YANKEE ATOMIC ELECTRIC COMPANY

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May 11, 2006
BYR 2006-037

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555-001

References: (a) License No. DPR-3 (Docket No. 50-29)

(b) BYR 2004-133, Submittal of Revision 1 to the Yankee Nuclear Power Station's License Termination Plan

(c) Yankee Nuclear Power Station – Issuance of Amendment 158 Re: License Termination Plan

Subject: Submittal of YNPS-FSS-AUX01-00 and YNS-FSS-NSY12-00, the Final Status Survey Reports for Survey Areas AUX-01 and NSY-12, Respectively

Dear Madam/Sir:

This letter submits YNPS-FSS-AUX01-00, Final Status Survey Report for AUX-01, and YNPS-FSS-NSY12-00, Final Status Survey Report for NSY-12. These reports were written in accordance with Section 5 of the YNPS License Termination Plan, "Final Status Survey Plan," and are consistent with the guidance provided in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).

We trust that this information is satisfactory; however if you should have any questions or require any additional information, please contact Alice Carson at (301) 916-3995 or the undersigned at (413)-424-2261.

Sincerely,

YANKEE ATOMIC ELECTRIC COMPANY

Joseph Lynch
Regulatory Affairs Manager

Enclosure: YNPS-FSS-AUX01-00
YNPS-FSS-NSY12-00 (2 hard copies plus CD)

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Yankee Nuclear Plant Station
Final Status Survey Report
For NSY-12

Yankee Atomic Electric Company

YANKEE NUCLEAR POWER STATION
FINAL STATUS SURVEY REPORT

REPORT NO.: YNPS-FSS-NSY-12-00

Prepared by: _____ Date: May 8th 2006
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Reviewed by: _____ Date: 5-8-2006
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(In the electronic version, every Table of Contents, Figures, Appendices and Attachments, as well as every mention of a Table, Figure, Appendix or Attachment is a hyperlink to the actual location or document.)

List of Abbreviations and Acronyms

AL	Action Level
ALARA	As Low As Reasonably Achievable
c/d	Counts per Disintegration
DCGL	Derived Concentration Guideline Level
$DCGL_{EMC}$	DCGL for small areas of elevated activity
$DCGL_W$	DCGL for average concentration over a wide area, used with statistical tests
DQO	Data Quality Objectives
EMC	Elevated Measurement Comparison
ETD	Easy-to-Detect
FSS	Final Status Survey
FSSP	Final Status Survey Plan
GPS	Global Positioning System
H_o	Null Hypothesis
HSA	Historical Site Assessment
HTD	Hard-to-Detect
ISOCS	*In-situ* Object Counting System®
LBGR	Lower Bound of the Grey Region
LTP	License Termination Plan
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
PAB	Primary Auxiliary Building
QAPP	Quality Assurance Project Plan
QC	Quality Control
RCA	Radiological Controlled Area
RP	Radiation Protection
RSS	Reactor Support Structure
SFP	Spent Fuel Pool
VC	Vapor Container
VCC	Vertical Concrete Cask
VSP	Visual Sample Plan
YNPS	Yankee Nuclear Power Station

1.0 EXECUTIVE SUMMARY

A Final Status Survey (FSS) was performed of Survey Area NSY-12 in accordance with Yankee Nuclear Power Station's (YNPS) License Termination Plan (LTP). This FSS was conducted as a structure surface FSS with building occupancy Derived Concentration Guideline Levels (DCGLs) even though the NSY-12 structure will be subsurface at license termination. This practice conservatively implements LTP criteria that subsurface structure surfaces be evaluated for the presence of contamination.

1.1 Identification of Survey Area and Units

NSY-12 Survey Area consists of a single Survey Unit, NSY-12-01, which comprises the base for Tank-1 (TK-1) and a subsurface pipe chase that connected the TK-1 base to the Auxiliary Boiler Room in the Turbine Building. NSY-12 is bounded entirely by NOL-06. NSY-12 is part of the original plant structure. There is no documentation indicating that NSY-12 is contaminated; however, there is information that indicates that the area around NSY-12 is potentially contaminated. However, based upon the radiological condition of this survey area identified in the operating history and as a result of the decommissioning activities performed to date, Survey Area NSY-12 is identified as a Class 1 Area.

1.2 Dates(s) of Survey

The FSS of the NSY-12 Survey Area was performed between November 16th, 2005, and December 14th, 2005.

1.3 Number and Types of Measurements Collected

Final Status Survey Plan (FSSP) was developed for this Survey Unit in accordance with YNPS LTP and FSS procedures using the MARSSIM protocol. The planning and design of the survey plan employed the Data Quality Objective (DQO) process, ensuring that the type, quantity and quality of data gathered was appropriate for the decision-making process and that the resultant decisions were technically sound and defensible. A total of 36 direct measurements were taken, providing data for the non-parametric testing of the Survey Area. In addition to the direct measurements, hand-held survey instrument scans, were performed to provide 100 percent coverage of the Survey Area.

1.4 Summary of Survey Results

Following the survey, the data were reviewed against the survey design to confirm completeness and consistency, to verify that the results were valid, to ensure that the survey plan objectives were met and to verify Survey Unit classification. Fixed point surveys indicated no measurements exceeded the $DCGL_W$ as depicted in Attachment B. Retrospective power curves were generated which demonstrated that adequate power was achieved. Therefore, the null hypothesis (H_o) (that the Survey Unit exceeds the release criteria) is rejected.

1.5 Conclusions

Based upon the evaluation of the data acquired for the FSS, NSY-12 meets the release requirements set forth in the YNPS LTP. The Total Effective Dose Equivalent (TEDE) to the average member of the critical group does not exceed 25 mrem/yr, including that from groundwater. 10CFR20 Subpart E ALARA requirements have been met as well as the site release criteria for the administrative level DCGLs that ensure that the Massachusetts Department of Public Health's 10 mrem/yr limit will also be met.

2.0 FSS PROGRAM OVERVIEW

2.1 Survey Planning

The YNPS FSS Program employs a strategic planning approach for conducting final status surveys with the ultimate objective to demonstrate compliance with the DCGLs, in accordance with the YNPS LTP. The DQO process is used as a planning technique to ensure that the type, quantity, and quality of data gathered is appropriate for the decision-making process and that the resultant decisions are technically sound and defensible. Other key planning measures are the review of historical data for the Survey Unit and the use of peer review for plan development.

2.2 Survey Design

In designing the FSS, the questions to be answered are: "Does the residual radioactivity, if present in the Survey Unit, exceed the LTP release criteria?" and "Is the potential dose from this radioactivity ALARA?" In order to answer these questions, the radionuclides present in the Survey Units must be identified, and the Survey Units classified. Survey Units are classified with respect to the potential for contamination: the greater the potential for contamination, the more stringent the classification and the more rigorous the survey.

The survey design additionally includes the number, type and locations of fixed measurements/samples (as well as any judgmental assessments required), scanning requirements, and instrumentation selection with the required sensitivities or

detection levels. DCGLs are developed relative to the surface/material of the Survey Unit and are used to determine the minimum sensitivity required for the survey. Determining the acceptable decision error rates, the lower bound of the gray region (LBGR), statistical test selection and the calculation of the standard deviation and relative shift allows for the development of a prospective power curve plotting the probability of the Survey Unit passing FSS.

2.3 Survey Implementation

Once the planning and development has been completed, the implementation phase of the FSS program begins. Upon completion of remediation and final characterization activities, a final walk down of the Survey Unit is performed. If the unit is determined to be acceptable (i.e. physical condition of the unit is suitable for FSS), it is turned over to the FSS team, and FSS isolation and control measures are established. After the Survey Unit isolation and controls are in place, grid points are identified for the fixed measurements/samples, using Global Positioning System (GPS) coordinates whenever possible, consistent with the Massachusetts State Plane System, and the area scan grid is identified. Data is collected and any required investigations are performed.

2.4 Survey Data Assessment

The final stage of the FSS program involves assessment of the data collected to ensure the validity of the results, to demonstrate achievement of the survey plan objectives, and to validate Survey Unit classification. During this phase, the DQOs and survey design are reviewed for consistency between DQO output, sampling design and other data collection documents. A preliminary data review is conducted to include: checking for problems or anomalies, calculation of statistical quantities and preparation of graphical representations for data comparison. Statistical tests are performed, if required, and the assumptions for the tests are verified. Conclusions are then drawn from the data, and any deficiencies or recommendations for improvement are documented.

2.5 Quality Assurance and Quality Control Measures

YNPS FSS activities are implemented and performed under approved procedures, and the YNPS Quality Assurance Project Plan (QAPP) assures plans, procedures and instructions have been followed during the course of FSS, as well as providing guidance for implementing quality control measures specified in the YNPS LTP.

3.0 SURVEY AREA INFORMATION

3.1 Survey Area Description

Survey Area NSY-12 consists of the reinforced concrete pad, pipe trench, and subsurface structures of the base of the Primary Water Storage Tank (TK-1) that

remains after the demolition of the tank and system piping. NSY-12 is located in the RCA yard area entirely within the bounds of NOL-06. The footprint of the area is approximately 330 ft^2 (31 m^2).

3.2 History of Survey Area

The Primary Water Storage Tank (TK-1) was designated "primary" because of the water grade, not because of any connection with the primary coolant system liquid inventories. This tank fed make-up water to the Auxiliary Boilers and Steam Generators. There is no documentation indicating that NSY-12 is contaminated; however, there is information that indicates that the area around NSY-12 is potentially contaminated.

Table 1 Survey Area NSY-12 Events/Conditions

Date	Event/Condition
Various	Was used as base for TK-1
Post-HSA	Removal of TK-1
Winter 2005	Final Remediation and FSS performed

3.3 Division of Survey Area into Survey Units

Survey Area NSY-12 consists of a single Survey Unit, NSY-12-01

3.4 Survey Unit NSY-12-01 Description

NSY-12-01 Survey Unit consists of the base for Tank-1 (TK-1) and a subsurface pipe chase that connects the TK-1 base to the Auxiliary Boiler Room in the Turbine Building. NSY-12-01 is bounded entirely by NOL-06. The footprint area of the unit is approximately 330 ft^2 (31 m^2).

4.0 SURVEY UNIT INFORMATION

4.1 Summary of Radiological Data Since Historical Site Assessment (HSA)

4.1.1 Chronology and Description of Surveys Since HSA

Isolation and control measures were implemented for the FSS. The condition of NSY-12 Survey Unit at the time of FSS was smooth to heavily remediated steel reinforced concrete.

4.1.2 Radionuclide Selection and Basis

During the initial DQO process, Co-60 was identified as the radiological nuclide of concern due to its more restrictive DCGL value when compared

to Cs-137 (sampling of soil adjacent to the concrete indicated a relationship of approximately 80% Co-60 to 20% Cs-137). Adjacent soil characterization and survey data indicate no other LTP-specified radionuclides warrant consideration in the NSY-12 Survey Units.

