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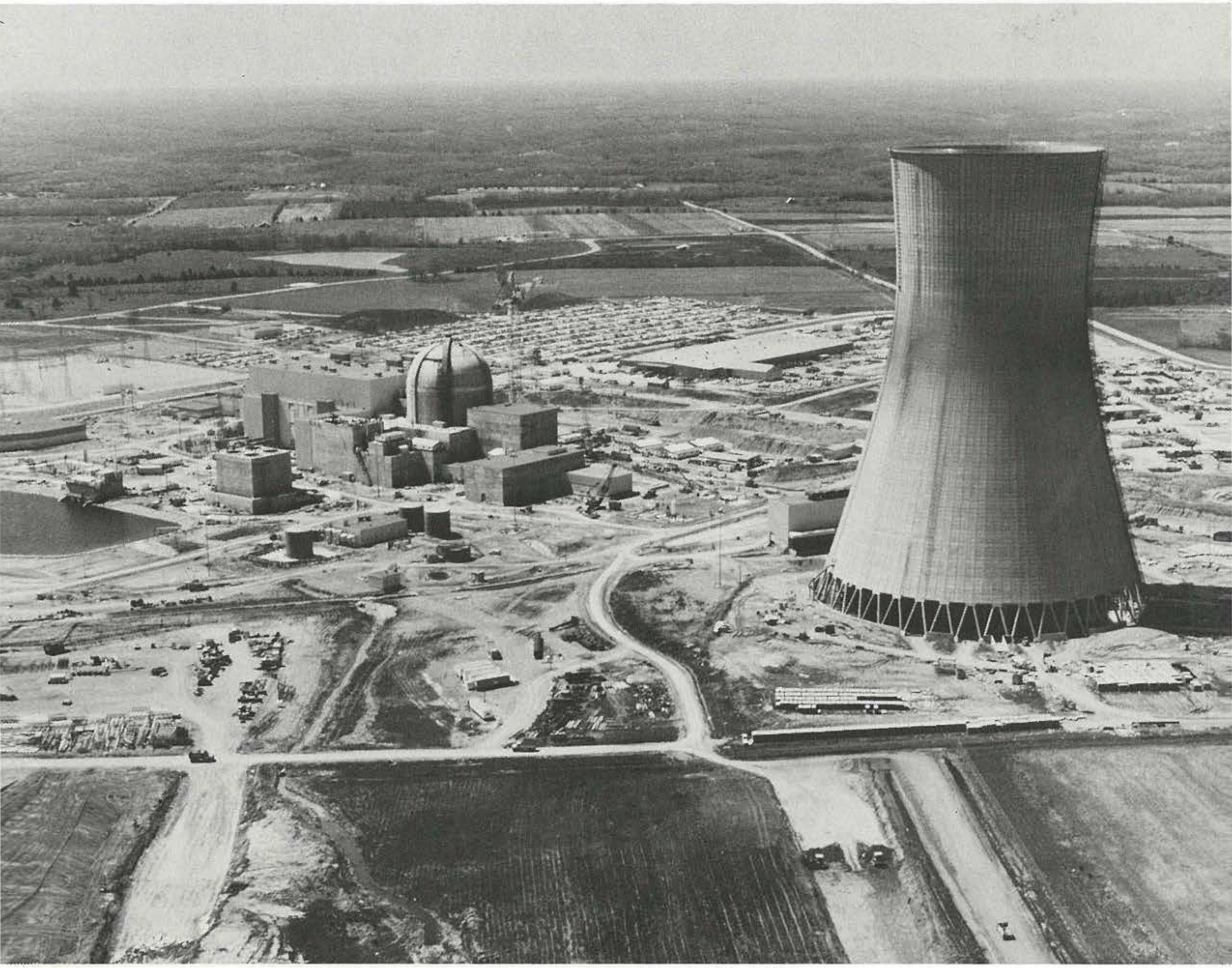

AN AERIAL RADIOLOGICAL SURVEY OF THE

CALLAWAY PLANT

AND SURROUNDING AREA

FULTON, MISSOURI

DATE OF SURVEY: APRIL 1982

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This Document is UNCLASSIFIED

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ABSTRACT

An aerial gamma survey was conducted over the Callaway Plant and the surrounding area in April 1982. The survey included the plant water intake and discharge location on the Missouri River. Separate ground-based ion chamber measurements and soil samples were collected in the survey area to support the aerial data.

