EGG 11265-1121
UC-702
AUGUST 1995

THE
REMOTE
SENSING
LABORATORY
OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM

AN AERIAL RADIOLOGICAL SURVEY OF THE WRIGHT-PATTERSON AIR FORCE BASE AND SURROUNDING AREA

FAIRBORN, OHIO

DATE OF SURVEY: JULY 7-20, 1994

MASTER

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ABSTRACT

An aerial radiological survey was conducted over areas of Wright-Patterson Air Force Base (WPAFB) and the immediate surrounding area, during the period July 7 through 20, 1994. The survey was conducted to measure and map the gamma radiation in the area. This mission was the first aerial radiation survey conducted at WPAFB.

In the surveyed area, five small localized sources of gamma radiation were detected which were atypical of naturally-occurring radionuclides. On WPAFB property, these sources included a radiation storage facility in Area B (krypton-85) and an ash pile near the Area C flight line (low energy gamma activity). In the area covered outside WPAFB boundaries, sources included cesium-137 in excess of worldwide fallout over a landfill in a northern Dayton industrial area, an X-ray radiography source over a steel plant in the same industrial area, and a mixture of cesium-137 in excess of worldwide fallout and possibly iridium-192 in an area near Crystal Lakes, Ohio.

The naturally-occurring gamma emitters (uranium-238 and progeny, thorium and progeny, and potassium-40) were detected in the remaining area with a total exposure rate range of 4 to 16 $\mu\text{R/h}$; this range is typical of that found in the United States, 1 to 20 $\mu\text{R/h}$.

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CONTENTS

Abstract	ii
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Sections

1.0 Introduction	1
2.0 Site Description and History	1
3.0 Survey Operations	1
4.0 Data Analysis	1
4.1 Search Algorithms	3
4.2 Data Uncertainty	4
4.3 Inherent Uncertainties	5
4.4 Large-Area Averaging of the Detector System	5
4.5 Ground-Based Measurements	5
5.0 Results	6
5.1 Data Summary	6
5.2 Detected Man-Made Activity	6
6.0 Conclusion	6

Figures

1 Survey Flight Pattern and Flight Lines	2
2 Total Terrestrial Plus Cosmic Isoradiation Exposure Rate Contour Map	7
3 Man-Made Isoradiation Count Rate Contour Map	8
4 Total Terrestrial and Man-Made Count Rate Algorithm Results of the Ash Pile	9
5 Total Terrestrial and Man-Made Count Rate Algorithm Results of the Radiation Storage Facility	9
6 Gamma Energy Spectrum of the Ash Pile Anomaly	10
7 Gamma Energy Spectrum of the Radiation Storage Facility	10
8 Total Terrestrial and Man-Made Count Rate Algorithm Results of the Northern Dayton Landfill	11

9	Total Terrestrial and Man-Made Count Rate Algorithm Results of a Steel Plant in the Northern Dayton Industrial Area	11
10	Gamma Energy Spectrum of the Northern Dayton Landfill	12
11	Gamma Energy Spectrum of a Steel Plant in Northern Dayton	12
12	Total Terrestrial and Man-Made Count Rate Algorithm Results of Crystal Lakes, Ohio	13
13	Gamma Energy Spectrum Collected near Crystal Lakes, Ohio	13
14	Gamma Energy Spectrum Typical of the Natural Background Radiation	14

Tables

1	Survey Area Flight Coverage	3
2	WPAFB Count Rates and Estimated Exposure Rate Levels	4
3	Summary of Terrestrial Exposure Rates for the WPAFB Area	14
4	Comparison of the Aerial and Ground-Based Measurements	15
5	Soil Sample Analysis Results	15

Appendix

A	Survey Parameters	16
	References	17

1.0 INTRODUCTION

From July 7-20, 1994, an aerial radiological survey was conducted at the request of the U.S. Department of Defense over Wright-Patterson Air Force Base (WPAFB) and nearby areas. Gamma radiation data were collected over 64 mi² (165.8 km²) including: 1) a 60-mi² (155.4-km²) area centered on WPAFB, which includes portions of Dayton, Fairborn, Beavercreek, and Crystal Lakes, Ohio; and 2) a 4-mi² (10.4-km²) area centered on a 95-acre property of WPAFB, located approximately 2 mi (3.2 km) east of WPAFB. The survey was conducted by the U.S. Department of Energy's (DOE) Remote Sensing Laboratory (RSL) using an aerial radiation measurement system. The RSL is operated by EG&G Energy Measurements, Inc. (EG&G/EM), a contractor for DOE.

