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AN AERIAL RADIOLOGICAL SURVEY OF THE OAK RIDGE RESERVATION

OAK RIDGE, TENNESSEE

DATE OF SURVEY: APRIL 1992

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ABSTRACT

An aerial radiological survey of the Oak Ridge Reservation (ORR) and surrounding area in Oak Ridge, Tennessee, was conducted during the period March 30 to April 14, 1992. The purpose of the survey was to measure and document the terrestrial radiological environment of the Oak Ridge Reservation for use in environmental management programs and emergency response planning. The aerial survey was flown at an altitude of 150 feet (46 meters) along a series of parallel lines 250 feet (76 meters) apart and included X-10 (Oak Ridge National Laboratory), K-25 (former Gaseous Diffusion Plant), Y-12 (Weapons Production Plant), the Freels Bend Area and Oak Ridge Institute for Science and Education, the East Fork Poplar Creek (100-year floodplain extending from K-25 to Y-12), Elza Gate (former uranium ore storage site located in the city of Oak Ridge), Parcel A, the Clinch River (river banks extending from Melton Hill Dam to the city of Kingston), and the CSX Railroad Tracks (extending from Y-12 to the city of Oak Ridge). The survey encompassed approximately 55 square miles (141 square kilometers) of the Oak Ridge Reservation and surrounding area.

The results of the aerial survey are reported as inferred exposure rates at 1 meter above ground level (AGL) in the form of radiation contour maps superimposed on high altitude aerial photographs. Typical background exposure rates were found to vary from 8 to 13 microroentgens per hour (μR/h). The man-made radionuclides, cobalt-60 and cesium-137, and the man-concentrated radionuclides, uranium-235 and uranium-238, were detected at several facilities on the Oak Ridge Reservation and surrounding area. A comparison of the present radiological data with that from past aerial surveys is also presented.

In support of the aerial survey, ground-based exposure rates and soil sample measurements were obtained at seven locations within the survey sites. The results of the aerial and ground-based measurements were found to agree within ± 30%.

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1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains an aerial radiological surveillance capability called the Aerial Measuring System[1] (AMS). The AMS is based at the DOE Remote Sensing Laboratories located at Nellis Air Force Base in Las Vegas, Nevada, and at Andrews Air Force Base outside of Washington, D.C. Since its inception in 1958, the AMS has been used in a nationwide program to map the terrestrial gamma radiation environment at facilities which produce, use, or store radioactive materials owned by the Department of Energy, the Nuclear Regulatory Commission, and other government agencies. The AMS is presently operated and maintained by EG&G Energy Measurements Inc. (EG&G/EM), under contract to the DOE, Nevada Operations Office.

The aerial radiological data are used to produce radiation contour maps which support environmental management programs and function as background templates in the event of a large scale radioactive release. The aerial radiological surveys have been effective in detecting areas exhibiting anomalous radiation levels, determining average ground level exposure rates, and identifying specific radionuclides associated with anomalous radiation areas.

The first aerial radiological survey[2] of the Oak Ridge Reservation was conducted by EG&G/EM in 1973 using a fixed-wing aircraft flying at an altitude of 500 feet (152 meters) above ground level (AGL) and a speed of 170 knots (87 meters/second). Sites identified as having anomalous radiation levels were then resurveyed with a helicopter at an altitude of 250 feet (76 meters) and a speed of 70 knots (36 meters/second) to provide a more detailed map of the radiological environment at the anomalous radiation sites. In 1980, an aerial radiological survey[3] of the entire Oak Ridge Reservation and nearby surrounding area, encompassing 170 square miles (440 square kilometers), was conducted. The survey consisted of flying a series of parallel lines 500 feet (152 meters) apart at an altitude of 300 feet (91 meters). In 1987, an aerial radiological survey[4] was conducted over the White Oak Creek Floodplain. In order to provide a detailed map of the terrestrial radiological environment, parallel flight lines 125 feet (38 meters) apart were flown at an an altitude of 150 feet (46 meters). The entire Oak Ridge Reservation and nearby surrounding area was resurveyed[5] in 1989 using parameters identical to those used in the 1980 survey. A comparison of the results provides insight into the effect that a decade of nuclear operations has had on the environment.

During the period March 30 to April 14, 1992, aerial radiological surveys of several sites on the Oak Ridge Reservation were conducted. The purpose of the aerial surveys was to determine the extent of the radiological impact of DOE operations on the Oak Ridge Reservation in support of the Oak Ridge Environmental Restoration Program. The survey area included the X-10 site (Oak Ridge National Laboratory [ORNL]), the K-25 site (former Gaseous Diffusion Plant), Y-12 (Weapons Production Plant), Freels Bend Area/Oak Ridge Institute for Science and Education (FBA/ORISE), the East Fork Poplar Creek (100-year floodplain extending from K-25 to Y-12), Elza Gate (former uranium ore storage site located in the city of Oak Ridge), Parcel A, the Clinch River (river banks extending from Melton Hill Dam to the city of Kingston), and the CSX Railroad Tracks (from Y-12 to the city of Oak Ridge). The purpose of the Clinch River survey was to obtain radiation measurements over the exposed river banks before the scheduled late-April water level increase.

In support of the aerial measurements, ground-based exposure rates and soil samples were obtained from seven "benchmark" sites located within the survey sites. The ground-based measurements were conducted during the period April 8-9, 1992 and are used to verify the integrity of the aerial measurements. Radionuclide assay of the soil samples was performed to determine radioisotopic concentrations.

In addition, high altitude aerial photographs were obtained for use as base maps for the aerial radiation contour data, and oblique aerial photographs were obtained for site documentation.

2.0 SURVEY SITE DESCRIPTION

The facilities at the Oak Ridge Reservation, located in Oak Ridge, Tennessee, are operated for the DOE by Martin Marietta Energy Systems, Inc., Oak Ridge Associated Universities. The Oak Ridge Associated Universities (ORAU) also operates the Oak Ridge Institute for Science and Education (ORISE) facilities on the Oak Ridge Reservation for the DOE. The DOE owns approximately 58 square miles (150 square kilometers), bounded on the south and west by the

Clinch River and to the north and east by a fence line as outlined on the Tennessee Valley Authority (TVA) S-16A topographic map in Figure 1. The Oak Ridge Reservation is the site of three major facilities: the X-10 site (Oak Ridge National Laboratory), the K-25 site (former Gaseous Diffusion Plant), and the Y-12 site (Weapons Production Plant). The aerial survey boundaries for each of the sites are denoted in Figure 1 along with the locations of the seven ground-based benchmark sites.

The Oak Ridge National Laboratory (X-10) operates several facilities which use, produce, or store nuclear materials. Most notable are several charged-particle accelerators and the High Flux Isotope Reactor (HFIR). The Gaseous Diffusion Plant (K-25) is no longer in operation but continues to support environmental characterization and restoration studies. The plant consists of a large industrial complex located in the northwest corner of the Oak Ridge Reservation bordering the Clinch River. The Y-12 plant has as its primary mission the production and fabrication of nuclear weapons components but is now in the downsizing mode. The plant also provides support to the Oak Ridge National Laboratory and other government agencies.

3.0 NATURAL BACKGROUND RADIATION

Natural gamma radiation originates from radioactive nuclides which are present in minute concentrations in the earth and atmosphere as well as cosmic rays originating from outer space. Terrestrial radiation, which originates primarily from nuclides in the uranium decay chain, thorium decay chain, and radioactive potassium, is detected at the surface of the earth and has exposure rates between 1 and 15 μR/h (9 and 130 mrem/yr).[6] The exposure rates from terrestrial radionuclides are dependent on the composition of the soil and bedrock near the point of interest. Cesium-137 (^{137}Cs), a nuclear fission by-product, is also present in trace quantities worldwide as a result of fallout from aboveground nuclear weapons tests conducted prior to the early 1980s. Exposure rates due to ^{137}Cs in the environment are typically less than 1 μR/h.[7]

Radon and thoron gases, by-products in the decay chain of uranium and thorium, respectively, diffuse through the soil into the atmosphere and contribute to the radiation level near the surface of the earth. The radon and thoron concentrations in a particular area, however, depend on several factors including meteorological conditions, mineral compositions, and soil permeability. Airborne radiation from radon and their decay products typically contribute from 1% to 10% to the natural background.

Cosmic rays, high energy radiation originating from outer space, also contribute to the natural radiation background. The cosmic rays from outer space shower the earth with a nearly constant flux of radiation which interacts with atoms in the earth's atmosphere and soil producing an additional source of background activity. Radiation levels due to cosmic rays vary with altitude and geomagnetic latitude. Typical values range from 3.3 μR/h at sea level to 12 μR/h (up to 100 mrem/yr) at elevations of 10,000 feet (3 kilometers).[6] For the Oak Ridge area, the cosmic ray contribution is estimated to be 3.8 μR/h.

4.0 SURVEY EQUIPMENT AND PROCEDURES

4.1 Aerial Measuring System

The Oak Ridge survey was conducted using an MBB BO-105 helicopter (Figure 2). The helicopter was outfitted with two large detector pods and a computer-based data acquisition system, the Radiation and Environmental Data Acquisition and Recorder System version IV (REDAR IV). The two large detector pods were mounted underneath the helicopter on the skid rack. Each pod contained four 2-in × 4-in × 16-in sodium iodide, NaI(Tℓ), gamma ray detectors. The energy response for the detector arrays was calibrated using gamma rays from americium-241 (^{241}Am) and sodium-22 (^{22}Na) radiation sources. At a survey altitude of 150 feet (46 meters), the large detector array will accurately measure ground-level exposure rates up to 55 μR/h. The data from one of the eight detectors are also recorded separately and are used to extend the dynamic range of the aerial measuring system to 440 μR/h. The ground-level exposure rates measured by the AMS are accurate to ±15% for naturally-occurring terrestrial radioactivity distributed uniformly over the field of view of the detector array. The field of view of the detector array is approximately two times that of the aircraft altitude.

Data acquisition was performed using the REDAR IV, a compact computer system designed for use in aircraft. Data from the detector array, the aircraft positioning system, and environmental (temperature and

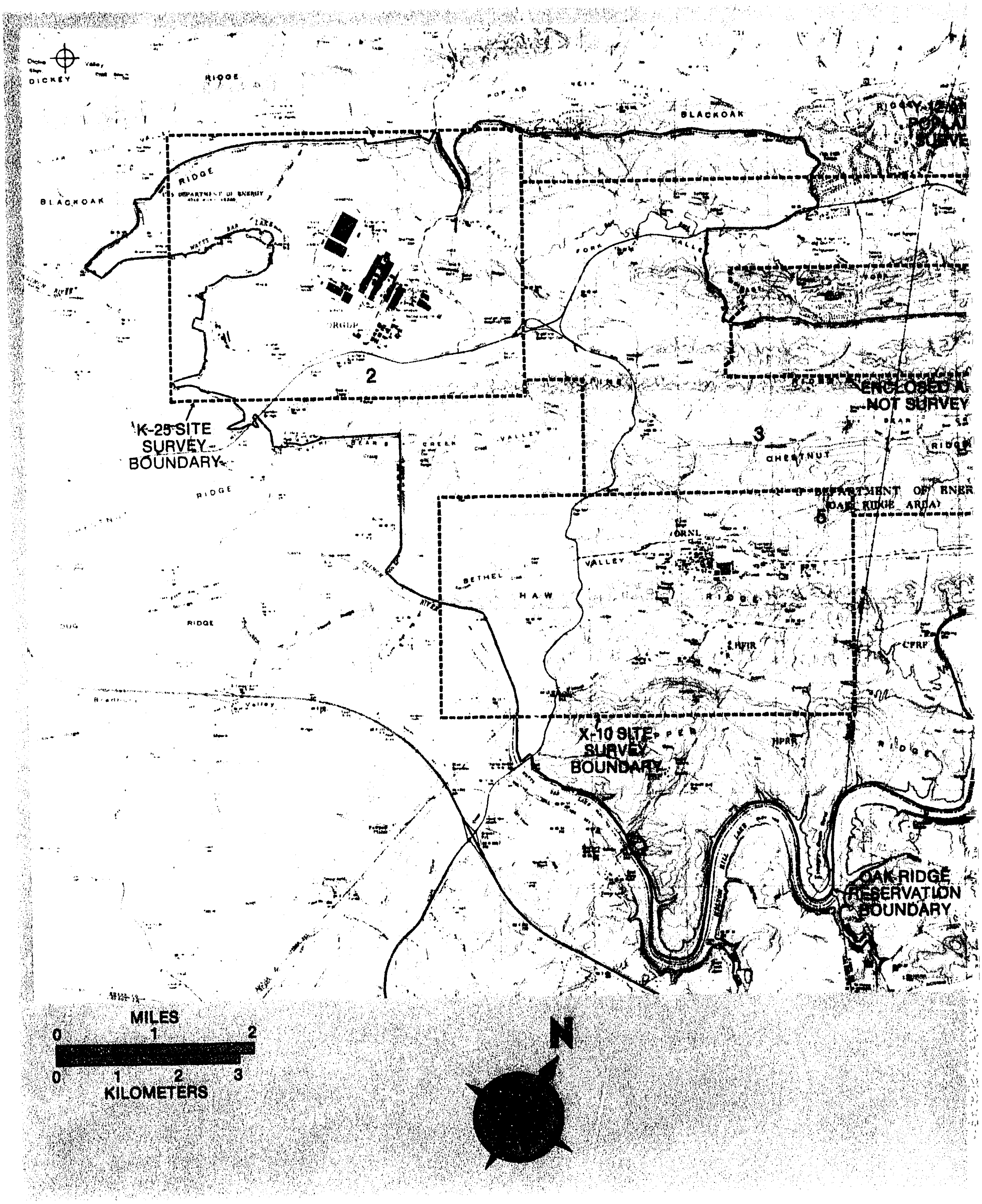
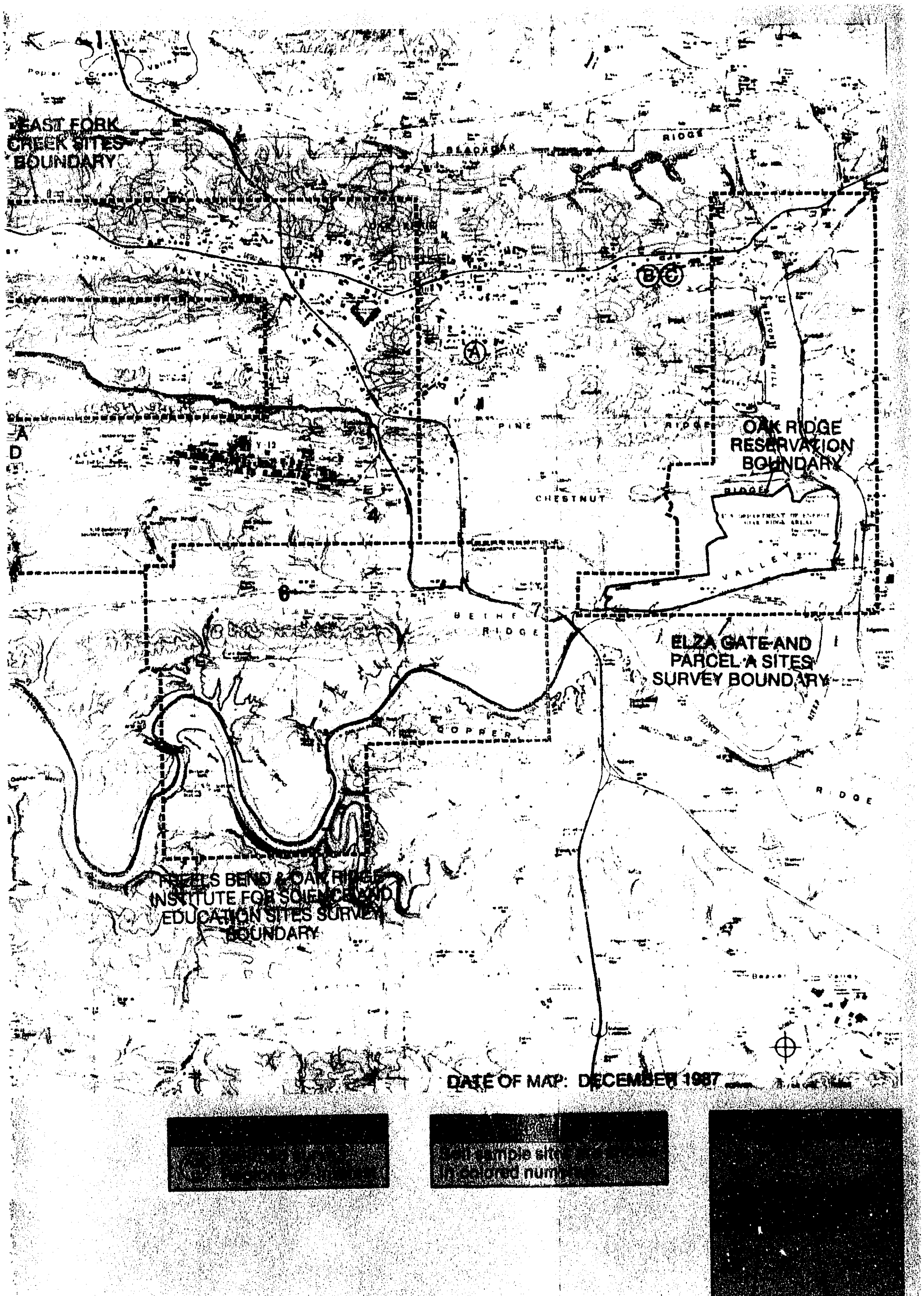


