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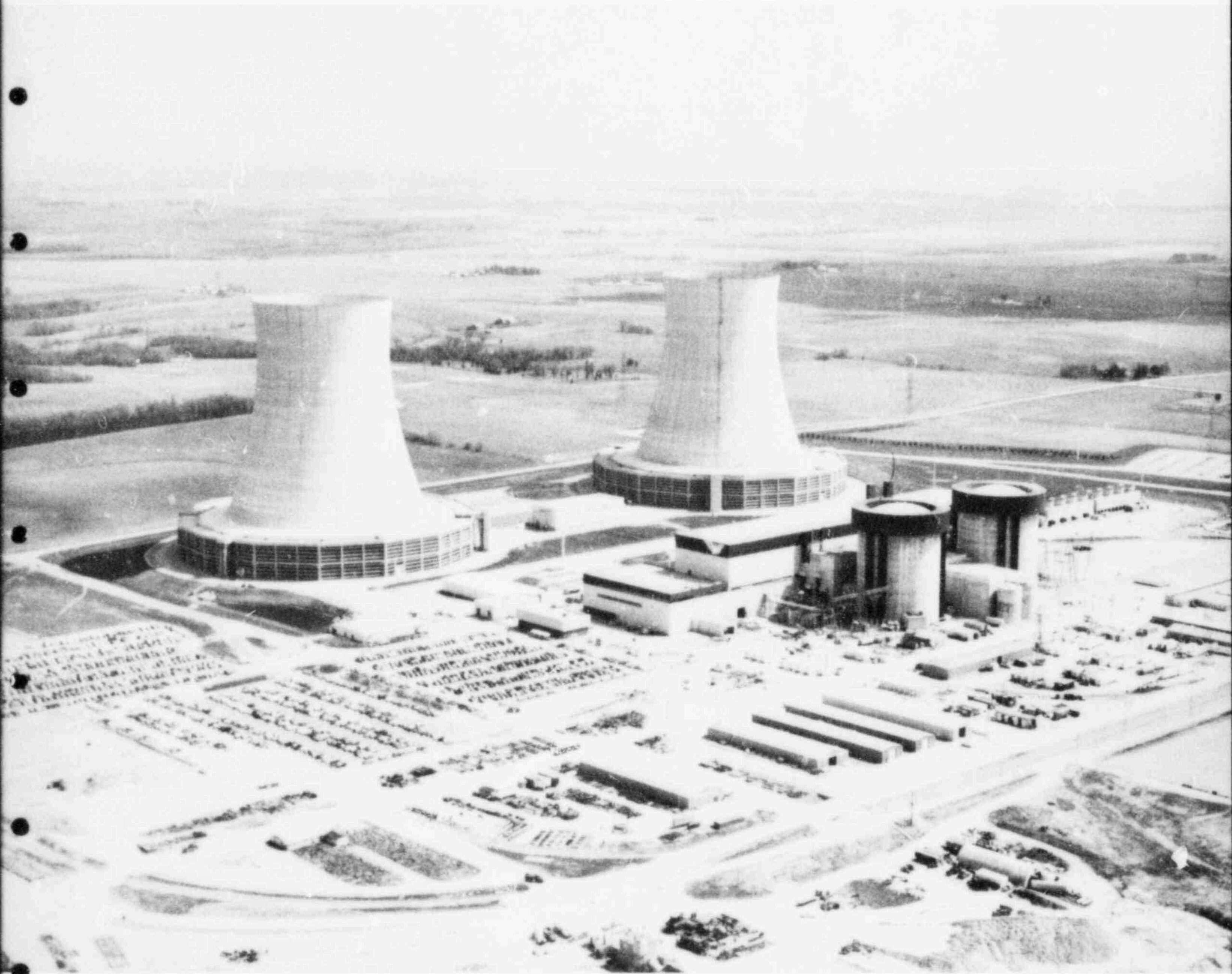

AN AERIAL RADIOLOGICAL SURVEY OF THE

BYRON STATION

AND SURROUNDING AREA

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BYRON, ILLINOIS

DATE OF SURVEY: APRIL 1985

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Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS price codes

Printed copy: A02
Microfiche copy: A01

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This work was performed by EG&G/EM for the United States Department of Energy, Office of Nuclear Safety, and the United States Nuclear Regulatory Commission under Contract Number DE-AC08-83NV10282.

