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AN AERIAL RADIOLOGICAL SURVEY OF PROJECT RULISON AND SURROUNDING AREA

BATTLEMENT CREEK VALLEY, COLORADO

DATE OF SURVEY: JULY 1993

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ABSTRACT

An aerial radiological survey was conducted over the Project Rulison site, 40 miles (64 kilometers) northeast of Grand Junction, Colorado, from July 6 through July 12, 1993. Parallel lines were flown at intervals of 250 feet (76 meters) over a 6.5-square-mile (17-square-kilometer) area at a 200-foot (61-meter) altitude surrounding Battlement Creek Valley. The gamma energy spectra obtained were reduced to an exposure rate contour map overlaid on a high altitude aerial photograph of the area. The terrestrial exposure rate varied from 3.5 to 12.5 μR/h (excluding cosmic) at 1 meter above ground level. No anomalous or man-made isotopes were found.

CONTENTS

1.0 INTRODUCTION

An aerial radiological survey of the Project Rulison site in Battlement Creek Valley, Colorado, took place from July 6 through July 12, 1993. Battlement Creek Valley is located approximately 40 miles (64 kilometers) northeast of Grand Junction, Colorado. The survey was conducted at the request of the Department of Energy (DOE) and performed by personnel of EG&G Energy Measurements, Inc. (EG&G/EM), which operates the Remote Sensing Laboratory (RSL) in Las Vegas, Nevada, for DOE/NV.[1]

One of RSL's missions is to maintain and manage an aerial surveillance capability called the Aerial Measuring System (AMS) program. Since its inception in 1958, AMS has continued a nationwide effort to document baseline radiological conditions at nuclear energy-related sites of interest to DOE. These sites include power plants, manufacturing and processing plants, and research laboratories using nuclear materials. The Project Rulison Site was of interest to DOE, since it was the location of the second underground explosion in the Plowshare experiment series designed to determine the potential of using nuclear stimulation for the development of gas-bearing formations.

Project Rulison was divided into three phases. Phase One included drilling the preshot exploratory and emplacement holes, as well as preshot gas production tests, and geologic and hydrologic investigations. Phase Two was the detonation of a 43-$\pm$8-kiloton-yield nuclear device on September 10, 1969, at a depth of 8,430 feet (2,570 meters) below the land surface. Phase Three was the controlled drillback into the cavity followed by flow testing of the gas to determine the cavity size and the rate and volume at which natural gas could be produced.[2] Surface Ground Zero is marked as "SGZ" in Figure 2.

Site cleanup activities were conducted and radioactively contaminated materials and equipment were packaged and removed for burial at the waste facility in Beatty, Nevada, in 1972. The purpose of this survey was to ensure that no radioactive contamination remains in the area. This is the first AMS survey of the site.

A gamma exposure rate map derived from the aerial data indicates the terrestrial exposure at 3 feet (1 meter) above the ground. A search for man-made gamma emitters in the data found none.

2.0 SITE DESCRIPTION

The Project Rulison site is located in Section 25, Township 7 south, Range 95 west, Garfield County, Colorado (39:24:19.4 N latitude, 107:56:52.3 W longitude). It is situated on the north slope of Battlement Mesa on the upper reaches of the Battlement Creek, where the elevation is approximately 8,200 feet (2,500 meters). The valley is open to the north-northwest and is bounded on the other three sides by steep mountain slopes rising above 9,600 feet (2,900 meters).[3]

3.0 NATURAL BACKGROUND RADIATION

Natural background radiation originates from three main sources: radioactive elements present in the soil, airborne radon, and cosmic rays of extraterrestrial origin. Natural terrestrial radiation levels depend upon the type of soil and bedrock immediately below and surrounding the point of measurement. Terrestrial gamma radiation originates primarily from the radioactive decay of elements naturally found in the soil and bedrock, namely, radioactive potassium and isotopes produced in the uranium and thorium decay chains. Local concentrations of these isotopes produce radiation levels at the surface typically ranging from 1 to 15 μR/h.[4] Areas with high uranium and/or thorium concentrations may exhibit slightly higher levels.

