OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION
Managed by ORAU for DOE

September 23, 2016

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**SUBJECT: PROJECT-SPECIFIC PLAN FOR THE CONFIRMATORY SURVEY OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY HARMON AVENUE COMPLEX ON THE UNIVERSITY OF NEVADA, LAS VEGAS CAMPUS IN LAS VEGAS, NEVADA**
**[RFTA No. 16-014, Docket No. 0300698I]**
**DCN 5297-PL-01-0**

Dear Ms. Browder:

ORAU, operating under the Oak Ridge Institute for Science and Education (ORISE) contract, is pleased to provide the enclosed final project-specific plan for the independent confirmatory survey in support of the U.S. Environmental Protection Agency's partial site release request of the Harmon Avenue Complex in Las Vegas, Nevada. Comments on the draft have been incorporated.

Please feel free to contact me at 865.574.0685 or Tim Vitkus at 865.576.5073 if you have any questions.

Sincerely,

David A. King, CHP, PMP
Sr. Health Physicist/Project Manager
ORAU

DAK:lw

Enclosure

electronic distribution: T. Carter, NRC; T. Vitkus, ORAU; E. Bailey, ORAU; D. Hagemeyer, ORAU; File/5297

| Distribution approval and concurrence: | Initials |
|---|---|
| Technical/Group Manager Review | /T for T. Vitkus |

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# PROJECT-SPECIFIC PLAN FOR THE CONFIRMATORY SURVEY OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY HARMON AVENUE COMPLEX ON THE UNIVERSITY OF NEVADA, LAS VEGAS CAMPUS IN LAS VEGAS, NEVADA


Prepared by
D.A. King
ORAU

**SEPTEMBER 2016**

**FINAL PLAN**

Prepared for the
U.S. Nuclear Regulatory Commission

Prepared by Oak Ridge Associated Universities under the Oak Ridge Institute for Science and Education contract, number DE-SC0014664, with the U.S. Department of Energy under interagency agreement (NRC FIN No. F-1244) between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

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## ACRONYMS

| | |
|---|---|
| AA | alternate action |
| CFR | Code of Federal Regulations |
| CHL | Chemistry Laboratory |
| CU | confirmatory unit |
| DCGL | derived concentration guideline levels |
| DQO | data quality objective |
| EAX | Exposure Assessment Annex |
| EPA | U.S. Environmental Protection Agency |
| EXC | Executive Center |
| FSSR | final status survey report |
| HAC | Harmon Avenue Complex |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual |
| MDC | minimum detectable concentration |
| MSL | Monitoring Systems Laboratory |
| NCRFO | National Center for Radiation Field Operations |
| NRC | U.S. Nuclear Regulatory Commission |
| OAR | Office of Air and Radiation |
| ORD | Office of Research and Development |
| ORISE | Oak Ridge Institute for Science and Education |
| POS | Program Operations Support |
| PSQ | principal study question |
| QAL | Quality Assurance Laboratory |
| ROC | radionuclide of concern |
| UNLV | University of Nevada Las Vegas |

# PROJECT-SPECIFIC PLAN FOR THE CONFIRMATORY SURVEY OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY HARMON AVENUE COMPLEX ON THE UNIVERSITY OF NEVADA, LAS VEGAS CAMPUS IN LAS VEGAS, NEVADA

## 1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) has requested that ORAU, via the Oak Ridge Institute for Science and Education (ORISE) contract, perform confirmatory surveys of three buildings located within the U.S. Environmental Protection Agency's (EPA) Harmon Avenue Complex (HAC) on the campus of the University of Nevada, Las Vegas (UNLV). The HAC is located at 944 East Harmon Avenue, Las Vegas, Nevada, and includes the Exposure Assessment Annex (EAX), Quality Assurance Laboratory (QAL) building, and Monitoring Systems Laboratory (MSL) (sometimes called Program Operations Support [POS] building).

The EPA Office of Research and Development (ORD) and Office of Air and Radiation (OAR) operates the HAC under the National Center for Radiation Field Operations' (NCRFO) NRC radioactive materials License #27-05861-02. EPA's current lease of the HAC with UNLV expires on September 30, 2016, and they would like the facilities cleared prior to the lease's expirations date. EPA has ceased radiological operations and cleared the movable contents out of the buildings. When EPA turns over these buildings, it is anticipated that UNLV will reoccupy the space with the exception of the EAX, which will be demolished (EPA 2016A). EPA performed a final status survey using guidance found in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). ORAU will perform an independent radiological survey to confirm that residual surface activity levels for the radionuclides of concern (ROCs), primarily Pb-210 and Am-241, to satisfy derived concentration guideline levels (DCGLs) and to ensure that the EPA's final status survey data accurately represent final site conditions.