ABSTRACT

An aerial gamma survey was conducted over the Byron Station, located 5 kilometers (3 miles) south of Byron, Illinois, during the period 11 April through 17 April 1985. The survey included a 260-square-kilometer (100-square-mile) area centered on the Station.

A contour map of the terrestrial gamma exposure rate plus cosmic exposure rate at the 1-meter level was prepared and overlaid on an aerial photograph and a USGS topographic map of the area. The terrestrial plus cosmic gamma exposure rate ranged from a minimum of 5.0 microroentgens per hour (μR/h) over the Rock River to a maximum of 12 μR/h 7 kilometers (4 miles) west of the facility. A machine-aided search of the data showed no man-made gamma emitters in the survey area.

Soil samples and ion chamber measurements were obtained at four locations to support the aerial data.

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Tables

1.0 INTRODUCTION

An aerial gamma survey was conducted from 11 April through 17 April 1985 over the Byron Station and surrounding area. The survey covered a 260-square-kilometer (100-square-mile) area centered on the Station. The purpose of the survey was to map the gamma environment of the area surrounding the Station. The survey was performed at the request of the United States Nuclear Regulatory Commission.

The Byron reactor was in the process of being brought to a significant power level when the operation was scrammed on 10 April 1985, the day prior to the start of the aerial survey. A significant reactor power level was again achieved by 13 April 1985.

The Byron facility is located in Ogle County, Illinois, 5 kilometers (3 miles) south of the town of Byron, Illinois. The Rock River, 3 kilometers (2 miles) west of the plant, supplies the cooling water. The majority of the land surrounding the facility is cultivated and fairly level with 60-meter (200-foot) maximum elevation changes.

Large-area aerial photographic imagery of the Station was obtained in July 1983 and many oblique photographs of the site were taken 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 four 10.2 cm × 10.2 cm × 40.6 cm log-type NaI(T*l*) gamma detectors as well as one 10.2 cm × 10.2 cm cylindrical gamma detector. The smaller detector was used to extend the dynamic range if necessary of the large and sensitive log-type detectors.

Gamma signals originating in the NaI(T*l*) detectors were routed to the Radiation and Environmental Data Acquisition and Recorder (REDAR IV) system for conversion and storage on magnetic tape. Pressure, temperature, and radar altitude transducer data were also acquired and stored by the REDAR.

Figure 1. *AERIAL GAMMA MEASURING SYSTEM*

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

The aircraft pilot was guided over the programmed flight lines by an indicator that derived its signal from the triangulation of two UHF transponders on the ground and a master unit in the aircraft. These position data were also stored by the REDAR.

2.2 Data Van

A minicomputer-based system (Figure 2) housed in a van was used during the survey to evaluate the aerial data immediately following each survey flight. The system contains hardware and software that operates on the survey data stored on magnetic tape. The system operator can plot both gamma energy spectra from any portion of the gamma survey and count rate isopleths or contours of the survey scaled to a map or photograph. In this manner the isotope emitters, their intensity, and location can be identified.

2.3 Ground-Based Measurements

Exposure rates were measured and soil samples obtained at four locations during the Byron 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-meter (396 ft) diameter measurement area. Soil samples, to a depth of 15.0 cm, were also obtained at the center and at four points of the compass on the circumference of the

Figure 2. *DATA REDUCTION VAN SYSTEM*

circular area. The soil samples were dried and their gamma activities measured on a germanium-based detector system in the EG&G/EM Santa Barbara laboratory.[1,2]

2.4 Byron Survey Method

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

1. One UHF transponder unit was placed at the Greater Rockford Airport and a second unit on a farm 2 kilometers (1 mile) south of Seward, Illinois. These transponders, together with the Byron Station, formed an approximate equilateral triangle.

2. A perimeter survey of roads in the 260-square-kilometer (100-square-mile) area was then flown. The position data from the transponders were used to scale each subsequent survey datum to its correct position on a map and an aerial photograph of the area.

3. A test line, approximately 2 kilometers (1 mile) long, was located during the perimeter flight. This line was flown at several altitudes so that the gamma and meteorological data could be used to compute and separate the terrestrial from the background gamma component. The background consists of gamma sources from the aircraft, cosmic rays, and airborne radon.