One member of both the uranium and thorium radioactive decay chains is radon, a noble gas that can both diffuse through the soil and travel through the air. Therefore, the level of airborne radiation due to radon and its daughter products depends on a variety of factors for a given location, including meteorological conditions, mineral content of the soil, and soil permeability. Typically, airborne radiation from radon and its progeny contributes from 1 to 10 percent of the natural background radiation levels.

Cosmic rays (high energy radiation originating from outer space) interact with elements of the earth's atmosphere and soil, producing an additional source of gamma radiation. Across the United States, radiation levels due to cosmic rays vary with altitude from 3.3 μR/h at sea level to 9.8 μR/h at elevations of 9,000 feet (2,700 meters).[5] The cosmic ray contribution played a large role in the Rulison data analysis, since the elevation of Battlement Creek Valley varied from 5,000 to 8,500 feet (1,500 to 2,600 meters) above sea level.

Cesium-137 (^{137}Cs), a by-product of nuclear fission, is also present in trace quantities worldwide as a result of fallout from aboveground nuclear weapon tests conducted prior to the early 1960s by the United States and the former Soviet Union and, subsequently, by China and France. Exposure rates due to ^{137}Cs in the environment are typically less than 1 μR/h.[6]

4.0 SURVEY EQUIPMENT

4.1 Aerial Measuring System

The low-altitude aerial survey was flown using a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter shown in Figure 1. The twin-engine helicopter carried a crew of two and a lightweight version of the Radiation and Environmental Data Acquisition and Recorder System, Version IV (REDAR IV). The area of interest was in a steep-walled canyon. To enable the helicopter to maintain a nearly constant elevation above the terrain in a safe manner, the survey was oriented such that flight lines were nominally parallel to the canyon. The helicopter flew at an altitude of 200 feet (61 meters) using a grid pattern composed of parallel flight lines spaced 250 feet (76 meters) apart to cover the 6.5-square-mile (17-square-kilometer) area. The altitude chosen was the minimum safe altitude for the area; the line spacing provided more than 100% coverage of the area being surveyed. Detector pods mounted on the sides of the skid rack on the helicopter contained a total of eight 2- × 4- × 16-inch and one uplooking 2- × 4- × 4-inch log-type thallium-activated sodium iodide, NaI(*Tl*), scintillation detectors.

FIGURE 1. ***MBB BO-105 HELICOPTER WITH DETECTOR PODS***

The energy signals produced through the interaction of gamma rays with the NaI(*Tl*) crystals were analyzed by analog-to-digital convertors in the REDAR IV system. The REDAR IV is a multimicroprocessor data acquisition and real-time analysis system designed to operate in the severe environments associated with platforms such as helicopters, fixed-wing aircraft, and various ground-based vehicles. The system relays radiation and positional information in real time to the operator via video displays and multiple LED readouts. The gamma ray, aircraft position, and weather data are recorded at one-second intervals on magnetic cartridge tapes for postflight analysis on a ground-based minicomputer system.

The aircraft position was established using a Real-time Differential Global Positioning System (RDGPS) and a radar altimeter. A GPS base station transmitted a positional correction to a GPS unit housed in the helicopter. The transmitted correction received by the helicopter's GPS unit minimized the positional uncertainty to ±15 feet (5 meters). The position was recorded on magnetic tape and directed into the steering indicator which the pilot used to guide the aircraft along a predetermined set of flight lines.