## 2. SITE DESCRIPTION AND HISTORY

The HAC is located on the north side of East Harmon Avenue, approximately 0.5 kilometers east of its intersection with Swenson Street, on the UNLV campus in Las Vegas, Nevada. The HAC consists of a complex of five separate buildings on a contiguous piece of property and associated

parking lots. From west to east (left to right) in Figure 3.1 (EPA 2016A), the buildings include the EAX, the QAL building, the MSL/POS building, the Executive Center (EXC) building, and the Chemistry Laboratory (CHL) building. The facilities house laboratories, offices, common areas, and office supply, equipment, & hazardous material storage areas. Only EAX, QAL and about one-third of the MSL/POS are included in the scope of this confirmatoty effort, as indicated in red in Figure 2.1.

Construction of the buildings was completed between 1966 and 1967 with the exception of an addition to the EAX, which was completed in 1976. The EAX building was formerly used as a greenhouse and is mostly constructed of steel framing on a slab-on-grade foundation. Corrugated and flat sheet-metal panels cover the exterior walls and roof of the structure, which replaced glass panels that formerly covered the greenhouse. The northern portion of this structure is constructed of concrete brick walls and a flat built-up roof. QAL and POS are one-story structures constructed on slab-on-grade foundations of concrete brick walls, with some exterior stucco and stone veneer features, and flat built-up roofs. EXC is a similarly constructed two-story building with a concrete basement foundation under a small portion of the structure and a slab-on-grade foundation under the remainder of the structure. CHL is constructed similarly to the QAL and POS (EPA 2016A).


Figure 2.1. HAC – University of Nevada, Las Vegas

EPA's work at this facility emphasizes radiological monitoring, environmental sampling, radionuclide translocation and uptake studies, analytical chemistry and characterizing chemical and physical stressors based on ecological exposure. ORD and OAR Laboratory staff activities typically involve field-based sample collection, monitoring ecological exposures, computer-based modeling, radioactive contamination site assessments, applying monitoring technology, and laboratory work—both chemical and radiological (EPA 2016a).

## 3. PROJECT AND DATA QUALITY OBJECTIVES

The project objective is to provide an authoritative and unbiased assessment of the licensee's final status survey data and conclusions that may be used to independently evaluate the suitability of the HAC partial site release. ORAU will perform these tasks through the application of a formal data quality objectives (DQOs) process for planning confirmatory investigations, performing independent radiation surveys, and ensuring that the type, quality, and quantity of data collected are adequate for the intended decision applications. The DQO development process consists of the following seven steps:

1. State the problem
2. Identify the decision/objective
3. Identify inputs to the decision/objective
4. Define the study boundaries
5. Develop a decision rule
6. Specify limits on decision errors
7. Optimize the design for obtaining data

DQO definition, implementation, and assessment can be considered an iterative process as newly collected data may form the basis for redefining the confirmatory objective. Examination and analysis of comprehensive data sets (i.e., historical data plus newly collected data for a specific population) may result in the formation of new decisions and objectives, requiring the seven DQO steps be repeated.

### STEP 1 – STATE THE PROBLEM

The first step in the DQO process defines the problem that necessitates the study, identifies the planning team, and examines the budget and schedule. ORAU has been selected to perform independent document reviews and to collect radiological data to ensure that the licensee's final status survey data and reports are adequate for demonstrating that the requirements for radiological release under 10 CFR 20, Subpart E have been met. Based on this, the problem statement is as follows:

> An independent confirmatory assessment is required that ensures that residual radioactivity in the UNLV HAC areas requested for partial site release satisfy the requirements in 10 CFR 20, Subpart E.

### STEP 2 – IDENTIFY THE DECISION/OBJECTIVE

The second step in the DQO process identifies the principal study question(s) (PSQs) and alternate actions (AAs), develops a decision statement, and organizes multiple decisions, as appropriate. This is done by specifying AAs that could result from a "yes" response to the PSQ and combining the PSQ and AAs into a decision statement. Table 3.1 presents the PSQ and AAs combined into the decision statement.

**Table 3.1. Independent Confirmation Survey Decision**

| Principal Questions | Actions |
|---|---|
| **PSQ1:** Are radioactive surface activity levels less than limits for release without radiological restrictions and/or below expected levels for the survey unit classification and therefore provide sufficient evidence that survey procedures were appropriately planned and implemented? | **Yes:** The licensee's surface activity results are less than the DCGLs; are within, or less than, the survey unit classification levels and therefore were properly classified.<br>**No:** Should confirmatory activities identify undocumented and/or unacceptable levels of residual contamination in a survey unit classification, determine the magnitude of the finding(s) (number of anomalies identified, size of the anomalies, classification of the area where they were identified) and determine the site's proposed remedy. Document probable cause/deficiencies and reevaluate confirmatory DQOs. |