4.1.3 Scoping & Characterization

The radiological characteristics of Survey Unit NSY12-01 are similar to other concrete structures in the RSS area. Eleven concrete survey units in the RSS area have been found to meet LTP release criteria based on FSS data. The FSS data set from survey unit BRT-01-01 was used in the planning for NSY12-01 because it showed the highest variability (σ = 1.6E3 dpm/100cm^2), and a higher variability in data requires the collection of more measurements.

4.2 Basis for Classification

Based upon the radiological condition of this Survey Area identified in the operating history and as a result of the decommissioning activities performed to date, Survey Area NSY-12 is identified as a Class 1 Area.

4.3 Remedial Actions and Further Investigations

No further investigations or remediation were required for Survey Area NSY-12.

4.4 Unique Features of Survey Unit

Survey Unit NSY-12-01 exhibited surface characteristics ranging from smooth surfaces to heavily remediated irregular surfaces. Most of the pits and irregularities increased the source-to-detector distance by approximately ¼ - ½ inch, although some increase it as much as 1 - 2 inches. These types of irregularities in the concrete surfaces were taken into account through the efficiency factor applied to the measurements collected with the HP-100. Technical report YA-REPT-00-015-04 (Appendix B) provides instrument efficiency factors (ε_i) for various source-to-detector distances. The ε_i value for a source-to-detector distance of 1 inch was selected as a representative efficiency for data collected with the HP-100 from the irregular surfaces because it accounts for the ½ inch stand-off and the most common depth of pits and surface irregularities (¼ - ½ inch). In contrast to the irregular surfaces, the vertical walls of the structures are relatively smooth. Table 4.2 of the YA-REPT-00-015-04 (Appendix B) provides instrument efficiency factors (ε_i) for various source-to-detector distances. Detector efficiencies (HP-100C) were applied as follows: smooth surface 0.0603 c/d, irregular surface 0.0373 c/d.

4.5 ALARA Practices and Evaluations

An ALARA evaluation was developed for the NSY-12 Survey Area which concluded that additional remediation was not warranted. This evaluation is found in Appendix C.

5.0 SURVEY UNIT FINAL STATUS SURVEY

5.1 Survey Planning

5.1.1 Final Status Survey Plan and Associated DQOs

The FSS for NSY-12 Survey Unit was planned and developed in accordance with the LTP using the DQO process. Form DPF-8856.1, found in YNPS Procedure 8856, "*Preparation of Survey Plans*," was used to provide guidance and consistency during development of the FSS Plan. The FSS Plan can be found in Appendix A. The DQO process allows for systematic planning and is specifically designed to address problems that require a decision to be made in a complex survey design and, in turn, provides alternative actions.

The DQO process was used to develop an integrated survey plan providing the Survey Unit identification, sample size, selected analytical techniques, survey instrumentation, and scan coverage. The Sign Test was specified for non-parametric statistical testing for this Survey Unit, if required. The design parameters developed are presented in Table 2.

Table 2 Survey Area NSY-12 Design Parameters

Survey Unit	Design Parameter	Value	Basis
NSY-12-01	Area	31 m^2	Class 1, ≤1000 m^2
	Number of Direct Measurements	15 (calculated) + 21 (added) Total: 36	α (Type I) = 0.05, β (Type II) = 0.05 σ: 1600 Relative Shift: 2.1 LBGR:3200
	Sample Area	2.1 m^2	Area / Sample #
	Sample Grid Spacing, triangular pitch	1.5 m (Based on 15 original samples.)	$(Area/(0.866*Sample\ \#))^{1/2}$
	Scan area	31 m^2	Class 1 Area – 100%
	Scan Investigation Level	> Background Audible	SPA-3 & HP-100 Scan

5.1.2 Deviations from the FSS Plan as Written in the LTP

The FSSP design was performed to the criteria of the LTP; therefore, no LTP deviations with potential impact to this Survey Area need to be evaluated.

5.1.3 DCGL Selection and Use

It must be noted that for the final evaluation of the NSY-12 Survey Unit and throughout this report, the acceptance criteria of Building Surface LTP-listed DCGL values has been applied. However, given that all of the remaining slab and foundation structure will be at least a few feet subsurface before site grading is complete and will be in such a state at license termination, the LTP, section 5.6.3.1.2, "Exterior Surfaces of Building Foundations," establishes the applicable guidance, as it addresses methods that may be applied to determine if subsurface structure surfaces will be acceptable by meeting LTP-required concrete volumetric DCGLs.

With the established LTP guidance, given that Co-60 and Cs-137 have been found to be the only radionuclides of significance in the area of concern, and conventional hand-held instrument survey criteria techniques being conservatively based on Co-60 beta emissions, performing a Class 1 survey applying Building Surface DCGLs has led to a very conservative approach in determining the final status of the Survey Unit. However, in applying this approach, in addition to evaluating subsurface conditions, there is no unanswered concern should the question of future subsurface structure occupancy arise.

5.1.4 Measurements

Error tolerances and characterization sample population statistics drove the selection of the number of fixed point measurements. Professional judgment was exercised adding additional direct measurements to achieve a tighter sampling grid building conservatism into the sampling design.

The direct measurement grid was developed as a systematic grid with spacing consisting of a triangular pitch pattern with a random starting point. Sample measurement locations are provided in Attachment A

5.2 Survey Implementation Activities

Table 3 provides a summary of daily activities performed during the Final Status Survey of Survey Unit NSY-12-01.

Table 3 FSS Activity Summary for NSY-12 Survey Units

Survey Unit	Date	Activity
NSY-12-01	11-16-05	Performed Sample Quantity Calculations, established DQOs
	11-17-05	Performed Job Hazard Analysis, and Unit Classification
	11-17-05	Generated FFS Sample Plans
	11-22-05	Performed walk-down of Survey Unit, established Isolation and Controls
	11-23-05	Initiated Scans, and Direct measurements.
	12-14-05	Performed DQA, FSS Complete

5.3 Surveillance Surveys

5.3.1 Periodic Surveillance Surveys

Upon completion of the FSS of Survey Area NSY-12, the Survey Area was placed into the program for periodic surveillance surveys on a quarterly basis in accordance with YNPS procedure DP-8860, "*Area Surveillance Following Final Status Survey.*" These surveys provide assurance that areas with successful FSS remain unchanged until license termination.

5.3.2 Resurveys

No resurveys were required for this Survey Unit due to surveillance surveys.

5.3.3 Investigations

No additional investigations were required for this Survey Unit due to surveillance surveys.

5.4 Survey Results

A total of 36 direct measurements were taken in Survey Unit NSY-12-01. None of the direct measurements used in the statistical analysis of the Survey Unit exceeded the $DCGL_W$. Table 4 includes the direct measurements that were gathered for the Survey Unit in NSY-12.

Table 4 Survey Area NSY-12 Direct Measurements

Location	Surface	Results (cpm)	Results (dpm/100cm2)
NSY-12-01-001-F-FM	Smooth	58	958
NSY-12-01-002-F-FM	Smooth	75	1240
NSY-12-01-003-F-FM	Smooth	14	228
NSY-12-01-004-F-FM	Smooth	82	1356
NSY-12-01-005-F-FM	Smooth	50	825
NSY-12-01-006-F-FM	Rough	57	1522
NSY-12-01-007-F-FM	Smooth	71	1173
NSY-12-01-008-F-FM	Smooth	74	1223
NSY-12-01-009-F-FM	Smooth	64	1057
NSY-12-01-010-F-FM	Smooth	39	643
NSY-12-01-011-F-FM	Rough	50	1334
NSY-12-01-012-F-FM	Smooth	43	709
NSY-12-01-013-F-FM	Smooth	26	427
NSY-12-01-014-F-FM	Smooth	64	1057
NSY-12-01-015-F-FM	Smooth	112	1853
NSY-12-01-016-F-FM	Smooth	34	560
NSY-12-01-017-F-FM	Smooth	81	1339
NSY-12-01-018-F-FM	Smooth	27	444
NSY-12-01-019-F-FM	Smooth	32	527
NSY-12-01-020-F-FM	Smooth	41	676
NSY-12-01-021-F-FM	Smooth	36	593
NSY-12-01-022-F-FM	Smooth	13	212
NSY-12-01-023-F-FM	Rough	106	2835
NSY-12-01-024-F-FM	Rough	86	2299
NSY-12-01-025-F-FM	Smooth	110	1820
NSY-12-01-026-F-FM	Smooth	70	1157
NSY-12-01-027-F-FM	Smooth	46	759
NSY-12-01-028-F-FM	Smooth	81	1339
NSY-12-01-029-F-FM	Smooth	63	1041
NSY-12-01-030-F-FM	Smooth	107	1771
NSY-12-01-031-F-FM	Smooth	56	925
NSY-12-01-032-F-FM	Smooth	103	1704
NSY-12-01-033-F-FM	Smooth	66	1091
NSY-12-01-034-F-FM	Smooth	39	643
NSY-12-01-035-F-FM	Smooth	66	1091
NSY-12-01-036-F-FM	Smooth	67	1107

5.5 Data Quality Assessment

The Data Quality Assessment phase is the part of the FSS where survey design and data are reviewed for completeness and consistency, ensuring the validity of the results, verifying that the survey plan objectives were met, and validating the classification of the Survey Unit.

The sample design and the data acquired were reviewed and found to be in accordance with applicable YNPS procedures DP-8861, "*Data Quality Assessment*"; DP-8856, "*Preparation of Survey Plans*"; DP-8853, "*Determination of the Number and Locations of FSS Samples and Measurements*"; DP-8857, "*Statistical Tests*"; DP-8865, "*Computer Determination of the Number of FSS Samples and Measurements*" and DP-8852, "*Final Status Survey Quality Assurance Project Plan*".

A data review was performed on NSY-12-01 and statistical quantities were calculated. The average concentrations from Table 4 are smaller than the respective characterization data and the standard deviation is higher. However, the retrospective power curve maintained sufficient power to pass the Survey Unit. The data range for the unit was less than two standard deviations. The frequency plot exhibits a normal Poisson distribution. The scatter plot graphically illustrates that the data varies about the arithmetic mean. The data posting plot does not clearly reveal any systematic spatial trends.

The power curves, scatter plot and frequency plots are found in Attachment B.

6.0 QUALITY ASSURANCE AND QUALITY CONTROL

6.1 Instrument QC Checks

Operation of the E-600 w/SPA-3 was in accordance with DP-8535,"*Setup and Operation of the Eberline E-600 Digital Survey Instrument,*" with QC checks preformed in accordance with DP-8504, "*Control and Accountability of Radiation Protection Portable Survey Instruments.*" Instrument response checks were performed prior to and after use for the E-600 w/SPA-3. All instrumentation involved with the FSS of NSY-12 satisfied the above criteria for the survey. QC records are found in Attachment C.

6.2 Split Samples and Recounts

DP-8864,"*Split Sample Assessment for Final Status Survey*" deals strictly with soil samples and provides no criteria for direct measurements therefore no measurement comparison were made.

6.3 Self-Assessments

No self-assessments were performed during the FSS of NSY-12.