FIGURE 1. *TVA MAP S-16A OF THE OAK RIDGE RESERV*



ATION SHOWING SURVEY BOUNDARIES

FIGURE 2. MBB BO-105 HELICOPTER WITH DETECTOR PODS

barometric pressure) sensors were recorded on magnetic tape. The REDAR IV is also equipped with a multichannel spectrum analyzer and video display capabilities for in-flight monitoring of the gamma energy spectrum as well as the other flight parameters.

The aircraft positioning was established using the ultra-high frequency (UHF) ranging system and the radar altimeter. Two ground-based transponders were periodically interrogated by a master unit in the helicopter, and the precise position of the helicopter was constantly monitored by triangulation. The precision of the UHF ranging system is ±10 feet; however, this accuracy is reduced due to photograph base map uncertainties of ±60 feet. The position information was recorded on magnetic tape and directed to a steering indicator to aid the pilot in flying the aircraft along a predetermined set of flight lines. Ground-based tracking antennae were installed at three locations: Buffalo Mountain to the north (microwave tower), Parcel A to the east (TVA microwave tower), and Blue Bird Ridge to the east (firetower). The ground-based antenna sites ensured complete helicopter tracking throughout the survey area.

4.2 Ground-Based Measurements

Total exposure rates and soil samples were obtained at the X-10, K-25, Y-12, and FBA/ORISE sites to provide ground-based benchmark sites for verification of the aerial measurements. The ground-based measurements were conducted during the period April 8-9, 1992. The seven sites (labeled 1-7 in Figure 1) were identified by the aerial survey as having only natural radioactivity. At each site, total exposure rates were measured using a pressurized ionization chamber, and five soil samples were taken for laboratory analysis. Radionuclide assay of the soil samples was performed at EG&G/EM Santa Barbara Operations in accordance with previously outlined procedures.[8]

4.3 Mobile Data Processing Laboratory

The operations base for the survey was the Knoxville Downtown Island Airport in Knoxville, Tennessee, located about 15 miles (24 kilometers) due east of the Oak Ridge Reservation. The Radiation and Environmental Data Analyzer and Computer (REDAC) system (Figure 3) was located at the operations base. The REDAC system is a mobile computer laboratory for analysis of the aerial survey data recorded on the REDAR IV system. The mobile laboratory hosts a wide range of computer hardware which includes a Data General MV7800 XP computer with 4 megabytes of memory, 1.1 gigabytes of disk space for data storage, two 9-track tape drives for data transfer and archiving, a 36-inch-wide plotter for data contouring, and three video graphics displays for data viewing. The REDAC system also houses an extensive library of software which was used to provide on-site preliminary analysis of the aerial data on a flight-by-flight basis.

FIGURE 3. MOBILE COMPUTER PROCESSING LABORATORY

4.4 Survey Procedures

The aerial radiological survey of the Oak Ridge Reservation and surrounding area was conducted according to EG&G/EM standard procedures[1,9] which will be discussed only briefly in this section.

The survey consisted of flying a series of parallel flight lines 250 feet (76 meters) apart at an altitude of 150 feet (46 meters) AGL. The flight lines were flown at a constant speed of 70 knots (36 meters/second). A series of measurements was also conducted to determine the average air attenuation coefficient for gamma radiation as a function of altitude for use in the data analysis. The measurements consisted of altitude profiles flown over a large body of water and a designated land test line. An altitude profile consisted of a series of one-minute measurements over the water and land test lines at altitudes ranging from 150 feet (46 meters) to 800 feet (244 meters). A section of the Clinch River was chosen for the water measurements. Data accumulated during the altitude profile over water were used to determine the nonterrestrial radiation; *i.e.*, radiation which originates from airborne radon, the helicopter and detector system, and cosmic rays. For the land test line, an open field en route from the operations base to the survey area was chosen. The terrestrial radiation measured over the land test line, corrected for the nonterrestrial radiation measured over water, was used to derive the air attenuation coefficient for the gamma radiation.

Several quality assurance checks are conducted for each flight. These are designed to verify the operation of the AMS and to ensure the integrity of the AMS data. Prior to each data flight, a diagnostic of the AMS system is conducted. This includes checks of the detector calibration and sensitivity, the UHF tracking system, and the operation of the radar altimeter and temperature and pressure sensors. The highly variable radon concentration, which can contribute from 1% to 10% to the natural radiation background, is monitored during each flight by conducting an overflight of the land test line at the beginning and end of each data flight. A post-flight diagnostic similar to the pre-flight diagnostic is conducted on all data collected during the survey flight. The quality assurance data for each flight is compiled and reviewed throughout the survey to ensure the integrity of the data.

5.0 DATA REDUCTION PROCEDURES

Two methods were used to analyze the aerial radiation data. The first was the gross count rate method which was used to determine ground level exposure rates. The second was the spectral window method which was used to determine the man-made radioactivity and the photopeak count rates for specific man-made radionuclides.

5.1 Gross Count Rate Method

The gross count rate is defined as the integrated count rate in the 38 to 3,026 keV energy window of a gamma energy spectrum. For natural background, the gross count rate consists primarily of gamma rays from potassium-40 (^{40}K), uranium-238 (^{238}U), thorium-232 (^{232}Th), and their decay products. The algorithm used to convert the gross count rate in counts per second (cps) measured at survey altitude to exposure rate in μR/h at 1 meter is given by:

$$\text{Exposure Rate} = \frac{GC - BG}{917} e^{(A-150)C} \qquad (1)$$

where

GC = gross count rate at survey altitude (cps)

BG = background count rate at survey altitude (cps)

A = survey altitude (ft)

C = air attenuation coefficient (ft^{-1})

The term, $e^{(A-150)C}$, is used to correct the count rate for variations in the survey altitude. The background count rate, BG, is comprised of gamma rays from trace concentrations of radionuclides in the helicopter and detector system, airborne radon, and cosmic rays. An air attenuation coefficient having a value of 0.0020 ft^{-1} was deduced empirically from the altitude profile data. A conversion factor of 917 cps/(μR/h) for 150 feet (46 meters) AGL was derived from measurements taken during flights over the documented[10] EG&G/EM calibration range near Washington, D.C. The applicability of the conversion factor assumes a uniformly distributed radiation source which covers an area which is large compared to the field of view of the detector system.

5.2 Man-Made Gross Count Rate Method

The aerial radiation data were also used to determine the location of man-made radionuclides. The man-made gross count (MMGC) is defined as the fraction of the gross counts which is directly attributed to gamma rays from man-made radionuclides. In general, evidence for the detection of man-made radionuclides can be found from increases in the gross count rate. However, slight increases in the gross count rate are not considered adequate reason to suspect the presence of a man-made radionuclide since slight variations in the gross count rate may be attributed to fluctuations in the geologic structure or variations in the ground cover.

A more conclusive approach to detecting man-made radionuclides involves a comparison of the gross count rates from various spectral windows of the gamma energy spectrum. In particular, the ratio of the integrated count rates from different spectral windows of the gamma energy spectrum will remain nearly constant when only background radiation is present. Although this procedure can be applied to any region of the gamma spectrum, the most common practice is to place into the source window all counts below 1,394 keV (*i.e.*, the region of the gamma energy spectrum where most long-lived, man-made radionuclides emit radiation) and to place into the background window all counts above 1,394 keV (*i.e.*, the region of the gamma energy spectrum where primarily naturally-occurring radionuclides emit gamma radiation). The MMGC algorithm has been found to be sensitive to low levels of man-made radiation (*i.e.*, < 1 μR/h) which occur even in the presence of significant variations in the natural background.

The MMGC rate can be expressed analytically in terms of the integrated count rates in specific spectral energy windows from the gamma energy spectrum as

$$\mathrm{MMGC} = \sum_{38\ \mathrm{keV}}^{1394\ \mathrm{keV}} \mathrm{Counts} - K_{MM} \sum_{1394\ \mathrm{keV}}^{3026\ \mathrm{keV}} \mathrm{Counts} \tag{2}$$

where

$\sum_{38\ \mathrm{keV}}^{1394\ \mathrm{keV}} \mathrm{Counts}$ = integral count rate in the energy window from 38 to 1,394 keV

$\sum_{1394\ \mathrm{keV}}^{3026\ \mathrm{keV}} \mathrm{Counts}$ = integral count rate in the energy window from 1,394 to 3,026 keV

and the constant, K_{MM}, is defined as

$$K_{MM} = \frac{\sum_{38\ \mathrm{keV}}^{1394\ \mathrm{keV}} \mathrm{Counts}_B}{\sum_{1394\ \mathrm{keV}}^{3026\ \mathrm{keV}} \mathrm{Counts}_B}$$

The constant, K_{MM}, was obtained from a gamma spectrum acquired over an area containing only natural background radioactivity. The resultant MMGC obtained from the above algorithm will yield a value equal to zero for areas containing only natural background radioactivity and a value greater than zero for areas containing man-made radionuclides.

Since the MMGC algorithm is quite general and will respond to a wide range of radionuclides, the primary function of the MMGC is to locate man-made radioactivity. Once a region of man-made radioactivity has been located, a detailed analysis of the gamma energy spectrum is conducted to identify the radionuclides present. A more sensitive algorithm optimized for specific radionuclides can then be applied.

5.3 Photopeak Count Rate Method

The gamma energy spectra from regions of the survey area exhibiting man-made radioactivity were further analyzed to provide radioisotopic identification. The analysis of the gamma spectra revealed the presence of two man-made radionuclides, ^{137}Cs and cobalt-60 (^{60}Co), and two man-concentrated radionuclides, uranium-235 (^{235}U) and ^{238}U. The presence of ^{238}U is detected by measuring the gamma radiation from the decay of protactinium-234m (^{234m}Pa), a short-lived radionuclide in the decay chain of ^{238}U.

Spectral stripping algorithms, which include background subtraction, were derived for the ^{137}Cs and ^{60}Co photopeaks. The photopeak energies for ^{137}Cs (662 keV) and ^{60}Co (1,173 keV and 1,332 keV) were used to determine optimum energy windows for the photopeak spectral stripping algorithms.

The ^{137}Cs algorithm is given by:

$$^{137}\text{Cs} = \sum_{590\text{ keV}}^{734\text{ keV}} \text{Counts} - K_{CsCo} \sum_{1082\text{ keV}}^{1466\text{ keV}} \text{Counts}$$

$$- K_{Cs} \sum_{1466\text{ keV}}^{3026\text{ keV}} \text{Counts} \tag{3}$$

where

$\sum_{590\text{ keV}}^{734\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 590 to 734 keV

$\sum_{1082\text{ keV}}^{1466\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 1,082 to 1,466 keV

$\sum_{1466\text{ keV}}^{3026\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 1,466 to 3,026 keV

and constants, K_{CsCo} and K_{Cs}, are defined as:

$$K_{CsCo} = \frac{\sum_{590\text{ keV}}^{734\text{ keV}} \text{Counts}}{\sum_{1082\text{ keV}}^{1466\text{ keV}} \text{Counts}}$$

and

$$K_{Cs} = \frac{\sum_{590\text{ keV}}^{734\text{ keV}} \text{Counts}}{\sum_{1466\text{ keV}}^{3026\text{ keV}} \text{Counts}}$$

The constants, K_{CsCo} and K_{Cs}, were determined from a "pure" gamma spectrum for the ^{137}Cs and ^{60}Co radioisotopes. Regions of the survey area containing only ^{137}Cs and ^{60}Co were first identified and a gamma spectrum extracted. The radionuclide-specific spectrum was background subtracted to obtain a "pure" gamma spectrum of that radioisotope. The constants were then obtained from the "pure" spectrum of each radioisotope.