| Table 3.1. Independent Confirmation Survey Decision | |
|---|---|
| **Principal Questions** | **Actions** |
| **PSQ2:** Do ORAU and site data agree for selected survey units and does the licensee's final status survey documentation accurately reflect the as-found surface activity levels such that ORAU may confidently conclude that the final radiological conditions are adequately represented? | **Yes:** Confirmatory results concur with the licensee's results and demonstrate that the decommissioning processes follow accepted final status/decommissioning survey guidance and adequately represent the final status radiological condition of each survey unit. No additional actions are necessary.<br>**No:** Confirmatory results and data do not agree with the licensee's results. Identify and communicate deficiencies with the final status survey, documentation, or reporting of the final radiological conditions. Provide recommendations for corrective action and evaluate whether demonstration of compliance must be revisited. |
| **Decision Statements** | |
| 1. The licensee's final status survey implementation was/was not appropriate, satisfied/did not satisfy the survey investigation coverage for the area classification, and did/did not identify any areas of residual contamination in excess of either the decommissioning criteria or the survey unit classification limits.<br>2. The confirmatory and licensee data are/are not within expected statistical agreement (or within expected deviation based on any identified systematic biases) and ORAU results confirm/do not confirm that the licensee's results and documentation demonstrate compliance with all licensing and regulatory requirements. | |

### STEP 3 – IDENTIFY INPUTS TO THE DECISION/OBJECTIVE

The third step in the DQO process identifies the information needed and the sources for this information, determines the basis for action levels, and identifies sampling and analytical methods that will meet data requirements. For the confirmatory surveys, the decision inputs include the following:

- Review of licensee's survey unit designations, instrumentation, procedures, final status survey results, and data quality assessments, as available
- Review of site data (e.g., used to select areas to independently survey and determine the required number of random measurements)
- Collection of independent total beta and alpha (fixed plus removable) surface scan and surface activity direct measurement data
- Collection of independent removable (smear) gross alpha and beta samples

Based on the review of historical records, process knowledge, and the results of characterization and remedial investigation surveys, the residual radioactivity potential for HAC facilities have been reduced to a few credible ROCs. The ROCs were further reduced based upon the results of the

characterization survey data. While only a few samples may have indicated the presence of H-3, these were very low in concentration, such that it was less than 1% of the total radioactivity as well as potential dose. Therefore, H-3 was eliminated as an ROC for this effort. Other potential ROCs include one beta emitter (Pb-210) and seven alpha emitters (Ra-226, U-234, U-235, U-238, Pu-238, Pu-239, and Am-241). The licensee selected the most restrictive of the corresponding alpha and beta DCGLs, which were for Am-241 and Po-210, for survey design and data comparison (EPA 2016a). The licensee's final status survey report (FSSR) presents release criteria for target HAC ROCs, which were taken directly from NUREG-1757 Appendix B (EPA 2016a; NRC 2006). These default criteria/DCGLs are listed in Table 3.2.

**Table 3.2. DCGL Concentration Limits Equivalent to 25 mrem/year**

| ROC | DCGL (dpm/100 cm²)[a] |
|---|---|
| Pb-210 | 550 |
| Am-241 | 27 |

[a]From NUREG/CR-5512, Vol. 3, (NRC 1999)

### STEP 4 – DEFINE THE STUDY BOUNDARIES

The fourth step in the DQO process defines target populations and spatial boundaries, determines the timeframe for collecting data and making decisions, addresses practical constraints, and determines the smallest subpopulations, area, volume, and time for which separate decisions must be made.

- The licensee's plans and procedures provide commitments and release requirements for bounding confirmatory decision points (EPA 2016a).
- The target areas for the evaluation are listed in Table 3.3 (EPA 2016a), which includes the survey unit and licensee's assigned MARSSIM classification.
- Multiple, related (conjoined, similar history and classification, or other criteria) survey units will be combined into individual confirmatory units.
- Confirmatory data will be compared with the licensee's results on a confirmatory unit (CU) basis.
- Three 10-hour work-days were estimated to complete surveys described in this plan, which is to be implemented in late September of 2016.

- The available on-site project schedule may preclude independent investigations of all proposed confirmatory units; thus areas with the highest potential for exceeding DCGLs will be selected based on the FSSR (EPA 2016a) and characterization report (EPA 2016b). To the extent possible, ORAU personnel will prioritize confirmatory data collection from Class 1 and 2 areas—CUs 1 through 3.

**Table 3.3. UNLV HAC Survey Units and MARSSIM Classification**

| FSS Unit Number | MARSSIM Class | Area ($m^2$) | Description of Rooms Surveyed | Confirmatory Unit (CU) # |
|---|---|---|---|---|
| FSS-QAL-1-1 | 1 | 26 | QAL 35 | CU-1 |
| FSS-QAL-1-2 | 1 | 22 | QAL 46 | |
| FSS-QAL-2-1 | 2 | 298 | QAL 2, 3, 4, 18, 19, 20, 21, 22, 25, 34, 47 | CU-2 |
| FSS-EAX-2-1 | 2 | 263 | EAX 1, 3, 4, 9, 11/12 | CU-3 |
| FSS-EAX-3-1 | 3 | 283 | EAX 2, *5,* 8, 10, 13, 14, 15, 16, 17.1-17.4, 18 | CU-4 |
| FSS-POS-3-1 | 3 | 405 | POS 2, 9, 10, 11, 12.1, 12.3, 13, 14, 15, 26, 27, 28, 29, 30 | CU-5 |
| FSS-QAL-3-1 | 3 | 518 | QAL 1, *5,* 6, 11, 12, 13, 14, 16.1, 17, 26/27, 28, 29/30, 31, 32, 33, 36, 39, 42.1, 45.1, 45.2 | CU-6 |

Source is EPA 2016a.