The purpose of the survey was to acquire radiation data to determine the spatial distribution, identity, and quantity of the naturally-occurring and man-made gamma-emitting radionuclides in the two areas described above.

WPAFB conducted operations in the past that involved transporting, storing, and using nuclear materials, including the operation of a 91B research reactor. Presently, there are a number of areas on base where radioactive materials are licensed for use, including the medical center and the Air Force Institute of Technology.

2.0 SITE DESCRIPTION AND HISTORY

WPAFB is located in western Ohio, 9 miles (14.5 km) northeast of Dayton, and is adjacent to Fairborn on its western boundary (Figure 1). The Air Force base covers approximately 8,100 acres, which is divided into three areas designated as Areas A, B, and C. Radioactive materials were used and stored in Area B. Presently, Area B contains an entombed reactor, a concrete-filled facility where research involving the use of radioactive materials was conducted, and a radioactive materials storage area. The reactor last operated in the late 1960s.

WPAFB is surrounded by the population centers of Dayton, Fairborn, Beavercreek, and Crystal Lakes, Ohio. The survey area includes a region which is farmed extensively. In the non-farming areas, the terrain is moderately to heavily vegetated, especially along the Miami River Valley.

3.0 SURVEY OPERATIONS

This survey was conducted to collect gamma radiation data over two areas comprising 64 mi² (165.8 km²) of WPAFB and the surrounding area using a thallium-activated sodium iodide, NaI(Tl), gamma ray detection system mounted on a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter. The system was flown at an airspeed of 70 knots (36 m/s), at an altitude of 150 feet (46 meters) above ground level (AGL), along parallel flight lines spaced 250 feet (76 meters) apart, totaling 1,352 (2,176 km) flight line miles. To minimize interference with Area C flight traffic at WPAFB, flight lines were oriented southwest-northeast (Figure 1). Position and aircraft steering information was provided by the Global Positioning System (GPS) input to the Radiation Environmental Data Acquisition and Recorder, Model IV (REDAR IV). Systems and procedures are discussed in detail in a separate publication.¹

The main area of 60 mi² (155 km²) centered on WPAFB was 5 miles (8.0 km) wide by 12 miles (19.3 km) long, extending from the northeast corner of Dayton, Ohio, to approximately 3 miles (4.8 km) northeast of the property perimeter of WPAFB. The width of the pattern extended westward 5 miles (8.0 km) from the western edge of the town of Fairborn, Ohio.

A second area covered was 4 mi² (10.4 km²) in size, centered on a .15-mi² (96-acre or 0.39-km²) WPAFB property located approximately 2 mi (3.2 km) east of the base, Figure 1. See Table 1 for details of the flight coverage.

4.0 DATA ANALYSIS

The data collected over the areas previously described were processed during field operations to map the radiation profile of the WPAFB area. The objectives of the processing were: 1) to establish the spatial distribution of the gamma radioactivity, 2) to identify the radionuclides contributing to the gamma exposure, and 3) to estimate the quantity of radionuclides present relative to the exposure rate. To achieve the desired results, isoradiation count rate contours of natural and man-made sources were generated and superimposed on high altitude aerial photographs. Gamma ray spectra were examined for all anomalies that were significantly elevated (by a factor of 2 or more) above typical terrestrial values. Isoradiation count rate contour maps were generated for those sources found to be significantly distributed in the surveyed areas.

FIGURE 1. SURVEY FLIGHT PATTERN AND FLIGHT LINES

AERIAL PHOTO: JAN., 1924

Table 1. Survey Area Flight Coverage						
Location	Area		Flight Lines		Flight Line Distance	
	mi ²	km ²	No.	Length (mi)	mi	km
Area 1	60	155.4	106	12	1,272	2,047
Area 2	4	10.4	40	2	80	129
Total	64	165.8	146		1,352	2,176

The primary data processing involves applying algorithms that extract net photopeak count rates of specific sources from multichannel spectral data collected and recorded each second of flight over the areas of interest. The count rate data are combined with position information to produce the isoradiation contour maps.