Gamma data, stored on magnetic tape, were searched for evidence of man-made gamma emitters. A contour map of the terrestrial exposure rate plus the cosmic exposure rate at 1 meter was prepared and overlaid on a photograph and a USGS topographic map of the area.

The exposure contour map is typical for farmland in the mid-western United States. Terrestrial plus cosmic exposure rates ranged from 4 microroentgens per hour (μR/h) over the Missouri River to a maximum of 12 μR/h over the cultivated land. A ^{137}Cs calibration source was detected at the Callaway Plant site.

CONTENTS

1.0 INTRODUCTION

An aerial gamma survey was conducted over the Callaway Plant, Fulton, Missouri, and over 260 square kilometers (100 square miles) surrounding the plant, from 23 to 27 April 1982. Ground-based exposure data and soil samples were obtained to support the aerial data. The purpose of this survey was to map the gamma environment in the areas surrounding the plant before commercial operation begins. The plant is nearing completion and is expected to produce electric power in 1984.[1]

The plant lies about 16 kilometers (10 miles) southeast of Fulton, Missouri at the former townsite of Reform, Missouri. The Missouri River, which provides cooling water and receives the plant discharge, flows within 8 kilometers (5 miles) of the plant. The intake/discharge point on the river was also surveyed.

Large area photographic imagery of this site was obtained prior to the survey and many oblique photographs* of the plant were obtained during the survey.

2.0 SURVEY EQUIPMENT AND METHODS

2.1 Aircraft System

A Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter was used as the aerial platform (Figure 1). The aircraft carried two detector pods, each containing ten 12.7-cm diameter × 5.1-cm thick cylindrical NaI(Tl) detectors. Gamma signals originating in the NaI(Tl) detectors were routed to the Radiation and Environmental Data Acquisition and Recorder (REDAR IV) system for analysis and storage on magnetic tape. Pressure, temperature and radar altitude transducer data were also acquired and stored by the REDAR.

Figure 1. *THE AERIAL GAMMA MEASURING SYSTEM*

* The photograph on the cover of this document was taken during the survey.

Real time gamma energy spectra, total gamma count rates, and other data were output to a small TV screen for the system operator.

The aircraft pilot was guided over fixed flight lines by an indicator that derived its signal from the triangulation of two microwave transponders on the ground with a master unit in the aircraft. A transponder overlooking the Callaway Plant is shown in Figure 2. The position information was also stored on magnetic tape by the REDAR system.

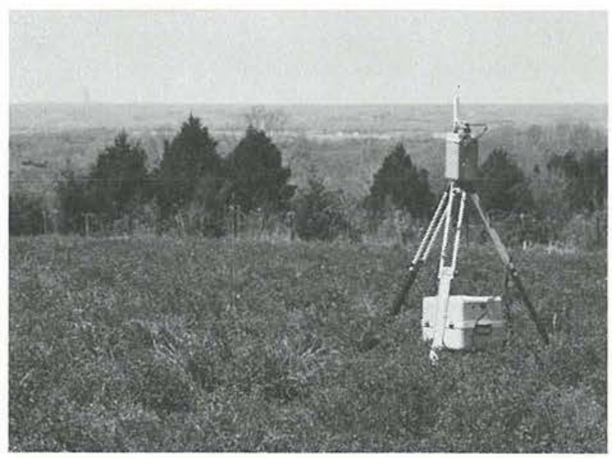


Figure 2. *A MICROWAVE TRANSPONDER OVERLOOKING THE CALLAWAY SITE*

2.2 Data Van

A minicomputer-based system (Figure 3) housed in a van was used during the survey to evaluate the aerial data immediately following each survey flight. The system contained hardware and software that operates on the survey data stored on magnetic tape. The system operator can plot gamma energy spectra from any portion of the gamma survey and can plot count rate isopleths or contours of the survey scaled to a map or photograph. In this manner the isotope emitters and their intensity and location can be identified.