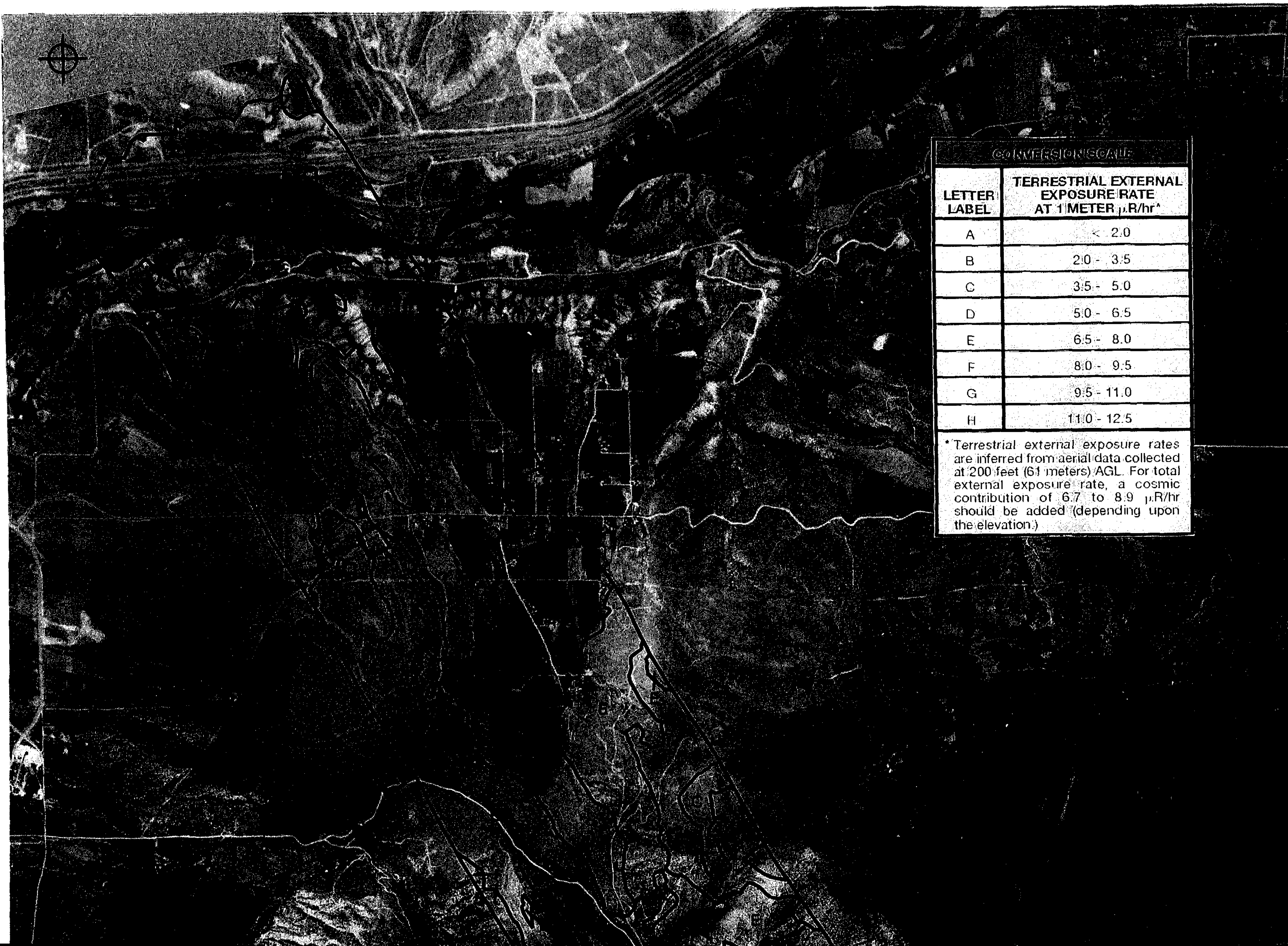
4.2 Ground-Based Measurements

Total exposure rates and soil samples were obtained from four ground-based benchmark sites, identified in Figure 2, for verification of the aerial measurements. One measurement was taken outside the survey boundary. At each site, total exposure rates were measured with a gamma ionization chamber and four soil samples were taken for laboratory analysis. Soil sample analysis was performed at the EG&G/EM Santa Barbara Laboratory in accordance with previously outlined procedures.[7,8]

4.3 Mobile Data Processing Laboratory

The base of operations for the survey was the Rifle Airport, located approximately 10 miles (16 kilometers) east of Battlement Creek Valley, in Rifle, Colorado. The Radiation and Environmental Data Analyzer and Computer (REDAC) system, a mobile computer laboratory for analysis of the aerial survey data, was located at the base of operations. The REDAC system consists of a Data General MV-7800XP computer with 4 megabytes of memory, a 2.8-gigabyte SCSI disk for mass storage, an 8mm tape drive, two 9-track tape drives for data transfer and archiving, a 36-inch-wide plotter for data contouring, a laser printer, and two IBM personal computers for terminal emulation.