4.1 Search Algorithms

Algorithms were generated to extract the count rate due to gamma rays emitted by the following sources:

- A. Total Terrestrial and Cosmic Radionuclides – Gross Count

$$CR_{GC} = \sum_{E=38}^{3026} CR_E - NTB \quad (1)$$

where

CR_{GC} = total terrestrial count rate;
i.e., count rate produced by gamma rays with energies in the range
 $E_\gamma \geq 38$ keV to $E_\gamma \leq 3,026$ keV

CR_E = count rate produced by a gamma ray with energy E

NTB = non-terrestrial background;
i.e., count rates produced by airborne radon, gamma emitters of the detector platform, and gamma rays of cosmic origin

- B. Total Terrestrial Man-Made Radionuclides – MMGC

$$CR_{MMGC} = \sum_{E=38}^{1394} CR_E - K \cdot \sum_{E=1394}^{3026} CR_E \quad (2)$$

CR_{MMGC} is the count rate from man-made terrestrial gamma emitters; i.e., count rate produced by gamma rays in the range $E_\gamma \geq 38$ keV to $E_\gamma \leq 1,394$ keV. Many frequently detected man-made gamma emitters fall in this range. This algorithm is also sensitive to elevated count rate levels of certain naturally-occurring gamma emitters.

The algorithm results are illustrated in Section 5 and their derivations are discussed in more detail in a separate publication.²

In the man-made algorithm, K is the ratio of the source photopeak window to the background photopeak window computed from data collected where no man-made sources are present.

$$K_i = \frac{\sum_{E_1}^{E_2} CR_E(\text{Source})}{\sum_{E_3}^{E_4} CR_E(\text{Background})} \quad (3)$$

K is derived from the data of each flight to minimize the effects of airborne radon-222 (²²²Rn) and minor system characterization differences between flights.

The count rate of the total terrestrial activity was converted to exposure rate at one meter AGL by applying a conversion factor of 1,071 counts per second (cps) per microrentgen per hour ($\mu R/h$). This conversion

factor was derived from count rate and exposure rate data collected over a test range in Calvert County, Maryland. The gross count rate conversion function is written as

$$ER = \frac{CR \text{ cps}}{1071 \frac{\text{cps}}{\mu\text{R/h}}} \quad (4)$$

where

CR = count rate from NaI(Tl) detectors in cps measured at the survey altitude

It should be noted that in areas of atypical mixes of gamma-emitting radionuclides, the converted values will incorrectly estimate the actual exposure rate. Table 2 lists the count rates measured at the survey altitude and their estimated equivalent exposure rate levels at one meter AGL. An estimated cosmic ray contribution of 4 $\mu\text{R/h}$ was added to the reported exposure rate levels.

The extracted count, using the man-made algorithm, was used to generate isoradiation count rate contour maps that aided in locating and identifying the relative intensity and spatial distribution of man-made gamma-emitting radionuclides that may be present in the surveyed areas.

4.2 Data Uncertainty

The uncertainty, σ_{CR} , in the count rate generated by the algorithms previously discussed is described in other EG&G/EM survey reports.² The general equation for σ_{CR} relative to the algorithms described previously is:

$$\sigma_{CR} = \sqrt{K_1^2 \cdot \sum_{E_3}^{E_4} CR_E + K_2^2 \cdot \sum_{E_3}^{E_4} CR_E + \dots + K_i^2 \cdot \sum_{E_{n-1}}^{E_n} CR_E} \quad (5)$$

Some multiple of the uncertainty, $n\sigma_{CR}$, is chosen to optimally separate source activity from statistical fluctuations in counting the source of interest at a particular confidence interval. Statistical excursions of various algorithm results were evaluated to determine their origin. Generally, several contour maps are generated for a specific radionuclide with selected values of n to ensure that the low-level trends in man-made source activity are not suppressed. Also, it is often useful to choose the levels to show variations in the natural environment (vegetation, waterways, land use, etc.) to verify the dynamic range of sensitivity of the detector system.