### STEP 5 – DEVELOP A DECISION RULE

The fifth step in the DQO process specifies appropriate population parameters and develops a decision rule statement or statements. The confirmatory decision rules were introduced in Table 3.1. The first decision rule is based on the results of the independent assessment of the licensee's decommissioning process and procedures and is further discussed in Section 4. The second decision rule is determined based on independent measurement results to determine whether any residual contamination is present in excess of DCGLs and whether the survey units were classified appropriately. The planned surveys are detailed in Section 6 of this project-specific plan. The third rule will be based on the comparison of confirmatory survey results to the licensee's final status survey results and release guidelines specified in Table 3.2.

## STEP 6 – SPECIFY LIMITS ON DECISION ERRORS

The sixth step in the DQO process examines the consequences of making an incorrect decision, specifies the range of values where consequences are minor (the gray region), and assigns values that reflect tolerable probability for potential decision errors. Decision errors are controlled both during the on-site investigations and during the data quality assessment phase.

Two orders of control will be established to limit decision errors. The first control is the establishment of *a priori* surface scan minimum detectable concentrations (MDCs) that are calculated to ensure a true positive detection proportion of 0.90 and a false positive proportion of no more than 0.15 for beta and gamma radiation. However, the surface scan sensitivities for both ROCs shown in Appendix A exceed the DCGLs. Adjustments to true/false positive proportions can lower the scan MDCs but not to levels equivalent to the DCGLs. The surface scans combined with liberal pausing will be effective for locating potential residual contamination hot spot at multiples of the respective DCGL. Second, the direct measurement, or static MDCs, and counting uncertainties are calculated based on the 95% confidence level, and MDCs are determined to be a fraction of the release criteria (between 10% and 50%).As shown in Appendix A, a count time of 5 minutes is required to achieve static measurement MDC to approximately 50% of the alpha DCGL—this same count time will also satisfy beta MDC objective. Surface activity measurement results will be directly compared to DCGLs.

The second order of control is to adopt a scientific approach for data quality assessment that uses hypothesis testing. This approach uses survey data to select between the baseline condition (the null hypothesis, $H_0$) and an alternative condition (the alternative hypothesis, $H_A$). The null hypothesis is assumed to be true in absence of strong evidence to the contrary. The confirmatory survey is not intended as a supplement to, or in lieu of, a final radiological release survey. Given that the ORAU effort is limited to a fraction of the area being considered for release, the primary objective of the confirmatory survey is to validate that the licensee has adequately and accurately described the final radiological conditions of the partial site release project areas. Therefore, as the confirmatory data will be used as the decision input for the acceptability of licensee's final status survey results, it is critical that the confirmatory data first be compared to licensee's data. This validation will be accomplished through a direct comparison of ORAU and licensee results via a two sample Sign test.

The objective of the Sign test is to assess dataset comparability, i.e., to determine if there are noticeable biases in the licensee's data that would require additional study. The method is to (1) take the difference in the licensee's and ORAU static measurement results and count the number of positive and negative difference, and (2) estimate the median of the differences (Gilbert 1987). If the number of positive and negative differences is similar and the median of the difference is near zero, then the datasets are comparable and no biases are assumed. The number of measurements will depend on the time available, though emphasis will be placed on areas with the highest potential for exceeding DCGLs, i.e., Class 1 survey units.

### STEP 7 – OPTIMIZE THE DESIGN FOR OBTAINING DATA

The seventh step in the DQO process reviews DQO outputs, develops data collection design alternatives, formulates mathematical expressions for each design, selects the sample size to satisfy DQOs, decides on the most resource-effective design of agreed alternatives, and documents details.

The survey design has been optimized to collect the appropriate data based on the survey and sampling procedures detailed in this plan (see Section 6 for additional details).

## 4. DOCUMENT REVIEW

The licensee's FSSP will be reviewed for consistency with the industry-accepted radiological survey practices described in MARSSIM and related documents such as ISO7503 and NUREG-1507. ORAU will also review the FSSR to ensure that the documents adequately and accurately describe the final radiological status of the facility.

## 5. PROJECT HEALTH AND SAFETY

Prior to mobilization, the ORAU project manager will prepare a work-specific hazard checklist that provides the scope of work, identifies the hazards associated with the work and any site-specific hazards, specifies the hazard controls, and determines the required training. All survey activities will be in accordance with the *ORAU Radiation Protection Manual*, the *ORAU Health and Safety Manual*, and the *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2014, ORAU 2015a, ORAU 2015b). Should ORAU identify a hazard not covered in the Survey Procedures Manual or

the project's work-specific hazard checklist, work will not be initiated or continued until it is addressed by an appropriate job hazard analysis and hazard controls.