In order to determine the ^{60}Co photopeak count rate, a three-window stripping algorithm was used. The photopeak count rate was determined by subtracting the background count rate estimated by averaging the count rates on the low energy side (962 to 1,058 keV) and the high energy side (1,394 to 1,622 keV) of the photopeak window. The ^{60}Co algorithm is given by:

$$^{60}\text{Co} = \sum_{1046\text{ keV}}^{1406\text{ keV}} \text{Counts}$$

$$- \left(\sum_{962\text{ keV}}^{1058\text{ keV}} \text{Counts} + \sum_{1394\text{ keV}}^{1622\text{ keV}} \text{Counts} \right) \tag{4}$$

where

$\sum_{1046\text{ keV}}^{1406\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 1,046 to 1,406 keV

$\sum_{962\text{ keV}}^{1058\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 962 to 1,058 keV

$\sum_{1394\text{ keV}}^{1622\text{ keV}} \text{Counts}$ = integral count rate in the energy window from 1,394 to 1,622 keV

6.0 RESULTS

6.1 Terrestrial Exposure Rate Contour Data

The terrestrial exposure rates were deduced from over 60,000 measurements, integrated with the corresponding aircraft position coordinates, and compiled to produce a contour map. The terrestrial exposure rate contour maps were superimposed on the high altitude aerial photographs (April 1992) and are presented for X-10 (Figure 4), K-25 (Figure 8), FBA/ORISE (Figure 10), Y-12 and East Fork Poplar Creek (Figure 12), and Elza Gate/Parcel A (Figure 14). The terrestrial exposure rates are given in units of μR/h at 1 meter AGL inferred from the aerial data. The exposure rates include an estimated cosmic ray contribution of 3.8 μR/h. The gross count rate contour maps show that the background terrestrial exposure rates in the Oak Ridge area vary from 8 to 13 μR/h.

6.2 Man-Made Gross Count Rate Contour Data

The man-made gross count rates were determined using the algorithm given in Equation 2. The data are presented in the form of a contour map superimposed on a high altitude aerial photograph for X-10 (Figure 5), K-25 (Figure 9), FBA/ORISE (Figure 11), Y-12 and East Fork Poplar Creek (Figure 13), and Elza Gate/Parcel A (Figure 15). The contour maps are used to determine the locations of man-made radiation sources detected at each survey site. The magnitude of the count rate provides an indicator of the relative intensities of the radiation sources. The radiation anomalies at each site are designated by the notation "Region of Interest" (ROI).

The man-made gross count rate algorithm was also used to determine the location of the anomalous radiation areas located along the banks of the Clinch River from Melton Hill Dam to the city of Kingston. The Clinch River survey data are presented in Figure 16 in the form of a man-made gross count rate position plot superimposed on a composite United States Geological Survey (USGS) topographic map. The magnitude of the count rate provides an indicator of the relative intensities of the anomalous radiation sources.

6.3 Photopeak Count Rate Contour Data

The photopeak count rates for ^{137}Cs and ^{60}Co were determined for the data using the photopeak extraction algorithms given in Equations 3 and 4, respectively. The photopeak count rates derived for ^{137}Cs and ^{60}Co are presented in Figures 6 and 7, respectively, in the form of a contour map superimposed on a high altitude aerial photograph. The photopeak count rates are in counts/second measured at survey altitude.

6.4 Gamma Ray Spectra

Presented in Figure 17 is a typical gamma energy spectrum showing only natural background radioactivity in the Oak Ridge area. The radioisotopes identified are those from naturally-occurring ^{238}U, ^{232}Th, their decay products, and ^{40}K.

For each of the ROIs identified in the MMGC contour maps, a background subtracted gamma ray spectrum was obtained from data collected directly over the site. The spectra for ROIs 1-40 are presented in Figures 18-57. The designation FS on the gamma spectral data indicates "Full Scale" and gives the maximum value for the rescaled spectral data. The spectra were used to determine the radioisotopes contributing to the anomalous radiation levels. The primary gamma photopeaks in each spectrum are identified. Several of the survey sites have one or more radioisotopes which include the man-made radioisotopes, ^{137}Cs and ^{60}Co, and the man-concentrated radioisotopes, ^{235}U and ^{238}U. The photopeaks for ^{235}U and ^{238}U (indicated by ^{234m}Pa) in the net gamma spectra are attributed to ^{235}U and ^{238}U in excess of their natural abundances.

6.5 Ground-Based Measurements

In situ gamma ionization chamber and soil sample measurements were obtained from seven benchmark sites to support the integrity of the aerial survey. Two sampling locations in the K-25, Y-12, and FBA/ORISE survey sites and one location in the X-10 survey site were chosen for the benchmark measurements. The sampling locations were determined from the aerial measurements to contain only naturally-occurring radioisotopes. The exposure rates from the inferred aerial and ground-based measurements[11] are listed in Table 1. The exposure rates inferred from the aerial survey were found to agree within ±30% with the ground-based measurements.

The results of the radionuclide assay for the soil samples are given in Table 2. The radionuclide concentrations are presented in units of picocuries per gram

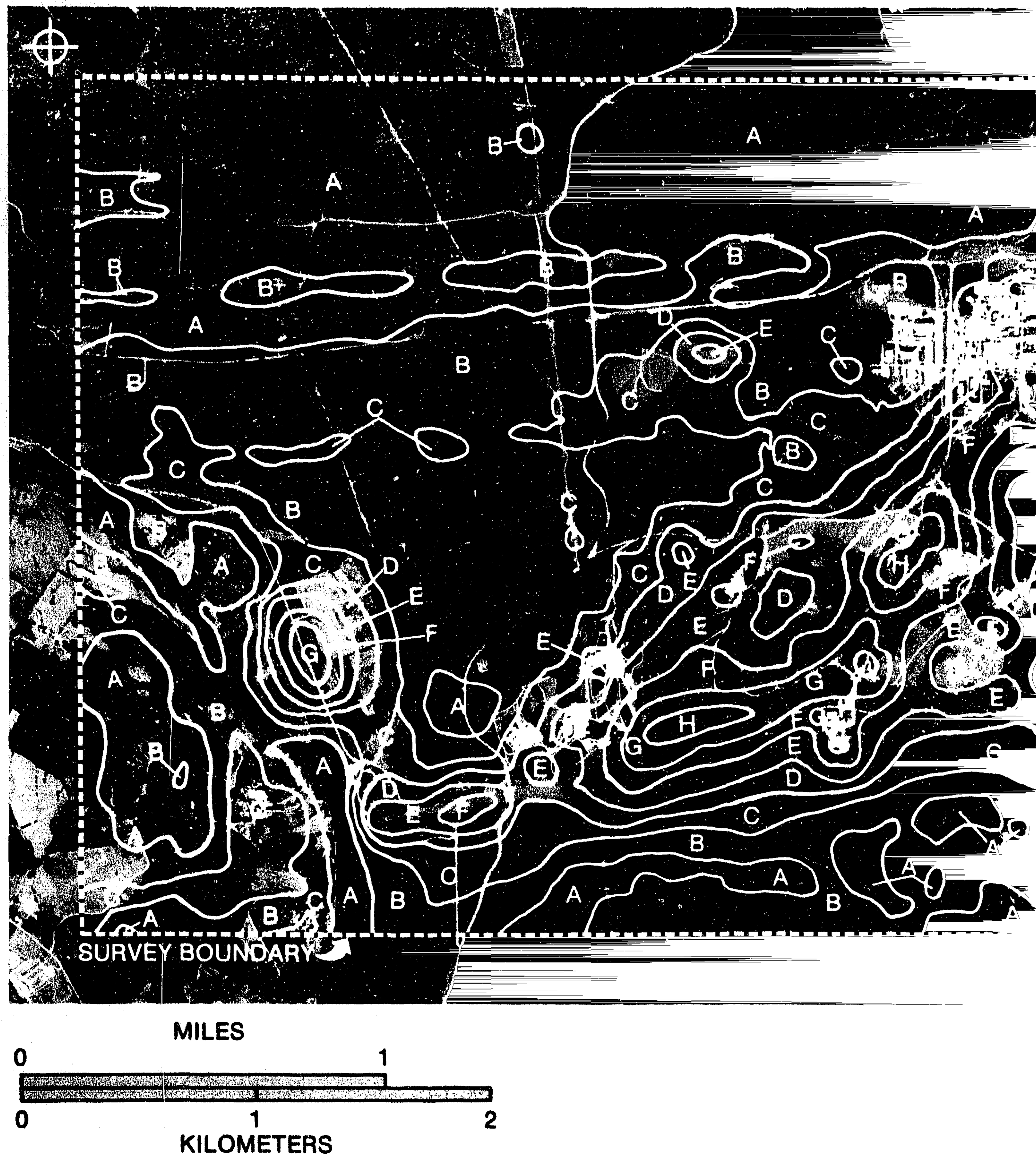
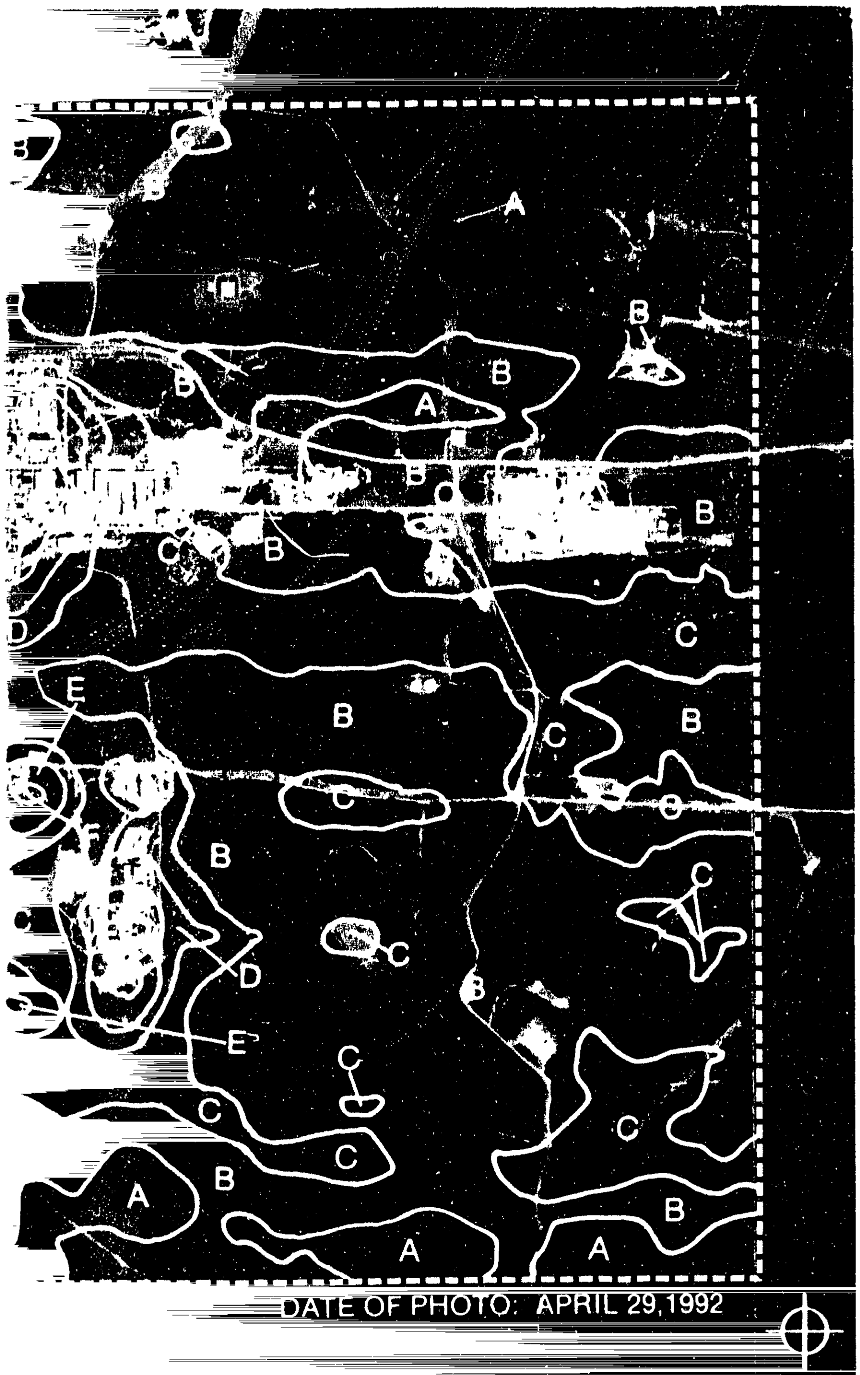
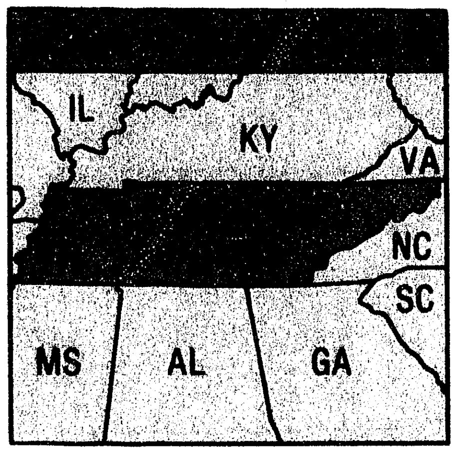


FIGURE 4. ***TERRESTRIAL GAMMA EXPOSURE***





CONVERSION SCALE

LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER μR/h*
A	< 8
B	8 - 10
C	10 - 13
D	13 - 20
E	20 - 50
F	50 - 200
G	200 - 800
H	800 - 3,000

*Values are inferred from aerial data collected at an altitude of 150 feet (46 meters) AGL. Also includes an estimated cosmic ray contribution of 3.8 μR/h.