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

   a. A pass over the test line at survey altitude.
   b. Passes in an north-south or south-north direction of 20 or more 16-kilometer-long (10-mile-long) survey lines.
   c. A repeat pass over the test line.

   All the survey flights were flown at an altitude of 90 meters (300 feet).

   After each survey flight the data were evaluated for integrity and anomalies in a routine manner on the computer-based data reduction system. All the gamma, position, and meteorological data were plotted and examined.

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

Table 1. Byron Survey Parameters

Parameter	Value
Survey altitude	91 m (300 ft)
Aircraft speed	37 m/s (120 ft/s)
Flight line spacing	152 m (500 ft)
Flight line length	16 km (10 mi)
Number of lines	107
Flight line direction	N-S
Area surveyed	260 sq km (100 sq mi)
Location of Byron Reactor	89° 16′55″ W, 42° 04′30″ N
Gamma data (energy spectra, livetime) acquire rate	1 per second

5. During the aerial survey, ground-based exposure rate measurements were made and soil samples collected at four locations within the survey area. These data were used to

support the aerial measurements. A special effort was made to obtain ground-based and aerial data at the same time at one of these locations.

6. After the data acquisition flights were completed, the total gamma count rates (less background) were plotted to form a contour map. The plot was overlaid on a USGS map and an EG&G/EM aerial photograph of the area before the survey crew left the operation site.

3.0 GENERAL DATA REDUCTION

The aerial system uses two primary methods to treat gamma fluence measurements as seen by NaI(T*l*) 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.[3]

3.1 Gross Count

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

$$GC = \sum_{38\ \text{keV}}^{3016\ \text{keV}} \text{Energy Spectrum} \qquad (1)$$

This integral includes all the natural gammas from potassium-40, uranium-238, and thorium-232 (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 concentration values and the 1-meter exposure rates have been measured separately. From this calibration the terrestrial gross count rate has been associated with the 1-meter exposure rate in microroentgens per hour (μR/h) for natural radioactivity. The conversion equation is:

$$\text{Exposure Rate}\ (1\ \text{m}) = \left[(GC(A)-B)/1440\right]\ \text{Exp}(0.001840 \times A)\ \mu\text{R/h} \qquad (2)$$

where

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

The coefficient, 0.001840, was normalized to the mean air temperature (17° C) and pressure (14.5 psi) during the Byron survey.

Equation 2 was used to compute the exposure rate from the terrestrial gross count rate. For the Byron survey, flown at 91 meters (300 feet), Equation 2 becomes:

$$\text{Exposure Rate}\ (1\ \text{m}) = (GC - B)/830\ \mu\text{R/h} \qquad (3)$$

The gross count has been used for many years in the aerial system 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 to, for example, 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

E = energy
$c > b > a$

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 ?8 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 Byron survey.

4.0 RESULTS

4.1 Exposure Rate Contour Map

The principal result obtained from the gamma survey of the Byron Station is the exposure rate contour map (Figure 3) of the 260-square-kilometer (100-square-mile) area surrounding the Station. The map represents the measured terrestrial gamma exposure rate plus an estimated cosmic component[4] (3.8 μR/h) at 1 meter above the earth's surface. The highly variable airborne radon daughter component is not included.

The contour map was composed from approximately 47,000 data points, each representing about 0.6 hectares (1.4 acres). Each data point is composed of a 256-channel gamma energy spectr n, a pressure and a temperature measurement, and measured spatial coordinates (altitude and two transponder distances).

The exposures at 1 m above the ground, shown on the map (Figure 3), range from a low of 6 μR/h in the vicinity of the reactor buildings and over the Rock River to 12 μR/h over some of the farm land. A more detailed contour map (not shown) indicates that exposure levels around the reactor and over the Rock River are as low as 5 μR/h. Note that these exposure values include a cosmic contribution of 3.8 μR/h. While the cosmic component is quite uniform, the varying terrestrial component (from K-40, the U-238 series, and the Th-232 series) causes most of the changes throughout the survey area.

The gamma energy spectra shown in Figures 4 and 5 (from the reactor area and immediately north of the reactor area) illustrate that only natural gammas exist there but in different quantities. The reactor area spectrum has smaller K-40, Bi-214, and T*l*-208 peaks than does the area just to the north.

