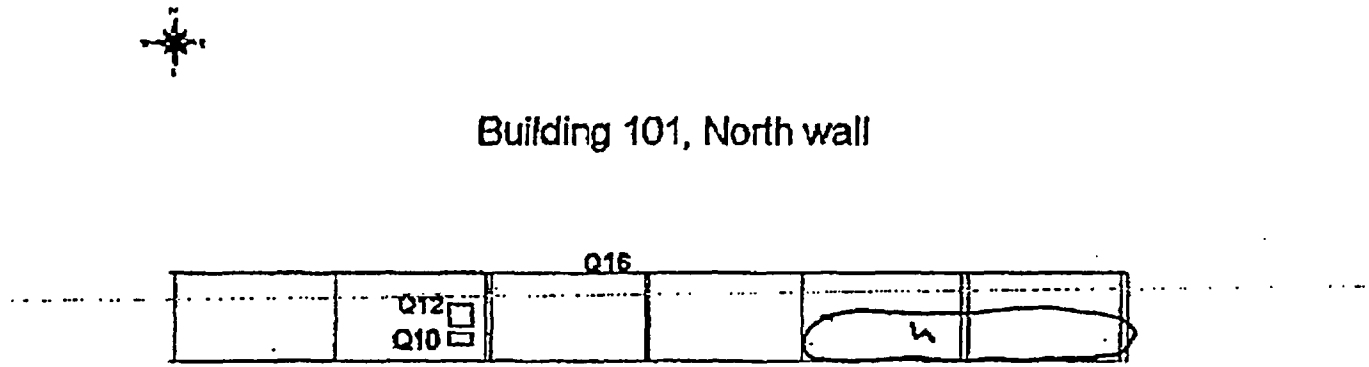


Figure 4.2
Survey Unit 101NESW North Wall Scans

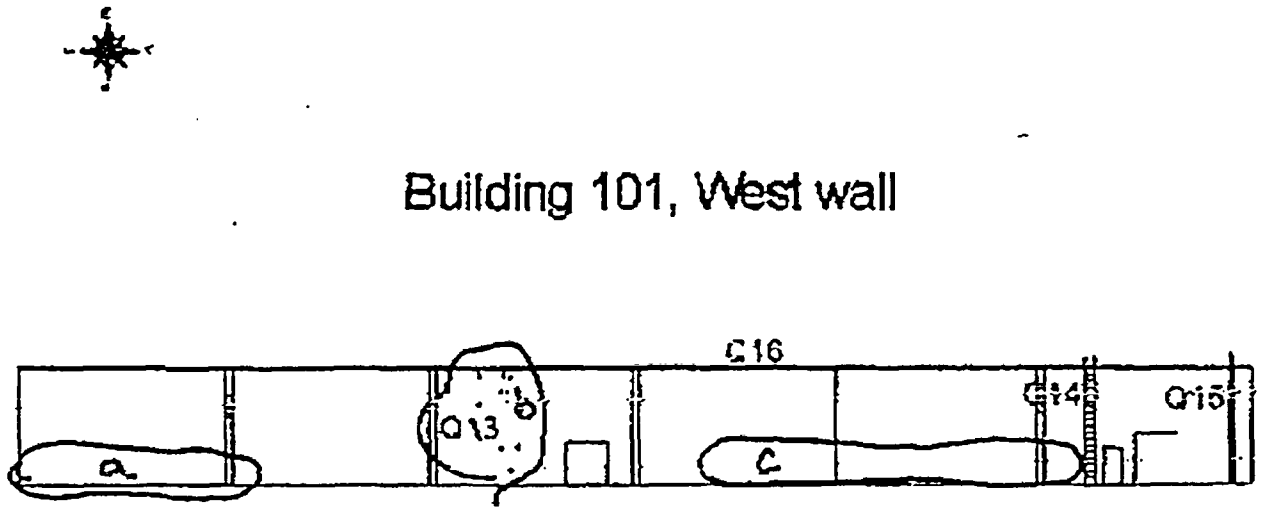
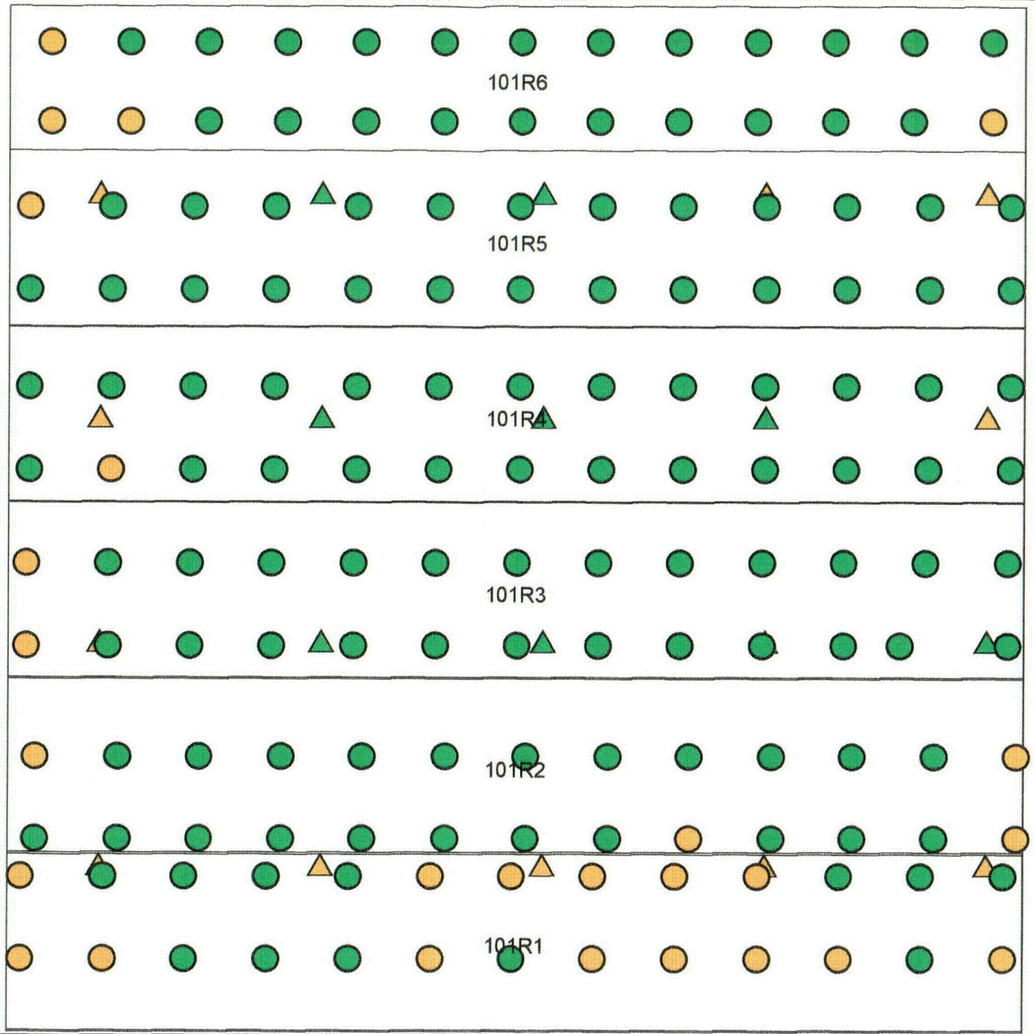


Figure 4.3
Survey Unit 101NESW West Wall Scans



MALLINCKRODT

NEXTEP ENVIRONMENTAL

Legend

Survey Unit

Direct Gamma Measurements ($dpm_p/100\ cm^2$)

Grid Bias

Under 2600

2600 - 13000

13000 or More

N

W E

S

20 0 20 40 Feet

Mallinckrodt C-T Project Final Status Survey Report

Figure 4.4
Building 101 Roof
SU-101R1 - SU-101R6
Direct Gamma Measurements

Drawn by: DCW	Date: 12/16/2003
Building: 101	Revision: 0

C02

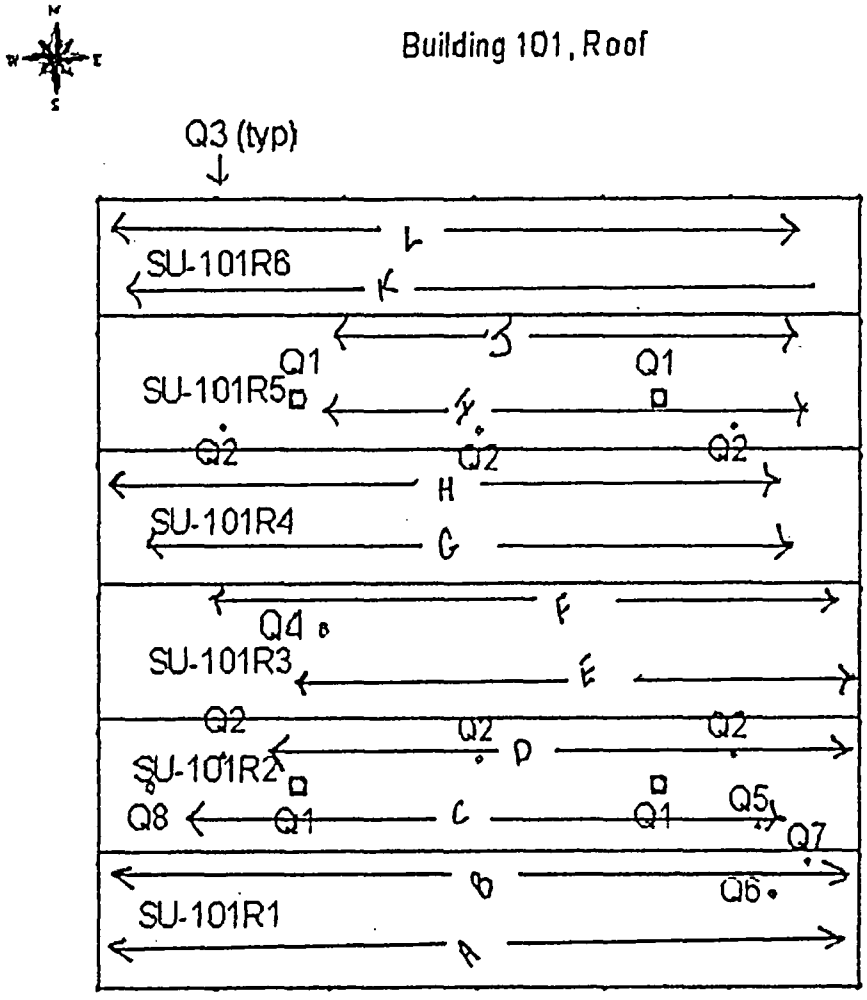


Figure 4.5
Survey Unit 101R1 – SU-101R6 Scans

APPENDIX 3
Calibration Sheets

Type	S/N	Cal Date	Sensitivity
Beta	131415/188704	6/17/2003	0.611
	163666/B426W	1/16/2003	0.774
Gamma	157020/020429-6	4/26/2003	N/A
Swipe	179562	11/8/2002 7/22/2003	
	179577	2/26/2003	

Ludlum
43-89
~~AG-3-7~~

CALIBRATION DATA SHEET

43-89
~~AG-3-7~~ SN: 188704 Property of: MALT

Readout Inst.: 2241-2 SN: 131415 Cal.Exp.Date: 6-12-04

~~Alpha~~ Beta Source: ~~TH~~ Sr-90 SN: 2158/96 Activity: 16700 DPM
RHS

Date of Cal.: 10-24-00

PLATEAU:

High Voltage	Source (CPM)	High Voltage	Source (CPM)
600	N/A	~~1050~~ 850	1598
650		~~1100~~ 875	2165
700		~~1150~~ 900	2631
750		~~1200~~ 925	3251
800	1552	~~1250~~ 950	3698
850	2771	~~1300~~ 975	4235
900	3737	1350	—
950	4542	1400	—
1000	5755		

Background Check

High Voltage	CPM
Op. Voltage ~~-50~~ -25	131
Op. Voltage	169
Op. Voltage ~~+50~~ +25	239

High Voltage set at: ~~900~~ 925 RHS volts

Efficiency:
5 Minute Gross Counts:

Pos "A": ———
Average (A + B)/2: ———
Background: CPM: ———

Pos "B": ———
Gross CPM: ———
Net CPM: ———

1 min Gr. 3213
1 min Bkg 183
3030 / 16700 dpm

$$\text{Efficiency} = \frac{\text{Net CPM}}{\text{DPM}} \times 100 = 18.1\ \%$$

18.1 %

Date of Calibration: 6-17-03 Expiration Date: 12-17-03

Calibrated by: Randall N. Sells (Print Name) (Signature)