ATE CONTOUR MAP FOR THE X-10 SITE

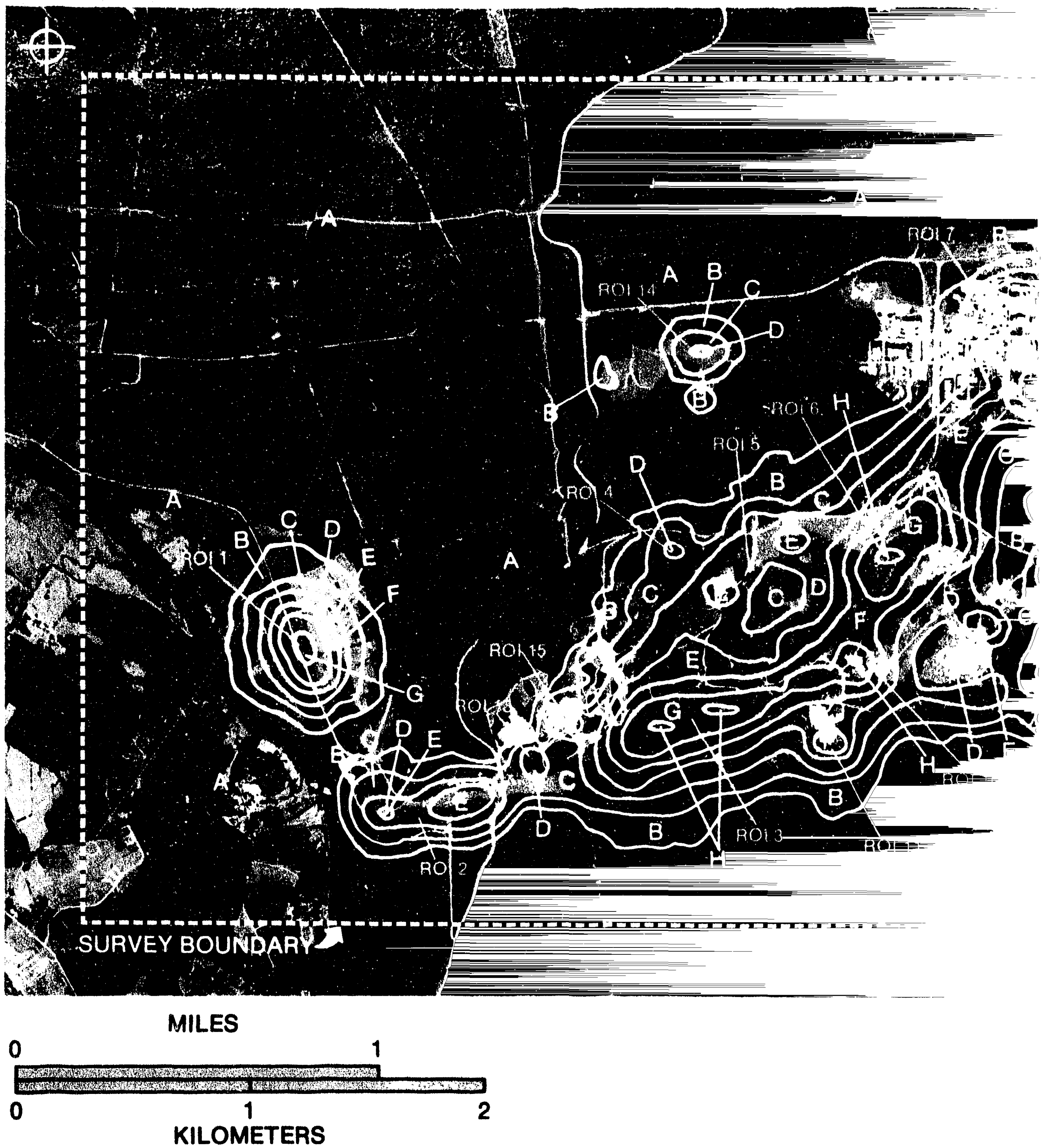
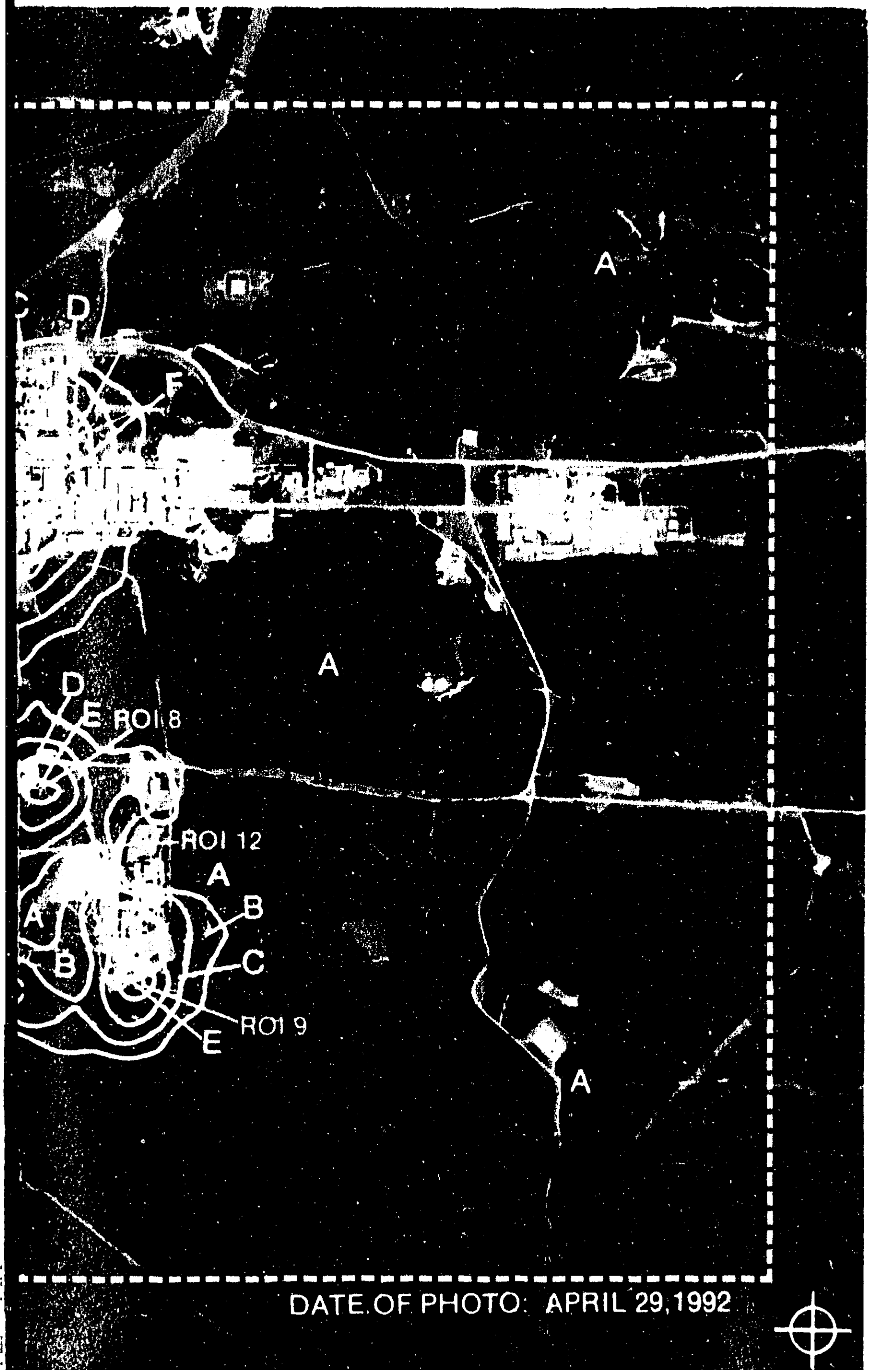
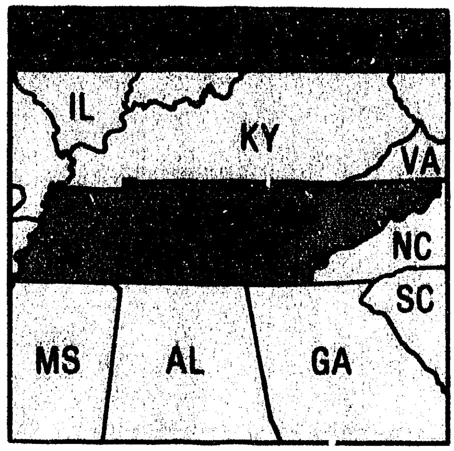


FIGURE 5. *MAN-MADE GROSS COUNT RAT*





CONVERSION SCALE

LETTER LABEL	MAN-MADE* GROSS COUNT COUNTS PER SECOND
A	< 1,000
B	1,000 - 3,200
C	3,200 - 10,000
D	10,000 - 32,000
E	32,000 - 100,000
F	100,000 - 320,000
G	320,000 - 1,000,000
H	1,000,000 - 3,200,000

*The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.

CONTOUR MAP FOR THE X-10 SITE

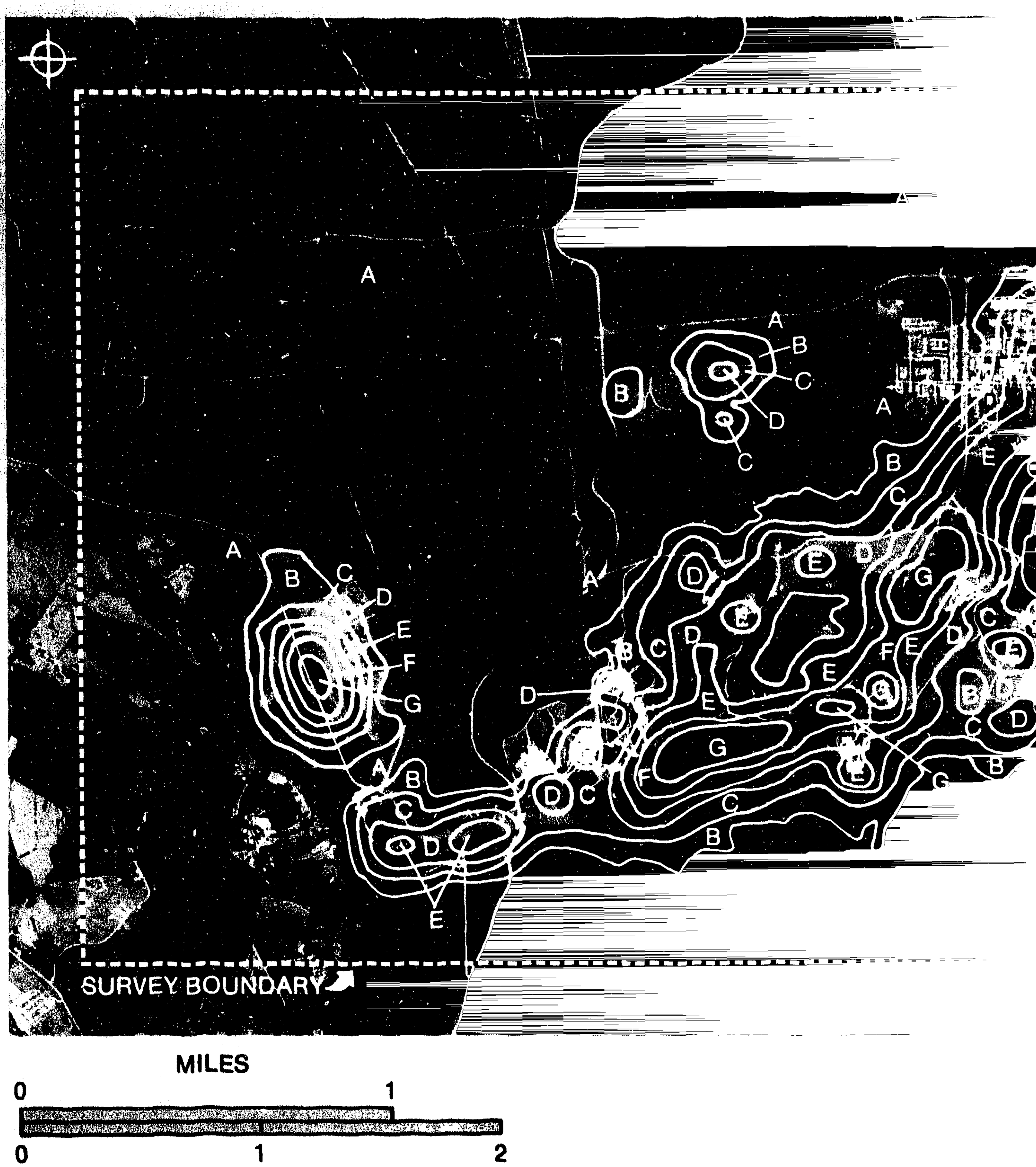
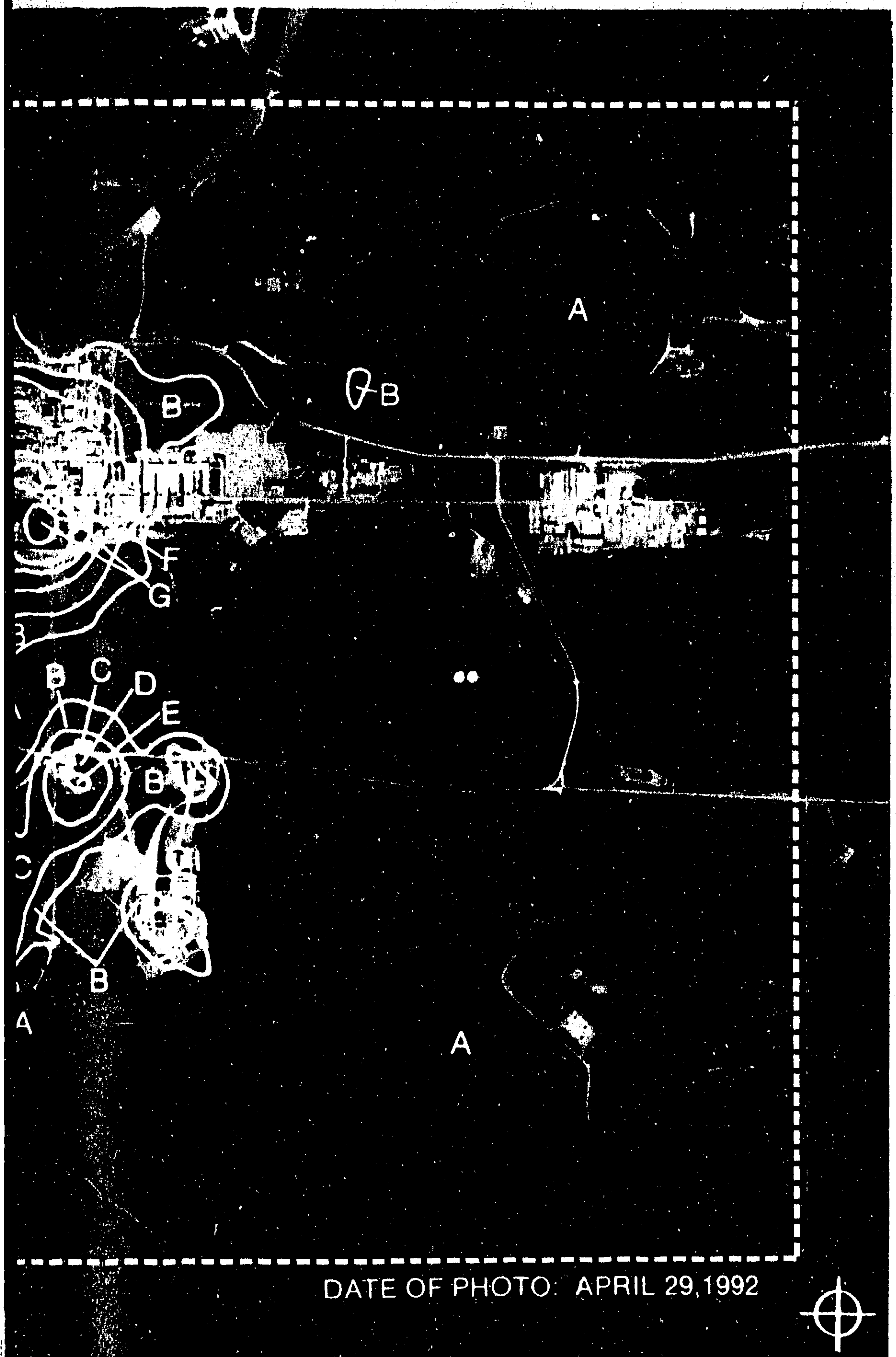
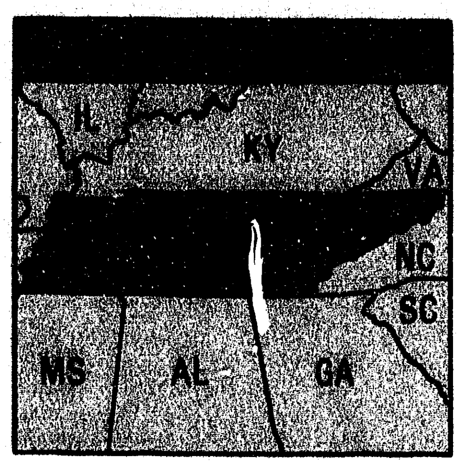


FIGURE 6. ***PHOTOPEAK COUNT RATE CONT***





LETTER LABEL	CESIUM-137 (PHOTOPEAK AT 662 keV) COUNTS PER SECOND*
A	< 50
B	50 - 200
C	200 - 800
D	800 - 3,000
E	3,000 - 12,000
F	12,000 - 40,000
G	40,000 - 150,000
*Summed counts from 590 to 734 keV.	