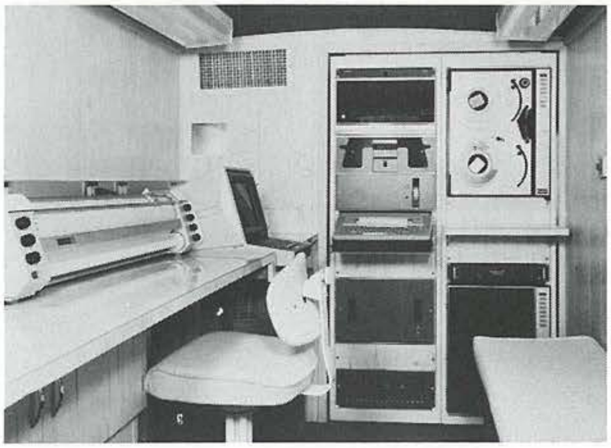


Figure 3. *THE DATA REDUCTION VAN SYSTEM*

2.3 Ground-Based Measurements

Exposure rates were measured and soil samples obtained at several locations during the Callaway survey. These measurements were made to support the integrity of the aerial results. A Reuter-Stokes pressurized ionization chamber was used for each exposure measurement at a 1 meter height at the center of a 120-m diameter measurement area. Soil samples, to a depth of 2.5 cm, were also obtained at the center and at the four points of the compass on the circumference of the circular area. The soil samples were dried and their gamma activities measured on a germanium-based detector system in the EG&G Santa Barbara laboratory.[2,3]

2.4 Callaway Survey Method

A standardized procedure for reactor surveys was followed at Callaway. The method seeks to obtain large area gamma environmental data in an efficient and timely manner at a minimum cost. Steps in the procedure are as follows:

1. The two microwave transponder units were placed on hill-tops about 16 km south of the Callaway Plant (south of the Missouri River) so that the transponders and plant formed a nearly equilateral triangle.

   A perimeter survey of roads in the 260-square-kilometer survey area was then flown. A plot of the road flight was used to scale each subsequent survey datum to its correct position on a map and a photograph of the area.

2. During the perimeter flight a low-altitude (15 m) pass down the center of the Missouri River was made. Gamma data acquired were used to obtain an absolute gamma background count rate (cosmic, aircraft, and radon contributions). A test line near the base of operations (Fulton Municipal Airport) was flown at three altitudes (30, 91 and 152 m). This test line was also flown at 91 m at the beginning and end of each survey flight to track changes in airborne radon. An increase or decrease in count rate over the test line suggested an increase or decrease in airborne radon. The change was either added to or subtracted from the original river count rates to yield the expected gamma background rate for each flight.

3. Following the perimeter, river and test line flights, routine survey flights began. Each flight—preceded by a preflight in which the system was calibrated, the data tape analyzed for proper operation, and the data tape rerecorded on a master tape—consisted of:

   a. Flight of the test line.
   b. Flight, in an east-west direction, of about 15 lines over the survey area.
   c. Reflight of the test line.

   After the flight the survey data were evaluated for integrity and anomalies in the gamma total count and energy spectra. A letter plot of the total gamma count rate less background was updated after each flight. This plot, overlaid on the area map, supplied a record of survey progress and general gamma levels.

   An outline of the survey parameters is given in Table 1.

4. During the aerial survey, ground-based exposure rate measurements were made and soil samples collected at four locations within the survey area. A separate exposure rate measurement and soil samples were obtained at the Fulton Airport (outside the survey area) while the aircraft collected data overhead.

5. After the data acquisition flights were complete, the total gamma count rates (less background) were plotted to form a contour map. The plot was overlaid on the USGS map and the EG&G photograph of the area. These were presented to the resident NRC inspector and interested Union Electric officials at the Callaway Plant on 28 April 1982.

Table 1. Callaway Survey Parameters	
Parameter	**Value**
Survey altitude	91 m (300 ft)
Aircraft speed	41 m/s (120 ft/s)
Flight line spacing	152 m (500 ft)
Flight line length	16 km (10 mi)
Number of lines	105
Flight line direction	E-W
Area surveyed	260 sq km (100 sq mi)
Location of Callaway Reactor	91° 46′53″W, 38° 45′41″N
Gamma data (energy spectra, livetime) acquire rate	1 per second

3.0 GENERAL DATA REDUCTION

The aerial system uses two primary methods to treat gamma fluence measurements as seen by NaI(Tl) detectors. The first is the gross count (GC) or total gamma count rate. The second is the spectral window technique. These and other methods are described in detail in a separate publication.[4]

3.1 Gross Count

The gross count is defined as the integral count in the energy spectrum between 38 keV and 3016 keV.

$$GC = \sum_{38\text{ keV}}^{3016\text{ keV}} \text{Energy Spectrum} \tag{1}$$

This integral includes all the natural gammas from K-40, U-238, and Th-232 (KUT, the major terrestrial, natural gamma emitters). Other natural contributors to this integral are cosmic rays, aircraft background, and airborne radon daughters.