An anomaly was found over the Farmers' Co-Op in the town of Byron. An examination of the net spectrum (anomaly spectrum minus a neighboring spectrum) showed an excess of K-40 (Figure 6). The K-40 is probably contained in the many tons of fertilizer stored there.

4.2 Exposure Rates From Airborne Radon Daughters

During the aerial survey, the computed background gamma count rates (cosmic, aircraft, and radon contributions) varied over a range from 560 to 980 cps. Since the aircraft and cosmic fractions of background are about 500 cps, the radon contribution ranges from 60 cps to 480 cps at the 300 ft survey altitude. These count rates imply exposures from airborne radon at the ground level of from less than 0.1 μR/h to 0.3 μR/h. The uncertainty is about 50 percent of these values.

4.3 Man-Made Gamma Emitters

The MMGC (discussed in Section 3.2) was used to search the Byron aerial data for man-made gamma emitters. None were found above the minimum detectable activity of about 0.1 μCi/m^2 for a large-area source or about 4 mCi for a point source on the ground surface. The minimum activity or source intensity that can be found by the MMGC method is limited primarily by the aerial system counting statistics.

4.4 Ground-Based Measurements

I n chamber measurements and soil samples were collected at four sites within the survey boundaries during the aerial survey. The site locations are labeled in Figure 3. The soil samples were dried and counted on a calibrated gamma spectrometer in the laboratory. The "in situ" exposures were computed from the primary isotopic concentrations in the soil samples[5] and