OUR MAP OF CESIUM-137 FOR THE X-10 SITE

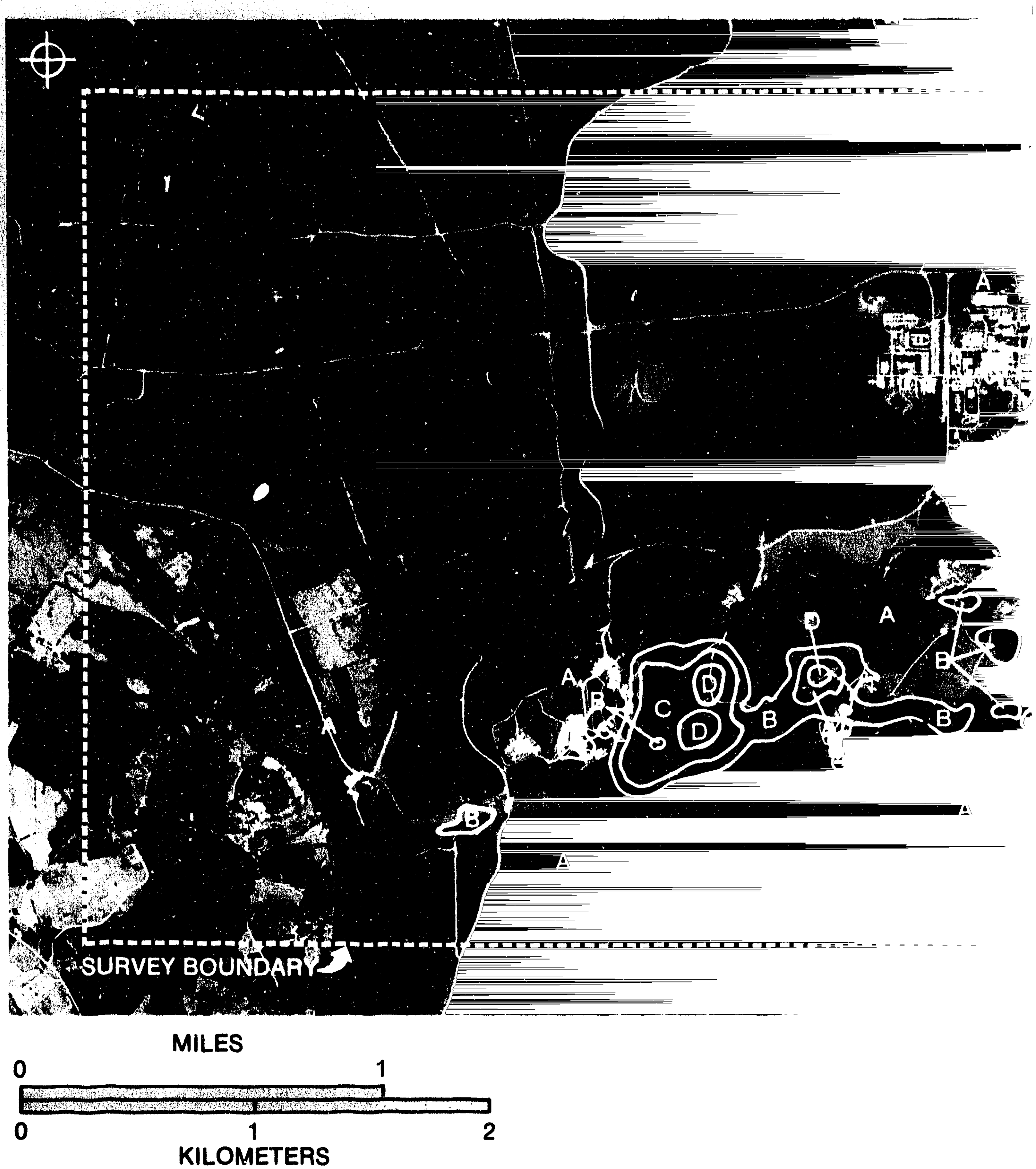
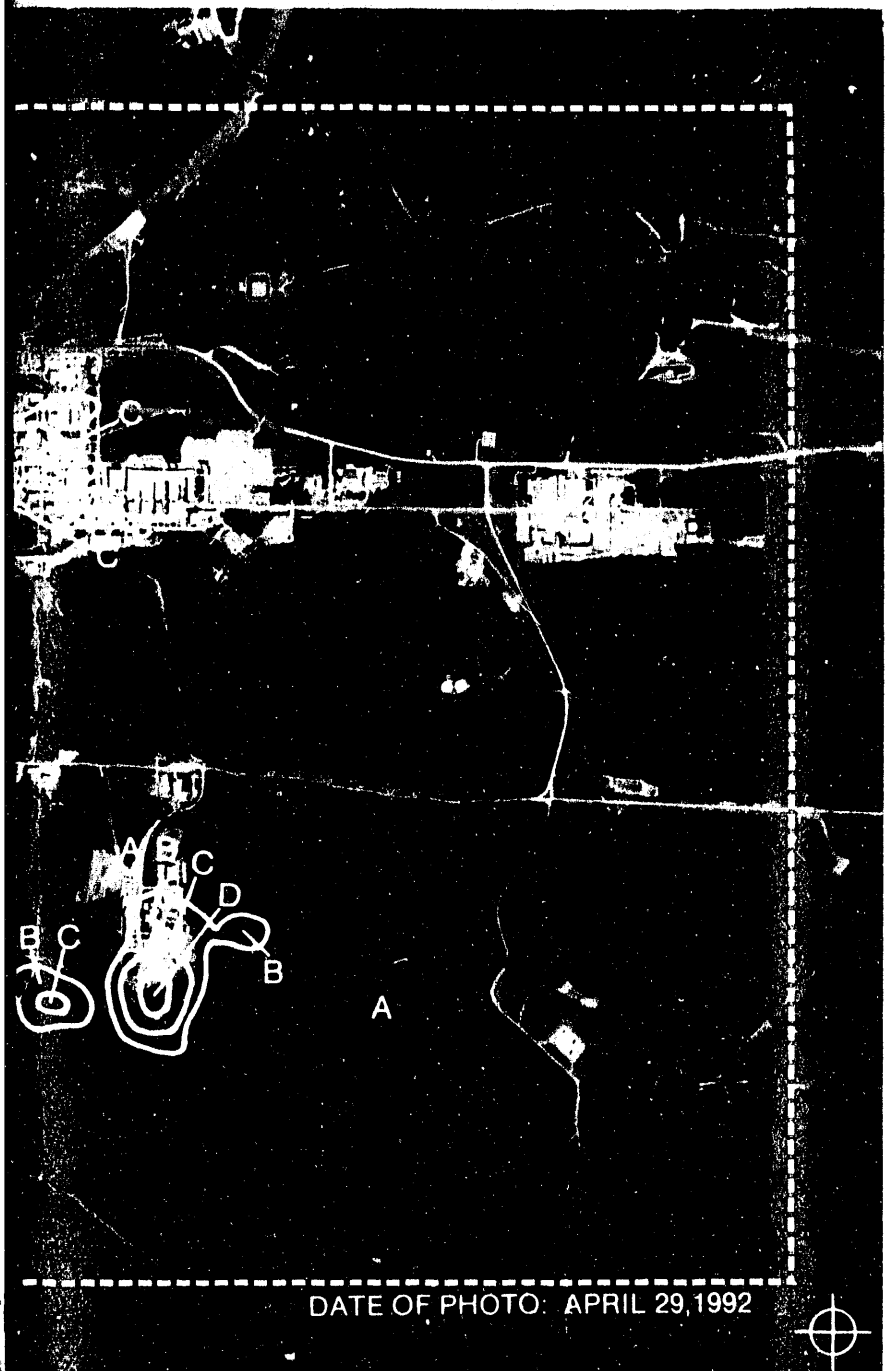
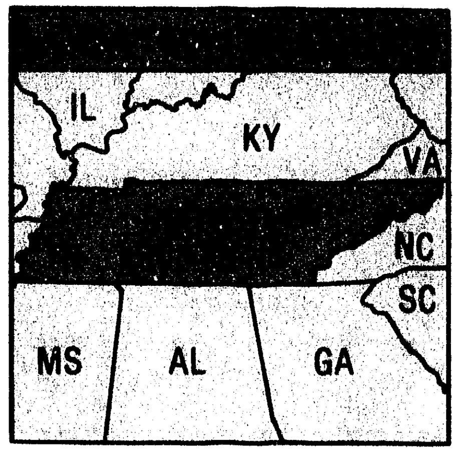


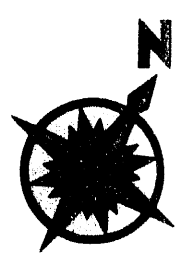
FIGURE 7. *PHOTOPEAK COUNT RATE CONT*





LETTER LABEL	COBALT-60 (PHOTOPEAK AT 1,173 AND 1,332 keV)*
A	< 100
B	100 - 400
C	400 - 1,500
D	1,500 - 6,000

*Summed counts from 1,046 to 1,406 keV.



JR MAP OF COBALT-60 FOR THE X-10 SITE

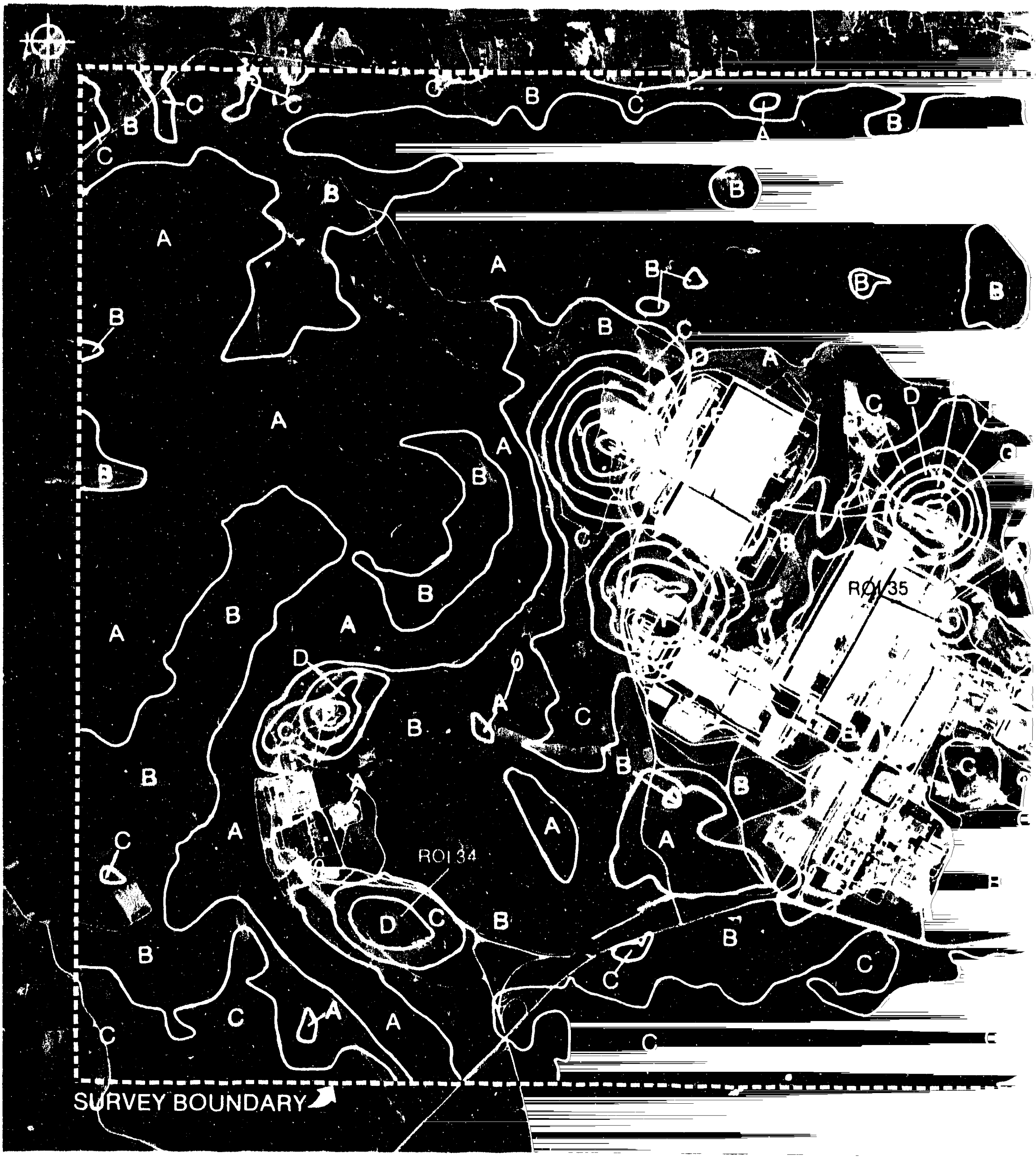
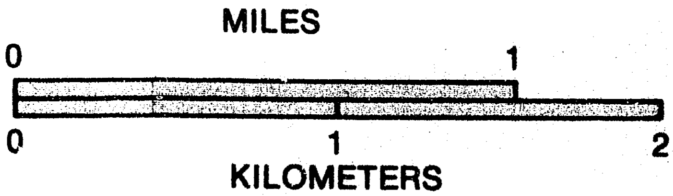
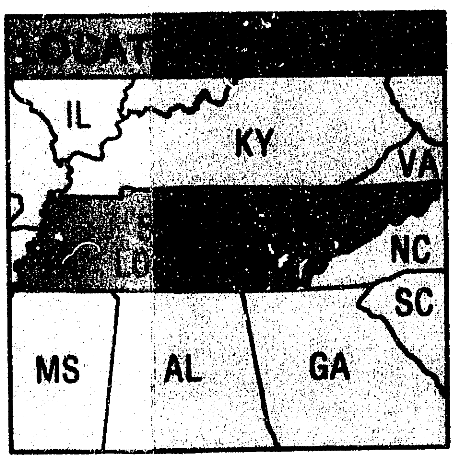


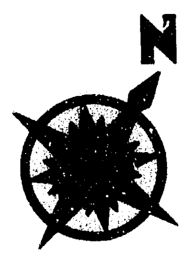
FIGURE 8. ***TERRESTRIAL GAMMA EXPOSURE RAT***



LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER μR/h*
A	< 8
B	8 - 10
C	10 - 13
D	13 - 20
E	20 - 50
F	50 - 200
G	200 - 800
H	800 - 3,000

*Values are inferred from aerial data collected at an altitude of 150 feet (46 meters) AGL. Also includes an estimated cosmic ray contribution of 3.8 μR/h.