7.0 CONCLUSION

The FSS of NSY-12 has been performed in accordance with YNPS LTP and applicable FSS procedures. Evaluation of the direct measurement data has shown that none of the direct measurements exceeded the $DCGL_W$, depicted in Attachment B. Retrospective power curves were generated and demonstrated that adequate power was achieved. Therefore, the null hypothesis (H_o) is rejected.

NSY-12 meets the objectives of the Final Status Survey.

Based upon the evaluation of the data acquired for the FSS, NSY-12 meets the release requirements set forth in the YNPS LTP. The Total Effective Dose Equivalent (TEDE) to the average member of the critical group does not exceed 25 mrem/yr, including that from groundwater. 10CFR20 Subpart E ALARA requirements have been met as well as the site release criteria for the administrative level DCGLs that ensure that the Massachusetts Department of Public Health's 10 mrem/yr limit will also be met.

List of Appendices

Appendix A – YNPS-FSSP-NSY-12, "Final Status Survey Planning Worksheet

Appendix B – YA-REPT-00-015-04, "*Instrument Efficiency Determination for Use in Minimum Detectable Concentration Calculations in Support of the Final Status Survey at Yankee Rowe*"

Appendix C – ALARA Evaluations NSY-12

List of Attachments

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Attachment C – Instrument QC Records

(In the electronic version, every Table of Contents, Figures, Appendices and Attachments, as well as every mention of a Table, Figure, Appendix or Attachment is a hyperlink to the actual location or document.)

Attachments A through C have been provided electronically on the enclosed CD.

Final Status Survey Planning Worksheet

GENERAL SECTION

Survey Area #: NSY-12	Survey Unit #: 01
Survey Unit Name: Tank-1 Concrete Base	
FSSP Number: YNPS-FSSP-NSY12-01-00	

PREPARATION FOR FSS ACTIVITIES

Check marks in the boxes below signify affirmative responses and completion of the action.

1.1 Files have been established for survey unit FSS records. ☑

1.2 ALARA review has been completed for the survey unit. ☑

1.3 The survey unit has been turned over for final status survey. ☑

1.4 An initial DP-8854 walkdown has been performed and a copy of the completed Survey Unit Walkdown Evaluation is in the survey area file. ☑

1.5 Activities conducted within area since turnover for FSS have been reviewed. ☑

Based on reviewed information, subsequent walkdown: ☑ not warranted ☐ warranted

If warranted, subsequent walkdown has been performed and documented per DP-8854. ☐

OR

The basis has been provided to and accepted by the FSS Project Manager for not performing a subsequent walkdown. ☐

1.6 A final classification has been performed. ☑

Classification: CLASS 1 ☑ CLASS 2 ☐ CLASS 3 ☐

DATA QUALITY OBJECTIVES (DQO)

1.0 Statement of problem:

Survey Unit NSY12-01 consists of the base for Tank-1 (TK-1), which is a concrete structure totally surrounded by Survey Unit NOL06-03. The footprint area of the unit is approximately 330 ft^2 (31 m^2). The data collected under this plan will be used to determine whether or not residual plant-related radioactivity on the exposed concrete surface of Survey Unit NSY12-01 meet LTP release criteria.

The planning team for this effort consists of the FSS Project Manager, FSS Radiological Engineer, FSS Field Supervisor, and FSS Technicians. The FSS Radiological Engineer will make primary decisions with the concurrence of the FSS Project Manager.

2.0 Identify the decision:

Does residual plant-related radioactivity, if present in the survey unit, exceed LTP release criteria? Alternative actions that may be implemented in this effort are investigations and remediation followed by re-surveying.

3.0 Identify the inputs to the decision:

Survey media: concrete

Types of measurements: Fixed-point measurements, beta scans, and supplemental gamma scans.

Radionuclides-of-concern: Co-60 (assumed as radionuclide-of-concern).

For planning purposes, it was assumed that the radiological characteristics of unit NSY12-01 are similar to other concrete structures in the RSS area. Eleven concrete survey units in the RSS area have been found to meet LTP release criteria based on FSS data. The FSS data set from survey unit BRT01-01 was used in the planning for NSY12-01 because it showed the highest variability (σ = 1.6E3 dpm/100cm^2), and a higher variability in data requires the collection of more measurements. Co-60 was assumed as the radionuclide-of-concern for unit NSY12-01 based on the same reasons given in the FSS plan for BRT01-01 (YNPS-FSSP-BRT01-01-00).

Average radiation level: 1.5E3 dpm/100cm^2 (the mean value of FSS fixed-point measurements from BRT01-01)

Standard deviation (σ): 1.6E3 dpm/100cm^2 (variability observed in FFS data from BRT01-01)

DCGLs:

(1) Applicable $DCGL_w$: 6.3E3 dpm/100cm^2 (Co-60 assumed)

Note: the $DCGL_w$ value corresponds to 8.73 mrem/y.

The concrete surface of the unit NSY12-01 contains pits and irregular surfaces, which will increase the source-to-detector distance for some localized areas under the 100cm^2 window of the detector. Most of the pits and irregularities increase the source-to-detector distance by approximately ¼ - ½ inch. These types of irregularities in the concrete surfaces will be taken into account through the efficiency factor applied to the measurements collected with the HP-100. Technical report YA-REPT-00-015-04 provides instrument efficiency factors (ε_i) for various source-to-detector distances. The ε_i value for a source-to-detector distance of 1 inch was selected as a representative efficiency for data collected with the HP-100 from the irregular concrete surface of the tank base because it accounts for the ½ inch stand-off and the most common depth of pits and surface irregularities (¼ - ½ inch). The ε_i value for a distance of ½ inch will be applied to HP-100 data collected from smooth concrete surfaces. The efficiency factors provided in YA-REPT-00-015-04 are used below:

- ε_i = 0.2413 c/e for smooth concrete surfaces (reflects a source to detector distance = ½ inch), and
  = 0.149 c/e for pitted/irregular surfaces (reflects a source to detector distance = 1 inch)
- ε_s = 0.25 e/d (consistent with the Co-60 assumption)
- total efficiency for smooth surface = $\varepsilon_i \cdot \varepsilon_s$ = 0.2413 c/e · 0.25 e/d = 0.0603 c/d
- total efficiency for pitted/irregular surfaces = $\varepsilon_i \cdot \varepsilon_s$ = 0.149 c/e · 0.25 e/d = 0.0373 c/d

(2) Gross measurement $DCGL_w$ (for HP-100): 6.3E3 dpm/100cm^2

- for smooth concrete surface: 6.3E3 dpm/100cm^2 * 0.0603 c/d = 3.8E2 cpm/100cm^2
- for pitted/irregular surface: 6.3E3 dpm/100cm2 * 0.0373 c/d = 2.3E2 cpm/100cm^2

(3) Applicable $DCGL_{EMC}$ for fixed-point measurements: $DCGL_w$ * AF = 6.3E3 dpm/100cm^2 * 2.4 = 1.5E4 dpm/100cm^2

- for smooth concrete surface: 1.5E4 dpm/100cm^2 * 0.0603 c/d = 9.1E2 cpm/100cm^2
- for pitted/irregular surface: 1.5E4 dpm/100cm2 * 0.0373 c/d = 5.6E2 cpm/100cm^2.

Note: the DCGL and $DCGL_{EMC}$ value refer to above-background radioactivity.

Investigation Level for fixed-point measurement:

- for smooth concrete surface: >9.1E2 cpm/100cm^2 above background
- for pitted/irregular concrete surface: >5.6E2 cpm/100cm^2 above background

Investigation Level for HP-100 scan: Reproducible indication above background using the audible feature with headphones

Investigation Level for SPA-3 scan: Reproducible indication above background using the audible feature with headphones

Scan coverage: Beta scan with HP-100: 100% of the accessible concrete surface area on the vertical walls. Supplemental SPA-3 scans on the irregular surfaces of the vertical walls and cracks in the concrete.

MDCR for HP-100: The accompanying table provides MDCR values by various background levels. The expected ambient background for the HP-100 range is 200 - 400 cpm.

Note: If the ambient background for the HP-100 exceeds 1000 cpm, notify the FSS Radiological Engineer before proceeding with the survey.

MDC(fDCGL$_{EMC}$) for HP-100 scans: The accompanying table provides MDC(fDCGL$_{EMC}$) values by various background levels.

QC checks and measurements: QC checks for the survey instruments will be performed in accordance with DP-8534. Pre- and post-use instrument QC checks will be performed.

Define the boundaries of the survey:

Boundary of NSY12-01 is as shown on the attached maps. Map 1 shows the footprint of the survey unit with the fixed-point locations on the top surface. Map 2 is the survey unit footprint with an overlay of the random-start systematic grid. Grid points that fall outside the footprint are measurement locations on the vertical walls. Map 3 shows the locations for the collection of ambient background measurements. The survey will be performed under normal weather conditions.

4.0 Develop a decision rule:

(a) If all the FSS data show that residual levels of plant-related radioactivity are below the $DCGL_w$, reject the null hypothesis (i.e., Survey Unit meets the release criteria).

(b) If the investigation level is exceeded, then perform an investigation.

(c) If the average of the FSS measurements is below the $DCGL_w$, but some individual measurements exceed the $DCGL_w$, then apply a statistical test as the basis for accepting or rejecting the null hypothesis.

(d) If the average of the FSS measurements exceeds the $DCGL_w$, then accept the null hypothesis (i.e., Survey Unit fails to meet the release criteria).

5.0 Specify tolerable limits on decision errors:

Null hypothesis: Residual plant-related radioactivity in Survey Unit BRT01-01 exceeds the release criteria.

Probability of type I error: 0.05

Probability of type II error: 0.05

6.0 *LBGR*: 6.3E3 dpm/100 $cm^2 \div 2 = 3.2E3$ dpm/100 cm^2

7.0 Optimize Design:

Type of statistical test: WRS Test ☐ Sign Test ☑

Basis including background reference location (if WRS test is specified): N/A

Number samples (per DP-8853): 15 (Note: this number was increased to 31 to extend the grid to the vertical sides of the survey unit.)

Biased Measurements: None

GENERAL INSTRUCTIONS

1. The FSS Field Supervisor is responsible for contacting the QA Department regarding the FSS activities identified as QA notification points.

2. Locate and mark the measurement points at the locations shown in the attached map.

(a) If a measurement location is obstructed such that a measurement cannot be collected, select an alternate location in accordance with DP-8856.

3. Collect a series of ambient background measurements in accordance with step B.1.c in DP-8866 with the following variation of step B.1.c.2) using the HP-100 that is to be used to collect the fixed-point measurements:

(a) Cover the detector with a 1/8-inch Lucite (or equivalent) shield and collect 7 one-minute readings with the shielded detector facing down but approximately 1m from the edge and approximately 1m above the concrete surface at the approximate locations of BG1, BG2, and BG3, as shown on map 3.

(b) Record the background data on the attached Form 1(even if the measurement was logged).

4. Collect 31 fixed-point (1-min) measurements in accordance with DP-8534.

(a) Designate the fixed-point measurements on the top surface as NSY-12-01-001-F-FM through NSY-12-01-015-F-FM, corresponding to the grid locations 001 through 015 on map 1.