Reviewed by: Dan Quigley Date: 6/18/03

EA4.10
Rev: 2
Date: 25 Feb 99

Page 4 of 4

L2241-2/L43-89
S/N: 131415/188704
6/17/03

CALN100A

Thermo NUtech

For Mallinckrodt Chemical, Inc

NATIONAL NUCLEAR ABP-100
MATERIAL SPECIFIC CALIBRATION DATA SHEET

43-89

~~ABP-100~~ SN: 188704 HIGH VOLTAGE: 925 V PROPERTY OF: MALT

READOUT INST: 2241-2 SN: 131415 CAL EXPIRE DATE: 12-12-03

ABP-100 EFFICIENCY TO SrY-90 ON 47 mm DISK: 18.1 % CAL DATE: 6-17-03

	BACKGROUND		BR	SOURCE		SR		SA	Efficiency
SURFACE MATERIAL	OPEN Cts/2 min	SHIELD Cts/2 min	NET CPM	OPEN Cts/1 min	SHIELD Cts/1 min	NET CPM	Source #	Source Activity	SR-BR / SA
Concrete	396	308	88	5005	181	9824	6-A	25900	18.2
				4945	179	4766			18.1
				4951	210	4741			18.0
				5113	184	4929			18.7
259 x 100 = 25900								Average =	18.5
								Std Dev =	0.3
Wood	0	0	0	4007	226	3781	M-2	17400	21.7
	0	0	0	3876	216	3660			21.0
	0	0	0	3971	211	3760			21.6
	0	0	0	3887	240	3647			21.0
174 x 100 = 17400								Average =	21.3
								Std Dev =	0.4
Masonite	0	0	0	3964	249	3715	M-2	17400	21.4
	0	0	0	3889	191	3698			21.3
	0	0	0	3853	234	3619			20.8
	0	0	0	3996	198	3798			21.8
								Average =	21.3
								Std Dev =	0.5
Aluminum	0	0	0	4362	224	4138	M-2	17400	23.8
	0	0	0	4399	211	4186			24.1
	0	0	0	4358	257	4101			23.6
	0	0	0	4390	230	4160			23.9
								Average =	23.9
								Std Dev =	0.3

DATE OF CALIBRATION: 6-17-03 EXPIRATION DATE: 12-17-03

CALIBRATED BY: Randall H. Sells (Print Name) Randall H. Sells (Signature)

REVIEWED BY: Alan Ziegler DATE: 6/18/03

@ Contact Geometry

L2241-2/L43-89
S/N: 131415/188704
6/17/03

CT-RP-66
Chi Squared Test

Instrument Model #	2241	Date:	06/24/2003
Instrument Serial#	131415	Source Nuclide:	SrY90
Probe Model #	43-89	Source Serial #	2178-96
Probe Serial #	188704	Source dpm (4π):	56039
Window Setting:		Efficiency (cpm/dpm):	0.19
Threshold Setting:		Background cpm:	135.2
High Voltage:	925	BKGD N-1	4
		BKGD Count Time (min):	1

Count # (n)	Gross Counts Observed	Expected	Background Counts
1	10358	10449	121
2	10405	10449	130
3	10502	10449	122
4	10336	10449	148
5	10281	10449	155
6	10196	10449	
7	10620	10449	
8	10468	10449	
9	10454	10449	
10	10328	10449	
11	10525	10449	
12	10403	10449	
13	10382	10449	
14	10418	10449	
15	10471	10449	
16	10669	10449	
17	10552	10449	
18	10690	10449	
19	10392	10449	
20	10525	10449	

sample mean (xbar) =	10449	Multiplier to convert	
sample variance (s^2) =	15903	to dpm:	5.4
background variance (b^2) =	239.7		
sample sigma (s) =	127		
(95% Confidence) 2.752 s =	350		
(99% Confidence) 3.615 s =	459		
		MDA(cpm) =	57
df = n-1 =	19	MDA(dpm) =	306
chitest = p(x<χ^2) =	6.727E-02		
chisquare (χ^2) =	28.919		
Acceptable χ^2 min =	8.907		
Acceptable χ^2 max =	32.852		
χ^2 test passes (yes/no)?	YES		
99% Conf. Interval Test min =	9854		
95% Conf. Interval Test min =	9964		
Daily Source Check Mean Net Counts	10313		
95% Conf. Interval Test max =	10663		
99% Conf. Interval Test max =	10773		

Test performed by: Steve Struck

Checked by: Date:

L2241-2/L43-89
S/N: 131415/188704
6/17/03

Thermo NUtech
A ThermoRetec Company
601 Scarboro Road
Oak Ridge, TN 37830

LUDLUM 2221
CALIBRATION DATA SHEET

ThermoRetec
Smart Solutions. Positive Outcomes.

(423) 481-0683 Phone
(423) 481-0121 Fax
www.thermoretec.com

Ludlum2221S/N: 163666 Property of:

Battery Check ok @ 5.6 Bits
Replace @ 6.4

High Voltage Check

HV Meter: Fluke 29 S/N: 65410232 Cal Exp. Date 1-30-03

Meter Reading	Pre Cal	Post Cal	Tolerance
600 Volts	660	605	10 %
1000 Volts	1100	1005	10 %
1400 Volts	1540	1410	10 %

Input Sensitivity:

(Threshold @ 10 mv) Pre Cal: 35 mV, Post Cal: 35 mV
MP-2 S/N: 1684 Calibration Exp. Date: 1-29-03

Rate/ Meter	MP-2	2221	Distal Display	Analog Display	Tol
400 CPM	x1		400	400	10%
4K CPM	x10		3998	4000	10%
40K CPM	x100		39999	40000	10%
400K CPM	x1000		400080	400000	10%
Scaler: 100K CPM	0.5 sec		50010	100000	10%
100K CPM	1.0 min		100020		10%
100K CPM	2.0 min		200039		10%
100K CPM	5.0 min		500097		10%

Log 400 400 4K 4K 40K 40K 400K 400K

Functional Check:

Ext Count ✓ Reset ✓ Speaker ✓ Headphones ✓ Light ✓

Date Of Calibration: 1-16-03 Expiration Date: 7-16-03

Calibrated By: Randall H. Sells (Print) (Signature)

Reviewed By: Date: 1/30/03

A subsidiary of Thermo TerraTech Inc.,
a Thermo Electron company

L2221/AB-100
S/N: 163666/B426W
1/16/03

CALN100A

Thermo NUtech

For Mallinckrodt Chemical, Inc

NATIONAL NUCLEAR ABP-100
MATERIAL SPECIFIC CALIBRATION DATA SHEET

RHS

ABP-100 SN: B426W HIGH VOLTAGE: 875 V PROPERTY OF: ~~TYCO~~ E.S.

READOUT INST: Lud 2221 SN: 163666 CAL EXPIRE DATE: 7-16-03

ABP-100 EFFICIENCY TO SrY-90 ON 47 mm DISK: 42.0 % CAL DATE: 1-22-03

	BACKGROUND		BR	SOURCE		SR		SA	Efficiency
SURFACE MATERIAL	OPEN Cts/2 min	SHIELD Cts/2 min	NET CPM	OPEN Cts/1 min	SHIELD Cts/1 min	NET CPM	Source #	Source Activity	SR-BG/ SA
Concrete	561	416	73	6857	232	6625	6-A	33250	19.9
	(	(	(	6853	246	6607	(	(	19.9
	(	(	(	6846	242	6604	(	(	19.9
	↓	↓	↓	6784	236	6548	↓	↓	19.7
266 X 125 = ~~333~~ 33250 dpm								Average =	19.9
								Std Dev =	0.1
Wood	0	0	0	5227	238	4984	M-2	22250	22.4
	0	0	0	5281	240	5041	(	(	22.3
	0	0	0	5181	224	4957	(	(	22.3
	0	0	0	5296	232	5064	↓	↓	22.8
178 dpm X 125 = 22250								Average =	22.5
								Std Dev =	0.2
Masonite	0	0	0	5296	232	5064	M-2	22250	22.8
	0	0	0	5302	234	5068	(	(	22.8
	0	0	0	5311	248	5063	(	(	22.8
	0	0	0	5366	236	5130	↓	↓	23.1
178 dpm X 125 = 22250								Average =	22.9
								Std Dev =	0.2
Aluminum	0	0	0	6037	223	5814	M-2	22250	26.1
	0	0	0	5706	236	5470	(	(	24.6
	0	0	0	6013	248	5765	(	(	25.9
	0	0	0	5892	227	5665	↓	↓	25.5
178 dpm X 125 = 22250								Average =	25.5
								Std Dev =	0.7

DATE OF CALIBRATION: 1-29-03 EXPIRATION DATE: 7-29-03

CALIBRATED BY: Randall H. Sells (Print Name) (Signature)

REVIEWED BY: M Dwyer DATE: 1/30/03

L2221/AB-100
S/N: 163666/B426W
1/16/03

CT-RP-66
Chi Squared Test

Instrument Model #	2221	Date:	02/04/2003
Instrument Serial#	163666	Source Nuclide:	SrY90
Probe Model #	AB 100	Source Serial #	2178-96
Probe Serial #	B426W	Source dpm (4π):	56489
Window Setting:	3720	Efficiency (cpm/dpm):	0.28
Threshold Setting:	352	Background cpm:	183.4
High Voltage:	875	BKGD N-1	4
		BKGD Count Time (min):	1

Count # (n)	Gross Counts Observed	Expected	Background Counts
1	15380	15546	185
2	15381	15546	193
3	15477	15546	179
4	15662	15546	179
5	15520	15546	181
6	15587	15546	
7	15478	15546	
8	16392	15546	
9	15639	15546	
10	15609	15546	
11	15401	15546	
12	15433	15546	
13	15601	15546	
14	15743	15546	
15	15608	15546	
16	15628	15546	
17	16577	15546	
18	15518	15546	
19	15510	15546	
20	15599	15546	

sample mean (xbar) =	15546	Multiplier to convert to dpm:	3.6
sample variance (s^2) =	15181		
background variance (b^2) =	34.8		
sample sigma (s) =	123		
(95% Confidence) 2.752 s =	339		
(99% Confidence) 3.615 s =	446		
		MDA (cpm) =	66
		MDA (dpm) =	240
df = n-1 =	19		
chitest = p(x<χ^2) =	4.858E-01		
chisquare (χ^2) =	18.654		
Acceptable χ^2 min =	8.907		
Acceptable χ^2 max =	32.852		
χ^2 test passes (yes/no)?	YES		
99% Conf. Interval Test min =	14917		
95% Conf. Interval Test min =	15023		
Daily Source Check Mean Net Counts	15363		
95% Conf. Interval Test max =	15702		
99% Conf. Interval Test max =	15809		

Test performed by: Steve Struck 2/4/03

Checked by: Date: 2-4-03

L2221/AB-100
S/N: 163666/B426W
1/16/03

Designer and Manufacturer of Scientific and Industrial Instruments

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER TYCO/MALLINCKRODT ST LOUIS ORDER NO. 296103/271822

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 157020

Mfg. Ludlum Measurements, Inc. Model 3X3 Serial No. 020429-6

Cal. Date 26-Apr-03 Cal Due Date 26-Apr-04 Cal. Interval 1 Year Meterface 202159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 77 °F RH 31 % Alt 693 ft mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 5.0 VDC

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set Comm1S V Input Sens. Comm1S mV Det. Oper. Comm1S V at Comm1S Threshold Dial Ratio 100= 10 mV

☑ HV Readout (2 points) Ref./Inst. 500 / 499 V Ref./Inst. 2000 / 1990 V

COMMENTS:

	Peak settings	Gross Counts
High Voltage:	434 v	650 v
Threshold dial:	642	100 (10mv)
Window dial:	40	n/a
Window Position:	"IN"	"OUT"
Resolution for Cs137:	~ 10 %	n/a

Model 2221 currently set for Gross Counts
High voltage set with detector connected.

Firmware: 26 10 10

Alpha Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

RANGE/MULTIPUER	REFERENCE CAL POINT	INSTRUMENT REC'D "AS FOUND READING"	INSTRUMENT METER READING*
X 1000	400 Kcpm	390	390
X 1000	100 Kcpm	100	100
X 100	40 Kcpm	390	390
X 100	10 Kcpm	110	110
X 10	4 Kcpm	390	390
X 10	1 Kcpm	110	110
X 1	400 cpm	400	400
X 1	100 cpm	100	100

*Uncertainty within ± 10% C.F. within ± 20% ALL Range(s) Calibrated Electronically

	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*		REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
Digital Readout	400 Kcpm	39810 (c)	39810(c)	Log Scale	500 Kcpm	450K	450K
	40 Kcpm	3984 (c)	3984(c)		50 Kcpm	50K	50K
	4 Kcpm	398 (c)	398(c)		5 Kcpm	4.5K	4.5K
	400 cpm	400 (c)	400(c)		500 cpm	500	500
	40 cpm	40 (c)	40		50 cpm	55	55

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of their International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration technique. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978 State of Texas Calibration License No. LC-1963

Reference Instruments and/or Sources:

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M566 ☐ 6105 ☐ T1006 ☐ T879 ☐ E562 ☐ E551 ☐ Neutron Am-241 Be S/N 7334

☐ Alpha S/N ☐ Beta S/N ☐ Other

Ratemeter 500 S/N 81084 ☐ Oscilloscope S/N ☑ Multimeter S/N 80240300

Calibrated By: Michael J Thomas Date 26-April-03

Reviewed By: Rhonda Harris Date 30 Apr 03

This certificate shall not be reproduced except in full, without the written approval of Ludlum Measurements, Inc.
FORM C22A 04/09/2003

AC Inst Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test Failed:

L2221/3x3
1507020/020429-6
4/26/03

Designer and Manufacturer of Scientific and Industrial Instruments

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556 U.S.A.