The REDAC system utilizes an extensive software library for analysis of the pre-and postflight REDAR IV



CONVERSION SCALE

LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER μR/hr*
A	< 2.0
B	2.0 - 3.5
C	3.5 - 5.0
D	5.0 - 6.5
E	6.5 - 8.0
F	8.0 - 9.5
G	9.5 - 11.0
H	11.0 - 12.5

* Terrestrial external exposure rates are inferred from aerial data collected at 200 feet (61 meters) AGL. For total external exposure rate, a cosmic contribution of 6.7 to 8.9 μR/hr should be added (depending upon the elevation.)

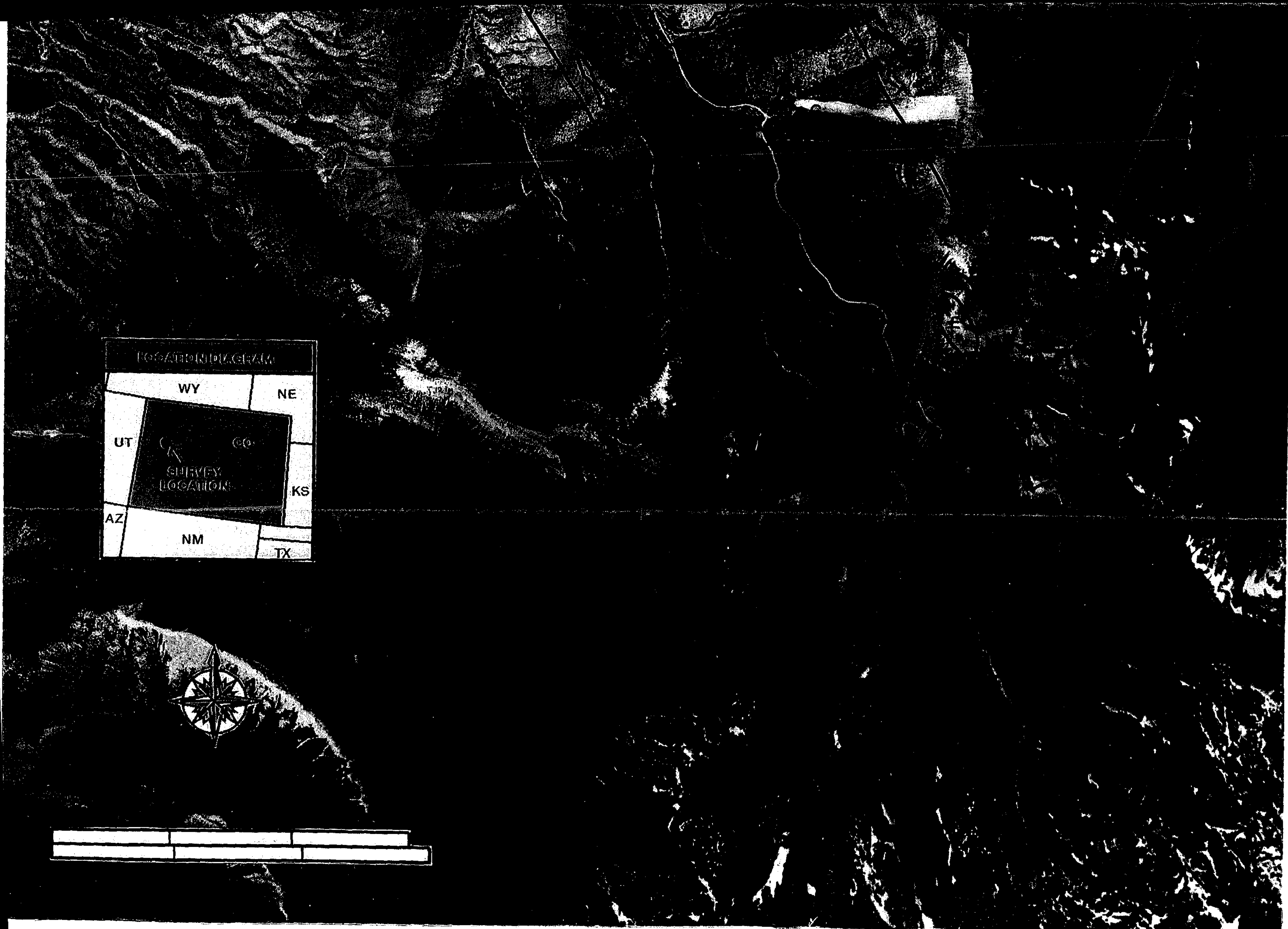


FIGURE 2. *TERRESTRIAL GAMMA RATE MAP OF BATTLEMINT CREEK VALLEY*

and detector system checks, and provides on-site preliminary analysis of the aerial measurements on a flight-by-flight basis.

5.0 GENERAL DATA REDUCTION

Two primary methods are used to evaluate the gamma fluence rate measurements made with the aerial system's NaI(Tℓ) detectors. The first is the gross count (GC) technique which is used to determine exposure rate; the second is the spectral window technique which is used to measure concentrations of specific nuclides. These are described in Appendix B.

6.0 SURVEY RESULTS

6.1 Aerial Survey Results

The principal result of the aerial survey and analysis is the terrestrial exposure rate contour map of the Battlement Creek Valley area shown in Figure 2. This map represents gamma exposure rates at 1 meter above ground level (AGL) due to gamma-emitting isotopes in the soil. Investigative analysis of the aerial data for man-made isotopes produced a negative result, though ground-based measurements indicated some ^{137}Cs from international fallout.