(b) Designate the fixed-point measurements on the vertical sides (using the distances from edge of survey unit footprint as shown on map 2) as NSY-12-01-016-F-FM through NSY-12-01-031-F-FM.

(c) The FSS planning assumed that 5 ft of the base wall was exposed by excavation. If the actual vertical space allows further extension of the grid, continue the grid on the vertical area using the dimensions shown on map 2. Additional measurement will be designated in sequence continuing with NSY-12-01-032-F-FM.

(d) Record each fixed-point measurement "as read" (in units of cpm) on the attached Form 2 (even if the measurement was logged). Record any additional measurement on Form 2, as necessary.

(e) When recording the measurements on Form 2, identify those measurements collected from an irregular concrete surface with an asterisk (*).

5. Perform HP-100 and SPA-3 scans as described in the Specific Instructions.

6 Survey instrument: Operation of the E-600 will be in accordance with DP-8534. Pre- and post-use QC checks for survey instruments are to be performed.

7. The job hazards associated with this survey are addressed in the attached JHA for NSY12-01. Use of fall protection will be addressed in the Yankee Rowe Project Daily Activity Plan and reviewed during the pre-survey briefing.

8. All personnel participating in this survey shall be trained in accordance with DP-8868.

SPECIFIC INSTRUCTIONS

1. Beta scans covering 100% of the accessible vertical wall surface:

(a) Perform the HP-100 scans by moving the detector at a speed no greater than 2 inches per second, using a ½ inch standoff.

(b) FSS Technicians will wear headphones while scanning and the survey instrument will be in the rate-meter mode. Surveyors will listen for upscale readings and respond to readings that exceed the investigation level.

(c) Ensure that the name of the FSS Technician(s) performing the scan and the instrument number(s) are record either on DP-8856.2 or the survey map.

(d) If the HP-100 scan investigation level is exceeded:

(1) confirm that the above background indication is reproducible and cannot be attributed to a nearby source (e.g., waste container),

(2) if a nearby source is identified, have it removed or shielded, document the finding on DP-8856.2, and repeat the scan,

(3) if reproducible and not caused by a nearby source, collect a fixed-point measurement at the location of the highest reading observed during the scan,

(4) The designation for a fixed-point measurement collected during a first-level investigation will continue in sequence beginning with NSY-12-01-032-F-FM-I. Record all investigation fixed-point measurements "as read" (in units of cpm) on the attached Form 2 (even if the measurement was logged).

(5) clearly mark the location of any fixed-point measurement collected during this level of investigation. If further investigation is required, it will be conducted under a separate survey plan.

(e) The FSS Field Supervisor will record information relevant to the HP-100 scans on DPF-8856.2.

2. Gamma scans on the irregular surfaces of the vertical walls and cracks in the concrete:

(a) Perform SPA-3 scans on the irregular surfaces and over cracks by moving the detector slowly (no greater than 0.25m/s) and keeping it < 3 inches from the surface.

(b) FSS Technicians will wear headphones while scanning with the survey instrument in the rate-meter mode. Surveyors will listen for upscale readings and respond to readings that exceed the SPA-3 investigation level.

(c) If a SPA-3 reading exceeds the investigation level:

(1) confirm that the above-background indication is reproducible and cannot be attributed to a nearby source,

(2) if the reading is reproducible and not caused by a nearby source, collect a fixed-point measurement with the HP-100 at the highest reading observed during the scan and clearly mark that location. Designate the investigation fixed-point measurement as described in step 1(c)(3) above. Record all investigation fixed-point measurements "as read" (in units of cpm) on the attached Form 2 (even if the measurement was logged). If further investigation is required, it will be conducted under a separate survey plan.

(d) The FSS Field Supervisor will record information relevant to the SPA-3 scans on DPF-8856.2.

NOTIFICATION POINTS

QA notification* point(s) (y/n) y

(1) Date/time of initial pre-survey briefing _____ QA signature: _____

(2) Date/time of commencement of HP-100 measurements QA signature: _____

(3) Date/time of commencement of SPA-3 measurement QA signature: _____

(4) Time(s) of daily pre-shift briefing QA signature: _____
(for each shift that the FSS is performed)

* Voice mail notification or E-mail notification to Trudeau@yankeerowe.com with a copy to Calsyn@yankeerowe.com satisfies this step.

FSI point(s) (y/n) n Specify: _____

Prepared by J. Bisson FSS Radiological Engineer Date 11-17-05

Reviewed by Mark C. Emiliani FSS Radiological Engineer Date 11/17/05

Approved by J. Smith FSS Project Manager Date 11/17/05

MDCR/MDC Table for Survey Unit NSY-07-01

Background (cpm)	scan speed (in/s)	MDCR (cpm)	MDC(fDCGL(emc))	scan speed (in/s)	MDCR (cpm)	MDC(fDCGL(10))
400	2	151	0.23			
1000	2	239	0.37			
1500	2	292	0.45			
2000	2	337	0.52			

detector = HP-100

TECHNICAL REPORT TITLE PAGE

COPY

Instrument Efficiency Determination for Use in Minimum Detectable Concentration Calculations in Support of the Final Status Survey at Yankee Rowe

Title

YA-REPT-00-015-04
REV. 0

Technical Report Number

Approvals	(Print & Sign Name)	
Preparer:		Date: 10-7-04
Reviewer:	James R. Hummer	Date: 10/7/04
Approver (Cognizant Manager):		Date: 10/7/04

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1.0 Executive Summary:

The minimum detectable concentration (MDC) of the field survey instrumentation is an important factor affecting the quality of the final status survey (FSS). The efficiency of an instrument inversely impacts the MDC value. The objective of this report is to determine the instrument and source efficiency values used to calculate MDC. Several factors were considered when determining these efficiencies and are discussed in the body of this report. Instrument efficiencies (ε_i), and source efficiencies (ε_s), for alpha beta detection equipment under various field conditions, and instrument conversion factors (E_i), for gamma scanning detectors were determined and the results are provided herein.

2.0 Introduction:

Before performing Final Status Surveys of building surfaces and land areas, the minimum detectable concentration (MDC) must be calculated to establish the instrument sensitivity. Table 5.4 of the License Termination Plan (LTP) [8.6] lists the available instrumentation and nominal detection sensitivities; however for the purposes of this basis document, efficiencies for the 100cm^2 gas proportional and the 2"x2" NaI (Tl) detectors will be determined. Efficiencies for the other instrumentation listed in the LTP shall be determined on an as needed basis. The 100 cm^2 gas proportional probe will be used to perform surveys (i.e. fixed point measurements). A 2" x2" NaI (Tl) detector will be used to perform gamma surveys (i.e., surface scans) of portions of land areas and possibly supplemental structural scans at the Yankee Rowe site. Although surface scans and fixed point measurements can be performed using the same instrumentation, the calculated MDCs will be quite different. MDC is dependent on many factors and may include but is not limited to:

- instrument efficiency
- background
- integration time
- surface type
- source to detector geometry
- source efficiency

A significant factor in determining an instrument MDC is the total efficiency, which is dependent on the instrument efficiency, the source efficiency and the type and energy of the radiation. MDC values are inversely affected by efficiency, as efficiencies increase, MDC values will decrease. Accounting for both the instrument and source components of the total efficiency provides for a more accurate assessment of surface activity.

3.0 Calibration Sources:

For accurate measurement of surface activity it is desirable that the field instrumentation be calibrated with source standards similar to the type and energy of the anticipated contamination. The nuclides listed in Table 3.1 illustrate the nuclides found in soil and building surface area DCGL results that are listed in the LTP.

Instrument response varies with incident radiations and energies; therefore, instrumentation selection for field surveys must be modeled on the expected surface activity. For the purposes of this report, isotopes with max beta energies less than that of C-14 (0.158 MeV) will be considered difficult to detect (reference table 3.1). The detectability of radionuclides with max beta energies less than 0.158 MeV, utilizing gas proportional detectors, will be negligible at typical source to detector distances of approximately 0.5

inches. The source to detector distance of 1.27 cm (0.5 inches) is the distance to the detector with the attached standoff (DP-8534 "Operation and Source Checks of Proportional Friskers")[8.5]. Table 3.1 provides a summary of the LTP radionuclides and their detectability using Radiological Health Handbook [8.4] data.

Table 3.1
Nuclides and Major Radiations: Approximate Energies (Reference 8.4)

Nuclide	α Energy (MeV)	$E_{\beta max}$ (MeV)	Average E_β (MeV)	Photon Energy (MeV)	α Detectable w/ Gas Proportional	β Detectable w/ Gas Proportional	γ Detectable w/ NaI 2x2"
H-3		0.018	0.005				
C-14		0.158	0.049				
Fe-55				0.23 (0.004%) bremsstrahlung			
Co-60		0.314	0.094	1.173 (100%), 1.332 (100%)		√	√
Ni-63		0.066	0.017				
Sr-90		0.544 2.245 (Y-90)	0.200 0.931			√	
Nb-94		0.50	0.156	0.702 (100%), 0.871 (100%)		√	√
Tc-99		0.295	0.085			√	
Ag-108m		1.65 (Ag-108)	0.624 (Ag-108)	0.434 (0.45%), 0.511 (0.56%) 0.615 (0.18%), 0.632 (1.7%)			√
Sb-125		0.612	0.084	0.6, 0.25, 0.41, 0.46, 0.68, 0.77, 0.92, 1.10, 1.34		√	√
Cs-134		1.453	0.152	0.57 (23%), 0.605 (98%) 0.796 (99%), 1.038 (1.0%) 1.168 (1.9%), 1.365 (3.4%)		√	√
Cs-137		1.167	0.195	0.662 (85%) Ba-137m X-rays		√	√
Eu-152		1.840	0.288	0.122 (37%), 0.245 (8%) 0.344 (27%), 0.779 (14%) 0.965 (15%), 1.087 (12%) 1.113 (14%), 1.408 (22%)		√	√
Eu-154		1.850 (10%)	0.228				
Eu-155		0.247	0.044	0.087 (32%), 0.105 (20%)		√	
Pu-238	5.50 (72%) 5.46 (28%)			0.099 (8E-3%) 0.150 (1E-3%) 0.77 (5E-5%)	√		
Pu-239	5.16 (88%) 5.11 (11%)			0.039 (0.007%), 0.052 (0.20%), 0.129 (0.005%)...	√		
Pu-241	4.90 (0.0019%) 4.85 (0.0003%)	0.021	0.005	0.145 (1.6E-4%)			
Am-241	5.49 (85%) 5.44 (13%)			0.060 (36%), 0.101 (0.04%)...	√		
Cm-243	6.06 (6%) 5.99 (6%) 5.79 (73%) 5.74 (11.5%)			0.209 (4%), 0.228 (12%), 0.278 (14%)	√		

NUREG-1507 and ISO 7503-1 provide guidance for selecting calibration sources and their use in determining total efficiency. It is common practice to calibrate instrument efficiency for a single beta energy; however the energy of this reference source should not be significantly greater than the beta energy of the lowest energy to be measured.