CONTOUR MAP FOR THE K-25 SITE

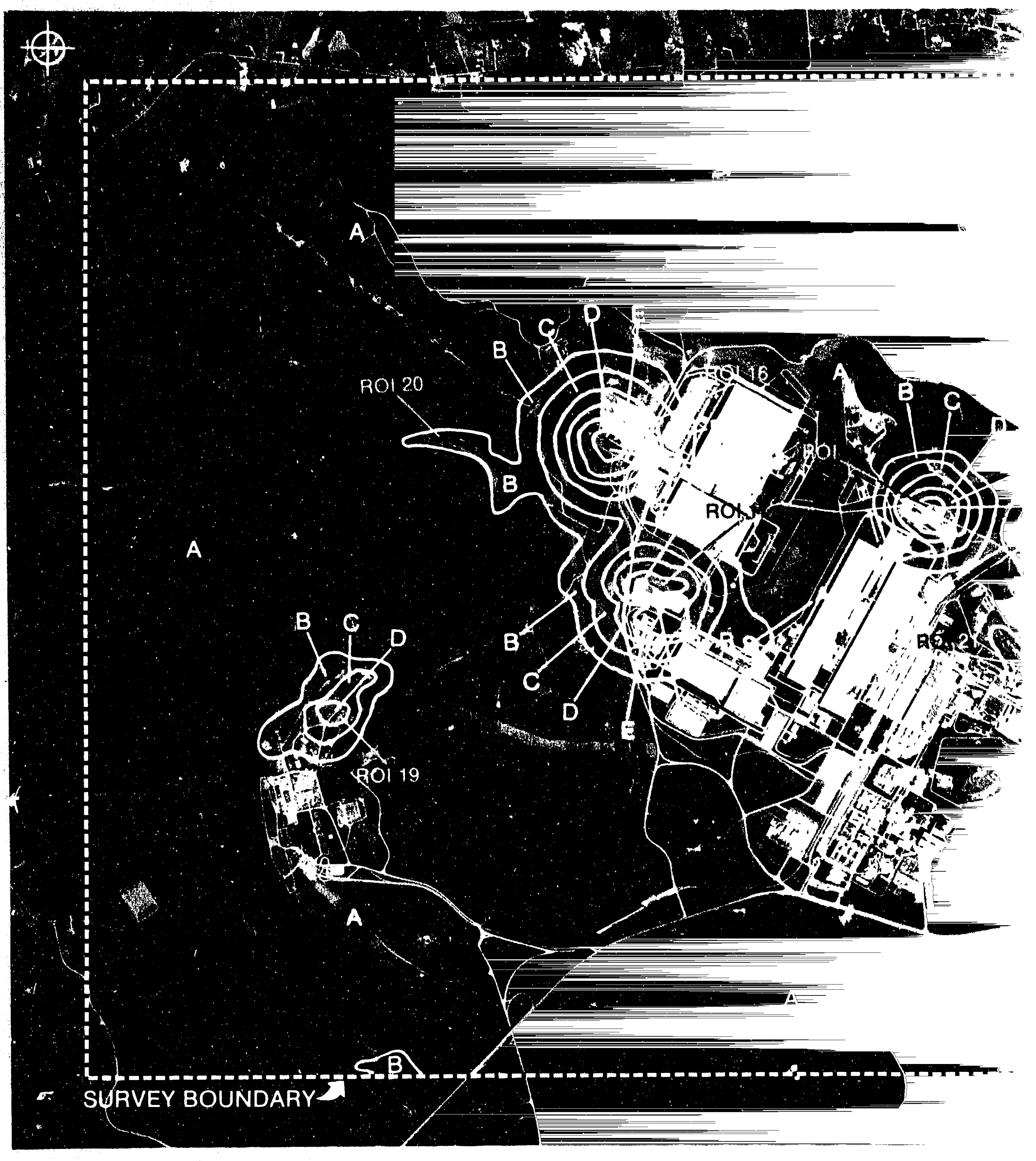
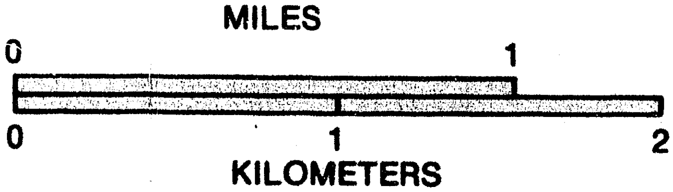
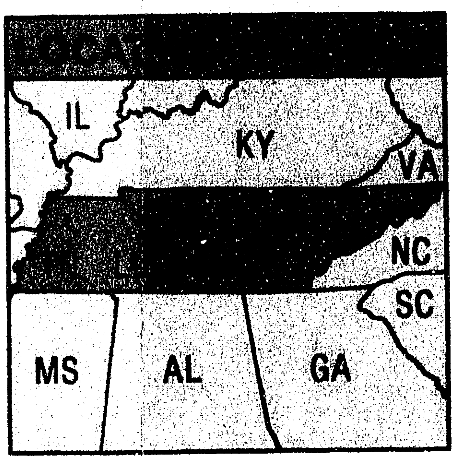


FIGURE 9. ***MAN-MADE GROSS COUNT RATE***



LETTER LABEL	MAN-MADE* GROSS COUNT COUNTS PER SECOND
A	< 1,000
B	1,000 - 3,200
C	3,200 - 10,000
D	10,000 - 32,000
E	32,000 - 100,000
F	100,000 - 320,000
G	320,000 - 1,000,000

*The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.



ONTOUR MAP FOR THE K-25 SITE

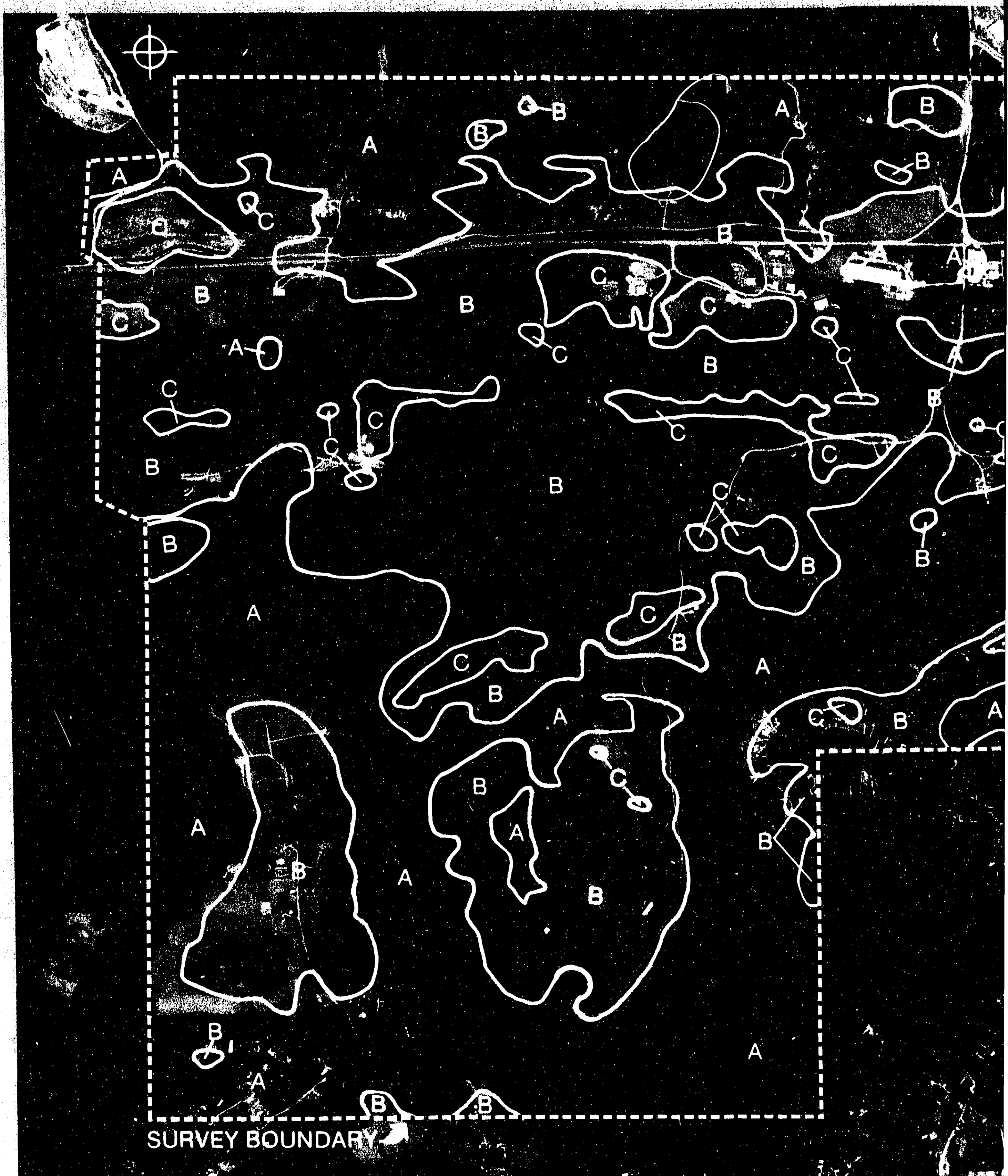
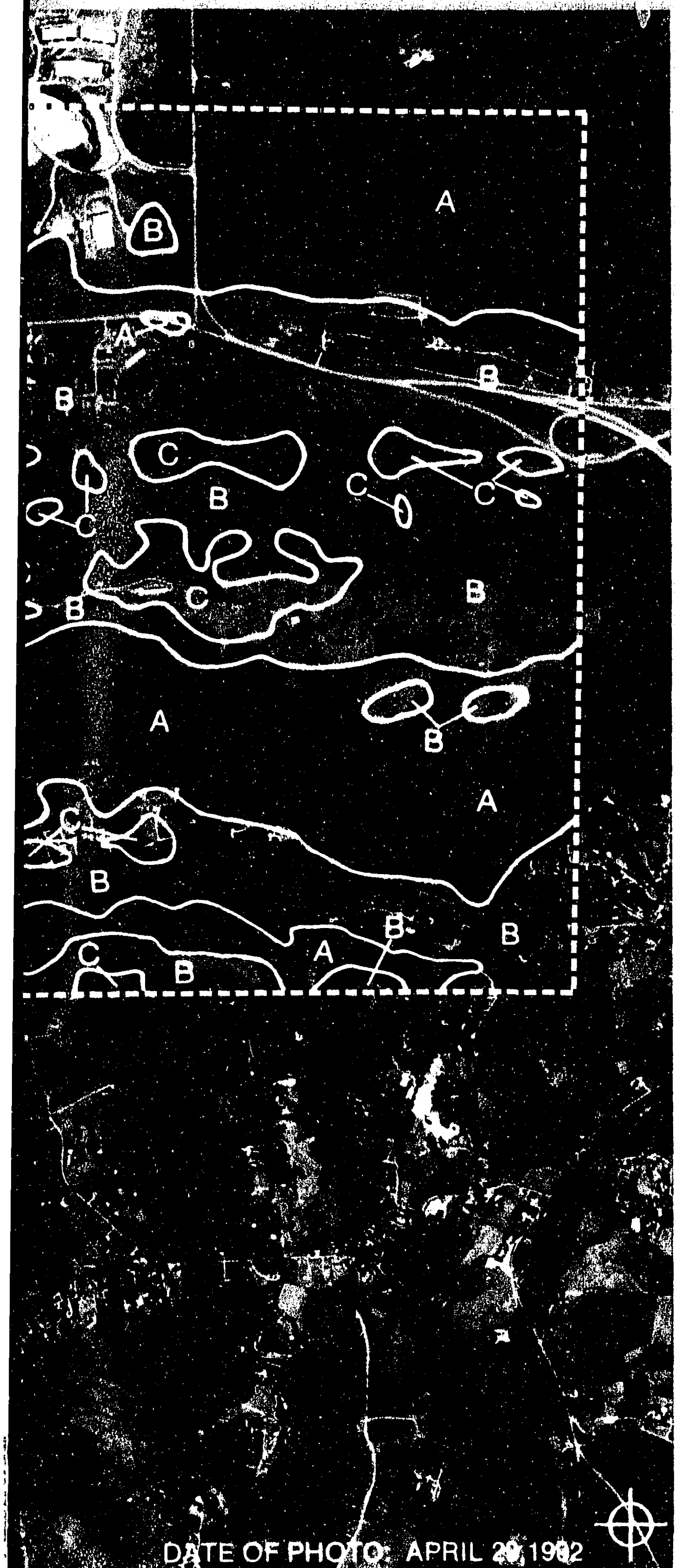
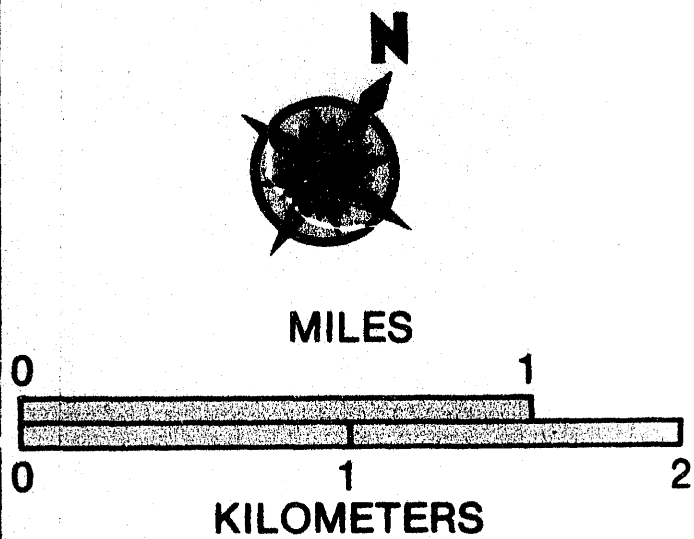


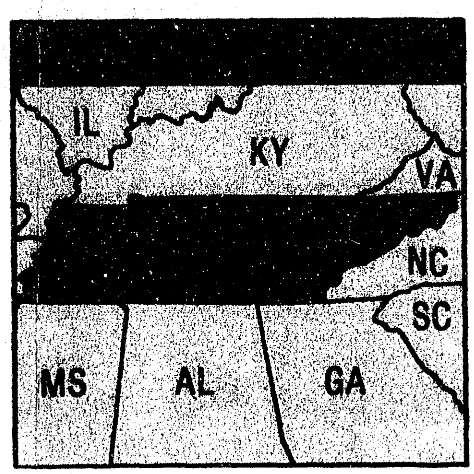
FIGURE 10. ***TERRESTRIAL GAMMA EXPOSURE RATE CONTOUR MAP FOR THE FRE***





LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER µR/h*
A	< 8
B	8 - 10
C	10 - 13

*Values are inferred from aerial data collected at an altitude of 150 feet (46 meters) AGL. Also includes an estimated cosmic ray contribution of 3.8 µR/h.