The uncertainty in the estimated exposure rate values is about 0.5 $\mu\text{R/h}$. Derivation of this value is discussed in detail in a separate publication.¹ The results of the man-made algorithm were normally distributed about

Table 2. WPAFB Count Rates and Estimated Exposure Rate Levels		
Letter Label	Total Count Rate (cps) ^a	Exposure Rate ($\mu\text{R/h}$) ^b
A	< 1,071	< 5
B	1,071 – 3,213	5 – 7
C	3,213 – 5,355	7 – 9
D	5,355 – 9,639	9 – 13
E	9,639 – 16,065	13 – 19
F	16,065 – 32,130	19 – 34

^a The airborne contributions have been removed from the count rates.

^b These exposure rate values are estimated from Column 2 and include an additional estimated cosmic contribution of 4 $\mu\text{R/h}$.

area surveyed. Exposure rates were measured with a pressurized ionization chamber for comparison to the values inferred from the aerial data. Soil samples were taken at all six ground sampling points in order to determine the radionuclide concentrations typical of the natural background in the area. In addition, estimates of the exposure rates due to these radionuclide concentrations were made from the soil sample analyses. The soil samples were analyzed and the results tabulated for this report by scientists at the former EG&G/EM Santa Barbara Laboratory. Systems and procedures for soil sample data collection and analysis are outlined in separate publications.^{3,4}

5.0 RESULTS

5.1 Data Summary

The results of the survey are presented as: 1) isoradiation contour maps of total terrestrial and man-made gamma ray count rates, and 2) gamma energy spectra of regions depicted on the man-made count rate contours. The total terrestrial count rates are converted to equivalent gamma ray exposure rates, in $\mu\text{R/h}$, as described in Section 4 and illustrated in Figure 2. The contour map illustrated in Figure 3 represents the count rate contours generated from the algorithm that is used to extract man-made gamma radiation as defined in Section 4.

5.2 Detected Man-Made Activity

Five localized sources of gamma radiation, (numbered from 1-5 on the man-made contour map, Figure 3) validated by the man-made algorithm and atypical of radionuclides found in the area, were detected in the larger of the two areas surveyed. Two of the five sources were detected on WPAFB property: an ash pile near the Area C flight line (location 1) and a radiation storage facility in Area B (location 2). Figures 4 and 5 show the way in which these man-made count rate anomalies were detected along their particular survey flight paths.

Figure 6 illustrates the gamma energy spectrum of the Area C ash pile. The gamma energy spectrum with typical natural background radiation removed depicts low energy, scattered gamma emitters with no dominant photopeaks.

Figure 7 shows the gamma energy spectrum taken over the radiation storage facility. The spectrum depicts the presence of a complex mix of man-made gamma emitters. The dominant photopeak is that of the 514-keV gamma ray of krypton-85 (^{85}Kr). This material was present in the storage facility at the time of the survey.

Three areas of atypical gamma activity were detected outside the WPAFB property. Two sources were detected in an industrial area of northern Dayton, Ohio. Spectral analysis revealed the presence of cesium-137 (^{137}Cs) in excess of worldwide fallout levels at a northern Dayton landfill. Apparently, an intermittently used source was detected over a steel plant in the same industrial area. Both aerial and ground-based measurements confirmed the intermittent use of a gamma radiation source at the steel plant, most likely from X-ray radiography. The total terrestrial and man-made algorithm results (count rate) of the two northern Dayton sources are shown in Figures 8 and 9.

The photopeak of ^{137}Cs is depicted in the gamma energy spectrum taken over the landfill anomaly, Figure 10. A mix of low energy gamma rays is depicted in the gamma energy spectrum taken over the steel plant anomaly, Figure 11.

A localized source atypical of the natural radionuclide mix in the area was detected at Crystal Lakes, Ohio, near the survey's north boundary. Figure 12 depicts the total terrestrial and man-made algorithm results over this anomaly. An ^{192}Ir source is known to exist in this area and is used in a number of industrial activities. The gamma ray spectrum collected in this area exhibits only a well-defined ^{137}Cs peak and some excess low energy gamma rays (see Figure 13). The ^{192}Ir source was shielded from the detectors or not present at the time of the flight in this area.

Only naturally-occurring gamma-emitting radionuclides (uranium-238 and progeny, thorium-232 and progeny, and potassium-40) typical of the entire area were detected on the 95-acre WPAFB site, Figure 14.