Bench Test Data For Detector

Detector 3X3 Serial No. 020429-6

Customer TYCO/MALLINCKRODT ST LOUIS Order #. 296103/271822

Counter 2221 Serial No. 157020 Counter Input Sensitivity 10 mV

Count Time 6 sec Distance Source to Detector Surface

Other

High Voltage	Background	Isotope Am-241 Size ≈0.17uCi	Isotope Size	Isotope Size	Isotope Size
450	1443	5324			
500	1654	18326			
550	1572	22461			
600	1614	22466			
→ 650	1687	22705			
700	1729	22867			
750	2057	23047			
800	2521	25948			
850	3899	29371			
900	6780	40237			
950	16139	53980			
1000	19708	78799			

Signature Michael J Thomas Date 26-Apr-03

FORM CAL 04/09/2003

• *Serving The Nuclear Industry Since 1962* •

L2221/3x3
1507020/020429-6
4/26/03

CT-RP-66
Chi Squared Test

Instrument Model #	2221	Date:	05/07/2003
Instrument Serial#	157020	Source Nuclide:	Cs137
Probe Model #	NaI 3x3	Source Serial #	2558
Probe Serial #	020429-6	Source dpm (4π):	21534000
Window Setting:	3700 3480	Efficiency (cpm/dpm):	0.01
Threshold Setting:	100mV / 104	Background cpm:	3676.2
High Voltage:	650V	BKGD N-1	4
		BKGD Count Time (min):	1

Count # (n)	Gross Counts Observed	Expected	Background Counts
1	226601	227689	3624
2	227278	227689	3830
3	226251	227689	3610
4	227614	227689	3701
5	228344	227689	3616
6	228647	227689	
7	227269	227689	
8	227708	227689	
9	227138	227689	
10	227004	227689	
11	227520	227689	
12	227819	227689	
13	228608	227689	
14	228689	227689	
15	227778	227689	
16	227078	227689	
17	227572	227689	
18	227573	227689	
19	227841	227689	
20	227443	227689	

sample mean (xbar) =	227689	Multiplier to convert to dpm:	94.6
sample variance (s^2) =	334344		
background variance (b^2) =	8750.2		
sample sigma (s) =	586		
(95% Confidence) 2.752 s =	1612		
(99% Confidence) 3.615 s =	2117		
		MDA (cpm) =	285
df = n-1 =	19	MDA (dpm) =	26948
chitest = p(x<χ^2) =	8.597E-02		
chisquare (χ^2) =	27.900		
Acceptable χ^2 min =	8.907		
Acceptable χ^2 max =	32.852		
χ^2 test passes (yes/no)?	YES		
99% Conf. Interval Test min =	221895		
95% Conf. Interval Test min =	222401		
Daily Source Check Mean Net Counts	224013		
95% Conf. Interval Test max =	225625		
99% Conf. Interval Test max =	226130		

Test performed by: S Struck 5-7-2003

Checked by: Date:

L2221/3x3
1507020/020429-6
4/26/03

CT-RP-66
Chi Squared Test

Instrument Model #	2221	Date:	06/04/2003
Instrument Serial#	157020	Source Nuclide:	Cs137
Probe Model #	NaI 3x3	Source Serial #	2538-99
Probe Serial #	020429-6	Source dpm (4π):	2286600
Window Setting:	3680	Efficiency (cpm/dpm):	0.01
Threshold Setting:	104mV	Background cpm:	3985.8
High Voltage:	650V	BKGD N-1	4
		BKGD Count Time (min):	1

Count # (n)	Gross Counts Observed	Expected	Background Counts
1	28742	28492	4019
2	28702	28492	4066
3	28477	28492	3976
4	28166	28492	3904
5	28711	28492	3964
6	28701	28492	
7	28491	28492	
8	28304	28492	
9	28412	28492	
10	28667	28492	
11	28084	28492	
12	28349	28492	
13	28087	28492	
14	28460	28492	
15	28454	28492	
16	28682	28492	
17	28441	28492	
18	28716	28492	
19	28606	28492	
20	28592	28492	

sample mean (xbar) =	28492	Multiplier to convert to dpm:	80.3
sample variance (s^2) =	44336		
background variance (b^2) =	3699.2		
sample sigma (s) =	219		
(95% Confidence) 2.752 s =	603		
(99% Confidence) 3.615 s =	792		
		MDA (cpm) =	297
df = n-1 =	19	MDA (dpm) =	23801
chitest = p(x<χ^2) =	5.759E-02		
chisquare (χ^2) =	29.566		
Acceptable χ^2 min =	8.907		
Acceptable χ^2 max =	32.852		
χ^2 test passes (yes/no)?	YES		
99% Conf. Interval Test min =	23714		
95% Conf. Interval Test min =	23903		
Daily Source Check Mean Net Counts	24506		
95% Conf. Interval Test max =	25110		
99% Conf. Interval Test max =	25299		

Test performed by: S Struck 6-4-03

Checked by: Date:

L2221/3x3
1507020/020429-6
4/26/03

OCT.16.2003 16:52 314 654 1251 MALLINCKRODT #2114 P.009

Designer and Manufacturer of Scientific and Industrial Instruments

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 915-235-5494
501 OAK STREET FAX NO. 915-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER TYCO/HEALTHCARE/MALLINCKRODT ORDER NO. 285367 / 268024

Mfg. Ludlum Measurements, Inc. Model 3030 Serial No. 179562

Cal. Date 8-Nov-02 Cal Due Date 8-May-03 Cal. Interval 6 Months

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 72 °F. RH 32 % Alt 699.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Window Operation

☑ Audio ck.

Alpha Sensitivity 120 mV Beta Sensitivity 4 mV Beta Window 50 mV

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89.

Instrument Volt Set 625 V High Voltage set with detector connected.

☑ HV Readout (2 points) Ref./Inst. 498 / 500 V Ref./Inst. 1506 / 1500 V

(EEPROM Settings)

Instrument in DPM mode.	(PC) Count Time: 10
SC mode turned OFF.	Alpha Alarm: 50000 cpm
Firmware version: 280110	Beta Alarm: 50000 cpm
Overload set at 1/4 turn past OFF.	Alpha/Beta Alarm: 50000 cpm
Battery voltage measured at 12vo Vdc.	Calibration Due Date: 8-May-03
C-14 Efficiency = 9 %(4 pi) Net	LOC (Loss of Count) time = 30 minutes (default)

Alpha Channel Digital Readout	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
	400K cpm	399264	399264
	40K cpm	39927	39927
	4K cpm	3993	3993
	400 cpm	400	400
	40 cpm	40	40

Beta/Gamma Channel Digital Readout	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
	400K cpm	399449	399449
	40K cpm	39950	39950
	4K cpm	3995	3995
	400 cpm	400	400
	40 cpm	40	40

*Uncertainty within ± 10% C.F. within ± 20% (1) indicates 0.1 minute count

COMMENTS:

Eff. for Th-230 s/n 2748-00, 3070cpm, read 4437 in 1 minute = 30% 2pi

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978. State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources:

☑ Alpha S/N Th-230 2748-00, Th-230 ... ☑ Beta S/N Tc-99 ... ☐ Other

☑ m 500 S/N 134709 ☐ Oscilloscope S/N ☐ Multimeter S/N

Calibrated By: Conrad ... Date 8 Nov 02

Reviewed By: Rhonda Harris Date 11 Nov 02

This certificate shall not be reproduced except in full, without the written approval of Ludlum Measurements, Inc.
FORM C22-2 06/03/2002

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

L3030
S/N: 179562
11/8/02

Ludlum Measurements, Inc.
Model 3030 Plateau Data

11/11/02
11:25:35 AM

Header 1: John Q Public
Header 2: Serial#179562
Header 3: Site:Building 1
Header 4: Room 7 EastWall
Header 5: More Comments?
Header 6: More Comments?

Calibration Due Date: 5/8/03

Model 3030 Date: 11/8/02
Model 3030 Time: 10:16:33 AM

User PC Time: 1.0

Alpha Isotope: Pu-239
Alpha Source Size (dpm): 25200
Alpha Source Size (µCi): 0.011351351

Beta Isotope: Tc-99
Beta Source Size (dpm): 22600
Beta Source Size (µCi): 0.01018018

Starting High Voltage: 625
Starting High Voltage: 750
High Voltage Increment: 25

Plateau Count Mode: SCALER
Source Count Time (min): 0001.0
Background Count Time (min): 1.0

	ALPHA				BETA			
HV	Source (Beta)	Background	Eff	CrossTalk	Source (Alpha)	Background	Eff	Crosstalk
625	9306 (348)	1	16.9%	3.5%	5347 (0)	25	23.5%	0.0%
650	9467 (311)	2	17.6%	2.9%	6243 (4)	40	27.4%	0.0%
675	9632 (328)	3	18.2%	3.0%	7209 (3)	41	31.7%	0.0%
700	9755 (340)	5	18.7%	3.0%	8087 (1)	43	35.6%	0.0%
725	9627 (267)	2	18.2%	2.1%	8928 (3)	68	39.2%	0.0%
750	9773 (316)	3	18.8%	1.4%	9646 (3)	163	41.9%	0.0%

L3030
S/N: 179562
11/8/02

JUL.16'2003 16:53 [illegible] MALLINCKRODT #2114 P.010

Ludlum Measurements, Inc.

Model 3030 MDA Calculation Data

11/11/02
11:25:19 AM

Alpha Background(cpm): 3.0
Beta Background(cpm): 41.0

Alpha Efficiency %: 38.2
Beta Efficiency %: 31.7

Confidence Level: 95%

Count Time	Alpha MDA(dpm)	Beta MDA(dpm)
0.1	120.4	305.9
0.5	40.0	132.2
1.0	28.2	102.5
2.0	21.8	85.7
5.0	17.8	74.5
10.0	16.4	70.6
50.0	15.2	67.1
PC (1.0)	28.2	102.5

L3030
S/N: 179562
11/8/02

Designer and Manufacturer of Scientific and Industrial Instruments

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER TYCO/ MALLINCKRODT ORDER NO. 200546 / 274002

Mfg. Ludlum Measurements, Inc. Model 3030 Serial No. 179562

Cal. Date 22-Jul-03 Cal Due Date 22-Jan-04 Cal. Interval 6 Months

Check mark ☑ copies to applicable instr. and/or detector IAW mfg. spec. T. 73 °F RH 39 % Alt 703.8 mm Hg

☐ New instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☐ Window Operation

☑ Audio ck.

Alpha Sensitivity 120 mV Beta Sensitivity 4 mV Beta Window 50 mV

☐ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89.

Instrument Volt Set 650 V High Voltage set with detector connected.

☑ HV Readout (2 points) Ref./Inst. 503 / 500 V Ref./Inst. 1512 / 1500 V

(EEPROM Settings)

(PC) Count Time: 1.0

Alpha Alarm: 999999 cpm

Beta Alarm: 999999 cpm

Alpha/Beta Alarm: 999999 cpm

Calibration Due Date: 01/22/2004

LOC (Loss of Count) time = 30 minutes (default)

GC mode turned OFF.

Firmware version: 39013N10

Overload set at 1/4 turn past OFF.

Battery voltage measured at 13.56 Vdc.

C-14 Efficiency = 7.1 %(4 pi) Net

	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
Alpha Channel Digital Readout	400K cpm	399903	399903
	40K cpm	39992	39992
	4K cpm	3995	3995
	400 cpm	400	400
	40 cpm	40	40
Beta/Gamma Channel Digital Readout	400K cpm	399507	399507
	40K cpm	39952	39952
	4K cpm	3997	3997
	400 cpm	400	400
	40 cpm	40	40

*Unacceptable within ± 10% C.F. within ± 20% (0) indicates 0.1 minute count

*COMMENTS:
Eff. for Th-230 s/n 2748-00, 3070cpm read 2377 in 1 minute = 77% 2pi

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978. State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources:

☐ Alpha S/N ☐ Beta S/N ☐ Other

☑ m 500 S/N 134709 ☐ Oscilloscope S/N ☑ Multimeter S/N 57390613

Calibrated By: Conrad Johnson Date 22 Jul 03

Reviewed By: [signature] Date 22 July 03

This certificate shall not be reproduced except in full, without the written approval of Ludlum Measurements, Inc.
FORM C25-3 04/09/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

L3030
S/N: 179562
7/22/03

Ludlum Measurements,Inc.
Model 3030 Plateau Data

7/22/03
8:46:42 AM

Header 1: John Q Public
Header 2: Serial#179562
Header 3: Site:Building 1
Header 4: Room 7 EastWall
Header 5: More Comments?
Header 6: More Comments?

Calibration Due Date: 5/8/03

Model 3030 Date: 7/19/04
Model 3030 Time: 8:32:16 AM

User PC Time: 1.0

Alpha Isotope: Pu-239
Alpha Source Size (dpm): 25200
Alpha Source Size (µCi): 0.011351351

Beta Isotope: Tc-99
Beta Source Size (dpm): 22600
Beta Source Size (µCi): 0.01018018

Starting High Voltage: 600
Starting High Voltage: 750
High Voltage Increment: 25

Plateau Count Mode: SCALER
Source Count Time (min): 0001.0
Background Count Time (min): 1.0

	ALPHA				BETA				
HV	Source (Beta)	Background	Eff	CrossTalk	Source (Alpha)	Background	Eff	Crosstalk
600	9397 (383)	0	37.3%	3.7%	4580 (2)	32	20.1%	0.0%
625	9455 (358)	1	37.5%	3.5%	5493 (3)	29	24.2%	0.0%
650	9483 (363)	0	37.6%	3.5%	6502 (3)	33	28.6%	0.0%
675	9586 (357)	1	38.0%	3.3%	7454 (3)	36	32.8%	0.0%
00	9537 (343)	0	37.8%	3.2%	8354 (0)	34	36.8%	0.0%
25	9618 (305)	0	38.2%	2.5%	9100 (6)	63	40.0%	0.1%
750	9666 (356)	1	38.4%	0.8%	10029 (5)	276	43.2%	0.0%

L3030
S/N: 179562
7/22/03

Ludlum Measurements, Inc.