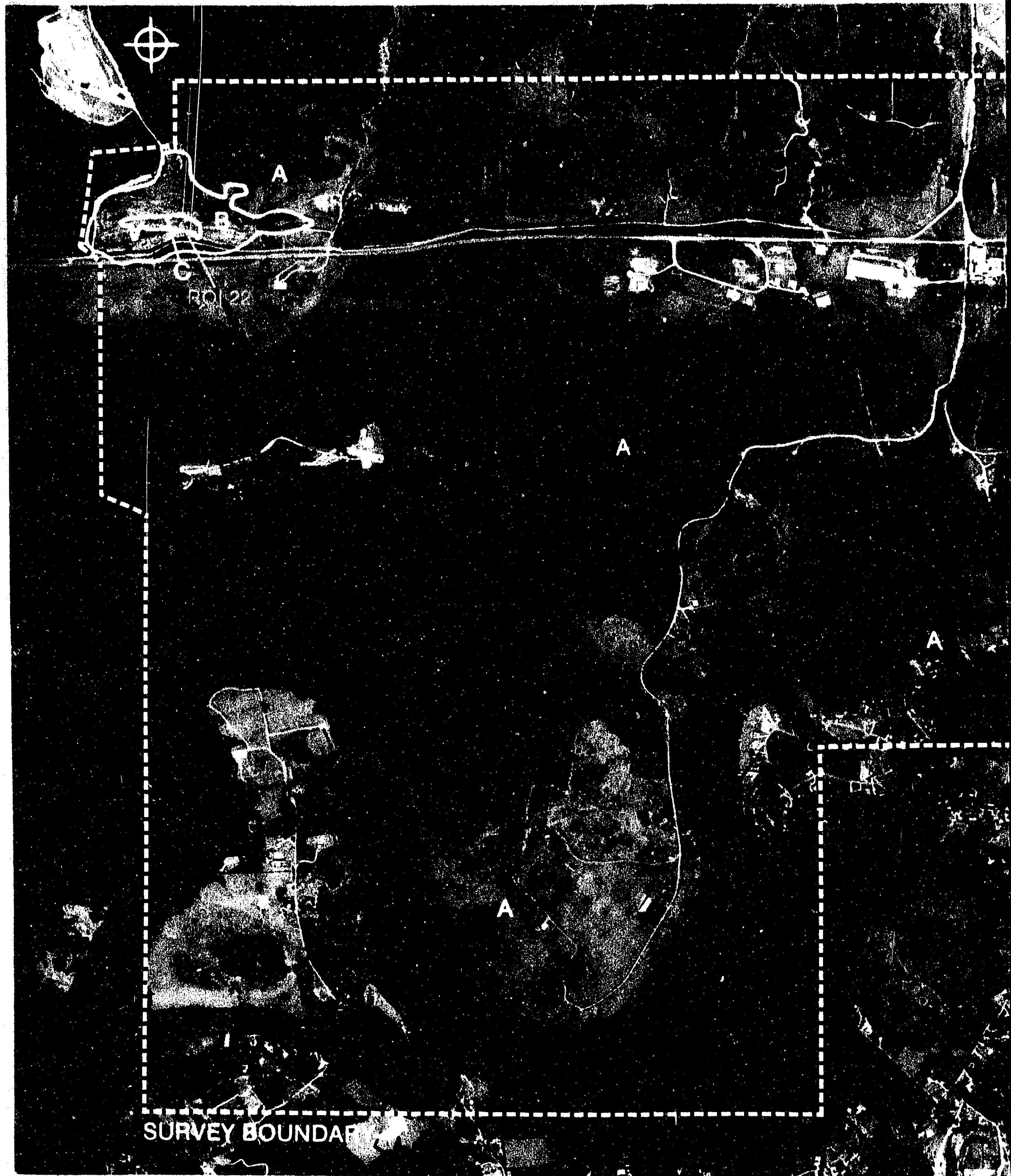
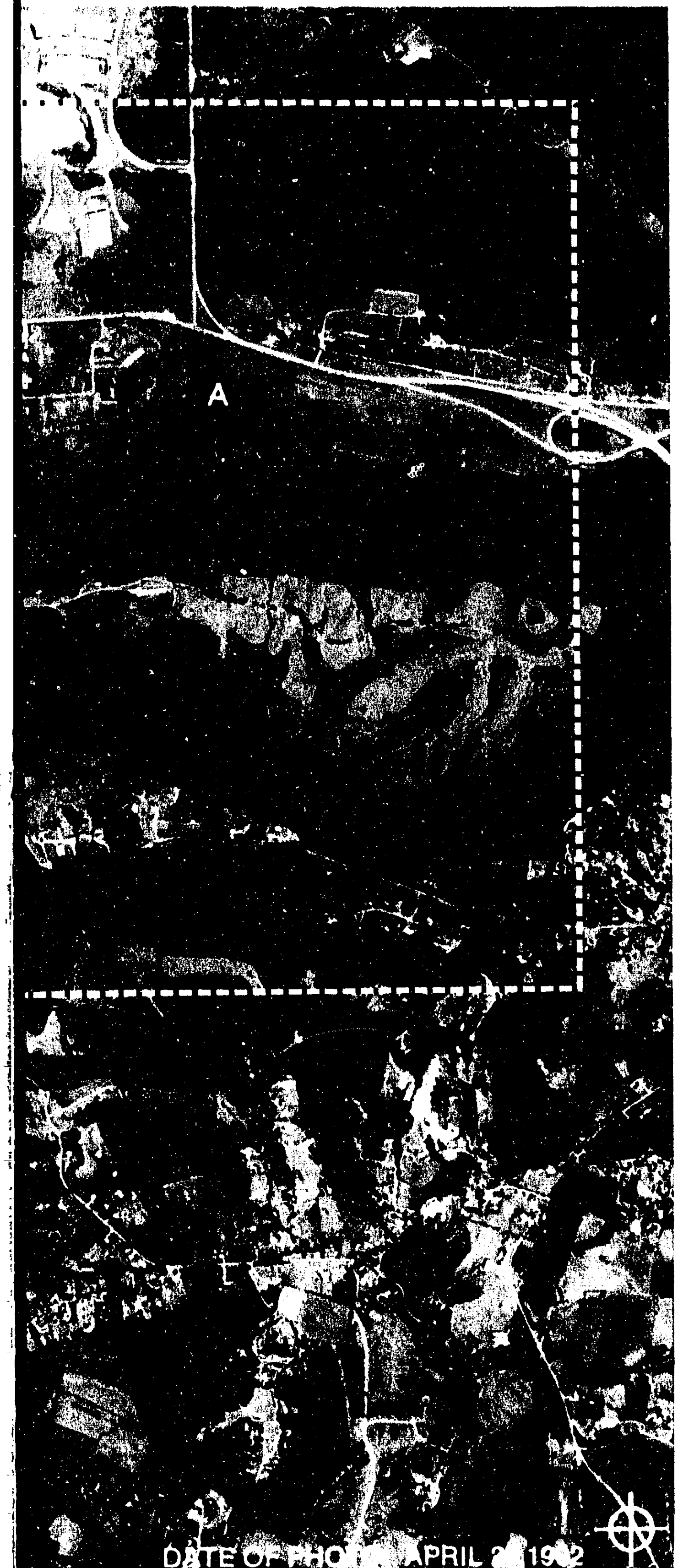
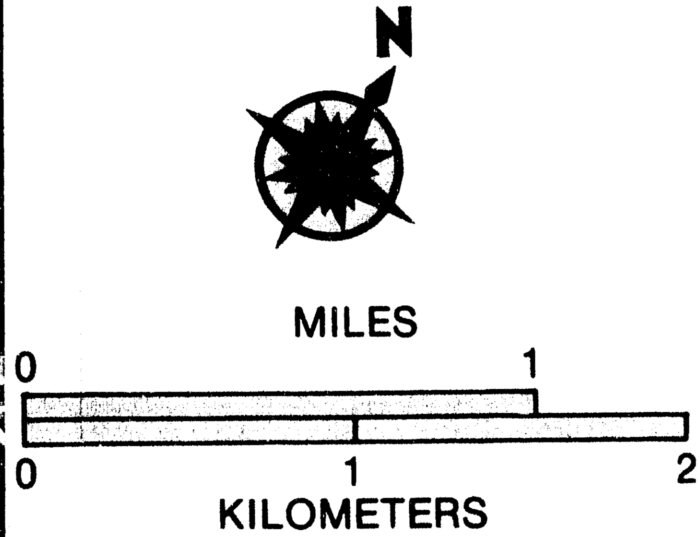


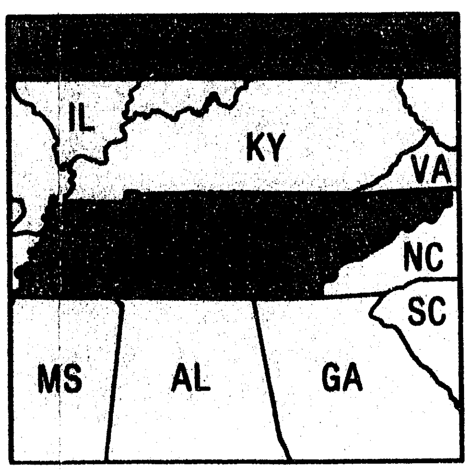
FIGURE 11. *MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE FREELS*





LETTER LABEL	MAN-MADE GROSS COUNT COUNTS PER SECOND
A	< 1,000
B	1,000 - 3,200
C	3,200 - 10,000

*The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.



BEND AND OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION SITES

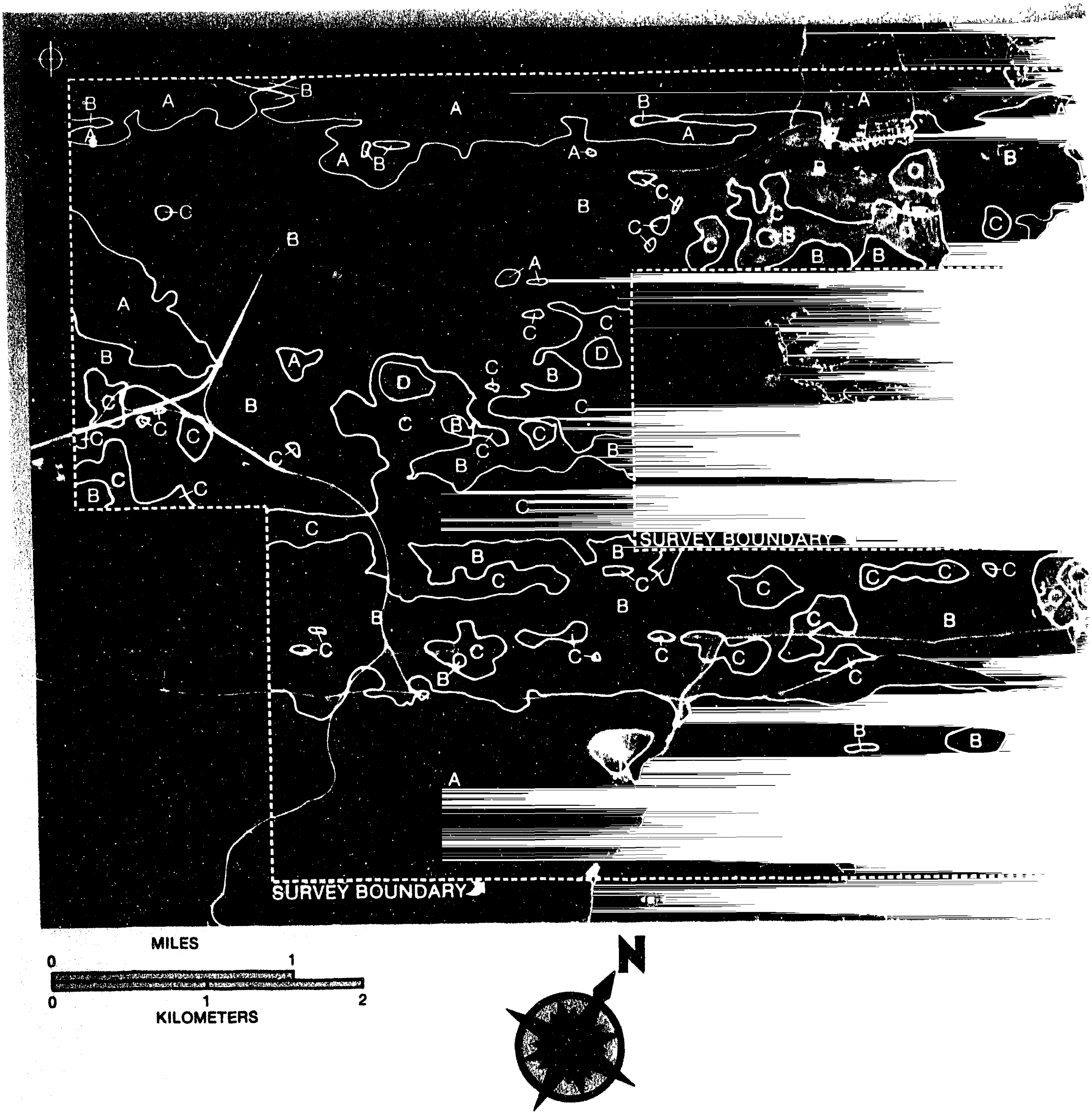
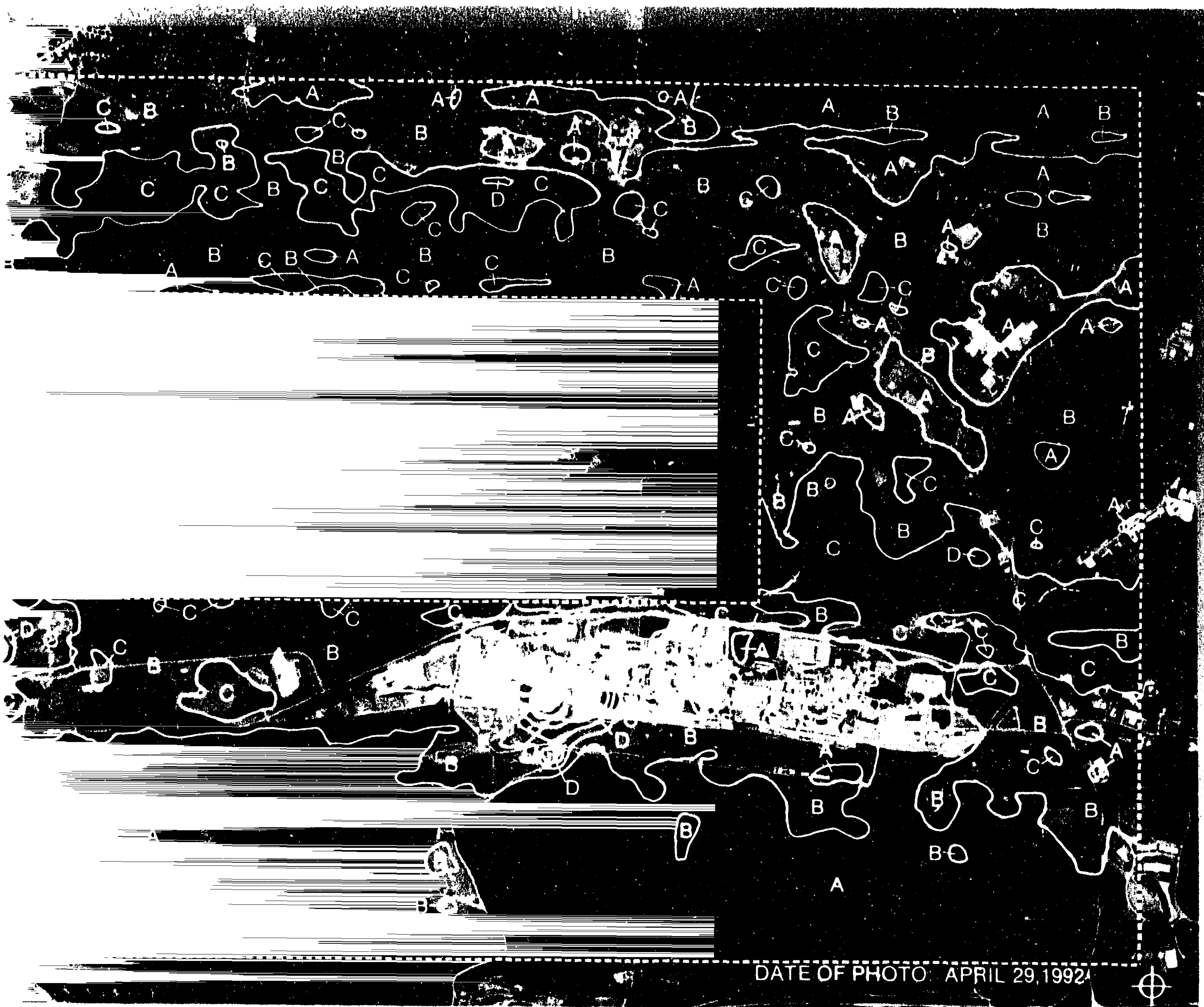
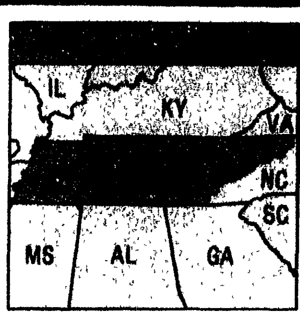