The response versus altitude of the aerial system to terrestrial gammas has been measured over a documented test line near Las Vegas, Nevada for which the concentrations of KUT and the 1-m exposure rates have been measured separately. From this calibration the terrestrial gross count rate has been associated with the 1-m exposure rate in microroentgens per hour (μR/h) for natural radioactivity. The conversion equation is:

$$\text{Exposure Rate}\ (1\text{ m}) = \big[[GC(A)\text{-}B]/1324\big]\ \text{Exp}(\ 0.001957 \times A)\,\mu\text{R/h} \tag{2}$$

where

A = altitude in ft
GC(A) = gross count rate at altitude A (cps)
B = cosmic, aircraft and radon background (cps) obtained over water

The exponent, 0.001957 ft^{-1}, is normalized to 20° C and 14.7 psi. The coefficient is always corrected to the ambient pressure and temperature.

Equation 2 was used to compute the exposure rate from the terrestrial gross count rate. For the Callaway survey, flown at 91 meters, Equation 2 becomes:

$$\text{Exposure Rate}\ (1\text{ m}) = (GC - B)/750\ \mu\text{R/h} \tag{3}$$

If a body of water is not available from which to obtain local background components, a local test line is flown at two altitudes (30 and 152 m). Two equations in two unknowns can then be written for terrestrial exposure rate and B using Equation 2.

The gross count has been used for many years in the aerial system as well as other dosimetric meters as a measure of exposure. Its simplicity yields a rapid assessment of the gamma environment.

Anomalous or non-natural gamma sources are found from increases in gross count rate over the natural count rates. However, subtle anomalies are difficult to find using the gross count rate in areas where its magnitude is variable due, for example, to geologic or ground cover changes.

Differential energy data reduction methods, as discussed in the next section, are used to increase the aerial system's sensitivity to anomalous gamma emitters.

3.2 Spectral Windows

The aerial system produces each second a gamma energy spectrum from which the GC is computed. Generally the ratio of natural components in any two integral sections (windows) of the energy spectrum will remain nearly constant in any given area:

$$\sum_{E=a}^{b} \Big/ \sum_{E=b}^{c} = \text{Constant} \qquad (4)$$

where $c > b > a$

If the window, a-b, is placed where gamma rays from a man-made emitter would occur in the spectrum, the result of Equation 4 could be expected to increase over the constant value. This equation is routinely applied in the data reduction software when a search is made for specific isotopes.

In general when a search is made for an unknown or non-specific gamma emitter, a and b are set to 48 keV and 1400 keV, respectively; this range includes most of the long-lived gammas from man-made isotopes. The upper limit of the background window, c, is set at 3016 keV. This window arrangement is called the man-made gross count (MMGC) ratio.

Plots of the MMGC were produced routinely in the post-flight data evaluations during the Callaway survey. A Cs-137 source was "found," as explained in Section 4.3.

4.0 RESULTS

4.1 The Exposure Rate Contour Map

The principal result of the Callaway gamma survey is the exposure rate contour map (Figure 4) of the 260-square-kilometer (100-square-mile) area surrounding the Callaway Plant. This map represents the measured terrestrial gamma exposure rate plus an estimated cosmic component of 3.8 μR/h. Only the terrestrial component was measured during this survey; the cosmic component was obtained from another source.[5] The highly variable airborne radon daughter component is not included, although it can be significant. Section 3.1 explains the terrestrial exposure method.