Model 3030 MDA Calculation Data

7/22/03

9:42:51 AM

Alpha Background(cpm): 0.0

Beta Background(cpm): 33.0

Alpha Efficiency %: 37.6

Beta Efficiency %: 28.6

Confidence Level: 95%

Count Time	Alpha MDA(dpm)	Beta MDA(dpm)
0.1	72.1	313.9
0.5	14.4	133.4
1.0	7.2	102.9
2.0	3.6	85.7
3.0	1.4	74.3
10.0	0.7	70.3
30.0	0.1	66.8
60 (1.0)	7.2	102.9

L3030
S/N: 179562
7/22/03

JUL 16 2003 16:52 314 654 1251 MALLINCKRODT #2114 P.006

Scientific and Industrial Instruments

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 915-235-5494
501 OAK STREET FAX NO. 915-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER TYCO / MALLINCKRODT ORDER NO. 292439 / 270031

Mfg. Ludlum Measurements, Inc. Model 3030 Serial No. 179577

Cal. Date 26-Feb-03 Cal Due Date 26-Aug-03 Cal. Interval 6 Months

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 72 °F RH 20 % Alt 701.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Window Operation

☑ Audio ck.

Alpha Sensitivity 120 mV Beta Sensitivity 4 mV Beta Window 50 mV

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89.

Instrument Volt Set 725 V High Voltage set with detector connected.

☑ HV Readout (2 points) Ref./Inst. 493 / 500 V Ref./Inst. 1480 / 1500 V

(EEPROM Settings)

(PC) Count Time: 1.0

QC mode turned OFF.

Firmware version: 39013NR

Overload set at 1/4 turn past OFF.

Battery voltage measured at 13.27 Vdc.

0.14 Efficiency = 11 %(4 pi) Net

Alpha Alarm: 999999 cpm

Beta Alarm: 999999 cpm

Alpha/Beta Alarm: 999999 cpm

Calibration Due Date: 08/26/2003

LOC (Loss of Count) time = 30 minutes (default)

	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
Alpha Channel Digital Readout	400K cpm	399414	399414
	40K cpm	39944	39944
	4K cpm	3995	3995
	400 cpm	400	400
	40 cpm	40	40

	REFERENCE CAL POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
Beta/Gamma Channel Digital Readout	400K cpm	399439	399439
	40K cpm	39945	39945
	4K cpm	3995	3995
	400 cpm	400	400
	40 cpm	40	40

*Uncertainty within ± 10% C.F. within ± 20% (D) indicates 0.1 minute count

COMMENTS:
Eff. for Sr-90/Y-90 S/N 4016, 44536 cpm, read 28782 in one minute = 64% 2pi
Eff. for Th-230 S/N 2745-00, 3070 cpm, read 2444 in one minute = 80% 2pi

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978. State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources:

☑ Alpha S/N Pu-239 3744 ☑ Beta S/N Tc-99 Ni-FV ☐ Other

☑ m 500 S/N 134709 ☐ Oscilloscope S/N ☐ Multimeter S/N

Calibrated By: Conrad Galindo Date 26 Feb 03

Reviewed By: Rhonda Hami Date 4 Mar 03

This certificate shall not be reproduced except in full, without the written approval of Ludlum Measurements, Inc.
FORM C25-3 10/22/2002

AC Inst. Only: ☑ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed

L3030
S/N: 179577
2/26/03

Ludlum Measurements, Inc.

Model 3030 Plateau Data

2/25/03
1:38:50 PM

Header 1: John Q Public
Header 2: Serial#179577
Header 3: Site:Building 1
Header 4: Room 7 EastWall
Header 5: More Comments?
Header 6: More Comments?

Calibration Due Date: 2/26/04

Model 3030 Date: 2/26/03
Model 3030 Time: 11:42:00 AM

User PC Time: 1.0

Alpha Isotope: Pu-239
Alpha Source Size (dpm): 365000
Alpha Source Size (µCi): 0.164414414

Beta Isotope: Tc-99
Beta Source Size (dpm): 22600
Beta Source Size (µCi): 0.01018018

Starting High Voltage: 675
Starting High Voltage: 800
High Voltage Increment: 25

Plateau Count Mode: SCALER
Source Count Time (min): 0001.0
Background Count Time (min): 1.0

	ALPHA				BETA				
HV	Source (Beta)	Background	Eff	CrossTalk	Source (Alpha)		Background	Eff	Crosstalk
675	137685 (3889)	0	37.7%	2.8%	6010	(1)	36	26.4%	0.0%
700	137877 (3657)	0	37.8%	2.6%	6966	(1)	45	30.6%	0.0%
725	138583 (2500)	2	38.0%	1.8%	7969	(1)	49	35.0%	0.0%
750	137851 (1483)	0	37.8%	1.0%	8551	(3)	50	37.6%	0.0%
775	137047 (1071)	1	37.5%	0.7%	9470	(1)	70	41.6%	0.0%
8	137105 (783)	1	37.6%	0.4%	10082	(2)	203	43.7%	0.0%

L3030
S/N: 179577
2/26/03

Ludlum Measurements, Inc.

Model 3030 MDA Calculation Data

2/26/03
1:42:00 PM

Alpha Background(cpm): 2.0
Beta Background(cpm): 49.0

Alpha Efficiency %: 38.0
Beta Efficiency %: 35.0

Confidence Level: 95%

Count Time	Alpha MDA(dpm)	Beta MDA(dpm)
0.1	111.9	295.7
0.5	35.5	129.5
1.0	24.4	100.8
2.0	18.6	84.5
5.0	14.8	73.6
10.0	13.6	69.8
50.0	12.5	66.5
EC (1.0)	24.4	100.8

L3030
S/N: 179577
2/26/03

APPENDIX 4
Threshold Comparison Test Reports (TCTR)

MALLINCKRODT C-T DECOMMISSIONING PROJECT

Threshold Comparison Test Report - Buildings

Run Date: Thursday, February 19, 2004
Survey Unit Number: 101NESW Class: 3 Data Points: Beta Grid Type: R

SURVEY UNIT TABLE

Bldg	*Rm*	*Surface*	*Fixed Equipment*	*Surface Area Included (sq. ft)*	*Remarks*
B101	999	NSEW	Q1-17	22833	external of building
			Total Area	22833	

INITIALIZATION DATA

Measurement Types Selected: RG, BI, QA, CH
Date Range: All
Thresholds:
EMC: 13,000 DCGLw: 2,600

SURVEY UNIT TEST STATUS

Test Performed	Status			$dpm_\beta/100\ cm^2$
Min/Max	Pass	Maximum Survey Value	CB	673.0
Background	Fail	Minimum Background	M	1.0
DCGLw	Pass	Difference		672.0
DCGLavg	Pass	Average Activity	201.1	
EMC	Pass	Average Below DCGL	201.1	
Wilcoxon Rank Sum Test	N/A	Average Background	55.1	
Sign Test for Paired Data	Pass			

MALLINCKRODT C-T DECOMMISSIONING PROJECT

Threshold Comparison Test Report - Buildings

THE FOLLOWING DATA POINTS FAILED THE EMC TEST:

NONE

THE FOLLOWING DATA POINTS FAILED THE DCGLw TEST:

NONE

THE FOLLOWING DATA POINTS FAILED THE BACKGROUND TEST:

Survey Unit # 101NESW Building: B101

Room	SFC	X (ft)	Y (ft)	Mtx	Meas. Type	Min	SID	Gross Activity (dpm/100cm²)	Remarks	Exc	Res.
999	E	72.0	14.2	CB	BI	1	7362	546.1		C	
999	E	125.0	14.2	CB	BI	1	7363	430.4		C	
999	E	231.0	14.2	CB	BI	1	7365	412.3		C	
999	E	104.3	3.1	C	RG	1	7778	400.9		C	
999	E	151.5	3.1	C	RG	1	7745	365.1		C	
999	E	19.0	14.2	CB	BI	1	7361	314.6		C	
999	E	222.3	3.1	C	RG	1	7748	300.6		C	
999	E	80.6	3.1	C	RG	1	7777	297.1		C	
999	E	178.0	14.2	CB	BI	1	7364	285.7		C	
999	E	57.0	3.1	C	RG	1	7776	261.3		C	
999	E	175.1	3.1	C	RG	1	7746	125.3		C	
999	E	127.8	3.1	C	RG	1	7744	100.2		C	
999	E	198.8	3.1	C	RG	1	7747	82.3		C	
999	N	198.0	5.6	CB	BI	1	7355	466.5		C	
999	N	39.0	5.6	CB	BI	1	7352	368.9		C	
999	N	14.0	3.0	C	RG	1	7734	311.4		C	
999	N	226.6	3.0	C	RG	1	7743	307.8		C	
999	N	92.0	5.6	CB	BI	1	7353	209.8		C	
999	N	108.5	3.0	C	RG	1	7738	207.6		C	
999	N	203.0	3.0	C	RG	1	7742	196.8		C	
999	N	132.1	3.0	C	RG	1	7739	196.8		C	
999	N	61.3	3.0	C	RG	1	7736	179.0		C	
999	N	155.8	3.0	C	RG	1	7740	150.3		C	
999	N	84.8	3.0	C	RG	1	7737	143.2		C	
999	N	37.6	3.0	C	RG	1	7735	136.0		C	
999	Q1	1.0	0.0	M	BI	1	7430	147.0		C	
999	Q11	1.0	0.0	M	BI	1	7445	91.3		C	
999	Q13	1.0	0.0	CB	BI	1	7447	228.7		C	
999	Q13	3.0	0.0	CB	BI	1	7449	171.8		C	
999	Q13	2.0	0.0	CB	BI	1	7448	168.0		C	
999	Q15	1.0	0.0	M	BI	1	7453	61.1		C	
999	Q17	1.0	0.0	M	BI	1	7457	68.9		C	
999	Q2	1.0	0.0	M	BI	1	7431	191.1		C	
999	Q3	1.0	0.0	O	BI	1	7432	122.7		C	
999	Q3	4.0	0.0	O	BI	1	7435	100.8		C	
999	Q3	3.0	0.0	O	BI	1	7434	65.9		C	
999	Q3	2.0	0.0	O	BI	1	7433	49.1		C	
999	Q5	1.0	0.0	M	BI	1	7437	83.6		C	
999	Q6	1.0	0.0	M	BI	1	7438	59.6		C	
999	Q7	1.0	0.0	M	BI	1	7439	101.3		C	
999	S	14.4	3.8	CB	BI	1	7356	672.7		C	
999	S	120.4	3.8	CB	BI	1	7358	585.9		C	
999	S	173.4	3.8	CB	BI	1	7359	470.1		C	

999	S	242.3	2.4	C	RG	1	7773	454.5	C
999	S	67.4	3.8	CB	BI	1	7357	448.4	C
999	S	191.1	2.4	C	RG	1	7771	408.0	C
999	S	165.5	2.4	C	RG	1	7770	204.0	C
999	S	226.4	3.8	CB	BI	1	7360	177.2	C
999	S	37.5	2.4	C	RG	1	7765	175.4	C
999	S	216.7	2.4	C	RG	1	7772	157.5	C
999	S	139.8	2.4	C	RG	1	7769	150.3	C
999	S	11.9	2.4	C	RG	1	7764	93.1	C
999	S	88.7	2.4	C	RG	1	7767	82.3	C
999	W	12.3	6.8	CB	BI	1	7366	528.0	C
999	W	171.3	6.8	CB	BI	1	7369	502.7	C
999	W	65.3	6.8	CB	BI	1	7367	495.5	C
999	W	115.8	2.3	C	RG	1	7811	422.3	C
999	W	36.0	22.3	C	RG	1	7795	422.3	C
999	W	118.3	6.8	CB	BI	1	7368	405.0	C
999	W	16.0	22.3	C	RG	1	7794	400.9	C
999	W	16.0	2.3	C	RG	1	7806	383.0	C
999	W	155.8	22.3	C	RG	1	7801	357.9	C
999	W	56.0	2.3	C	RG	1	7808	332.9	C
999	W	135.8	22.3	C	RG	1	7800	332.9	C
999	W	95.9	22.3	C	RG	1	7798	289.9	C
999	W	75.9	22.3	C	RG	1	7797	279.2	C
999	W	235.7	2.3	C	RG	1	7817	272.0	C
999	W	155.8	2.3	C	RG	1	7813	261.3	C
999	W	215.7	22.3	C	RG	1	7804	254.1	C
999	W	175.8	22.3	C	RG	1	7802	229.1	C
999	W	115.8	22.3	C	RG	1	7799	189.7	C
999	W	36.0	2.3	C	RG	1	7807	179.0	C
999	W	95.9	2.3	C	RG	1	7810	143.2	C
999	W	135.8	2.3	C	RG	1	7812	128.8	C
999	W	235.7	22.3	C	RG	1	7805	125.3	C
999	W	195.8	2.3	C	RG	1	7815	118.1	C

THE FOLLOWING DATA POINTS PASSED BACKGROUND, DCGLw, AND EMC SCREENING TESTS:

Survey Unit # 101NESW Building: B101

Room	SFC	X (ft)	Y (ft)	Mtx	Meas. Type	Min	SID	Gross Activity (dpm/100cm²)	Remarks	Exc	Res.
999	E	33.3	3.1	C	RG	1	7775	10.7	Concrete		
999	E	9.8	3.1	M	RG	1	7774	-11.0	Metal		
999	N	179.3	3.0	C	RG	1	7741	46.5			
999	N	145.0	5.6	M	BI	1	7354	-23.8			
999	Q10	2.0	0.0	M	BI	1	7444	7.0			
999	Q10	1.0	0.0	M	BI	1	7443	6.2			
999	Q12	1.0	0.0	M	BI	1	7446	3.1			
999	Q13	4.0	0.0	CB	BI	1	7450	135.7			
999	Q13	5.0	0.0	CB	BI	1	7451	121.4			
999	Q14	1.0	0.0	M	BI	1	7452	12.4			
999	Q16	2.0	0.0	M	BI	1	7455	28.6			
999	Q16	1.0	0.0	M	BI	1	7454	24.8			
999	Q16	3.0	0.0	M	BI	1	7456	23.2			
999	Q4	1.0	0.0	M	BI	1	7436	26.3			
999	Q8	1.0	0.0	M	BI	1	7440	-5.4			
999	Q9	2.0	0.0	M	BI	1	7442	41.0			
999	Q9	1.0	0.0	M	BI	1	7441	17.8			
999	S	63.1	2.4	C	RG	1	7766	64.4			
999	S	114.3	2.4	C	RG	1	7768	46.5			
999	W	175.8	2.3	C	RG	1	7814	71.6			
999	W	75.9	2.3	C	RG	1	7809	71.6			
999	W	195.8	22.3	C	RG	1	7803	32.2			
999	W	56.0	22.3	C	RG	1	7796	28.6			
999	W	224.3	6.8	M	BI	1	7370	-41.1			
999	W	215.7	2.3	M	RG	1	7816	-65.8			

MALLINCKRODT C-T DECOMMISSIONING PROJECT

Threshold Comparison Test Report - Buildings

Summary of Background Data and Thresholds Used in this Analysis

Measurement Type: BK *DCGL:* 2,600 *EMC:* 13,000

EMC	Matrix	Number of Data Points	Average Background	Sigma Threshold (Tbk)	Background Threshold (Td)	DCGLw Threshold (Tc)
			($dpm_p/100cm^2$)	($dpm_p/100cm^2$)	($dpm_p/100cm^2$)	($dpm_p/100cm^2$)
C	90	35.4	20.1	75.5	2,675	13,075
CB	51	96.1	21.7	139.4	2,739	13,139
M	10	24.0	15.7	55.3	2,655	13,055
O	0	0.0	0.0	0.0	2,600	13,000

MALLINCKRODT C-T DECOMMISSIONING PROJECT

Threshold Comparison Test Report - Buildings

STATISTICAL TEST RESULTS

Run Date: 2/19/2004 3:14:32 PM
Survey Unit Number: 101NESW Class: 3
Selected Test: SIGN TEST FOR PAIRED DATA
Test Status: Pass
Thresholds:

EMC 13,000 DCGL 2,600

DATA SUMMARY TABLE

54 Survey points processed and 2 matrices processed

S+ = 54 Wc = 33

******** The survey unit has passed the SIGN TEST FOR PAIRED DATA ********

APPENDIX 5
Gamma Readings on Building 101 Roof

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_p/100\ cm^2$)	SampleID	SurveyDate
999R1	RG	3.17	16.83	6,925	4,229	1	2,696	3,595	7020	08-Sep-03
999R1	RG	101.00	16.83	6,213	4,229	1	1,984	2,645	7025	08-Sep-03
999R1	BI	233.83	39.08	6,948	3,937	1	3,011	4,015	7409	05-Jun-03
999R1	BI	180.83	39.08	9,058	3,937	1	5,121	6,828	7408	05-Jun-03
999R1	BI	127.83	39.08	8,074	3,937	1	4,137	5,516	7407	05-Jun-03
999R1	BI	74.83	39.08	7,937	3,937	1	4,000	5,333	7406	05-Jun-03
999R1	BI	21.83	39.08	6,742	3,937	1	2,805	3,740	7405	05-Jun-03
999R1	RG	81.42	16.83	5,986	4,229	1	1,757	2,343	7024	08-Sep-03
999R1	RG	61.83	16.83	5,998	4,229	1	1,769	2,359	7023	08-Sep-03
999R1	RG	22.75	16.83	6,546	4,229	1	2,317	3,089	7021	08-Sep-03
999R1	RG	237.92	36.42	5,916	4,229	1	1,687	2,249	7019	08-Sep-03
999R1	RG	218.33	36.42	4,806	4,229	1	577	769	7018	08-Sep-03
999R1	RG	198.75	36.42	5,832	4,229	1	1,603	2,137	7017	08-Sep-03
999R1	RG	179.25	36.42	6,732	4,229	1	2,503	3,337	7016	08-Sep-03
999R1	RG	159.67	36.42	6,525	4,229	1	2,296	3,061	7015	08-Sep-03
999R1	RG	179.25	16.83	6,715	4,229	1	2,486	3,315	7029	08-Sep-03
999R1	RG	120.50	16.83	6,005	4,229	1	1,776	2,368	7026	08-Sep-03
999R1	RG	42.25	16.83	5,949	4,229	1	1,720	2,293	7022	08-Sep-03
999R1	RG	159.67	16.83	6,808	4,229	1	2,579	3,439	7028	08-Sep-03
999R1	RG	140.08	36.42	6,372	4,229	1	2,143	2,857	7014	08-Sep-03
999R1	RG	198.75	16.83	6,607	4,229	1	2,378	3,171	7030	08-Sep-03
999R1	RG	218.33	16.83	5,633	4,229	1	1,404	1,872	7031	08-Sep-03
999R1	RG	237.92	16.83	6,599	4,229	1	2,370	3,160	7032	08-Sep-03
999R1	RG	3.17	36.42	6,775	4,229	1	2,546	3,395	6997	08-Sep-03
999R1	RG	22.75	36.42	5,322	4,229	1	1,093	1,457	7001	08-Sep-03
999R1	RG	42.25	36.42	4,256	4,229	1	27	36	7009	08-Sep-03
999R1	RG	61.83	36.42	4,016	4,229	1	(213)	(284)	7010	08-Sep-03
999R1	RG	81.42	36.42	4,564	4,229	1	335	447	7011	08-Sep-03
999R1	RG	101.00	36.42	6,618	4,229	1	2,389	3,185	7012	08-Sep-03
999R1	RG	120.50	36.42	6,213	4,229	1	1,984	2,645	7013	08-Sep-03
999R1	RG	140.08	16.83	6,579	4,229	1	2,350	3,133	7027	08-Sep-03

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_\beta/100\ cm^2$)	SampleID	SurveyDate
999R2	RG	221.58	45.25	5,427	4,229	1	1,198	1,597	7057	08-Sep-03
999R2	RG	45.67	45.25	4,029	4,229	1	(200)	(267)	7048	08-Sep-03
999R2	RG	65.25	45.25	3,902	4,229	1	(327)	(436)	7049	08-Sep-03
999R2	RG	84.75	45.25	4,708	4,229	1	479	639	7050	08-Sep-03
999R2	RG	104.33	45.25	5,238	4,229	1	1,009	1,345	7051	08-Sep-03
999R2	RG	123.83	45.25	5,522	4,229	1	1,293	1,724	7052	08-Sep-03
999R2	RG	143.42	45.25	5,390	4,229	1	1,161	1,548	7053	08-Sep-03
999R2	RG	162.92	45.25	6,369	4,229	1	2,140	2,853	7054	08-Sep-03
999R2	RG	202.00	45.25	5,104	4,229	1	875	1,167	7056	08-Sep-03
999R2	RG	6.58	45.25	5,926	4,229	1	1,697	2,263	7046	08-Sep-03
999R2	RG	241.08	45.25	6,659	4,229	1	2,430	3,240	7058	08-Sep-03
999R2	RG	241.08	64.75	6,427	4,229	1	2,198	2,931	7045	08-Sep-03
999R2	RG	182.50	45.25	6,088	4,229	1	1,859	2,479	7055	08-Sep-03
999R2	RG	84.75	64.75	3,506	4,229	1	(723)	(964)	7037	08-Sep-03
999R2	RG	26.17	45.25	5,196	4,229	1	967	1,289	7047	08-Sep-03
999R2	RG	26.17	64.75	6,077	4,229	1	1,848	2,464	7034	08-Sep-03
999R2	RG	65.25	64.75	3,784	4,229	1	(445)	(593)	7036	08-Sep-03
999R2	RG	104.33	64.75	3,077	4,229	1	(1,152)	(1,536)	7038	08-Sep-03
999R2	RG	123.83	64.75	2,499	4,229	1	(1,730)	(2,307)	7039	08-Sep-03
999R2	RG	143.42	64.75	4,158	4,229	1	(71)	(95)	7040	08-Sep-03
999R2	RG	162.92	64.75	4,865	4,229	1	636	848	7041	08-Sep-03
999R2	RG	182.50	64.75	4,241	4,229	1	12	16	7042	08-Sep-03
999R2	RG	202.00	64.75	4,237	4,229	1	8	11	7043	08-Sep-03
999R2	RG	221.58	64.75	5,196	4,229	1	967	1,289	7044	08-Sep-03
999R2	RG	6.58	64.75	6,528	4,229	1	2,299	3,065	7033	08-Sep-03
999R2	RG	45.67	64.75	3,902	4,229	1	(327)	(436)	7035	08-Sep-03

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_\beta/100\ cm^2$)	SampleID	SurveyDate
999R3	BI	127.83	92.08	5,885	3,937	1	1,948	2,597	7402	05-Jun-03
999R3	RG	160.67	90.92	3,979	3,999	1	(20)	(27)	7080	09-Sep-03
999R3	RG	63.00	90.92	3,241	3,999	1	(758)	(1,011)	7075	09-Sep-03
999R3	RG	82.50	90.92	3,106	3,999	1	(893)	(1,191)	7076	09-Sep-03
999R3	RG	102.00	90.92	2,977	3,999	1	(1,022)	(1,363)	7077	09-Sep-03
999R3	RG	121.58	90.92	2,519	3,999	1	(1,480)	(1,973)	7078	09-Sep-03
999R3	RG	141.08	90.92	3,949	3,999	1	(50)	(67)	7079	09-Sep-03
999R3	RG	180.17	90.92	3,935	3,999	1	(64)	(85)	7081	09-Sep-03
999R3	RG	199.75	90.92	4,324	3,999	1	325	433	7082	09-Sep-03
999R3	RG	213.25	90.92	4,591	3,999	1	592	789	7083	09-Sep-03
999R3	RG	238.83	90.92	5,130	3,999	1	1,131	1,508	7084	09-Sep-03
999R3	RG	43.42	90.92	4,182	3,999	1	183	244	7074	09-Sep-03
999R3	BI	74.83	92.08	5,323	3,937	1	1,386	1,848	7401	05-Jun-03
999R3	RG	160.67	110.42	3,977	4,229	1	(252)	(336)	7067	08-Sep-03
999R3	BI	21.83	92.08	9,589	3,937	1	5,652	7,536	7400	05-Jun-03
999R3	RG	121.58	110.42	2,675	4,229	1	(1,554)	(2,072)	7065	08-Sep-03
999R3	BI	180.83	92.08	5,938	3,937	1	2,001	2,668	7403	05-Jun-03
999R3	RG	4.33	110.42	7,017	4,229	1	2,788	3,717	7059	08-Sep-03
999R3	RG	23.92	110.42	6,052	4,229	1	1,823	2,431	7060	08-Sep-03
999R3	RG	43.42	110.42	3,598	4,229	1	(631)	(841)	7061	08-Sep-03
999R3	RG	63.00	110.42	3,197	4,229	1	(1,032)	(1,376)	7062	08-Sep-03
999R3	RG	199.75	110.42	3,964	4,229	1	(265)	(353)	7069	08-Sep-03
999R3	RG	102.00	110.42	2,997	4,229	1	(1,232)	(1,643)	7064	08-Sep-03
999R3	RG	23.92	90.92	5,459	3,999	1	1,460	1,947	7073	09-Sep-03
999R3	RG	141.08	110.42	3,882	4,229	1	(347)	(463)	7066	08-Sep-03
999R3	BI	233.83	92.08	5,429	3,937	1	1,492	1,989	7404	05-Jun-03
999R3	RG	180.17	110.42	4,130	4,229	1	(99)	(132)	7068	08-Sep-03
999R3	RG	219.25	110.42	3,871	4,229	1	(358)	(477)	7070	08-Sep-03
999R3	RG	238.83	110.42	5,280	4,229	1	1,051	1,401	7071	08-Sep-03
999R3	RG	4.33	90.92	6,954	4,229	1	2,725	3,633	7072	08-Sep-03
999R3	RG	82.50	110.42	3,597	4,229	1	(632)	(843)	7063	08-Sep-03