Tc-99 (0.295 MeV max) and Th-230 (4.68 MeV at 76% and 4.62 MeV at 24%) have been selected as the beta and alpha calibration standards respectively, because their energies conservatively approximate the beta and alpha energies of the plant specific radionuclides.

4.0 Efficiency Determination:

Typically, using the instrument 4π efficiency exclusively provides a good approximation of surface activity. Using these means for calculating the efficiency often results in an under estimate of activity levels in the field. Applying both the instrument 2π efficiency and the surface efficiency components to determine the total efficiency allows for a more accurate measurement due to consideration of the actual characteristics of the source surfaces. ISO 7503-1 [8.2] recommends that the total surface activity be calculated using:

$$A_s = \frac{R_{S+B} - R_B}{(\varepsilon_i)(W)(\varepsilon_s)},$$

where:
A_S is the total surface activity in dpm/cm^2,
R_{S+B} is the gross count rate of the measurement in cpm,
R_B is the background count rate in cpm,
ε_i is the instrument or detector 2π efficiency
ε_s is the efficiency of the source
W is the area of the detector window (cm^2)

4.1 Alpha and Beta Instrument Efficiency (ε_i):

Instrument efficiency (ε_i) reflects instrument characteristics and counting geometry, such as source construction, activity distribution, source area, particles incident on the detector per unit time and therefore source to detector geometry. Theoretically the maximum value of ε_i is 1.0, assuming all the emissions from the source are 2π and that all emissions from the source are detected. The ISO 7503-1 methodology for determining the instrument efficiency is similar to the historical 4π approach; however the detector response, in cpm, is divided by the 2π surface emission rate of the calibration source. The instrument efficiency is calculated by dividing the net count rate by the 2π surface emission rate ($q_{2\pi}$) (includes absorption in detector window, source detector geometry). The instrument efficiency is expressed in ISO 7503-1 by:

$$\varepsilon_i = \frac{R_{S+B} - R_B}{q_{2\pi}}$$

where:
R_{S+B} is the gross count rate of the measurement in cpm,
R_B is the background count rate in cpm,
$q_{2\pi}$ is the 2π surface emission rate in reciprocal seconds

Note that both the 2π surface emission rate and the source activity are usually stated on the certification sheet provided by the calibration source manufacturer and certified as National Institute of Standards and Technology (NIST) traceable. Table 4.1 depicts instrument efficiencies that have been determined during calibration using the 2π surface emission rate of the source.

Table 4.1
Instrument Efficiencies (ε_i)

Source	Emission	Active Area of Source (cm^2)	Effective Area of Detector	100 cm^2 Gas Proportional HP-100 Instrument Efficiency (ε_i) (Contact)
Tc-99	β	*15.2*	100 cm^2	0.4148
Th-230	α	*15.2*	100 cm^2	0.5545

4.2 Source to Detector Distance Considerations:
A major factor affecting instrument efficiency is source to detector distance. Consideration must be given to this distance when selecting accurate instrument efficiency. The distance from the source to the detector shall to be as close as practicable to geometric conditions that exist in the field. A range of source to detector distances has been chosen, taking into account site specific survey conditions. In an effort to minimize the error associated with geometry, instrument efficiencies have been determined for source to detector distances representative of those survey distances expected in the field. The results shown in Table 4.2 illustrate the imposing reduction in detector response with increased distance from the source. Typically this source to detector distance will be 0.5 inches for fixed point measurements and 0.5 inches for scan surveys on flat surfaces, however they may differ for other surfaces. Table 4.2 makes provisions for the selection of source to detector distances for field survey conditions of up to 2 inches. If surface conditions dictate the placement of the detector at distances greater than 2 inches instrument efficiencies will be determined on an as needed basis.

4.2.1 Methodology:
The practical application of choosing the proper instrument efficiency may be determined by averaging the surface variation (peaks and valleys narrower than the length of the detector) and adding 0.5 inches, the spacing that should be maintained between the detector and the highest peaks of the surface. Select the source to detector distance from Table 4.2 that best reflects this pre-determined geometry.

Table 4.2
Source to Detector Distance Effects on Instrument Efficiencies for α- β Emitters

Source to Detector Distance (cm)	Instrument Efficiency (ε_i)	
	Tc-99 Distributed	Th-230 Distributed
Contact	0.4148	0.5545
1.27 (0.5 in)	0.2413	0.1764
2.54 (1 in)	0.1490	0.0265
5.08 (2 in)	0.0784	0.0002

4.3 Source (or Surface) Efficiency (ε_s) Determination:

Source efficiency (ε_s), reflects the physical characteristics of the surface and any surface coatings. The source efficiency is the ratio between the number of particles emerging from surface and the total number of particles released within the source. The source efficiency accounts for attenuation and backscatter. ε_s is nominally 0.5 (no self-absorption/attenuation, no backscatter)–backscatter increases the value, self-absorption decreases the value. Source efficiencies may either be derived experimentally or simply selected from the guidance contained in ISO 7503-1. ISO 7503-1 takes a conservative approach by recommending the use of factors to correct for alpha and beta self-absorption/attenuation when determining surface activity. However, this approach may prove to be too conservative for radionuclides with max beta energies that are marginally lower than 0.400 MeV, such as Co-60 with a βmax of 0.314 MeV. In this situation, it may be more appropriate to determine the source efficiency by considering the energies of other beta emitting radionuclides. Using this approach it is possible to determine weighted average source efficiency. For example, a source efficiency of 0.375 may be calculated based on a 50/50 mix of Co-60 and Cs-137. The source efficiencies for Co-60 and Cs-137 are 0.25 and 0.5 respectively, since the radionuclide fraction for Co-60 and Cs-137 is 50% for each, the weighted average source efficiency for the mix may be calculated in the following manner:

$$(0.25)(0.5)+(0.5)(0.5)=0.375$$

Table 4.3 lists guidance on source efficiencies from ISO 7503-1.

Table 4.3
Source Efficiencies as listed in ISO 7503-1

	$> 0.400\ MeV_{max}$	$\leq 0.400\ MeV_{max}$
Beta emitters	$\varepsilon_s = 0.5$	$\varepsilon_s = 0.25$
Alpha emitters	$\varepsilon_s = 0.25$	$\varepsilon_s = 0.25$

It should be noted that source efficiency is not typically addressed for gamma detectors as the value is effectively unity.

5.0 Instrument Conversion Factor (E) (Instrument Efficiency for Scanning):

Separate modeling analysis (Microshield™) was conducted using the common gamma emitters with a concentration of 1 pCi/g of uniformly distributed contamination throughout the volume. MicroShield is a comprehensive photon/gamma ray shielding and dose assessment program, which is widely used throughout the radiological safety community. An activity concentration of 1 pCi/g for the nuclides was entered as the source term. The radial dimension of the cylindrical source was 28 cm, the depth was 15 cm, and the dose point above the surface was 10 cm with a soil density of 1.6 g/cm^3. The instrument efficiency when scanning, E_i, is the product of the modeled exposure rate (MicroShield™) in mRhr^{-1}/pCi/g for and the energy response factor in cpm/mR/hr as derived from the energy response curve provided by Eberline Instruments (Appendix O). Table 5.1 demonstrates the derived efficiencies for the major gamma emitting isotopes listed in Table 3.1.

TABLE 5.1
Energy Response and Efficiency for Photon Emitting Isotopes

Isotope	Calculations for E_i See appendix A through L	E_i (cpm/pCi/g)
Co-60	See Appendix Aand B	**379**
Nb-94	See Appendix C and D	**416**
Ag-108m	See Appendix E and F	**637**
Sb-125	See Appendix G and H	**210**
Cs-134	See Appendix I and J	**506**
Cs-137	See Appendix K and L	**188**
Eu-152	See Appendix M and N	**344**

When performing gamma scan measurements on soil surfaces the effective source to detector geometry is as close as is reasonably possible (less than 3 inches).

6.0 Applying Efficiency Corrections Based on the Effects of Field Conditions for Total Efficiency:

The total efficiency for any given condition can now be calculated from the product of the instrument efficiency ε_i and the source efficiency ε_s.

$$\varepsilon_{tot} = \varepsilon_i \times \varepsilon_s$$

The following example illustrates the process of determining total efficiency. For this example we will assume the following:

- Surface activity readings need to be made in the Primary Auxiliary Building (PAB) on the concrete wall surfaces using the E-600 and C-100 gas proportional detector.
- Data obtained from characterization results from the PAB indicate the presence of beta emitters with energies greater than 0.400 Mev.
- The source (activity on wall) to detector distance is 1.27 cm (0.5 in detector stand off). To calculate the total efficiency, ε_{tot}, refer to Table 4.2 "Source to Detector Distance Effects on Instrument Efficiencies for α- β Emitters" to obtain the appropriate ε_i value.
- Contamination on all surfaces is distributed relative to the effective detector area.

- When performing fixed point measurements with gas proportional instrumentation the effective source to detector geometry is representative of the calibrated geometries listed in Table 4.2 "Source to Detector Distance Effects on Instrument Efficiencies for α- β Emitters".
- Corrections for temperature and pressure are not substantial.

In this example, the value for ε_i is 0.2413 as depicted in Table 4.2 "Source to Detector Distance Effects on Instrument Efficiencies for α- β Emitters". The ε_s value of 0.5 is chosen refer to Table 4.3 "Source Efficiencies as listed in ISO 7503-1". Therefore the total efficiency for this condition becomes $\varepsilon_{tot} = \varepsilon_i \times \varepsilon_s = 0.2413 \times 0.5 = 0.121$ or 12.1%.

7.0 Conclusion:

Field conditions may significantly influence the usefulness of a survey instrument. When applying the instrument and source efficiencies in MDC calculations, field conditions must be considered. Tables have been constructed to assist in the selection of appropriate instrument and source efficiencies. Table 4.2 "Source to Detector Distance Effects on Instrument Efficiencies for α-β Emitters" lists instrument efficiencies (ε_i) at various source to detector distances for alpha and beta emitters. The appropriate ε_i value should be applied, accounting for the field condition, i.e. the relation between the detector and the surface to be measured.

Source efficiencies shall be selected from Table 4.3 "Source Efficiencies as listed in ISO 7503-1". This table lists conservative ε_s values that correct for self-absorption and attenuation of surface activity. Table 5.1 "Energy Response and Efficiency for Photon Emitting Isotopes" lists E_i values that apply to scanning MDC calculations. The Microshield™ model code was used to determine instrument efficiency assuming contamination conditions and detector geometry cited in section 5.6.2.4.4 "MDCs for Gamma Scans of Land Areas" of the License Termination Plan [8.6].

Detector and source conditions equivalent to those modeled herein may directly apply to the results of this report.

8.0 References

8.1 NUREG-1507, "Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions," 1998

8.2 ISO 7503-1, "Evaluation of Surface Contamination – Part I: Beta Emitters and Alpha Emitters," 1988-08-01.

8.3 ISO 8769, "Reference Sources for the Calibration of Surface Contamination Monitors- Beta-emitters (maximum beta energy greater 0.15MeV) and Alpha-emitters," 1988-06-15.