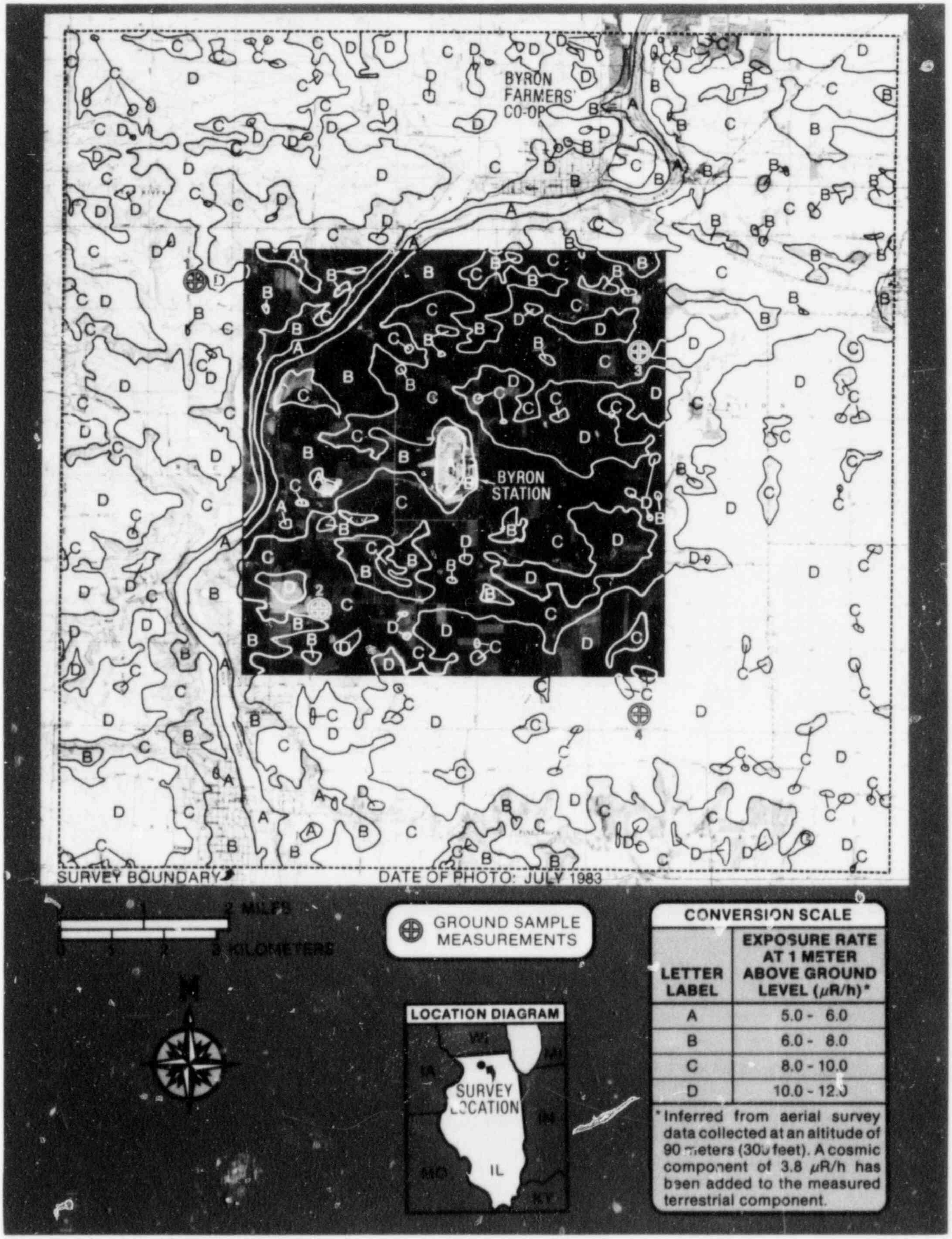
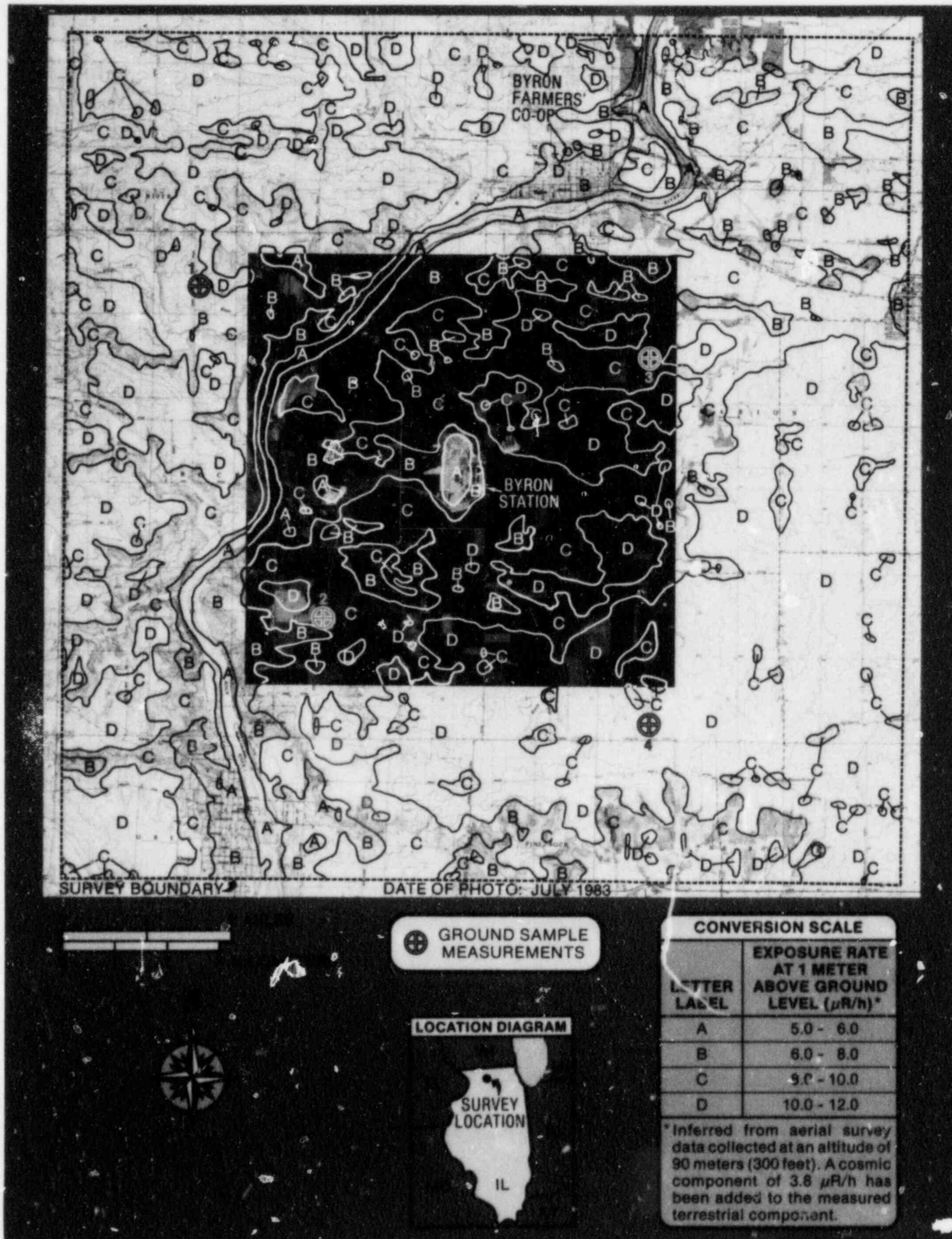