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_\beta/100\ cm^2$)	SampleID	SurveyDate
999R4	RG	180.75	132.58	4,147	3,999	1	148	197	7107	09-Sep-03
999R4	RG	4.92	152.17	5,689	3,999	1	1,690	2,253	7085	09-Sep-03
999R4	BI	233.83	145.08	6,750	3,937	1	2,813	3,751	7399	05-Jun-03
999R4	BI	180.83	145.08	5,395	3,937	1	1,458	1,944	7398	05-Jun-03
999R4	BI	127.83	145.08	4,401	3,937	1	464	619	7397	05-Jun-03
999R4	BI	74.83	145.08	4,858	3,937	1	921	1,228	7396	05-Jun-03
999R4	BI	21.83	145.08	6,601	3,937	1	2,664	3,552	7395	05-Jun-03
999R4	RG	239.42	132.58	5,253	3,999	1	1,254	1,672	7110	09-Sep-03
999R4	RG	200.33	132.58	3,665	3,999	1	(334)	(445)	7108	09-Sep-03
999R4	RG	161.25	132.58	4,315	3,999	1	316	421	7106	09-Sep-03
999R4	RG	141.75	132.58	4,306	3,999	1	307	409	7105	09-Sep-03
999R4	RG	122.17	132.58	3,192	3,999	1	(807)	(1,076)	7104	09-Sep-03
999R4	RG	102.67	132.58	3,003	3,999	1	(996)	(1,328)	7103	09-Sep-03
999R4	RG	83.08	132.58	3,150	3,999	1	(849)	(1,132)	7102	09-Sep-03
999R4	RG	63.58	132.58	2,871	3,999	1	(1,128)	(1,504)	7101	09-Sep-03
999R4	RG	141.75	152.17	4,319	3,999	1	320	427	7092	09-Sep-03
999R4	RG	219.83	132.58	4,338	3,999	1	339	452	7109	09-Sep-03
999R4	RG	44.00	132.58	4,379	3,999	1	380	507	7100	09-Sep-03
999R4	RG	63.58	152.17	3,041	3,999	1	(958)	(1,277)	7088	09-Sep-03
999R4	RG	83.08	152.17	3,539	3,999	1	(460)	(613)	7089	09-Sep-03
999R4	RG	122.17	152.17	3,931	3,999	1	(68)	(91)	7091	09-Sep-03
999R4	RG	44.00	152.17	3,769	3,999	1	(230)	(307)	7087	09-Sep-03
999R4	RG	161.25	152.17	4,613	3,999	1	614	819	7093	09-Sep-03
999R4	RG	24.50	152.17	4,992	3,999	1	993	1,324	7086	09-Sep-03
999R4	RG	180.75	152.17	4,001	3,999	1	2	3	7094	09-Sep-03
999R4	RG	200.33	152.17	3,625	3,999	1	(374)	(499)	7095	09-Sep-03
999R4	RG	219.83	152.17	4,421	3,999	1	422	563	7096	09-Sep-03
999R4	RG	239.42	152.17	5,558	3,999	1	1,559	2,079	7097	09-Sep-03
999R4	RG	4.92	132.58	5,812	3,999	1	1,813	2,417	7098	09-Sep-03
999R4	RG	24.50	132.58	7,107	3,999	1	3,108	4,144	7099	09-Sep-03
999R4	RG	102.67	152.17	2,780	3,999	1	(1,219)	(1,625)	7090	09-Sep-03

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_\beta/100\ cm^2$)	SampleID	SurveyDate
999R5	RG	83.25	175.08	3,631	4,175	1	(544)	(725)	7128	10-Sep-03
999R5	RG	200.42	175.08	3,967	4,175	1	(208)	(277)	7134	10-Sep-03
999R5	RG	102.75	175.08	2,568	4,175	1	(1,607)	(2,143)	7129	10-Sep-03
999R5	RG	122.25	175.08	2,208	4,175	1	(1,967)	(2,623)	7130	10-Sep-03
999R5	RG	141.83	175.08	3,485	4,175	1	(690)	(920)	7131	10-Sep-03
999R5	RG	161.33	175.08	3,951	4,175	1	(224)	(299)	7132	10-Sep-03
999R5	RG	180.92	175.08	3,358	4,175	1	(817)	(1,089)	7133	10-Sep-03
999R5	RG	220.00	175.08	4,559	4,175	1	384	512	7135	10-Sep-03
999R5	RG	239.50	175.08	5,534	4,175	1	1,359	1,812	7136	10-Sep-03
999R5	BI	21.83	198.08	6,361	3,937	1	2,424	3,232	7390	05-Jun-03
999R5	BI	74.83	198.08	4,754	3,937	1	817	1,089	7391	05-Jun-03
999R5	BI	127.83	198.08	3,858	3,937	1	(79)	(105)	7392	05-Jun-03
999R5	BI	233.83	198.08	6,742	3,937	1	2,805	3,740	7394	05-Jun-03
999R5	RG	63.67	175.08	2,705	4,175	1	(1,470)	(1,960)	7127	10-Sep-03
999R5	RG	239.50	194.67	5,508	3,999	1	1,509	2,012	7123	09-Sep-03
999R5	BI	180.83	198.08	6,353	3,937	1	2,416	3,221	7393	05-Jun-03
999R5	RG	24.58	194.67	5,231	3,999	1	1,232	1,643	7112	09-Sep-03
999R5	RG	24.58	175.08	3,814	4,175	1	(361)	(481)	7125	10-Sep-03
999R5	RG	44.17	175.08	2,559	4,175	1	(1,616)	(2,155)	7126	10-Sep-03
999R5	RG	5.08	194.67	6,034	3,999	1	2,035	2,713	7111	09-Sep-03
999R5	RG	44.17	194.67	3,675	3,999	1	(324)	(432)	7113	09-Sep-03
999R5	RG	63.67	194.67	3,024	3,999	1	(975)	(1,300)	7114	09-Sep-03
999R5	RG	83.25	194.67	3,838	3,999	1	(161)	(215)	7115	09-Sep-03
999R5	RG	102.75	194.67	2,901	3,999	1	(1,098)	(1,464)	7116	09-Sep-03
999R5	RG	141.83	194.67	3,355	3,999	1	(644)	(859)	7118	09-Sep-03
999R5	RG	161.33	194.67	3,306	3,999	1	(693)	(924)	7119	09-Sep-03
999R5	RG	180.92	194.67	2,969	3,999	1	(1,030)	(1,373)	7120	09-Sep-03
999R5	RG	200.42	194.67	4,417	3,999	1	418	557	7121	09-Sep-03
999R5	RG	220.00	194.67	4,859	3,999	1	860	1,147	7122	09-Sep-03
999R5	RG	122.25	194.67	2,352	3,999	1	(1,647)	(2,196)	7117	09-Sep-03
999R5	RG	5.08	175.08	5,828	3,999	1	1,829	2,439	7124	09-Sep-03

Room	Type	Xcoord (ft)	Ycoord (ft)	Survey_Gamma (counts)	Ambient (counts)	t (min.)	Net_Gamma (cpm)	Net_Gamma ($dpm_p/100\ cm^2$)	SampleID	SurveyDate
999R6	RG	160.00	214.92	4,271	3,937	1	334	445	7158	12-Sep-03
999R6	RG	28.83	214.92	6,448	3,937	1	2,511	3,348	7151	12-Sep-03
999R6	RG	47.58	214.92	3,811	3,937	1	(126)	(168)	7152	12-Sep-03
999R6	RG	66.33	214.92	3,375	3,937	1	(562)	(749)	7153	12-Sep-03
999R6	RG	85.00	214.92	4,232	3,937	1	295	393	7154	12-Sep-03
999R6	RG	103.75	214.92	3,635	3,937	1	(302)	(403)	7155	12-Sep-03
999R6	RG	122.50	214.92	3,460	3,937	1	(477)	(636)	7156	12-Sep-03
999R6	RG	197.42	214.92	5,067	3,937	1	1,130	1,507	7160	12-Sep-03
999R6	RG	141.25	214.92	4,454	3,937	1	517	689	7157	12-Sep-03
999R6	RG	178.75	214.92	4,645	3,937	1	708	944	7159	12-Sep-03
999R6	RG	10.08	214.92	6,436	3,937	1	2,499	3,332	7150	12-Sep-03
999R6	RG	85.00	233.70	4,783	3,937	1	846	1,128	7141	12-Sep-03
999R6	RG	216.17	214.92	5,212	3,937	1	1,275	1,700	7161	12-Sep-03
999R6	RG	234.92	233.67	5,207	3,937	1	1,270	1,693	7149	12-Sep-03
999R6	RG	216.17	233.67	5,065	3,937	1	1,128	1,504	7148	12-Sep-03
999R6	RG	197.42	233.67	4,626	3,937	1	689	919	7147	12-Sep-03
999R6	RG	178.75	233.67	5,047	3,937	1	1,110	1,480	7146	12-Sep-03
999R6	RG	160.00	233.67	4,728	3,937	1	791	1,055	7145	12-Sep-03
999R6	RG	141.25	233.67	5,534	3,937	1	1,597	2,129	7144	12-Sep-03
999R6	RG	103.75	233.67	5,054	3,937	1	1,117	1,489	7142	12-Sep-03
999R6	RG	66.33	233.67	4,715	3,937	1	778	1,037	7140	12-Sep-03
999R6	RG	47.58	233.67	4,755	3,937	1	818	1,091	7139	12-Sep-03
999R6	RG	28.83	233.67	5,717	3,937	1	1,780	2,373	7138	12-Sep-03
999R6	RG	10.08	233.67	6,667	3,937	1	2,730	3,640	7137	12-Sep-03
999R6	RG	234.92	214.92	5,919	3,937	1	1,982	2,643	7162	12-Sep-03
999R6	RG	122.50	233.67	5,271	3,937	1	1,334	1,779	7143	12-Sep-03

APPENDIX 6

Technical Memorandum 02-29:

MCNP Gamma Modeling of Mallinckrodt Roof Surfaces

NEXTEP Environmental

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TECHNICAL MEMORANDUM 02-29

November 17, 2002

Originator: Ning Zhang, HP Analyst, and Drew Thatcher, Senior HP Scientist

Subject: MCNP Gamma Modeling of Mallinckrodt Roof Surfaces

Revision: 0

ENDORSEMENT: This document contains the results of research and technical analysis which have been reviewed and approved for publication by the Technical Director, NEXTEP Environmental, Inc.

Signature on file at NEXTEP Environmental, Louisville, Ky.

Harry J. Newman, CHP, Technical Director Date

Introduction:

Final Status Surveys for the Mallinckrodt CT project will include several building roofs on-site. Regular survey methods (i.e. beta surveys) are not possible on certain roofs due to the fact that the original contaminated surfaces have been covered over. To overcome this limitation, MCNP models that simulate the geometry on these roofs were constructed to estimate several parameters used in the final status survey (FSS) reports.

Accordingly, the objectives of this tech memo are to:

1) Describe the roof configurations and specify the MCNP models for these configurations (Section 1);

2) Determine the effective detection area for a shielded 3"x 3" NaI detector (Section 2);

3) Estimate the degree of attenuation when the contaminated layer is covered by additional roof material layer(s) (Section 3);

4) Calculate the conversion factor for the shielded 3"x 3" NaI detector in terms of cpm/dpm/100cm^2 (Section 4);

5) Simulate the background counting rate for the 3"x 3" NaI detector (cpm) (Section 5 and Appendix B); and,

6) Validate and benchmark the MCNP models (Appendix A and Appendix D).

Section 1. Model Specifications:

Based on historical information at Mallinckrodt, certain roofs have been renovated following CT operations. During renovation, the original contaminated roof surfaces were covered by new roofing material. The model for such roofs was developed using the following assumptions:

1. There is a base of six-inch thick concrete covered with a ½" (1.27cm) layer of asphalt binder. (Baseline)

2. The contamination is embedded in a ½ cm thick asphalt binder layer above the baseline.

The contaminated layer then was covered by:

Configuration 1: A ½ inch thick layer of asphalt binder which is in turn covered by a one-inch thick layer of gravel.

Configuration 2: A ½ inch thick layer of asphalt binder material.

In all the following sections except in section 4, background activity densities will be assigned homogeneously throughout the various roof layers. The assumed background activity densities are listed in Table 1[1].

Table 1

Background Activity Densities

Nuclide	Activity density (pCi/g) For Gravel and Concrete layer	Activity density (pCi/g) For Asphalt Layer*
U-238	0.675	0.225
Th-232	0.216	0.072
Ra-226	0.6	0.2
K-40	1.89	0.63

* Because the asphalt consists only of C and H, the background levels for asphalt are much lower than that of gravel and concrete. One third (1/3) of the value for gravel and concrete was adopted for the asphalt layer.

[1] Based on NCRP Report No.94, Exposure of the Population in the United States and Canada From Natural Background Radiation. page 61, using carbonate rocks. The Ra-226 value was assigned using professional judgement.

According to the Mallinckrodt D-plan, natural Uranium and the natural Thorium are in radio-equilibrium throughout each decay chain. The ratio of Natural U to Natural Th in the mixture is 2:1. The contaminated layer is assumed to be contaminated at 26 dpm/cm^2.[2]

A 3"x3" NaI detector with ½" lead shielding will be used for scan surveys and direct measurements in the final status survey. The detector will be placed either 5.08 cm (2 inches) above the surface of the roof to simulate the scan survey cases or placed directly on the surface of the roof to simulate the direct measurement case. Figure 1 shows geometry configurations.