In addition, ORAU personnel will participate in general site-orientation training prior to beginning the field effort and will comply with applicable licensee health and safety and radiological protection procedures.

## 6. PROCEDURES

The ORAU survey team will perform visual inspections as well as radiological scanning, measurements, and sampling activities within each selected survey unit. Survey activities will be conducted in accordance with the ORAU survey procedures, the *ORAU Environmental Services and Radiation Training Quality Program Manual*, and guidance provided in MARSSIM (ORAU 2015b, ORAU 2016a, NRC 2000).

### 6.1 REFERENCE SYSTEM

All data, including measurement and sampling locations, will be documented and referenced thoroughly, with adequate detail to relocate specific areas on a given surface. Measurement locations will be referenced to either the HAC room reference system or to Cartesian coordinates corresponding to either the specific X,Y coordinates from the southwest corner of an individual room floor or ceiling and lower left corner of walls. Measurement and sampling locations may also be plotted on drawings and/or via photographs.

### 6.2 SURFACE SCANS

Due to time constraints and scan MDC limitations, scans will be concentrated on judgmentally selected locations, including locations selected by the licensee or locations that appear to have a high potential for contamination. Scans will be performed using a Ludlum model 44-92 zinc sulfide scintillation detector for alpha radiation and a Ludlum model 44-142 plastic scintillator for beta radiation.

### 6.3 SURFACE ACTIVITY MEASUREMENTS

Direct measurements using the same scintillation detectors used for scans to quantify total alpha and beta surface activity will be collected from both judgmental locations and, where identifiable, licensee locations as necessary for decision making. Appendix A presents the example multi-point calibrations used to estimate ROC-specific efficiencies, scan MDCs, and static MDCs.

Material-specific background measurements will be collected as necessary from non-impacted structures or surfaces of, to the extent possible, similar construction to the survey unit construction materials. These background measurements will be used for correcting gross survey unit measurement results when converting the data to surface activity levels. If suitable reference materials are not available in non-impacted areas, the data will be converted using an ambient "in air" background subtraction as a conservative measure.

### 6.4 REMOVABLE ACTIVITY SAMPLING

Smear samples will be collected from all direct measurement locations to quantify removable gross alpha and beta activity. Smears will be collected.

## 7. SAMPLE ANALYSIS AND DATA INTERPRETATION

Smear samples will be returned to the Radiological and Environmental Analytical Laboratory in Oak Ridge, Tennessee for analysis and interpretation. Sample analyses will be performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2016b). Smear samples will be analyzed for gross alpha and gross beta activity using a low-background proportional counter. The analytical results and surface activity measurement data will be reported in units of disintegrations per minute per 100 square centimeters (dpm/100 $cm^2$). The data generated will be provided in the confirmatory survey report together with a summary of the procedures, the findings and results, and a direct comparison of the data with the DCGLs established for the project.

## 8. REFERENCES

EPA 2016a. *EPA Las Vegas Facilities, Part 1- NRC License Amendment Submittal: Attachment 2 -Final Status Survey Report*. Las Vegas, Nevada. May 2016.

EPA 2016b. *EPA Las Vegas Facilities, Part 1- NRC License Amendment Submittal: Attachment 3 - Characterization Remedial Actions and Remedial Action Support Survey Summary*. EPA-LV-EDDP-P2-Sup.026. Las Vegas, Nevada. September 2016.

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NRC 2006. *Consolidated Decommissioning Guidance*. NUREG-1757. U.S. Nuclear Regulatory Commission. Washington, DC. September.

ORAU 2014. *Radiation Protection Manual*. ORAU. Oak Ridge, Tennessee. October.

ORAU 2015a. *ORAU Health and Safety Manual*. ORAU. Oak Ridge, Tennessee. June.

ORAU 2015b. *ORAU Radiological and Environmental Survey Procedures Manual*. ORAU. Oak Ridge, Tennessee. August 6.

ORAU 2016a. *ORAU Environmental Services and Radiation Training Quality Program Manual*. ORAU. Oak Ridge, Tennessee. September 8.

ORAU 2016b. *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual*. ORAU. Oak Ridge, Tennessee. September 8.