Figure 3. *TOTAL GAMMA EXPOSURE RATE CONTOURS FROM THE APRIL 1985 SURVEY OF THE BYRON STATION AND SURROUNDING AREA*



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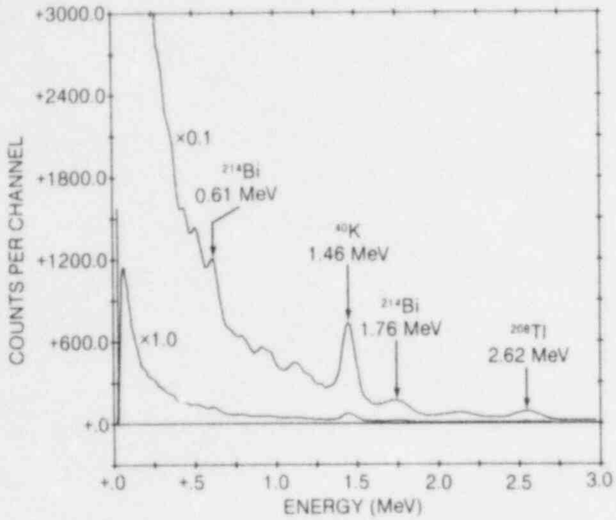

Figure 4. *TYPICAL GAMMA ENERGY SPECTRUM OVER THE BYRON STATION SURVEY AREA*

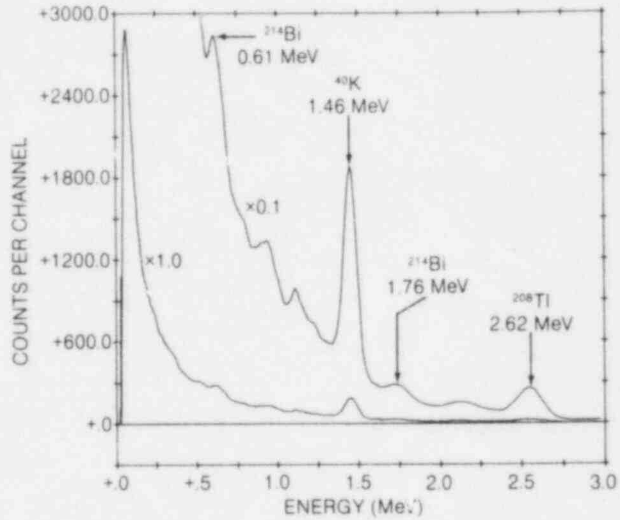

Figure 5. *GAMMA ENERGY SPECTRUM OVER THE AREA JUST NORTH OF THE BYRON STATION*

included the effect of soil moisture.[6] The exposure values are compared with the ion chamber measurements and the aerial measurements in Table 2. These exposure values represent the terrestrial plus the cosmic components only.

The isotopic and ion chamber measurements fall within the aerial measurement interval at each site except for site 3 where the aerial measurement is about 1 μR/h higher than the ion chamber and soil sample measurements. There are several contributors to differences among the measurement methods:

1. The aerial data were not taken at exactly the same places and times as the ground data, except for site 4.

2. The aerial system "sees" a larger area (6 to 10 hectares) than does the ground system (about 1 hectare).

3. Since only a limited number of soil samples were taken, statistical deviations are significant.

4. The ground cover reduces the computed isotopic exposure by as much as 5 percent.

A special effort to compare aerial and ground measurements was made at site 4. The aerial system flew slowly overhead at 30, 60, and 91-meter (100, 200, and 300-ft) altitudes while ion chamber measurements were made. Table 3 compares an experimental estimate of K-40, U-238, and Th-232 from the aerial data to the soil sample measurement as well as exposures from the ion chamber and aerial methods.