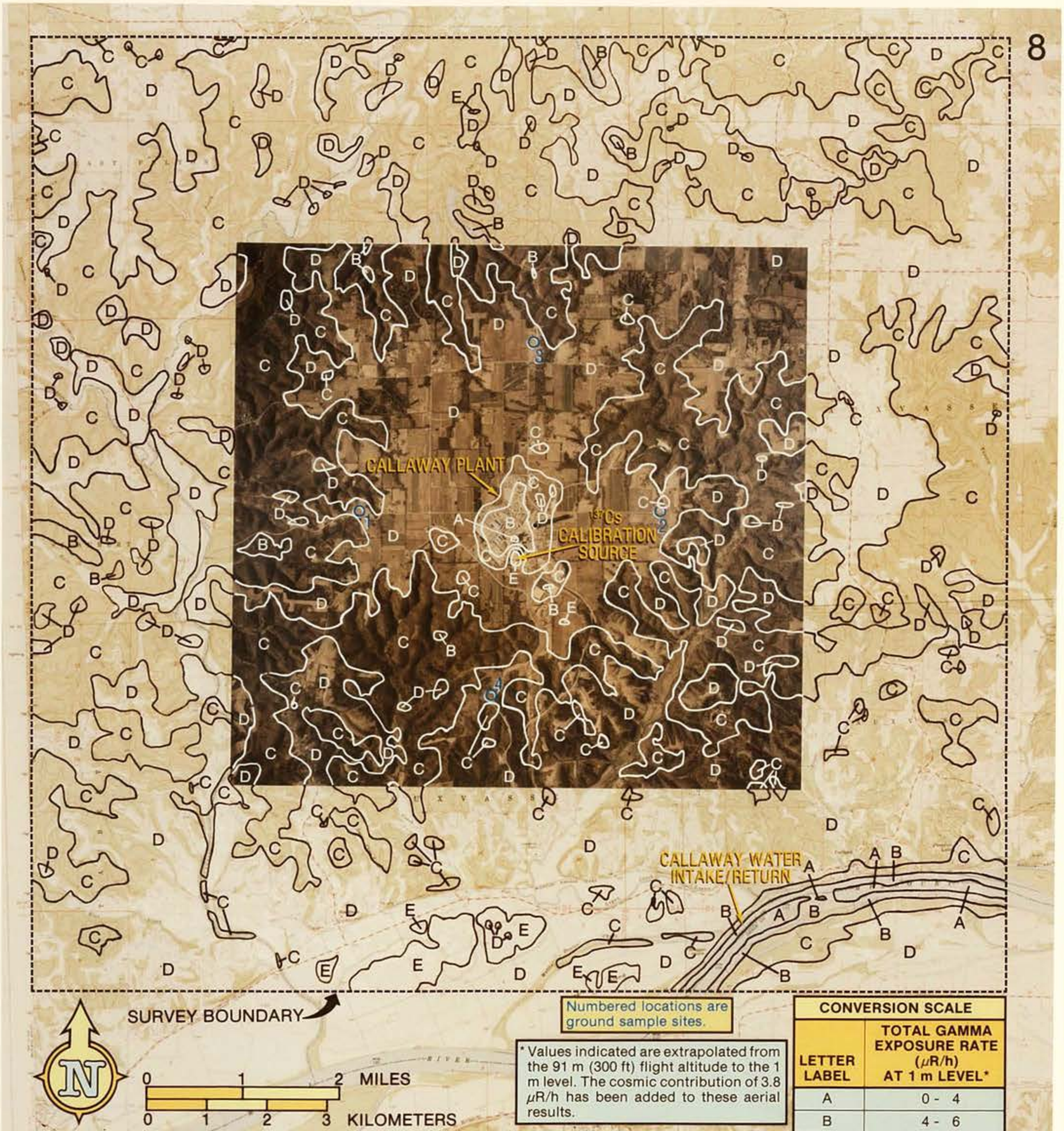
The contour map was composed from approximately 42,000 data points, each representing about 0.6 hectares (about 1.5 acres). Each data point is supported by a 256-channel gamma energy spectrum, a pressure and a temperature measurement, and position data (radar altitude and x, y coordinates). A typical gamma energy spectrum accumulated over a 16-kilometer (10-mile) line passing over the Callaway cooling tower is shown in Figure 5.

The contour map indicates that the exposure rate over most of the survey area ranged from 6 to 10 μR/h. The high flat areas were characterized by the higher exposure rate (8 to 10 μR/h) while the wooded stream valleys indicated a lower exposure rate (6 to 8 μR/h). The vegetation and soil moisture in the valleys absorbed the terrestrial gammas; the open tilled areas exposed the terrestrial emitters. The highest exposure rates (10 to 12 μR/h) occurred over the cultivated land in the Missouri River Valley and the lowest (4 μR/h) over the Missouri River itself. The levels over the river were nearly all due to cosmic ray contributions because only a small fraction of the terrestrial gammas reach the center of the 500-m wide river.