**APPENDIX A**
**Instrument Efficiency and Minimum Detectable Concentration Worksheets**

**Weighted Efficiency and Static/Scan MDC Calculation Worksheet (Sheet 1)**

| | |
|---|---|
| **Ratemeter/Scaler Model:** | 2221 |
| **Detector Model:** | 44-92 |
| **Mylar (mg/cm$^2$):** | 1.2 |
| **Voltage Setting (volts):** | 975 |
| **Measured Radiation Type:** | α |

| **Worksheet Results** | |
|---|---|
| Reported Result: | α |
| Total Efficiency ($\sum \varepsilon_t$): | 0.10 |
| Static MDC (dpm/100 cm$^2$): | 16 |
| Scan MDC (dpm/100 cm$^2$): | 726 |

**Table 1. Instrument Calibration Data, Source, and MDC Inputs**

| **Standard Source Inputs** | | | | | **Static and Scan MDC Inputs** | |
|---|---|---|---|---|---|---|
| **Nuclide** | **Radiation** | **Mean E (keV)[a]** | **Max. E (keV)[a]** | **$\varepsilon_i$** | Background ($C_b$) (cpm): | 1 |
| | | | | | *Probe Area* (cm$^2$): | 100 |
| U-238 | Alpha | 4,188 | N/A | 0.27 | Observation Interval ($i$) (sec): | 2 |
| Th-230 | Alpha | 4,663 | N/A | 0.33 | $P\ (n > 1)$(unitless): | 0.9 |
| Pu-239 | Alpha | 5,139 | N/A | 0.37 | Survey Efficiency ($p$) (unitless): | N/A |
| Am-241 | Alpha | 5,487 | N/A | 0.38 | | |
| Ni-63 | Beta | 17.4 | 66.9 | 0.00 | Static MDC = $\frac{3+4.65\sqrt{C_b}}{T \times \varepsilon_t \times \frac{Probe\ Area}{100\ \mathrm{cm}^2}}$ | |
| C-14 | Beta | 49.5 | 156 | 0.00 | | |
| Tc-99 | Beta | 84.6 | 294 | 0.00 | Scan MDC = | |
| Tl-204 | Beta | 244 | 764 | 0.00 | | |
| Sr/Y-90 | Beta | 565 | 1,413 | 0.00 | | |

**Table 2. Weighted Efficiency Input/Output Table**

| **Nuclide** | **Half-Life (yrs)** | **Total Intensity** | **Mean E (keV)[a]** | **Max. E (keV)[a]** | **Relative Fraction** | **$\varepsilon_i$** | **$\varepsilon_s$** | **$\varepsilon_t$[b]** |
|---|---|---|---|---|---|---|---|---|
| **Beta Emitters** | | | | | | | | |
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| **Alpha Emitters** | | | | | | | | |
| Am-241 | 4.33E+02 | 1.00 | 5,487 | N/A | 1.00 | 0.38 | 0.25 | 0.10 |
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[a] Excludes emission intensities < 0.1%; beta mean and maximum energies weighted based on emission intensity.

[b] Total efficiency per nuclide is *Total Intensity* × *Relative Fraction* × $\varepsilon_i$ × $\varepsilon_s$.



$T$, static count time (min).