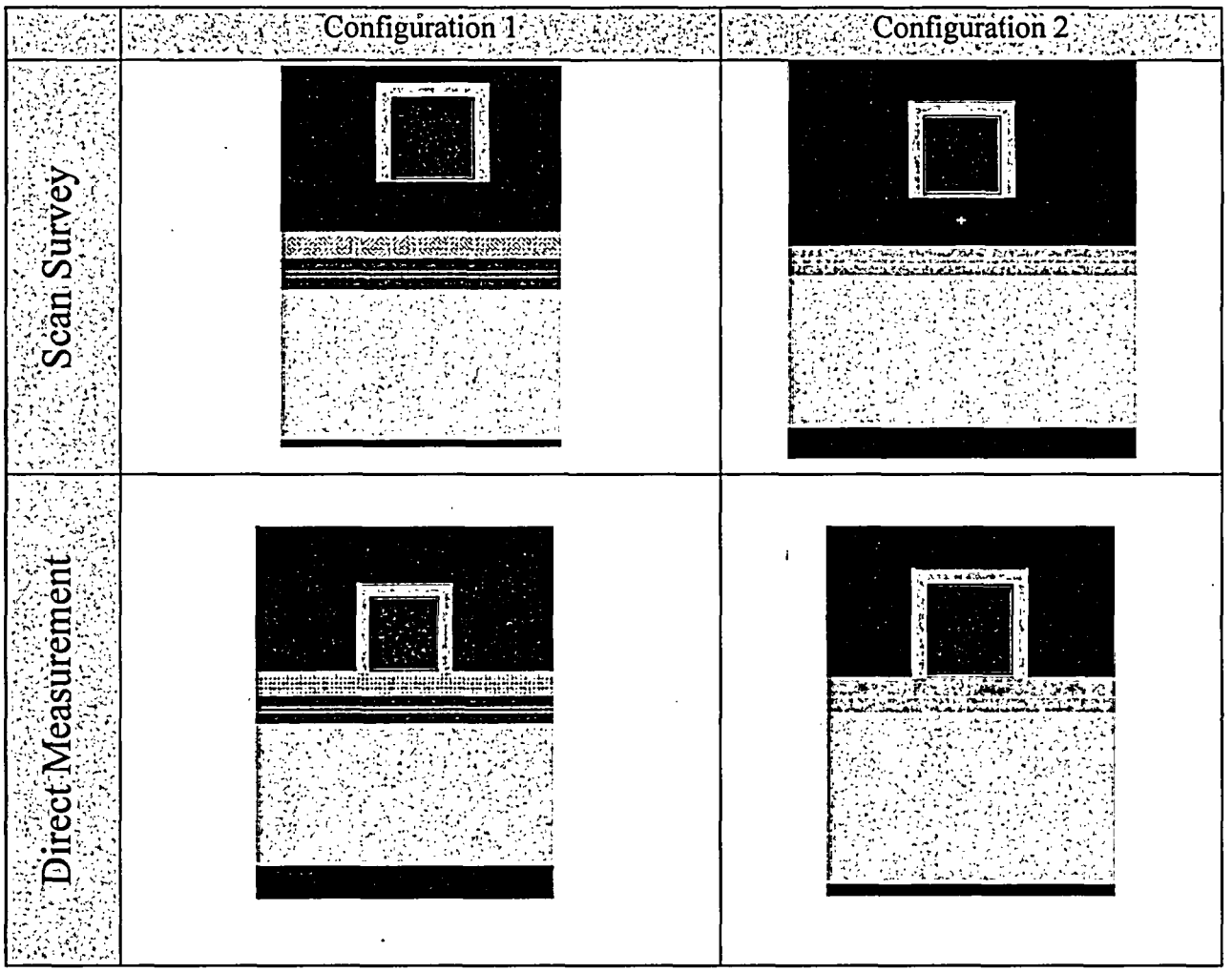

Figure 1

MCNP Model Geometries

In Figure 1, roofs with the same structure were placed in the same column and titled by "Configuration" number. For example, in Configuration 1, the roof is constructed of 5 layers,

[2] 26 dpm$_p$/cm^2 is equivalent to the Administration Release Guideline (ARG) per TM 02-11.

(gravel, clean asphalt, contaminated asphalt, clean asphalt, and concrete) from top to bottom. In Configuration 2, the roof is constructed of 4 layers (clean asphalt, contaminated asphalt, clean asphalt, and concrete), from top to bottom.

In Figure 1, the same row contains same detector-field position. Because the detector-field position determined by the survey method adopted, the rows were titled by the survey method. For example, the scan survey requires the detector be placed 2" above the roof surface and the direct measurement survey requires the detector be placed directly on the roof surface.

Section 2. Effective Detection Area

The effective detection area is the roof surface area that can be effectively measured by the NaI detector under the assumed geometry.

To find the effective detection area, the MCNP models were constructed as follows for either scan survey model or direct measurement model:

Set the roof structure to configuration 1 with a square surface shape. The detector was placed 2" above the center of the square roof surface (for scan surveys) or placed on the roof surface at the center of this square roof surface (for direct measurement). The background activity densities listed in Table 1 were uniformly assigned within the roof structure. Then, the model was run using different surface areas of roof structure. An increase in counting rate (cpm) was observed as the square roof surface in the model was increased, showing the effects of the increased radioactivity upon the detector. When the area of the roof structure becomes large enough, the counting rate of detector will not continuously increase and will be constant. The effective detection area is then determined as the surface area of roof structure at which the count rate is at least 90% of that constant.

Table 2 lists the results of running the model for the scan survey case. Figure 2 is the plot according to Table 2. From Table 2 and Figure 2, the effective detectable area for a 3"x 3" NaI detector with ½" lead shielding at 2" above the gravel roof surface is 10,000 cm^2, that is, 1 m^2.

Table 2
Effective Detection Area for the Scan Survey Case

Length(cm)/Area(cm^2)	MCNP Efficiency	Total Number of Gamma per Minute	CPM	% of CPM to CPM from 160,000 cm^2
30/900	0.004213	615,858	2,594	51.6
100/10,000	0.000671	6,842,864*	4,591	91.4
200/40,000	0.000181	27,371,455	4,954	98.6
400/160,000	0.0000459	109,485,821	5,025	100

* The example calculation for the total number of gammas/min in this cell will be displayed in Appendix B.

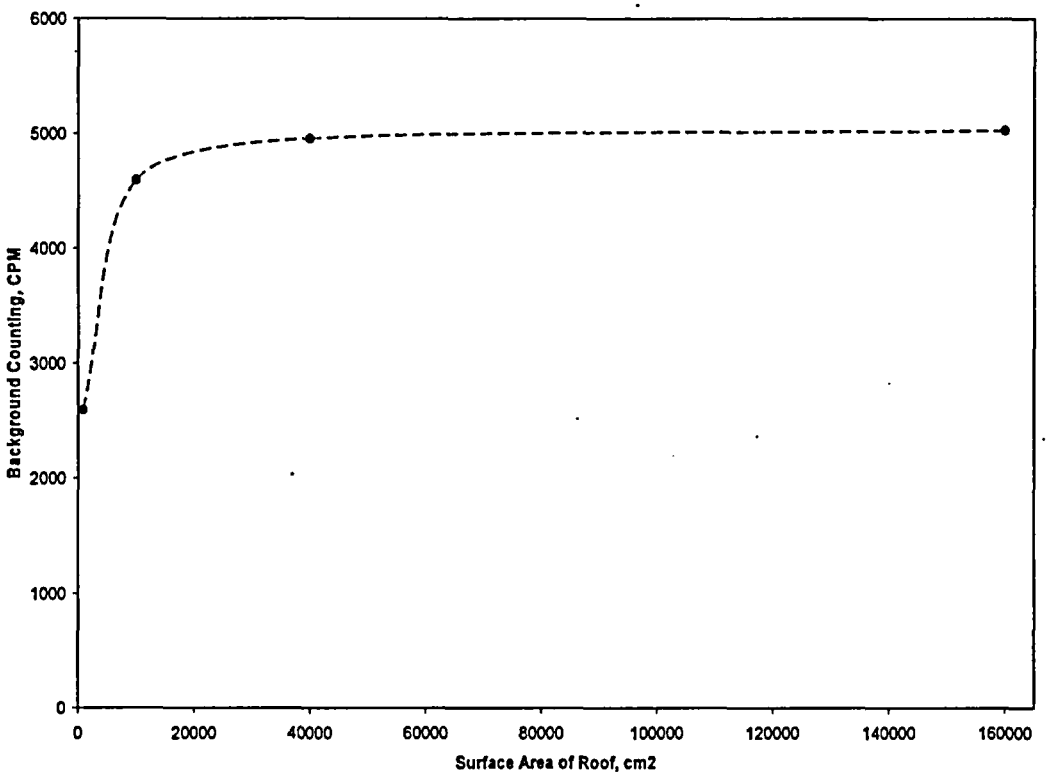

Figure 2

Counting Rate (CPM) vs. Surface Area of Roof Structure for the Scan Survey Case

Table 3 lists the modeling results for the direct survey case. Figure 3 is the plot according to Table 3. From Table 3 and Figure 3, the effective detectable area for a ½" lead shielded 3"x 3" NaI detector on the roof surface is 2,500 cm^2, that is, 0.25 m^2.

Table 3

Effective Detection Area for the Direct Measurement Case

Length(cm)/Area(cm^2)	MCNP Efficiency	Total Number of Gamma/MIN	CPM	% of CPM to CPM from 160,000 cm^2
10.77/116	0.018218	73,550	1,339	26.6
30/900	0.006686	570,682	3,815	75.7
50/2,500	0.002882	1,585,228	4,568	90.6
80/6,400	0.001203	4,058,183	4,882	96.8
90/8,100	0.000961	5,136,138	4,935	97.9
100/10,000	0.000789	6,340,911	5,002	99.2
400/160,000	0.0000497	101,454,571	5,042	100

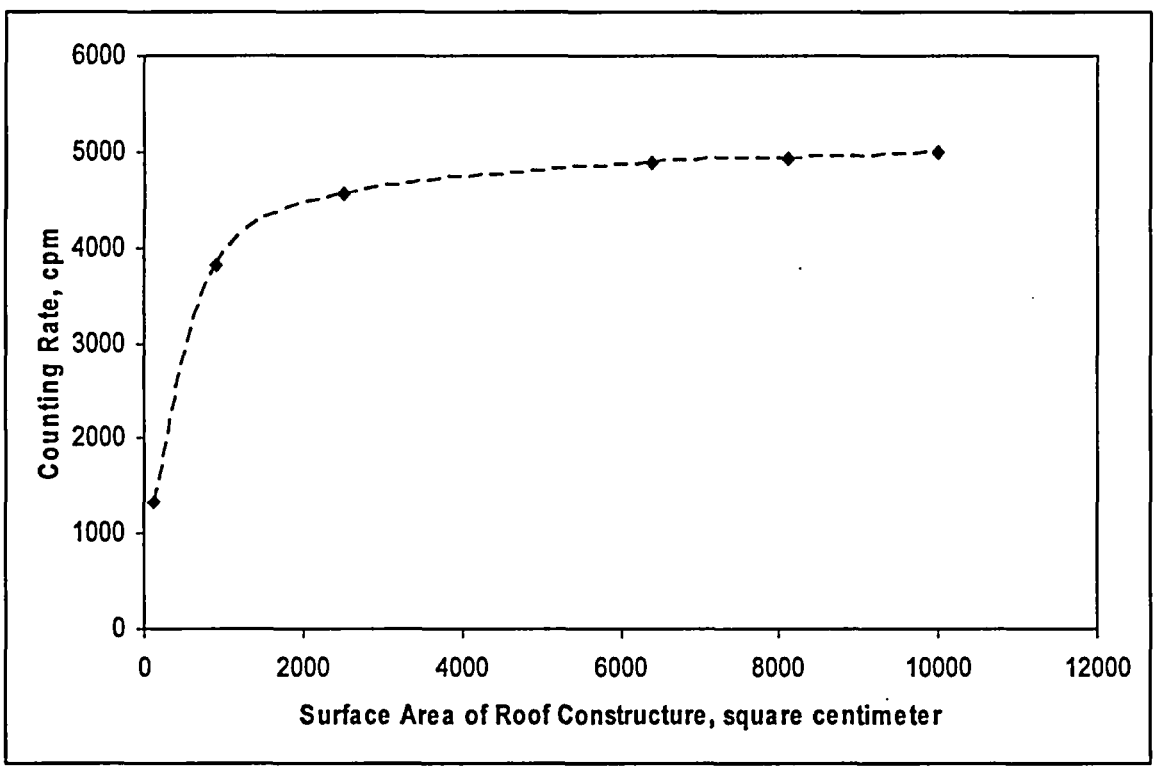

Figure 3

Count Rate (CPM) vs. Surface Area of Roof Structure for the Direct Measurement Case

Section 3. Attenuation

The attenuation factor is defined as follows:

$$Attenuation\ Factor = 1 - \frac{Counting\ Rate\ with\ \ certain\ \text{coverage}}{Counting\ Rate\ Without\ \ Coverage}$$

$$= 1 - \frac{MCNP\ Efficiency\ with\ certain\ \text{coverage} \times Total\ Number\ of\ photons\ per\ unit\ Time}{MCNP\ Efficiency\ Without\ Coverage \times Total\ Number\ of\ photons\ per\ unit\ Time}$$

$$= 1 - \frac{MCNP\ Efficiency\ \ with\ certain\ \text{coverage}}{MCNP\ Efficiency\ Without\ \ Coverage} \qquad (1)$$

To obtain the attenuation factor, the background activity densities were assigned only to the contaminated layer. The model for the contaminated layer without any attenuating coverings was run, followed by the models for the two configurations. The attenuation factor was calculated according to formula (1) from these results.