8.4 "Radiological Health Handbook," Revised Edition 1970.

8.5 DP-8534, "Operation and source Checks of Portable Friskers".

8.6 Yankee Nuclear Plant Site License Termination Plan, Rev.0, November 2003.

APPENDIX A

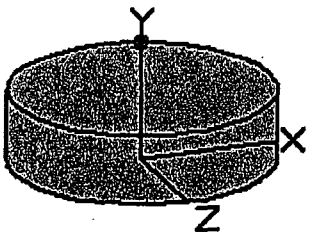
MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Co-60.ms6	**Date**	:
Run Date	: September 10, 2004	**By**	:
Run Time	: 8:56:50 AM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA3-EFF-Co-60
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Co-60
Geometry: 8 - Cylinder Volume - End Shields

Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)



Dose Points

A	**X**	**Y**	**Z**
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	**Dimension**	**Material**	**Density**
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	**curies**	**becquerels**	**µCi/cm³**	**Bq/cm³**
Co-60	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

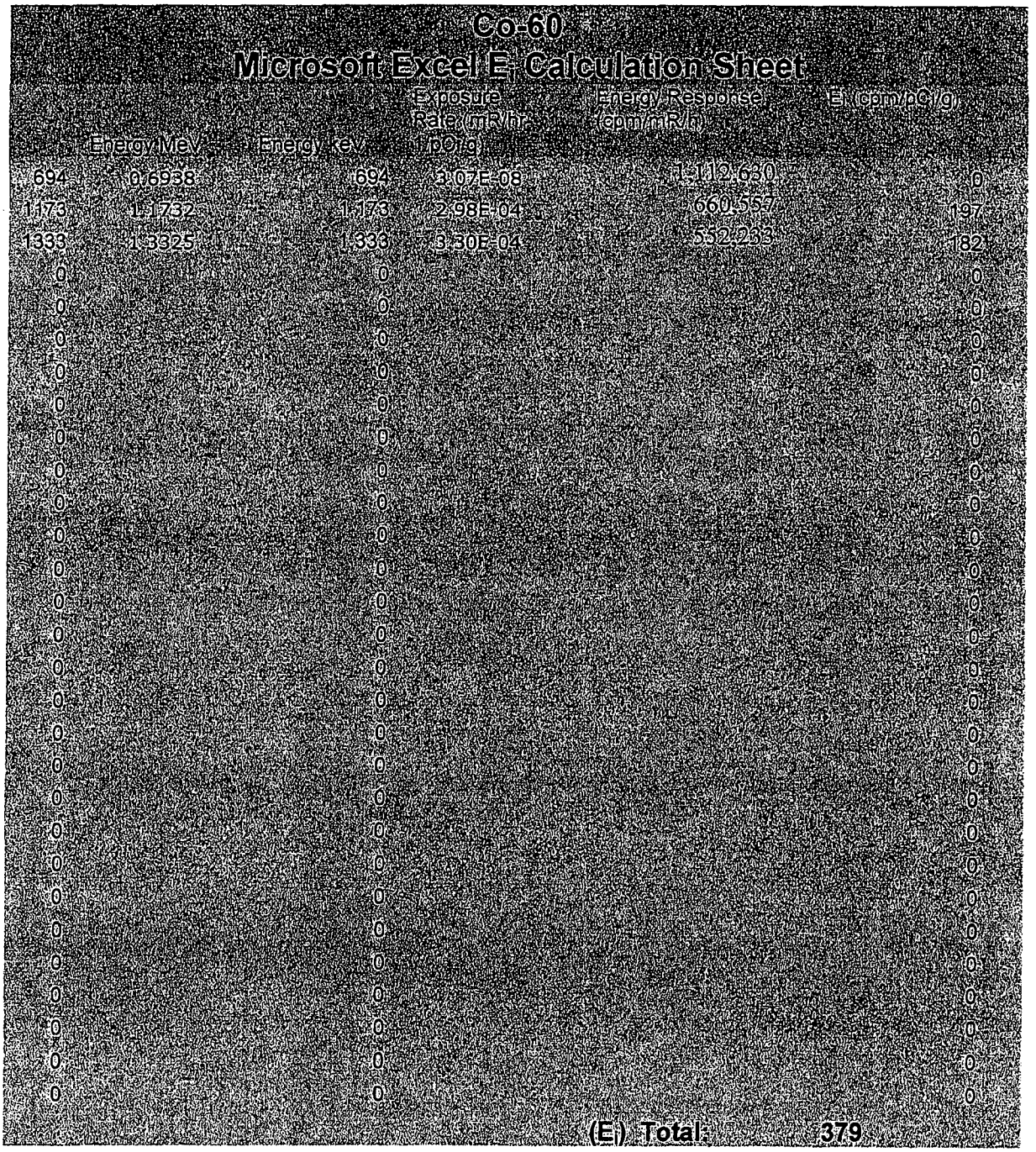
Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	**Activity Photons/sec**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.6938	2.230e-01	9.055e-06	1.590e-05	1.748e-08	3.070e-08
1.1732	1.367e+03	1.098e-01	1.669e-01	1.962e-04	2.982e-04
1.3325	1.367e+03	1.293e-01	1.904e-01	2.244e-04	3.303e-04
Totals	**2.734e+03**	**2.391e-01**	**3.573e-01**	**4.205e-04**	**6.286e-04**

APPENDIX B



Co-60

Microsoft Excel E Calculation Sheet

	Energy MeV	Energy keV	Exposure Rate, mR/hr (pCi/g)	Energy Response (cpm/mR/h)	Ei (cpm/pCi/g)
694	0.6938	694	3.07E-08	1,912,630	0
1173	1.1732	1,173	2.98E-04	660,557	197
1333	1.3325	1,333	3.30E-04	552,233	182
0		0			0
0		0			0
0		0			0

APPENDIX C

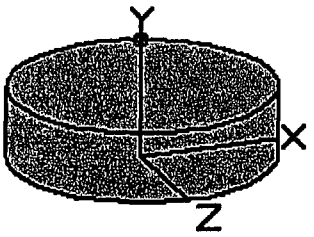
MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Nb-94.ms6	**Date**	:
Run Date	: September 16, 2004	**By**	:
Run Time	: 3:22:38 PM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA3-EFF-Nb-94
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Nb-94
Geometry: 8 - Cylinder Volume - End Shields

Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)



Dose Points

A	**X**	**Y**	**Z**
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	**Dimension**	**Material**	**Density**
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	**curies**	**becquerels**	**µCi/cm³**	**Bq/cm³**
Nb-94	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	**Activity Photons/sec**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.0023	9.067e-02	1.391e-10	1.430e-10	1.861e-10	1.913e-10
0.0174	4.834e-01	8.762e-09	9.129e-09	4.729e-10	4.927e-10
0.0175	9.260e-01	1.719e-08	1.792e-08	9.104e-10	9.491e-10
0.0196	2.720e-01	7.924e-09	8.356e-09	2.925e-10	3.085e-10
0.7026	1.367e+03	5.643e-02	9.872e-02	1.088e-04	1.904e-04
0.8711	1.367e+03	7.464e-02	1.228e-01	1.405e-04	2.312e-04
Totals	**2.736e+03**	**1.311e-01**	**2.216e-01**	**2.493e-04**	**4.216e-04**

APPENDIX D

Nb-94

Energy MeV	Energy keV	Exposure Rate (mR/hr / pCi/g)	Energy Response (cpm/mR/h)	Ei, cpm/pCi/g
0.0023	2	1.91E-10		0
0.0174	17	4.93E-10		0
0.0175	18	9.49E-10		0
0.0196	20	3.09E-10		0
0.7026	703	1.90E-04	1,110,370	211
0.8711	871	2.31E-04	884,689	205
	0			0
	0			0
	0			0

APPENDIX E

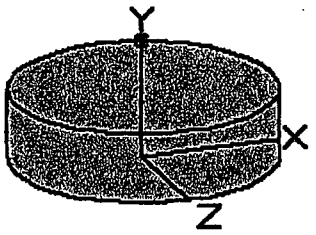
MicroShield v6.02 (6.02-00253)

Page	:1		
DOS File	:SPA3-EFF-Ag-108m.ms6	**File Ref**	:
Run Date	: September 16, 2004	**Date**	:
Run Time	: 3:30:40 PM	**By**	:
Duration	: 00:00:00	**Checked**	:

Case Title: SPA3-EFF-Ag-108m
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Ag-108m
Geometry: 8 - Cylinder Volume - End Shields

Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)



Dose Points

A	**X**	**Y**	**Z**
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	**Dimension**	**Material**	**Density**
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	**curies**	**becquerels**	**µCi/cm³**	**Bq/cm³**
Ag-108m	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	**Activity Photons/sec**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.0028	6.580e+01	1.252e-07	1.287e-07	1.351e-07	1.388e-07
0.003	7.853e+00	1.568e-08	1.612e-08	1.612e-08	1.657e-08
0.021	2.491e+02	9.534e-06	1.015e-05	2.824e-07	3.007e-07
0.0212	4.727e+02	1.862e-05	1.985e-05	5.389e-07	5.744e-07
0.022	7.024e+00	3.202e-07	3.434e-07	8.233e-09	8.831e-09
0.0222	1.330e+01	6.251e-07	6.714e-07	1.568e-08	1.685e-08
0.0238	1.501e+02	9.273e-06	1.010e-05	1.863e-07	2.029e-07
0.0249	4.289e+00	3.145e-07	3.464e-07	5.492e-09	6.050e-09
0.0304	2.902e-04	4.431e-11	5.248e-11	4.230e-13	5.010e-13
0.0792	9.687e+01	2.008e-04	4.802e-04	3.190e-07	7.629e-07
0.4339	1.229e+03	2.705e-02	5.514e-02	5.294e-05	1.079e-04
0.6144	1.236e+03	4.282e-02	7.808e-02	8.347e-05	1.522e-04
0.7229	1.237e+03	5.300e-02	9.194e-02	1.019e-04	1.768e-04
Totals	**4.768e+03**	**1.231e-01**	**2.257e-01**	**2.398e-04**	**4.389e-04**

APPENDIX F

Ag-108m
Microsoft Excel E_i Calculation Sheet

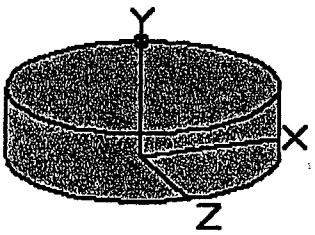
	Energy MeV	Energy kev	Exposure Rate (mR/hr /pCi/g)	Energy Response (cpm/mR/h	Ei (cpm/pCi/g)
3	0.0028	3	1.39E-07		0
3	0.003	3	1.66E-08		0
21	0.021	21	3.01E-07		0
21	0.0212	21	5.74E-07		0
22	0.022	22	8.83E-09		0
22	0.0222	22	1.69E-08		0
24	0.0238	24	2.03E-07		0
25	0.0249	25	6.05E-09		0
30	0.0304	30	5.01E-13	1086720	0
79	0.0792	79	7.63E-07	11696000	9
434	0.4339	434	1.08E-04	2061265	222
614	0.6144	614	1.52E-04	1402440	213
723	0.7229	723	1.77E-04	1086291	192
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
				(Ei) Total:	637