Figure 3 is a representation of the average gamma ray energy spectrum obtained of the Battlement Creek Valley. Visible peaks in the energy spectrum identify only natural background radiation made up of natural radioactive potassium (^{40}K), uranium daughter bismuth-214 (^{214}Bi), and thorium daughters thallium-208 (^{208}Tl) and actinium-228 (^{228}Ac).

Most fission and activation isotopes emit gamma rays and may be detected at some minimum activity level by the AMS. The man-made gross count (MMGC) algorithm, outlined in Appendix B, yielded no measurable man-made gamma activity in the survey area. Man-made radioactivity may exist at activities below the minimum detectable levels of the aerial system. Minimum detectable levels for the MMGC algorithm are geometry and isotope dependent. The statistical threshold for man-made activity on this survey was approximately 800 counts/second at altitude. Any area whose detected man-made activity (an average over the approximate 400-foot-diameter detector footprint) exceeded this value would have been detected. No such areas were detected. The exposure rate conversion for man-made isotopes from

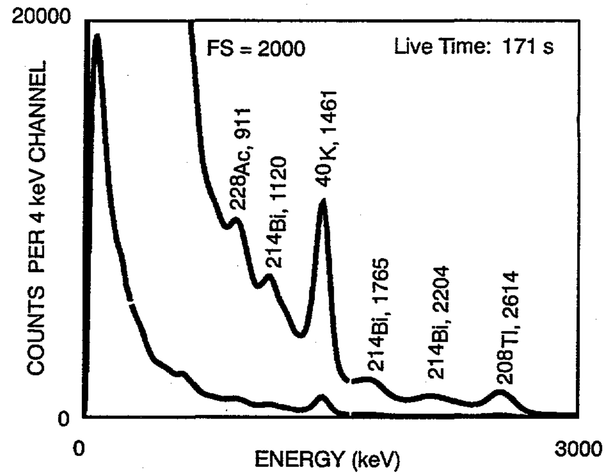


FIGURE 3. *TERRESTRIAL GAMMA ENERGY SPECTRUM OF BATTLEMENT CREEK VALLEY*

counts/second to μR/h is energy dependent and cannot be defined in general. However, one may get a feel for the magnitude of this threshold from a known conversion. If one assume the man-made conversion to be the same as the conversion for natural isotopes, the 800-count-per-second threshold would correspond to 0.98 μR/h. Also, buried or shielded radioactivity may not be detected.