4.2 Exposure Rates From Airborne Radon Daughters

The Callaway contour map (Figure 4) does not contain exposure rates from airborne radon because that component changes from zero to about 10% of the terrestrial component. Approximate values for the 1-m radon daughter exposure rate were obtained from the Missouri River and the test line data. The river data provided a baseline or absolute radon level and the test line provided the increases and decreases in the radon level (assuming the changes in test line count rates were from radon changes only, other physical parameters being equal).

The approximate exposure rate levels from airborne radon ranged from 0.3 to 0.6 μR/h during this survey.



CONVERSION SCALE	
LETTER LABEL	TOTAL GAMMA EXPOSURE RATE (μR/h) AT 1 m LEVEL*
A	0 - 4
B	4 - 6
C	6 - 8
D	8 - 10
E	10 - 12

Figure 4. *EXPOSURE RATE CONTOUR MAP OF THE CALLAWAY PLANT AREA*

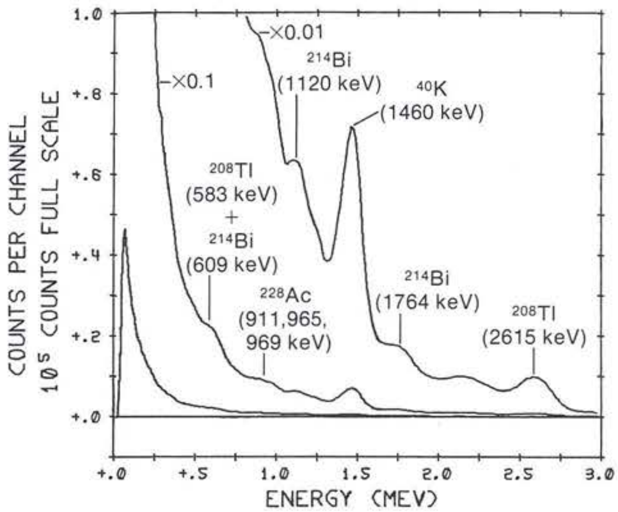


Figure 5. *A TYPICAL GAMMA ENERGY SPECTRUM. (Representing an entire flight line passing over the Callaway Plant)*

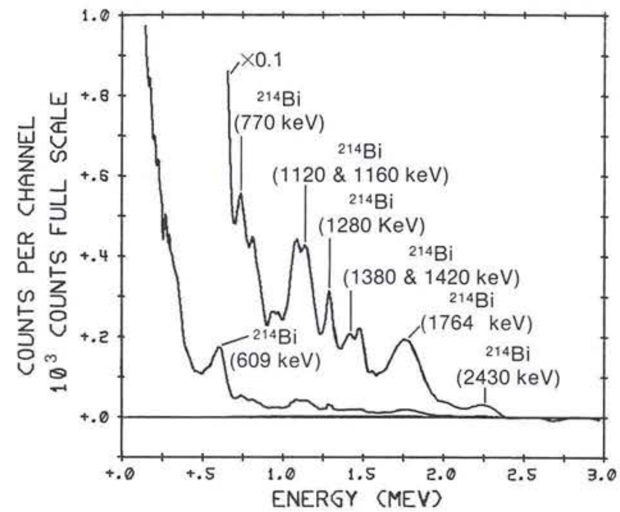


Figure 6. *THE GAMMA ENERGY SPECTRUM OF RADON DAUGHTERS. (Deposited by rain onto the ground)*

An interesting radon daughter effect was observed toward the end of the survey. A local light rain shower passed over the survey area. The test line count rate at survey altitude rose by 28% (1460 cps) immediately following the shower. If one assumes that all the radon daughters had been washed from the air by the rain shower, the exposure rate at 1 m had increased by approximately 2 μR/h due to terrestrial gammas (1460 cps $\div$ 740 cps per μR/h $\simeq$ 2 μR/h). Later flights over the test line showed that these washed out radon daughters died away rapidly (with a half-life of about 35 minutes).

The energy spectrum of these radon daughters, shown in Figure 6, was obtained by subtracting the pre-shower test line energy spectrum from the post-shower spectrum. The energy components (photopeaks) are essentially attributable to Bi-214 and Pb-214 (daughters of Rn-222).