The aerial and ground-based exposure measurements in Tables 2 and 3 agree within the limits of the measurements' errors. The aerial measurement of U-238, Th-232, and K-40 is less than the soil sample measurement by about 10 percent but, nonetheless, it is reasonable.

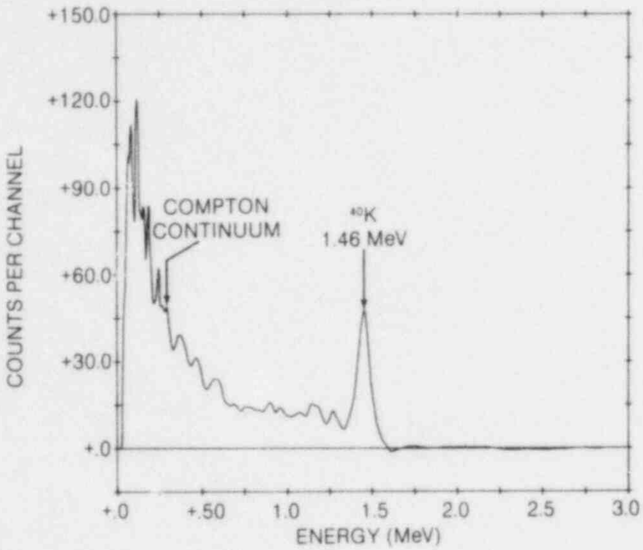

Figure 6. *POTASSIUM-40 GAMMA ENERGY SPECTRUM OBTAINED OVER THE FARMERS' CO-OP IN BYRON, ILLINOIS*

Table 2. Comparison of Aerial and Ground-Based Measurements

		Dry Soil Isotopic Composition				Exposure Rate (μR/h)		
Site [1]	Soil Moisture (%)	U-238 (ppm)	Th-232 (ppm)	Cs-137 (pCi/g)	K-40 (pCi/g)	Isotopic [2]	Ion Chamber [3]	Aerial
1	17.2 ± 1.5	2.8 ± 0.3	9.2 ± 0.7	0.29 ± 0.02	15.7 ± 0.8	10.2 ± 0.6	9.7 ± 0.5	8 - 10
2	16.9 ± 1.1	2.7 ± 0.2	8.7 ± 0.2	0.24 ± 0.01	16.2 ± 0.7	10.0 ± 0.5	10.0 ± 0.5	8 - 10
3	11.5 ± 1.0	1.3 ± 0.2	4.6 ± 0.7	0.30 ± 0.04	9.8 ± 1.2	7.4 ± 0.4	7.8 ± 0.5	8 - 10
4	18.9 ± 1.5	3.5 ± 0.2	11.[illegible] ± 0.6	0.35 ± 0.04	17.5 ± 0.7	11.3 ± 0.5	10.6 ± 0.5	10 - 12

[1] The site locations are shown in Figure 3.

[2] The exposure rate from the isotopic concentrations was computed using Beck's conversion.[5] The exposure rate computed from the isotopic concentrations includes the effect of soil moisture and a cosmic component of 3.8 μR/h.

[3] The measured airborne radon exposure rate, 0.3 μR/h, has been subtracted from the ion chamber measurements at sites 3 and 4 where a radon estimate was available from the aerial data.

Table 3. Detailed Comparison of Aerial and Ground-Based Measurements at Site 4		
	Ground-Based Measurement	**Aerial Measurement[1]**
U-238	3.5 ± 0.2 ppm	3.2 ppm
Th-232	11.5 ± 0.6 ppm	10.2 ppm
Cs-137	0.35 ± 0.04 pCi/g	(2)
K-40	17.5 ± 0.7 pCi/g	16.0 ppm
Isotopic Exposure[3]	11.3 ± 0.5 μR/h	10.5 μR/h
Ion Chamber Exposure[4]	10.7 ± 0.5 μR/h	
Aerial Total Count Exposure		10.5 ± 1.0 μR/h

[1] The errors in this experimental isotopic extraction method are being evaluated and are probably on the order of the soil sample method.

[2] The absolute isotopic extraction routine does not include Cs-137 for the aerial data.

[3] Exposures include the terrestrial and cosmic components only. Exposures also include the effect of soil moisture.

[4] A radon exposure estimate (from the aerial data) of 0.3 μR/h has been subtracted from the ion chamber exposure measurement.

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