No attempt has been made in this report to map the very low levels of ^{137}Cs, an international fallout fission product. This isotope is found nearly everywhere in the northern hemisphere at or below the minimum detectable activity of the aerial gamma system. Concentrations of ^{137}Cs above the minimum detectable activity would have been found in the MMGC search method discussed in Appendix B.

6.2 Ground-Based Measurement Results

Total exposure rates and soil samples were obtained at four benchmark sites in the Battlement Valley area (Figure 2). Three of these sites can be compared to the aerial measurements.[9] From the soil sample activity results, a terrestrial exposure rate of 1 meter AGL may be computed. Adding a cosmic contribution of 6.7 to 8.9 μR/h (depending on the site elevation) to these computed values yields the majority of the exposure, terrestrial plus cosmic, at 1 meter AGL. These values, along with the ion chamber measurement and the aerial measurement over each ground location, are listed in Table 1. The aerial terrestrial measurement includes a cosmic contribution, whereas the ion chamber measures both the terrestrial and cosmic components.

Table 1. Exposure Rates from Aerial and Ground-Based Measurements[a]			
Site	**Soil Analysis[b,c]**	**Ion Chamber[d,e,f]**	**Aerial Survey[g]**
1	16.0 ± 1.0	15.0 ± 0.8	15.2 ± 0.8
2	17.8 ± 0.7	17.5 ± 0.9	17.0 ± 0.8
3	15.7 ± 0.7	15.3 ± 0.8	h
4	16.3 ± 0.7	15.7 ± 0.8	14.4 ± 0.8

[a] Exposure rate (μR/h at 1 meter AGL) ± the standard deviation
[b] Calculations include a cosmic ray contribution of 6.7-8.9 μR/h and a moisture correction of the form 1/(1+m).
[c] The soil sample estimates include the effect of soil moisture.
[d] Reuter-Stokes PIC Model #RSS-112, Serial #G-003.
[e] The uncertainty in the ion chamber measurement is 1.0 μR/h.
[f] The airborne radon component is measured by the ion chamber only; no radon exposure rate estimate has been added to the soil sample or the aerial values.
[g] A cosmic exposure component has been added for the following sites:
Site 1: 8.9 μR/h Site 2: 7.8 μR/h Site 4: 6.7 μR/h
[h] Field sample #3 was taken outside of the survey area; aerial comparison is impossible.

Ground-based measurements may differ from aerial measurements for a number of reasons.

A. The aerial system measures approximately 4,400 times the area measured by the ground-based system.

B. The aircraft did not fly directly over the ground measurement sites.

C. The ground data were taken before the start of the aerial survey. Therefore, soil moisture was probably different between the time of the ground-based measurement or sample and the time of the aerial measurement. Fluctuations in soil moisture change the observed exposure rate.

Table 2 shows the results of the radionuclide assay and concentration of specific radionuclides of the soil samples from the four benchmark sites. Soil sample results represent averages of four closely spaced samples obtained from each site. In addition to the naturally-occurring isotopes from the decay chains (uranium and thorium) and ^{40}K, all sampling sites exhibited the presence of ^{137}Cs, due to worldwide fallout. The level of ^{137}Cs activity measured at the benchmark sites is typical of that measured at several locations within the continental United States.[6]

7.0 SUMMARY

An aerial radiological survey of the Project Rulison site, Battlement Creek Valley, Colorado, was conducted during the period of July 6 through July 12, 1993. An area of 6.5 square miles (17 square kilometers) was surveyed at an altitude of 200 feet (61 meters) using a grid pattern consisting of nominally parallel flight lines. The typical terrestrial gamma radiation exposure rate was found to vary from 3.5 to 12.5 μR/h (excluding cosmic). No significant man-made radioactivity was found.