The results and calculated attenuation factor for each case are presented in the Table 4.

Table 4
Calculated Attenuation Factor

Roof Configuration	MCNP Efficiency	Attenuation factor
Scan, Coverage of Configuration 1	0.00271	0.33
Scan, Coverage of Configuration 2	0.003874	0.05
Scan, no Coverage	0.004073	
Direct, Coverage of Configuration 1	0.002879	0.49
Direct, Coverage of Configuration 1	0.004569	0.19
Direct, no Coverage	0.005642	

Section 4. Conversion Factor in cpm/dpm/100cm^2

The conversion factor in cpm/dpm/100cm^2 for a ½" lead shielded 3" x 3" NaI detector for two roof configurations was calculated as follows. The ARG limit criteria activity (section 1) was uniformly distributed within the contaminated layer. The counting rate for the detector from simulation was then obtained using MCNP. Since the activity density in the contaminated layer was known to be 2,600 dpm/100 cm^2, the conversion factor could be calculated by dividing the simulated CPM by 2,600 dpm/100cm^2. The final calculation results are listed in Table 5.

Table 5

Calculated Conversion Factor (cpm/dpm/100cm^2)

Roof Type		MCNP Eff	Total No. of Gamma within 10,000cm^2 x 0.5cm asphalt layer (for activity density is 2,600dpm/cm^2, U:Th=2:1)*	CPM for Detector	Density Activity (dpm/100cm^2)	cpm/dpm/100cm^2
Scan	Configuration 1	0.00163	710,961	1156	2,600	0.44
	Configuration 2	0.00232	710,961	1652	2,600	0.64
Direct	Configuration 1	0.00173	710,961	1238	2,600	0.48
	Configuration 2	0.00274	710,961	1948	2,600	0.75

* This number was calculated according to Appendix A. The detailed calculations are listed in Appendix C.

Section 5. Background Simulation

For further estimation work, such as reporting the scan MDA, etc., the background counting rate for the ½" shielded 3" x 3" NaI detector was estimated. Table 6 demonstrates the simulation results of the background model for the two measurement configurations. These results should be confirmed in the field and the appropriate field background value used for survey work.

Table 6
Simulated Background Counting Rate, CPM

	Background Counting Rate, CPM
Scan	4,591
Direct	4,568

Recommendations and Conclusions

1) Roof configurations and MCNP model specifications and assumptions were provided. Two configurations were modeled using MCNP (Section 1).

2) The effective detection area for a ½" lead shielded 3"x 3" NaI detector was found to be .1m^2 for scans and 0.25m^2 for direct measurements (Section 2).

3) The degree of attenuation when the contaminated layer is covered by additional roof material layer(s) was found to range from 0.05 to 0.49 depending on measurement type and roof configuration per Table 4 (Section 3)

4) The conversion factor for the shielded 3"x 3" NaI detector in terms of cpm/dpm/100cm^2 of the 2:1 Uranium to Thorium mixture was found to range from 0.44 to 0.75 per Table 5 (Section 4).

5) The background counting rate for the shielded 3"x 3" NaI detector was estimated as approximately 4,600 cpm for the modeled assumptions per Table 6 (see Section 5 and Appendix B).

6) Validation and benchmarking of the MCNP models used in this Technical Memo were performed and are exhibited good agreement with the MICROSHIELD code as presented in Appendix A and Appendix D.

Appendix A

Assumptions and Calculational Results for Microshield Validation/Benchmarking

THE MICROSHIELD CODE WAS RUN WITH THE FOLLOWING ASSUMPTIONS:

- 10,000 cm² rectangular area of contamination
- 2/1 U/Th mixture of contamination, in equilibrium, 2 dpm/cm² U, 1 dpm/cm² Th
- Contamination on surface
- Location of interest for flux – 5 cm from the contaminated surface.

The flux (γ/cm²/s) is calculated[34] as 0.1648 γ/cm²/s. In order to convert this to cpm for the detector the following assumptions were used:

1. Average energy of U/Th mix is 755 keV (this was provided by the Microshield code).
2. Mass attenuation coefficient[35] (μ/ρ) for NaI at 755 keV is 0.0699 cm²/g.
3. The density of NaI is 4.36 g/cm³ and the mean path length for the γ is 5 cm (2/3 of 7.62 cm width) such that the mean estimated path length is 21.9 cm²/g.
4. Average area ($Area_{probe}$) subjected to γ flux is 200 cm² in the unshielded configuration (bottom and most of sides of detector, not top). The average area is 27 cm² in the shielded configuration[36].

The resulting calculation is as follows:

$$\text{Detector counts (cpm)} = [0.1648\frac{\gamma}{cm^2 s} * Area_{probe}(cm^2) * 60\frac{s}{m}] * [1 - e^{\left(-\frac{\mu}{\rho} * (path_{length})\right)}]$$

Adjusting this calculated value for the expected counts at the Administrative Release Guideline (ARG) of 26 dpm/cm², the total counts are estimated to be 13,000 cpm for an unshielded configuration and 1,800 cpm for a shielded detector.

---

[34] Calculated by MICROSHIELD code.
[35] Calculated by MICROSHIELD code.
[36] The area of exposure is estimated based upon previous analytical runs for other applications. As the intent of these calculations are merely to provide an error check for the MCNP runs, further effort to refine these values is not warranted. The average area subjected to flux should be within +/- 25%.

Appendix B
Example Calculation of the
Total Number of Gammas in Background

INP File Name **MIRF19**

Modified From MIRF20

Modified Time **11/22/2002 17:41**

Geometry Specification

Source Specification

Detector Part

D/S Dis(cm)	0
Form	Cylinder
Radius	1.5"(3.81cm)
Height	3"
Al Housing	0.051cm

Radio Nuclide

115 Gamma Ray Peaks Input into this model

Field Part

Activity Distribution

Layer1	Asphalt(Gravel Level)	1	Nuclide	ratio	Activity(pCi/g)
Form	Rectangular Cubic	Layer1	U-234	0	0
Status	Clean		U-235	0.001394	0.004895246
Length(cm)	100		U-238	0.192232	0.675
Width(cm)	100		Th-232	0.195597	0.216
Height(cm)	2.5	1	Ra-226	0.341745	0.6
Volume(cm3)	25000		K-40	0.269124	1.89
Center	(0 -1.25)		Total Unit activity(pCi/g)		7.022772892
Density(g/cm3)	1.3		Sut total Activity(pCi)		228240.119
Mass(g)	32500		Activity Ratio		0.074046931

Layer2	Clean Asphalt	1	Nuclide	ratio	Activity(pCi/g)
Form	Triangular Cubic	Layer1	U-234	0	0
Status	Asphalt Binder		U-235	0.001394	0.001631749
Length(cm)	100		U-238	0.192214	0.225

Width	100		Th-232	0.195579	0.072
Height(cm)	1.27	1	Ra-226	0.341714	0.2
Volume(cm3)	12700		K-40	0.2691	0.63
Center	(0 0 -3.135)		Total Unit activity(pCi/g)		2.341140297
Density(g/cm3)	1		Sub total Activity(pCi)		29732.48177
Mass(g)	12700		Activity Ratio		0.009645977

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MCNP Model Running Record

808 Gordon Lane, Suite 201, Louisville, KY 40222

By: Ning Zhang

Field Part		Activity Distribution			
Layer 3	Asphalt	1	Nuclide	ratio	Activity(pCi/g)
Form	Rectangular Cubic	Layer1	U-234	0	0
Status	Contaminated		U-235	0.001394	0.001631749
Length(cm)	100		U-238	0.192214	0.225
Width(cm)	100		Th-232	0.195579	0.072
Height(cm)	0.5	1	Ra-226	0.341714	0.2
Volume(cm3)	5000		K-40	0.2691	0.63
Center	(0 0 -4.02)		Total Unit activity(pCi/g)		2.341140297
Density(g/cm3)	1		Sub total Activity(pCi)		11705.70149
Mass(g)	5000		Activity Ratio		0.003797629

Layer 4	Asphalt Binder	1	Nuclide	ratio	Activity(pCi/g)
Form	Rectangular Cubic	Layer1	U-234	0	0
Status	Clean Asphalt		U-235	0.001394	0.001631749
Length(cm)	100		U-238	0.192214	0.225
Width	100		Th-232	0.195579	0.072
Height(cm)	1.27	1	Ra-226	0.341714	0.2
Volume(cm3)	12700		K-40	0.2691	0.63

Center	(0 0 -4.905)		Total Unit activity(pCi/g)		2.341140297
Density(g/cm3)	1		Sub total Activity(pCi)		29732.48177
Mass(g)	12700		Activity Ratio		0.009645977
Layer 5	Concrete	1	Nuclide	ratio	Activity(pCi/g)
Form	Rectangular Cubic	Layer1	U-234	0	0
Status	Clean Concrete		U-235	0.001394	0.004895246
Length(cm)	100		U-238	0.192214	0.675
Width	100		Th-232	0.195579	0.216
Height(cm)	15.24	1	Ra-226	0.341714	0.6
Volume(cm3)	152400		K-40	0.2691	1.89
Center	(0 0 -13.16)		Total Unit activity(pCi/g)		7.023420892
Density(g/cm3)	2.6		Sub total Activity(pCi)		2782960.294
Mass(g)	396240		Activity Ratio		0.902863485
OK			Total Activity(pCi)		3082371.078
			Total Activity(Bq)		114047.7299
Particles	114,048	/second			

Note:

Background Testing: Individually

cps:	114,048	CPM	6,842,864

Specification:

- The above calculation is an example for the 10,000cm^2 field.
- The number 1 or 0 in the blue cell will control how the activity density be treated:

  0: indicates that the activity density is activity of whole chain including the daughter activity.

  1: indicates that the activity density is only the activity for parent.

- The number in yellow cell will be used to control how Rn-222 will be included in the calculation.
- The ratios in the table will be used by the MCNP model for the photon distribution.

Appendix C
Calculation of the Total Number of Photons Emitted from the Contaminated Layer
(U:Th ratio = 2:1; activity density = 26 dpm/cm^2)

Field Part		Activity Distribution			
Layer 3	Asphalt	1	Nuclide	ratio	Activity(dpm/cm^2)
Form	Rectangular Cubic	Layer1	U-234	0.00	0.00
Status	Contaminated		U-235	0.00	0.12
Length(cm)	100.00		U-238	0.24	17.21
Width(cm)	100.00		Th-232	0.39	8.67
Height(cm)	0.50	1	Ra-226	0.36	17.21
Volume(cm3)	5000.00		K-40	0.00	0.00
Center	(0 0 -4.02)		Total Unit activity(dpm/cm^2)		142.19
Density(g/cm^3)	1.00		Sub total Activity(dpm)		**710,961**
Mass(g)	5000.00		Activity Ratio		1.00

Appendix D
Model Benchmarking

The model was benchmarked by the following method.

According to Appendix A, the MICROSHIELD code was run to estimate the response of the 3"x 3" NaI detector by the settings in Table D-1. The result of running this model is listed in Table D-2.

Table D-1: Model Specification according to Appendix A

Setting	Description
Detector	3" x 3" NaI Detector with half inch lead shielding
Roof Structure	4-layer model with surface area of 10,000 cm^2: 1. The first layer is 0.5" (1.27cm) thick layer which is filled by asphalt binder material; 2. The second layer is 0.5cm thick and consists of asphalt binder material contaminated with licensed radioactivity; 3. The third layer is also 0.5"(1.27cm) thick and consist of asphalt binder material; 4. The fourth layer is a 6"(15.24cm) thick concrete layer simulating the concrete roof support structure.
Geometry	The NaI detector with shielding was 5 cm above the roof structure.
Activity Setting	U:Th=2:1 by 2,600dpm/100cm^2 Radio Equilibrium is assumed throughout the decay chains

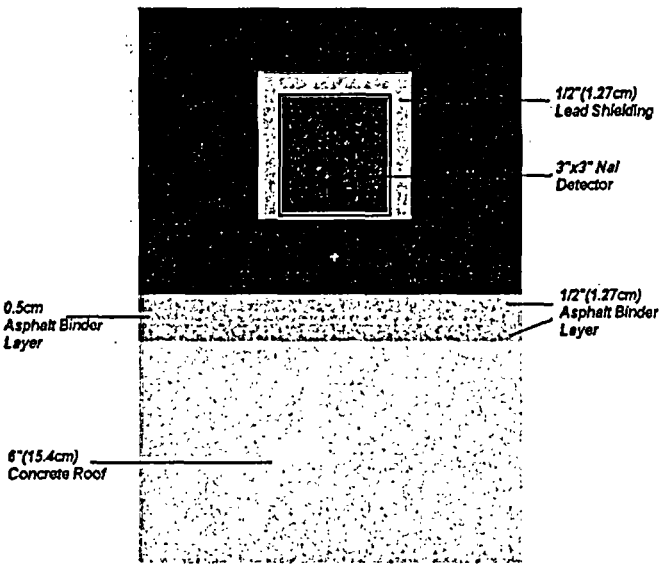

Figure D-1: MCNP Model for Bechmark

Table D-2: MCNP Results vs. MICROSHIELD Results

MCNP			MICROSHIELD
MCNP Efficiency	Total Number of Gammas/Minute	CPM Measured by Detector	CPM Measured by Detector
0.002594	710,961*	1,839	1,800

* Please See Appendix C.

From the Table D-2, the two results from MCNP and MICROSHIED show excellent agreement.