6.0 CONCLUSION

An aerial radiological survey was conducted over areas of Wright-Patterson Air Force Base and the surrounding area during the period July 7 through 20, 1994. Five localized gamma radiation sources were found. Table 3 summarizes the distribution of exposure rates at WPAFB and its surrounding area.

FIGURE 2. TOTAL TERRESTRIAL PLUS COSMIC ISORADIATION EXPOSURE RATE CONTOUR MAP

AERIAL PHOTO: JAN, 1964

CONVERSION SCALE

LETTER LABEL	EXPOSURE RATE (μ R/h)
A	< 5
B	5 - 7
C	7 - 9
D	9 - 13
E	13 - 19

*Inferred from gross gamma count rate observed at 150-foot (46-meter) survey altitude in the gamma energy window 38 keV through 3,026 keV. Includes an estimated cosmic ray contribution of 4 μ R/h.

are shown
S.

FIGURE 3. MAN-MADE ISORADIATION COUNT RATE CONTOUR MAP

AIRCRAFT PHOTO: MAR. 1984

CONVERSION SCALE

LETTER LABEL	MAN-MADE (cps)
A	< 250
B	250 - 650
C	650 - 1,500
D	1,500 - 2,500
E	2,500 - 5,000

FIGURE 4. TOTAL TERRESTRIAL AND MAN-MADE COUNT RATE ALGORITHM RESULTS OF THE ASH PILE

FIGURE 5. TOTAL TERRESTRIAL AND MAN-MADE COUNT RATE ALGORITHM RESULTS OF THE RADIATION STORAGE FACILITY

FIGURE 6. GAMMA ENERGY SPECTRUM OF THE ASH PILE ANOMALY

FIGURE 7. GAMMA ENERGY SPECTRUM OF THE RADIATION STORAGE FACILITY

FIGURE 8. TOTAL TERRESTRIAL AND MAN-MADE COUNT RATE ALGORITHM RESULTS OF THE NORTHERN DAYTON LANDFILL

FIGURE 9. TOTAL TERRESTRIAL AND MAN-MADE COUNT RATE ALGORITHM RESULTS OF A STEEL PLANT IN THE NORTHERN DAYTON INDUSTRIAL AREA

FIGURE 10. GAMMA ENERGY SPECTRUM OF THE NORTHERN DAYTON LANDFILL

FIGURE 11. GAMMA ENERGY SPECTRUM OF A STEEL PLANT IN NORTHERN DAYTON

FIGURE 12. TOTAL TERRESTRIAL AND MAN-MADE COUNT RATE ALGORITHM RESULTS OF CRYSTAL LAKES, OHIO

FIGURE 13. GAMMA ENERGY SPECTRUM COLLECTED NEAR CRYSTAL LAKES, OHIO

FIGURE 14. GAMMA ENERGY SPECTRUM TYPICAL OF THE NATURAL BACKGROUND RADIATION

Table 3. Summary of Exposure Rates for the WPAFB Area

Terrain Description (type)	Terrestrial and Cosmic Exposure Rates (μ R/h)	Terrestrial Source	Origin
Farm Land	9 - 13	^{40}K , ^{238}U , ^{232}Th	Natural
River/River Basin	5 - 7	^{40}K , ^{238}U , ^{232}Th	Natural
Heavy Vegetation	5 - 7	^{40}K , ^{238}U , ^{232}Th	Natural
Housing Areas	7 - 9	^{40}K , ^{238}U , ^{232}Th	Natural
Concrete/Asphalt	7 - 9	^{40}K , ^{238}U , ^{232}Th	Natural
*Ash Pile (1)	10+	Enhanced Natural	Enhanced Natural
*Radiation Storage Facility (2)	9+	^{85}Kr	Man-Made
*Steel Plant (3)	16+	X-Ray	Radiography
*Landfill (4)	14+	^{137}Cs , ^{232}Th	Refractory Bricks
*Anomaly northwest of Crystal Lakes, Ohio (5)	14+	^{137}Cs , ^{192}Ir	Unknown

* Numbers in parentheses refer to locations on the man-made radiation contour map, Figure 3.