**Weighted Efficiency and Static/Scan MDC Calculation Worksheet (Sheet 2)**

**Figure 1. Alpha Detector Source Calibration Curve**

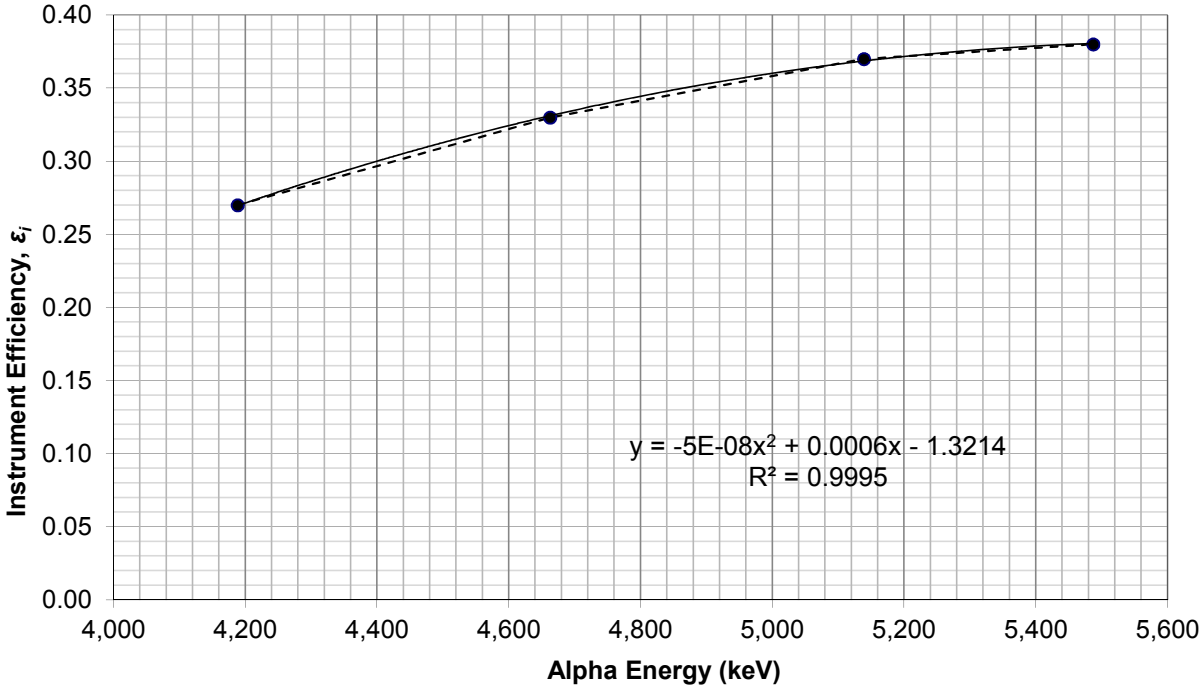
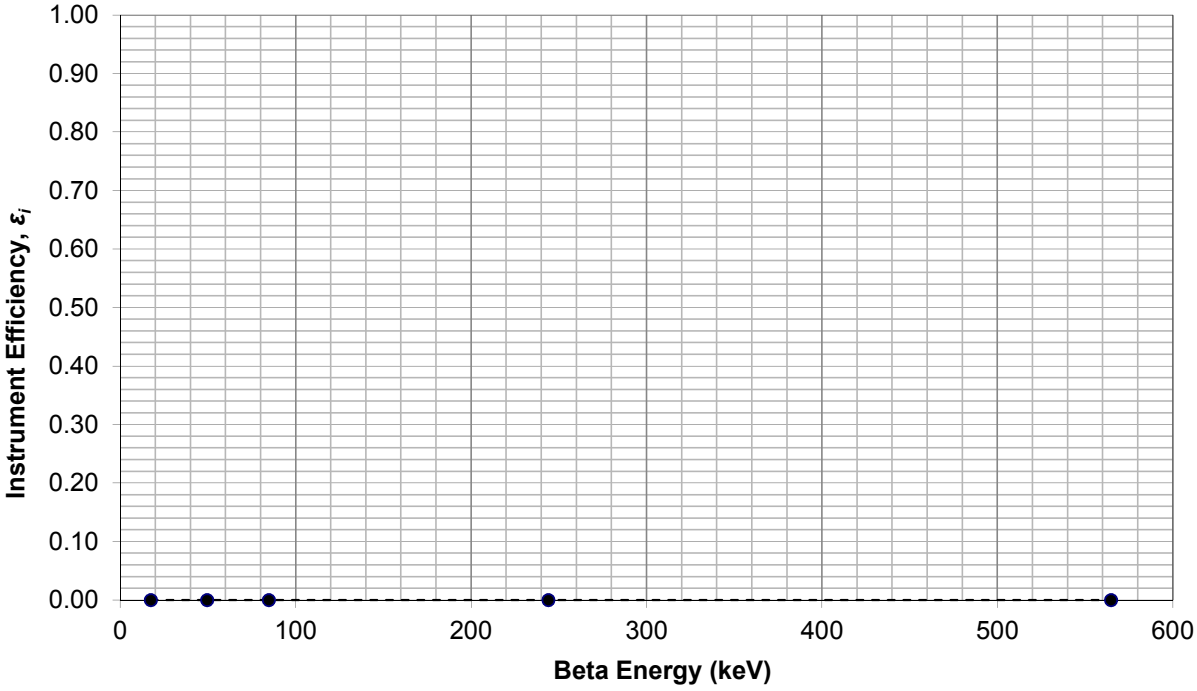



**Figure 2. Beta Detector Source Calibration Curve**



**Weighted Efficiency and Static/Scan MDC Calculation Worksheet (Sheet 1)**

| | |
|---|---|
| **Ratemeter/Scaler Model:** | 2221 |
| **Detector Model:** | 44-142 |
| **Mylar (mg/cm$^2$):** | 1.2 |
| **Voltage Setting (volts):** | 1,100 |
| **Measured Radiation Type:** | β |

| **Worksheet Results** | |
|---|---|
| Reported Result: | β |
| Total Efficiency ($\sum \varepsilon_t$): | 0.28 |
| Static MDC (dpm/100 cm$^2$): | 79 |
| Scan MDC (dpm/100 cm$^2$): | 1,208 |