Table 2. Radionuclide Assay of Soil Samples					
Site	**% Moisture**	**^{226}Ra (pCi/g)**	**^{232}Th (pCi/g)**	**^{137}Cs (pCi/g)**	**^{40}K (pCi/g)**
1	9.0 ± 2.0	1.1 ± 0.1	1.1 ± 0.3	0.4 ± 0.3	17.0 ± 2.0
2	6.8 ± 0.8	1.3 ± 0.1	1.4 ± 0.1	0.2 ± 0.2	24.0 ± 1.0
3	4.0 ± 2.0	1.1 ± 0.1	1.2 ± 0.1	0.5 ± 0.3	20.0 ± 1.0
4	4.1 ± 0.5	1.2 ± 0.1	1.4 ± 0.1	0.6 ± 0.4	21.0 ± 1.0

APPENDIX A

SURVEY PARAMETERS

Survey Site:	Project Rulison Battlement Creek Valley, Colorado
Survey Date:	July 6-12, 1993
Nominal Site Elevation:	5,000-8,500 ft (1,500-2,600 m)
Survey Altitude:	200 ft (61 m)
Line Spacing:	250 ft (76 m)
Line Direction:	Southeast-Northwest (one direction only)
Lines Surveyed:	22
Ground Speed:	70 knots (36 m/s)
Survey Coverage:	6.5 mi^2 (17 km^2)
Survey Aircraft:	MBB BO-105 helicopter Tail #N60EG
Navigation System:	RDGPS
Acquisition System:	REDAR IV
Detector Array 1:	Eight 2- × 4- × 16-inch NaI(T*l*) detectors
Detector Array 2:	One 2- × 4- × 4-inch NaI(T*l*) detector
Project Scientist:	R.C. Hopkins

APPENDIX B

GENERAL DATA ANALYSIS METHODS

A few useful methods to treat gamma energy spectra as measured by NaI(T*l*) are discussed below.

Gross Count Rate

The gross count (GC) rate is defined as the integral count in the energy spectrum between 38 keV and 3,026 keV.

$$GC = \sum_{E=38\text{ keV}}^{3026\text{ keV}} \textit{Energy Spectrum} \qquad \text{(B-1)}$$

This integral includes all the natural isotope gammas from ^{40}K, ^{238}U, and ^{232}Th (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-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:

$$E(1m) = \frac{GC(A)-B}{1167} \cdot e^{0.00179A} \qquad \text{(B-2)}$$

where

$E(1m)$ = Exposure rate extrapolated to 1 m AGL (μR/h)

A = Altitude in feet

$GC(A)$ = Gross count rate at altitude A (cps)

B = Cosmic, aircraft,and radon background (cps) B is obtained from flights over bodies of water, where the terrestrial count rate is absent.

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 the gross count rate over the natural count rate. 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 sensitivity of the aerial system to anomalous gamma emitters.

Man-Made Gross Count Search Method

Each second, the aerial system produces 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:

$$\sum_{E=a}^{b} ES \Big/ \sum_{E=b}^{c} ES = \textit{Constant} = K \qquad \text{(B-3)}$$

where

ES = Energy Spectrum

E = Energy

$a < b < c$

The window, a-b, is placed where gamma rays from a man-made emitter would occur in the spectrum. The result of Equation B-3 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.

$$S = \sum_{E=a}^{b} ES - K \sum_{E=b}^{c} ES \qquad \text{(B-4)}$$

The net signal, S, is zero unless anomalous gamma rays are measured in the window defined by a and b.

Equation B-4 is used to locate specific isotopes by setting a and b to enclose the photopeak of the particular gamma from the isotope. For the general case when any man-made isotope is sought, a, b, and c are set at 38 keV, 1,394 keV, and 3,026 keV, respectively. Because most long-lived man-made isotopes emit gammas in the energy range 38 keV to 1,394 keV, Equation B-4 becomes a general search tool and is called the man-made gross count.

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