The typical exposure rate levels, including those occurring naturally and those found in the five localized areas, were 9 to 13 $\mu\text{R/h}$ at one meter above ground level in uncovered ground area forms. Areas covered with road tops, concrete, housing, and heavy vegetation had exposure rate levels ranging from 5 to 7 $\mu\text{R/h}$. The detected exposure rates are well within the range (1 to 20 $\mu\text{R/h}$) found throughout the contiguous United States, Hawaii, and Alaska.⁵

Table 4 compares the exposure rate results obtained from the aerial data with the results obtained from

ground-based measurements taken during the survey. The fact that the aerial system measures an area several thousand times larger than a typical ion chamber measurement taken at 1 meter above ground and several million times larger than a typical soil sample should be considered when comparing these different types of measurements. The ground measurement results are listed in Table 5. The values given in Table 4 show that good agreement was obtained between the different measurement techniques for the WPAFB survey.

Table 4. Comparison of the Aerial and Ground-Based Measurements^a			
Site	Exposure Rate ($\mu\text{R/h}$ at 1 Meter AGL)		
	Soil Analysis^b	Ion Chamber^c	Aerial Data^d
1	10.7 $\pm$ 1.0	10.0 $\pm$ 0.5	9.6 $\pm$.1
2	8.6 $\pm$ 0.9	8.9 $\pm$ 0.5	7.9 $\pm$.1
3	7.7 $\pm$ 1.7	8.0 $\pm$ 0.5	8.1 $\pm$.3
4	7.4 $\pm$ 0.6	8.1 $\pm$ 0.5	7.3 $\pm$.2
5	11.1 $\pm$ 0.9	9.6 $\pm$ 0.5	9.9 $\pm$.2
6	10.5 $\pm$ 0.9	9.3 $\pm$ 0.5	9.2 $\pm$.3

^a All numbers have the cosmic ray contribution included.

^b Exposure rate value includes a cosmic ray contribution of 4 $\mu\text{R/h}$ and a moisture correction factor of the form $1/(1+m)$.

^c Reuter-Stokes Pressurized Ion Chamber Model #RSS-112, Serial No. # G-003.

^d Uncertainties in aerial data are statistical counting uncertainties only.

Table 5. Soil Sample Analysis Results					
Site	Soil Moisture (%)	²²⁶Ra (pCi/g)	²³²Th (pCi/g)	¹³⁷Cs (pCi/g)	⁴⁰K (pCi/g)
1	4.0 $\pm$ 1.0	0.9 $\pm$ 0.1	0.95 $\pm$.19	0.43 $\pm$.19	16.0 $\pm$ 0.9
2	2.3 $\pm$ 1.0	0.6 $\pm$ 0.1	0.6 $\pm$ 0.1	0.03 $\pm$ 0.02	12.6 $\pm$ 1.5
3	1.5 $\pm$ 0.2	0.6 $\pm$ 0.2	0.5 $\pm$ 0.2	0.12 $\pm$.06	9.0 $\pm$ 3.0
4	8.1 $\pm$ 0.7	0.7 $\pm$ 0.1	0.4 $\pm$ 0.07	0.29 $\pm$.09	8.2 $\pm$ 1.1
5	7.0 $\pm$ 1.0	1.1 $\pm$ 0.1	1.0 $\pm$ 0.06	0.27 $\pm$.04	16.4 $\pm$ 0.8
6	11.0 $\pm$ 3.0	1.1 $\pm$ 0.1	0.94 $\pm$.07	0.48 $\pm$.04	16.0 $\pm$ 0.4

APPENDIX A

SURVEY PARAMETERS

Survey Site: Wright-Patterson Air Force Base

Survey Area: 64 mi² (165.8 km²)

Survey Date: July 7-20, 1994

Survey Altitude: 150 ft (46 m)

Line Spacing: 250 ft (76 m)

Line Direction: Southwest/Northeast

Line Miles: 1,352

Airspeed: 70 knots (36 m/s)

Detector Array: Eight 2- × 4- × 16-in NaI(Tl) detectors
Two 2- × 4- × 4-in NaI(Tl) detectors

Acquisition System: REDAR IV

Aircraft: MBB BO-105 Helicopter (N40EG)

Project Scientist: E.L. Feimster

Data Processing:

- Man-Made Energy Window: 38-1,394 keV
- Gross Count Energy Window: 38-3,026 keV
- Conversion Factor: 1,071 cps per μ R/h
- Cosmic Ray Contribution: 4 μ R/h

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