APPENDIX G

MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Sb-125.ms6	**Date**	:
Run Date	: September 16, 2004	**By**	:
Run Time	: 3:34:07 PM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA3-EFF-Sb-125
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Sb-125
Geometry: 8 - Cylinder Volume - End Shields



Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)

Dose Points

A	X	Y	Z
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	curies	Becquerels	µCi/cm³	Bq/cm³
Sb-125	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	Activity Photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0038	6.762e+01	1.708e-07	1.756e-07	1.388e-07	1.427e-07
0.0272	1.748e+02	1.785e-05	2.020e-05	2.376e-07	2.689e-07
0.0275	3.262e+02	3.453e-05	3.922e-05	4.461e-07	5.067e-07
0.031	1.132e+02	1.857e-05	2.221e-05	1.670e-07	1.997e-07
0.0355	5.693e+01	1.492e-05	1.918e-05	9.090e-08	1.169e-07
0.117	3.568e+00	1.380e-05	3.715e-05	2.146e-08	5.778e-08
0.159	9.531e-01	5.634e-06	1.499e-05	9.416e-09	2.505e-08
0.1726	2.478e+00	1.634e-05	4.295e-05	2.787e-08	7.326e-08
0.1763	9.422e+01	6.392e-04	1.674e-03	1.096e-06	2.870e-06
0.2041	4.410e+00	3.630e-05	9.230e-05	6.435e-08	1.636e-07
0.2081	3.324e+00	2.805e-05	7.103e-05	4.994e-08	1.264e-07
0.2279	1.796e+00	1.708e-05	4.229e-05	3.098e-08	7.670e-08
0.321	5.701e+00	8.474e-05	1.899e-04	1.620e-07	3.632e-07
0.3804	2.045e+01	3.792e-04	8.052e-04	7.364e-07	1.564e-06
0.408	2.486e+00	5.051e-05	1.049e-04	9.853e-08	2.047e-07
0.4279	4.009e+02	8.668e-03	1.774e-02	1.695e-05	3.470e-05
0.4435	4.130e+00	9.356e-05	1.894e-04	1.832e-07	3.709e-07
0.4634	1.415e+02	3.395e-03	6.781e-03	6.658e-06	1.330e-05
0.6006	2.430e+02	8.174e-03	1.501e-02	1.595e-05	2.930e-05
0.6066	6.864e+01	2.340e-03	4.283e-03	4.564e-06	8.355e-06
0.6359	1.548e+02	5.609e-03	1.012e-02	1.091e-05	1.967e-05
0.6714	2.478e+01	9.640e-04	1.710e-03	1.867e-06	3.311e-06
Totals	**1.916e+03**	**3.060e-02**	**5.901e-02**	**6.046e-05**	**1.158e-04**

APPENDIX H

Sb-125

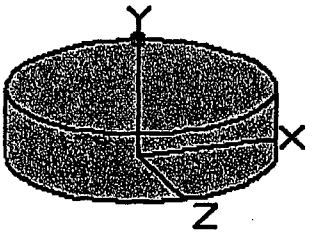
Energy MeV	Energy keV	Exposure Rate (mR/hr, 1pCi/g)	Energy Response (cpm/mR/h)	Ei (cpm/pCi/g)	Ei
4	0.0038	4	1.43E-07	6618312	0
27	0.0272	27	2.69E-07	510290	0
28	0.0275	28	5.07E-07	554334	0
31	0.031	31	2.00E-07	1219281	0
36	0.0355	36	1.17E-07	2418948	0
117	0.117	117	5.78E-08	9167000	1
159	0.159	159	2.51E-08	8917000	0
173	0.1726	173	7.33E-08	6859000	1
176	0.1763	176	2.87E-06	6192600	18
204	0.2041	204	1.64E-07	6011300	1
208	0.2081	208	1.26E-07	4073050	1
228	0.2279	228	7.67E-08	3110500	0
321	0.321	321	3.63E-07	3000500	1
380	0.3804	380	0.000001564	2348000	4
408	0.408	408	2.047E-07	2155800	0
428	0.4279	428	0.0000347	2083165	72
444	0.4435	444	3.709E-07	2026225	1
463	0.4634	463	0.0000133	1953590	26
601	0.6006	601	0.0000293	1452810	43
607	0.6066	607	0.000008355	1430910	12
636	0.6359	636	0.00001967	1323965	26
671	0.6714	671	0.00000311	1194390	4
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
			(Ei) Total:		210

APPENDIX I

MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Cs-134.ms6	**Date**	:
Run Date	: September 16, 2004	**By**	:
Run Time	: 3:39:09 PM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA3-EFF-Cs-134
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Cs-134
Geometry: 8 - Cylinder Volume - End Shields



Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)

Dose Points

A	X	Y	Z
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Cs-134	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	Activity Photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	1.222e+00	3.658e-09	3.760e-09	2.507e-09	2.577e-09
0.0318	2.931e+00	5.271e-07	6.386e-07	4.391e-09	5.320e-09
0.0322	5.407e+00	1.014e-06	1.236e-06	8.157e-09	9.943e-09
0.0364	1.968e+00	5.611e-07	7.321e-07	3.188e-09	4.160e-09
0.2769	4.839e-01	5.931e-06	1.391e-05	1.113e-08	2.610e-08
0.4753	1.996e+01	4.950e-04	9.808e-04	9.712e-07	1.924e-06
0.5632	1.146e+02	3.545e-03	6.648e-03	6.940e-06	1.302e-05
0.5693	2.109e+02	6.619e-03	1.237e-02	1.295e-05	2.421e-05
0.6047	1.334e+03	4.529e-02	8.300e-02	8.836e-05	1.619e-04
0.7958	1.167e+03	5.668e-02	9.564e-02	1.079e-04	1.820e-04
0.8019	1.193e+02	5.852e-03	9.853e-03	1.113e-05	1.874e-05
1.0386	1.367e+01	9.377e-04	1.472e-03	1.717e-06	2.696e-06
1.1679	2.461e+01	1.964e-03	2.990e-03	3.514e-06	5.349e-06
1.3652	4.156e+01	4.055e-03	5.936e-03	6.993e-06	1.024e-05
Totals	**3.058e+03**	**1.254e-01**	**2.189e-01**	**2.405e-04**	**4.202e-04**

APPENDIX J

Cs-134

Microsoft Excel E_i Calculation Sheet

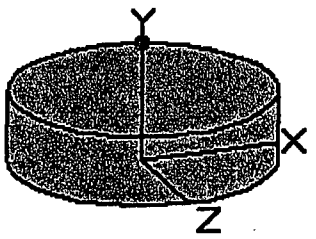
	Energy MeV	Energy keV	Exposure Rate (mR/h-1 pCi/g)	Energy Response (cpm/mR/h)	Ei (cpm/pCi/g)
15	0.0045	5	2.58E-09		0
32	0.0318	32	5.32E-09	1,406,947	0
32	0.0322	32	5.94E-09	1,505,273	0
36	0.0364	36	4.16E-09	2,696,122	0
277	0.2769	277	2.61E-08	3,637,000	0
475	0.4753	475	1.92E-06	1,910,155	4
563	0.5632	563	1.30E-05	1,589,320	21
569	0.5693	569	2.42E-05	1,567,055	38
605	0.6047	605	1.62E-04	1,437,845	233
796	0.7958	796	1.82E-04	998,082	182
802	0.8019	802	1.87E-05	939,149	18
1039	1.0386	1,039	2.70E-06	752,085	2
1168	1.1679	1,168	5.35E-06	664,161	4
1365	1.3652	1,365	1.02E-05	573,136	6
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
0		0			0
			(Ei) Total:		**506**

APPENDIX K

MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Cs-137.ms6	**Date**	:
Run Date	: September 10, 2004	**By**	:
Run Time	: 8:52:18 AM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA3-EFF-Cs-137
Description: SPA-3 Soil scan - 28 cm radius 1pCi/cm3 Cs-137 and Daughters
Geometry: 8 - Cylinder Volume - End Shields



Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)

Dose Points

A	X	Y	Z
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.4950e-008	1.2932e+003	9.4600e-007	3.5002e-002
Cs-137	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	Activity Photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	1.342e+01	4.020e-08	4.133e-08	2.755e-08	2.833e-08
0.0318	2.677e+01	4.815e-06	5.834e-06	4.011e-08	4.860e-08
0.0322	4.939e+01	9.260e-06	1.129e-05	7.452e-08	9.084e-08
0.0364	1.797e+01	5.126e-06	6.688e-06	2.912e-08	3.800e-08
0.6616	1.164e+03	4.442e-02	7.913e-02	8.611e-05	1.534e-04
Totals	**1.271e+03**	**4.444e-02**	**7.915e-02**	**8.628e-05**	**1.536e-04**

APPENDIX L

Cs-137
Microsoft Excel E_i Calculation Sheet

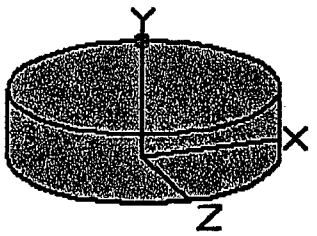
	Energy MeV	Energy kev	Exposure Rate (mR/hr per 1 pCi/g)	Energy Response (cpm/mR/h)	Ei (cpm/pCi/g)
5	0.0045	5	2.83E-08		0
32	0.0318	32	4.86E-08	1,406,947	0
32	0.0322	32	9.08E-08	1,505,273	0
36	0.0364	36	3.80E-08	2,696,122	0
662	0.6616	662	1.53E-04	1,228,700	188
0		0			0
0		0			0
0		0			0

APPENDIX M

MicroShield v6.02 (6.02-00253)

Page	:1	**File Ref**	:
DOS File	:SPA3-EFF-Eu-152.ms6	**Date**	:
Run Date	: October 7, 2004	**By**	:
Run Time	: 11:25:11 AM	**Checked**	:
Duration	: 00:00:00		

Case Title: SPA-3-EFF-Eu-152
Description: SPA-3 Soil scan - 28cm radius 1 pCi/cm3 Eu-152
Geometry: 8 - Cylinder Volume - End Shields



Source Dimensions:

Height	15.0 cm	(5.9 in)
Radius	28.0 cm	(11.0 in)

Dose Points

A	X	Y	Z
# 1	0 cm	25 cm	0 cm
	0.0 in	9.8 in	0.0 in

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm³	Concrete	1.6
Air Gap		Air	0.00122

Source Input : Grouping Method - Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Included
Library : Grove

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Eu-152	3.6945e-008	1.3670e+003	1.0000e-006	3.7000e-002