4.3 Man-Made Gamma Emitters

The gamma energy spectra were searched during the course of the survey for the presence of man-made gamma emitters. This was done during each post-flight data evaluation using the automated man-made gross count (MMGC) technique. The MMGC (Section 3.2) is a plot of the ratio of lower energy components of the spectrum (50 to 1400 keV) to the higher energy components (1400 to 3000 keV). The presence of man-made gamma emitters will generally increase this ratio over the normal value from natural gammas.

A man-made source was discovered on the Callaway site in this fashion. The source location is shown in Figure 4. A net spectrum of the area (Figure 7) showed the presence of Cs-137. An inquiry to Union Electric confirmed the discovery; thermoluminescent detectors (TLD's) were being calibrated with a 120 mCi Cs-137 source at the time of the survey.

No other man-made gamma sources were found during the Callaway survey.

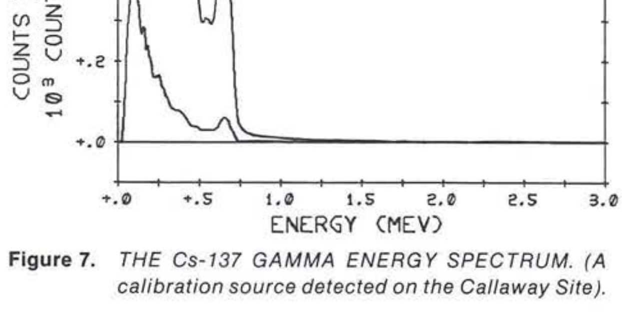


Figure 7. *THE Cs-137 GAMMA ENERGY SPECTRUM. (A calibration source detected on the Callaway Site).*

4.4 Soil Sample and Ion Chamber Measurements

The results of the soil sample radiometric analysis and the ion chamber measurements are given in Table 2. The aerial exposure rates obtained over the same locations are listed for comparison.

The mean aerial result appears to be 0.8 to 1.8 μR/h less than the mean isotopic (soil sample) and ion chamber results. Some probable causes for the differences are:

1. The ion chamber exposure rate contains airborne radon, which is not part of either the isotopic or aerial result. The airborne radon exposure rate varied about 0.3 to 0.6 μR/h during the Callaway survey.
2. The aerial data were not taken exactly over each of the first four ground sites, but from Figure 4 in the general area of the ground site.
3. Each aerial datum measures a larger area (6 to 10 hectares) than does the ground measurement (about 1 hectare).
4. The aerial data were not acquired at the same time as the ground data except at site 5.
5. The ground cover (or flora) reduces the isotopic estimate by perhaps 5%. No general measurements of the effect of flora have been made.

Perhaps the best comparison between aerial and ground-based exposure measurements is illustrated from site 5 (Fulton airport) data. The aerial system hovered for 1 minute at each of four altitudes (30, 60, 90 and 150 m) while the ground data were collected. The aerial data were reduced to exposure rates by the method of Section 3.1. The three measurements (isotopic, ion chamber, and aerial) agreed within 1 μR/h.

Table 2. Comparison of Aerial and Ground-Based Measurements

Site[1]	Soil Moisture (%)	U-238 (ppm)	Th-232 (ppm)	Cs-137 (pCi/g)	K-40 (pCi/g)	Exposure Rate (μR/h) Isotopic[2]	Ion Chamber	Aerial[3]
1	25	3.8	11.7	0.44	12.4	10.4	11.3	8 - 10
2	26	3.6	11.7	0.84	9.1	9.8	10.0	8 - 10
3	24	3.1	10.7	0.39	10.5	9.5	10.7	8 - 10
4	22	3.3	10.4	0.43	12.3	10.0	11.6	8 - 10
5	24	3.7	11.3	0.42	12.6	10.3	11.2	9.9 - 10.1
					Averages	10	11	9.2

[1] The locations of sites 1 through 4 are shown on Figure 4. Site 5 was at Fulton Municipal Airport and is not on the map.

[2] The exposure rate from each of the isotopic concentrations (U-238, Th-232, Cs-137, and K-40) was computed using Beck's conversions (see Reference 6). This computed exposure rate also includes the effect of the measured soil moisture (see Reference 7) and the cosmic component of 3.8 μR/h.

[3] The aerial exposure rate (which also includes the cosmic exposure rate of 3.8 μR/h) was obtained from Figure 4 except for site 5. The aerial exposure rate at site 5 was measured more carefully during the hover experiment (see text).

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