**Table 1. Instrument Calibration Data, Source, and MDC Inputs**

| **Standard Source Inputs** | | | | | **Static and Scan MDC Inputs** | |
|---|---|---|---|---|---|---|
| **Nuclide** | **Radiation** | **Mean E (keV)[a]** | **Max. E (keV)[a]** | **$\varepsilon_i$** | Background ($C_b$) (cpm): | 540 |
| | | | | | *Probe Area* (cm$^2$): | 100 |
| U-238 | Alpha | 4,188 | N/A | 0.37 | Observation Interval ($i$) (sec): | 2 |
| Th-230 | Alpha | 4,663 | N/A | 0.50 | Index of Sensitivity ($d'$) (unitless): | 2.32 |
| Pu-239 | Alpha | 5,139 | N/A | 0.58 | Survey Efficiency ($p$) (unitless): | 0.75 |
| Am-241 | Alpha | 5,487 | N/A | 0.62 | | |
| Ni-63 | Beta | 17.4 | 66.9 | 0.01 | Static MDC = $\frac{3+4.65\sqrt{C_b}}{T \times \varepsilon_t \times \frac{Probe\ Area}{100\ \mathrm{cm}^2}}$ | |
| C-14 | Beta | 49.5 | 156 | 0.23 | | |
| Tc-99 | Beta | 84.6 | 294 | 0.38 | | |
| Tl-204 | Beta | 244 | 764 | 0.53 | Scan MDC = $\frac{d' \times \sqrt{C_b \times (i/60)} \times (60/i)}{\sqrt{p} \times \varepsilon_t \times \frac{Probe\ Area}{100\ \mathrm{cm}^2}}$ | |
| Sr/Y-90 | Beta | 565 | 1,413 | 0.58 | | |

**Table 2. Weighted Efficiency Input/Output Table**

| **Nuclide** | **Half-Life (yrs)** | **Total Intensity** | **Mean E (keV)[a]** | **Max. E (keV)[a]** | **Relative Fraction** | **$\varepsilon_i$** | **$\varepsilon_s$** | **$\varepsilon_t$[b]** |
|---|---|---|---|---|---|---|---|---|
| **Beta Emitters** | | | | | | | | |
| Pb-210 | 2.22E+01 | 1.00 | 6.1 | 24 | 1.00 | 0.00 | 0.25 | 0.00 |
| Bi-210 | 1.37E-02 | 1.00 | 389 | 1,160 | 1.00 | 0.56 | 0.50 | 0.28 |
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| **Alpha Emitters** | | | | | | | | |
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[a] Excludes emission intensities < 0.1%; beta mean and maximum energies weighted based on emission intensity.

[b] Total efficiency per nuclide is *Total Intensity* × *Relative Fraction* × $\varepsilon_i$ × $\varepsilon_s$.



$T$, static count time (min).

**Weighted Efficiency and Static/Scan MDC Calculation Worksheet (Sheet 2)**

**Figure 1. Alpha Detector Source Calibration Curve**

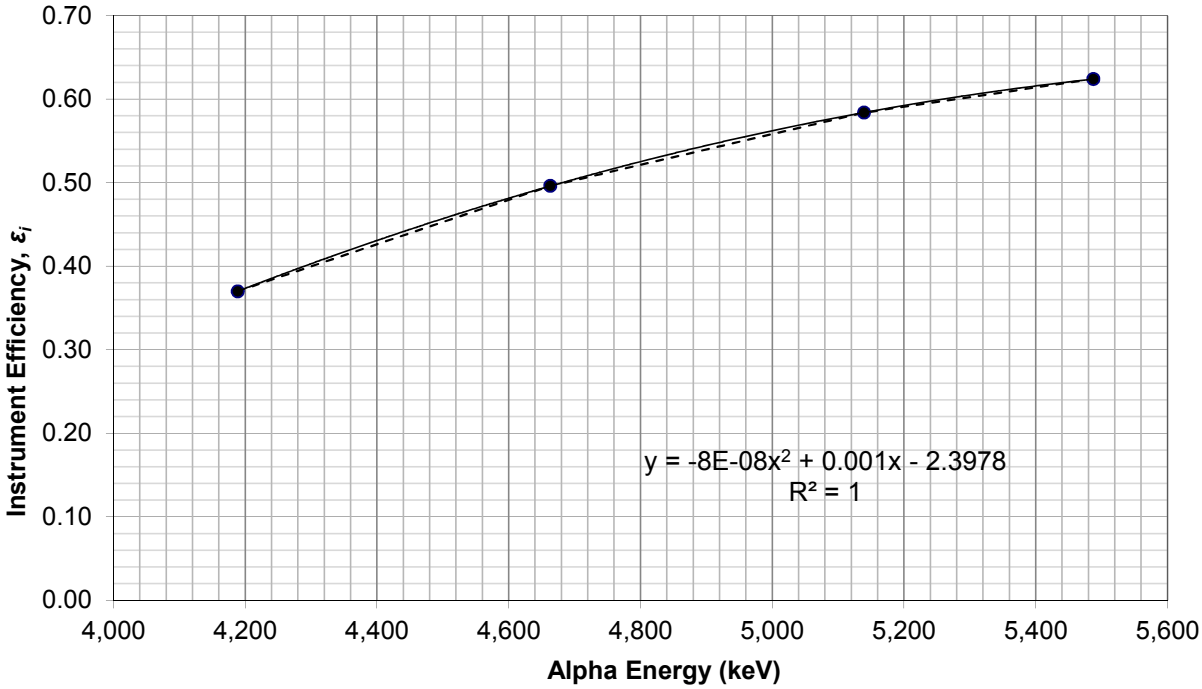


**Figure 2. Beta Detector Source Calibration Curve**