Buildup : The material reference is - Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy MeV	Activity Photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	2.077e+02	2.087e-06	2.146e-06	1.790e-07	1.841e-07
0.04	8.088e+02	3.131e-04	4.331e-04	1.385e-06	1.916e-06
0.05	2.022e+02	1.507e-04	2.467e-04	4.014e-07	6.572e-07
0.1	3.887e+02	1.189e-03	3.118e-03	1.819e-06	4.770e-06
0.2	1.024e+02	8.207e-04	2.097e-03	1.448e-06	3.700e-06
0.3	3.696e+02	5.029e-03	1.151e-02	9.540e-06	2.184e-05
0.4	8.590e+01	1.701e-03	3.555e-03	3.314e-06	6.926e-06
0.5	7.711e+00	2.043e-04	3.984e-04	4.010e-07	7.819e-07
0.6	5.797e+01	1.948e-03	3.579e-03	3.802e-06	6.985e-06
0.8	2.434e+02	1.190e-02	2.005e-02	2.263e-05	3.813e-05
1.0	5.849e+02	3.820e-02	6.058e-02	7.042e-05	1.117e-04
1.5	3.171e+02	3.490e-02	4.999e-02	5.871e-05	8.411e-05
Totals	**3.376e+03**	**9.635e-02**	**1.556e-01**	**1.740e-04**	**2.817e-04**

APPENDIX N

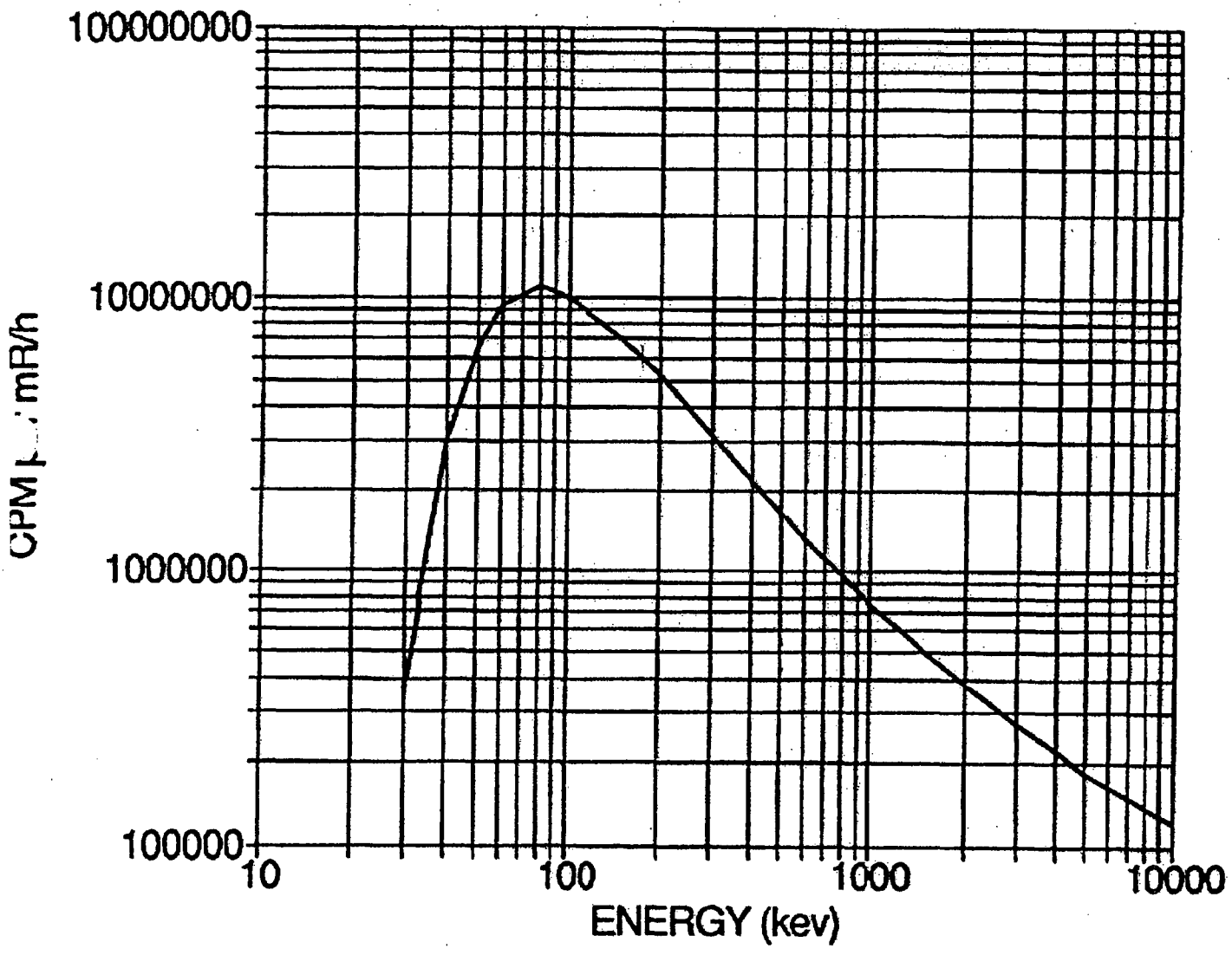
Eu-152

	Energy, MeV	Energy, keV	Exposure Rate (mR/h per Bq)	Energy Response (cpm/mR/h)	E*(cpm*Bq/g)
15	0.015	15	1.84E-07		0
40	0.04	40	1.92E-06	3,897,600	7
50	0.05	50	8.57E-07	6,500,000	4
100	0.1	100	4.77E-06	9,958,333	48
200	0.2	200	3.70E-06	4,850,000	18
300	0.3	300	2.18E-05	3,200,000	70
400	0.4	400	6.93E-06	2,185,000	15
500	0.5	500	7.82E-07	1,820,000	1
600	0.6	600	6.99E-06	1,455,000	10
800	0.8	800	3.81E-05	993,000	38
1000	1	1,000	1.12E-04	783,019	87
1500	1.5	1,500	8.41E-05	530,000	45
0		0			0
0		0			0
0		0			0

APPENDIX O

Calculated Energy Response (Eberline Instruments)

CPM/mR/h



ALARA Analysis Worksheet

Survey Area: NSY-12 **Survey Unit:** 01 .

A. Estimation of Total Cost ($Cost_T$)

1. Cost of performing remediation work ($Cost_R$) (assume 3-staff crew for 1 day@average $60 per hour; cost for heavy equipment not included)	$ 1800
2. Cost of waste disposal ($Cost_{WD}$) = (2.a) · (2.b) a. estimated waste volume: 1 m^3 b. cost of waste disposal: $670/$m^3$	$ 670
3. Cost of workplace accident ($Cost_{ACC}$) = \$3,000,000 $person^{-1}$ · $4.2x10^{-8}$ h^{-1} · (3.a) a. time to perform remediation action: 30 person-hours	$ 3.78
4. Cost of traffic fatality ($Cost_{TF}$) = {\$3,000,000 · $3.8x10^{-8}$ km^{-1} · (2.a) · (4.a)}/(4.b) a. total distance traveled per shipment: 4100 km b. waste volume per shipment: 13.6 m^3, if unknown, use 13.6m^3 as a default value	$ 34.37
5. Cost of worker dose ($Cost_{WDose}$) = \$2,000 per person-rem · (5.a) · (5.b) a. worker TEDE: _____ rem/h b. remediation exposure time _____ person-hour	$ 0
$Cost_T$	$ 2508

B. Survey Unit Radiological Information

Radionuclide	Average Concentration	Relative Fraction[a]	Half-Life (y)	Decay Constant[b] (y^{-1})
1. Co-60	a. 6622 dpm/100cm^2	b. 1	c. 5.271	d. 0.13
2.	a.	b.	c.	d.
3.	a.	b.	c.	d.
4.	a.	b.	c.	d.
5.	a.	b.	c.	d.
6.	a.	b.	c.	d.
7.	a.	b.	c.	d.
8.	a.	b.	c.	d.

Total Concentration: _____

[a] Relative fraction = average concentration divided by the total concentration.

[b] Decay constant = 0.693 divided by half-life.

C. Calculation of ALARA Action Level (AL)

1. Removable fraction for remediation action being evaluated: 1.0

2. Monetary discount rate: 0.03 y^{-1}

3. Number of years over which the collective dose is calculated: 1000 y

4. Population density for the critical group: 0.0004 people/m^2

5. Area being evaluated: 100 m^2

6. AL for each radionuclide-of-interest:

a. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.1.d)/(1-e^{-(C.2+B.1..d) \cdot C.3}\} \cdot \{B.1.b\} =$ 1356

b. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.2.d)/(1-e^{-(C.2+B.2..d) \cdot C.3}\} \cdot \{B.2.b\} =$ _____

c. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.3.d)/(1-e^{-(C.2+B.3..d) \cdot C.3}\} \cdot \{B.3.b\} =$ _____

d. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.4.d)/(1-e^{-(C.2+B.4..d) \cdot C.3}\} \cdot \{B.4.b\} =$ _____

e. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.5.d)/(1-e^{-(C.2+B.5..d) \cdot C.3}\} \cdot \{B.5.b\} =$ _____

f. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.6.d)/(1-e^{-(C.2+B.6..d) \cdot C.3}\} \cdot \{B.6.b\} =$ _____

g. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.7.d)/(1-e^{-(C.2+B.7..d) \cdot C.3}\} \cdot \{B.7.b\} =$ _____

h. $AL = \{Cost_T/(\$2000 \cdot C.4 \cdot 0.025 \cdot C.1 \cdot C.5)\} \cdot \{(C.2 + B.8.d)/(1-e^{-(C.2+B.8..d) \cdot C.3}\} \cdot \{B.8.b\} =$ _____

7..... Sum of ALs (= ALARA AL) = 1356

D. ALARA Evaluation

Radionuclide	DCGL	DCGL Fraction[a]
1. Co-60	a 6622 dpm/100cm^2	b. (B.1.a)/(D.1.a) = 1.0
2. _____	a. _____	b. (B.2.a)/(D.3.a) = _____
3. _____	a. _____	b. (B.3.a)/(D.4.a) = _____
4. _____	a. _____	b. (B.4.a)/(D.5.a) = _____
5. _____	a. _____	b. (B.5.a)/(D.6.a) = _____
6. _____	a. _____	b. (B.7.a)/(D.7.a) = _____
7. _____	a. _____	b. (B.8.a)/(D.8.a) = _____
8. _____	a. _____	b. (B.9.a)/(D.9.a) = _____

9.....Sum of DCGL Fractions = 1.0

[a] DCGL fraction = average residual concentration in survey unit (from Section B) divided by the DCGL.

10. Comparison of the sum of the DCGL fractions (D.9) to ALARA AL (C.7):

Check one: Sum of the DCGL Fractions < ALARA AL ✓ Sum of the DCGL Fractions > ALARA AL _____

12. **Decision Criteria**: If the sum of the DCGL fractions < AL, then additional remediation is not cost beneficial. If the sum of the DCGL fractions > AL, then additional remediation is cost beneficial.

Check one: Additional remediation **IS NOT** cost beneficial ✓

Additional remediation **IS** cost beneficial _____

Prepared by J. Bisson Date 11-9-05
FSS Radiological Engineer

Reviewed by D. C. Smith Date 11/17/05
FSS Project Manager