FIGURE 12. *TERRESTRIAL GAMMA EXPOSURE RATE CON*





*Values are inferred from aerial data collected at an altitude of 150 feet (46 meters) AGL. Also includes an estimated cosmic ray contribution of 3.8 μR/h.

LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER μR/h*
A	< 8
B	8 - 10
C	10 - 13
D	13 - 20
E	20 - 50
F	50 - 200

UR MAP FOR THE Y-12 AND EAST FORK POPLAR CREEK SITES

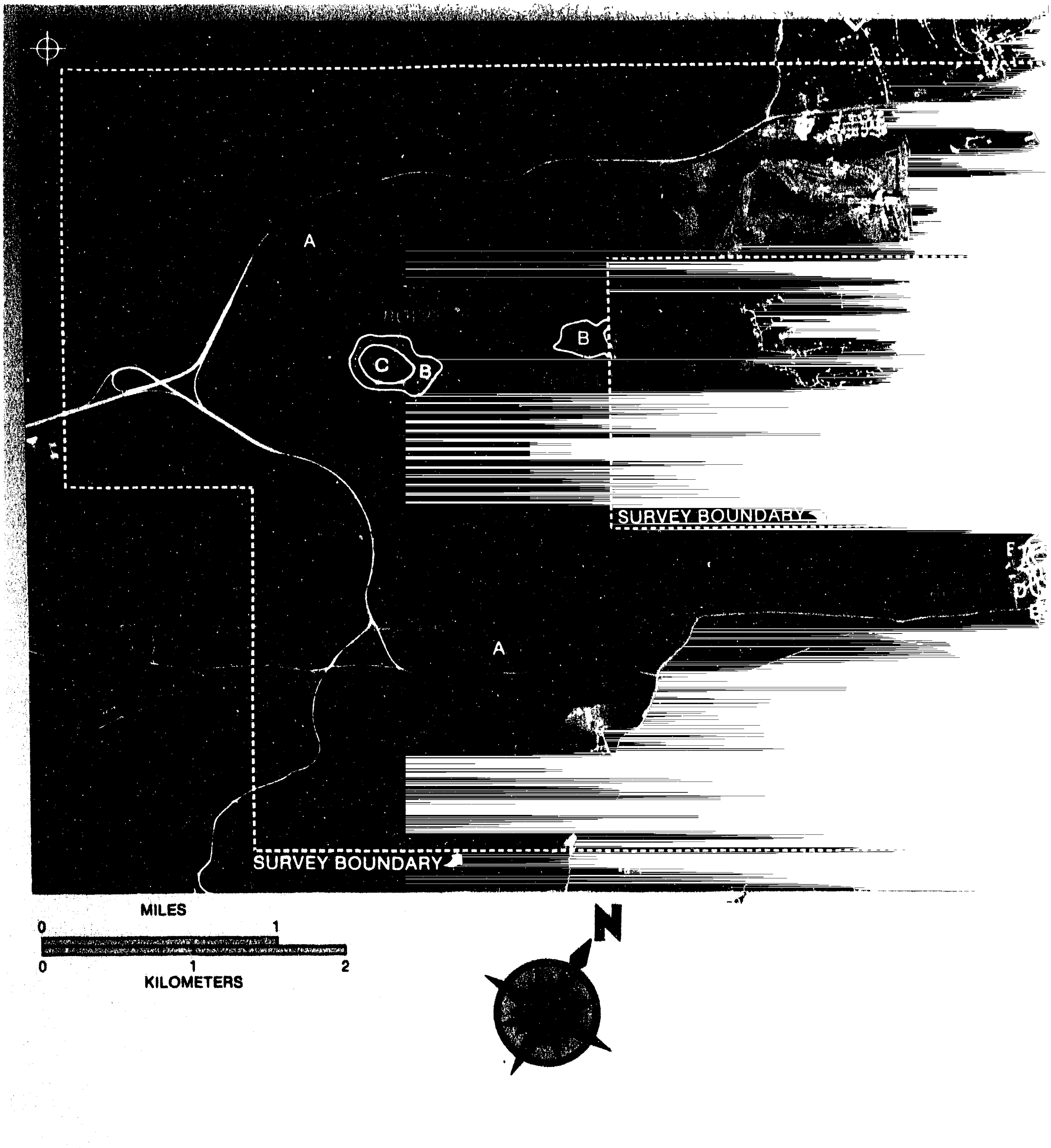
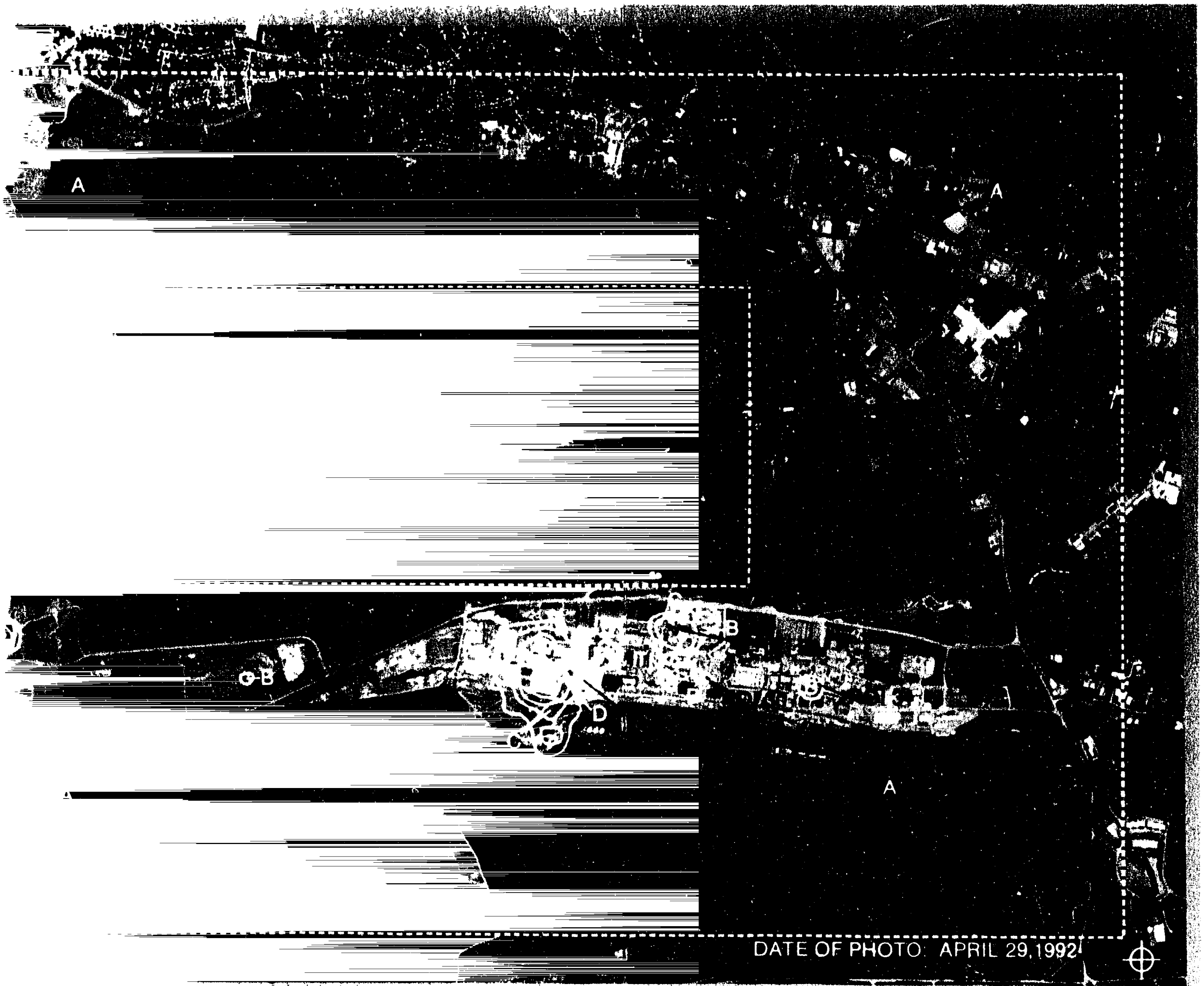


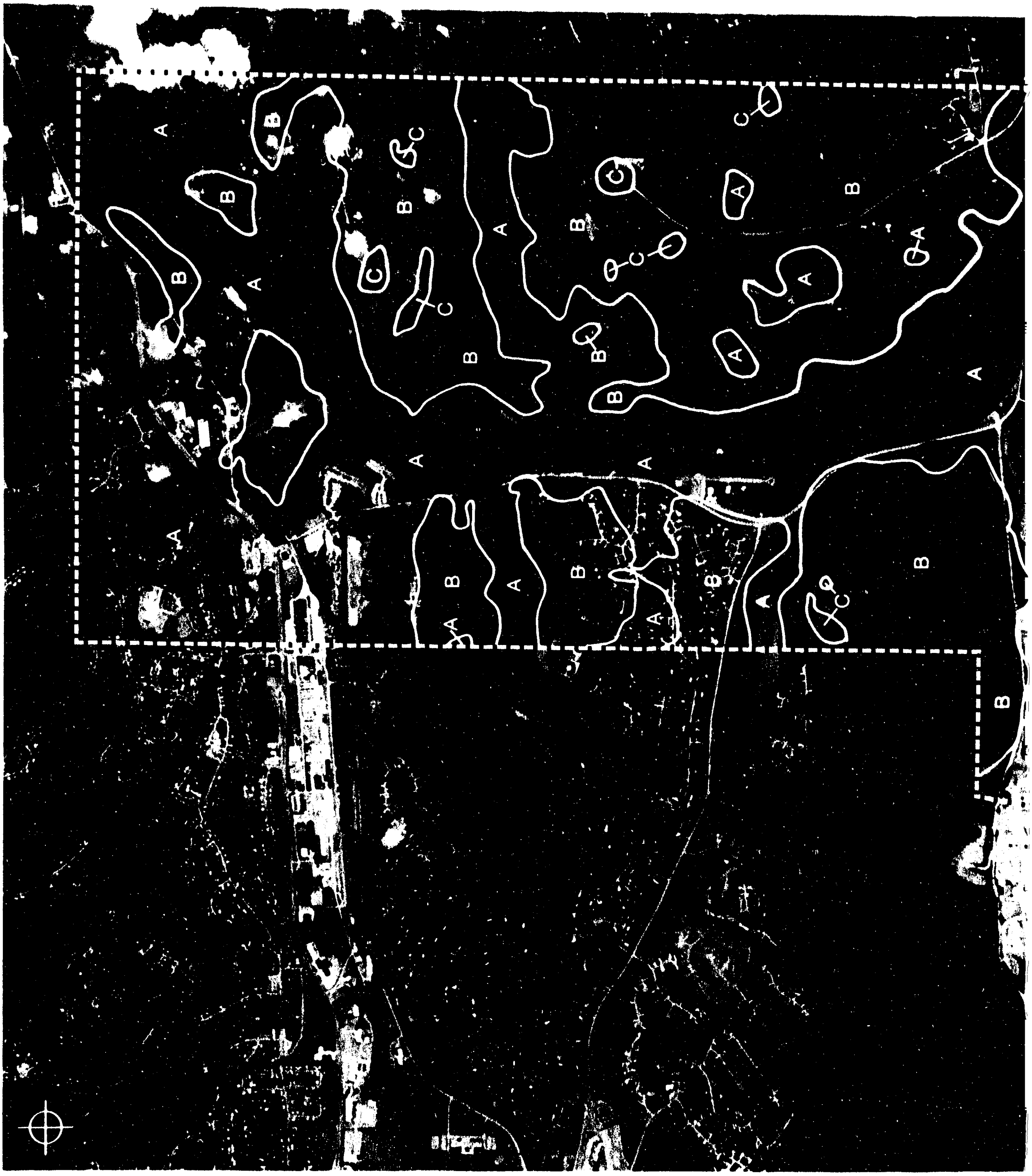
FIGURE 13. *MAN-MADE GROSS COUNT RATE CONTOU*

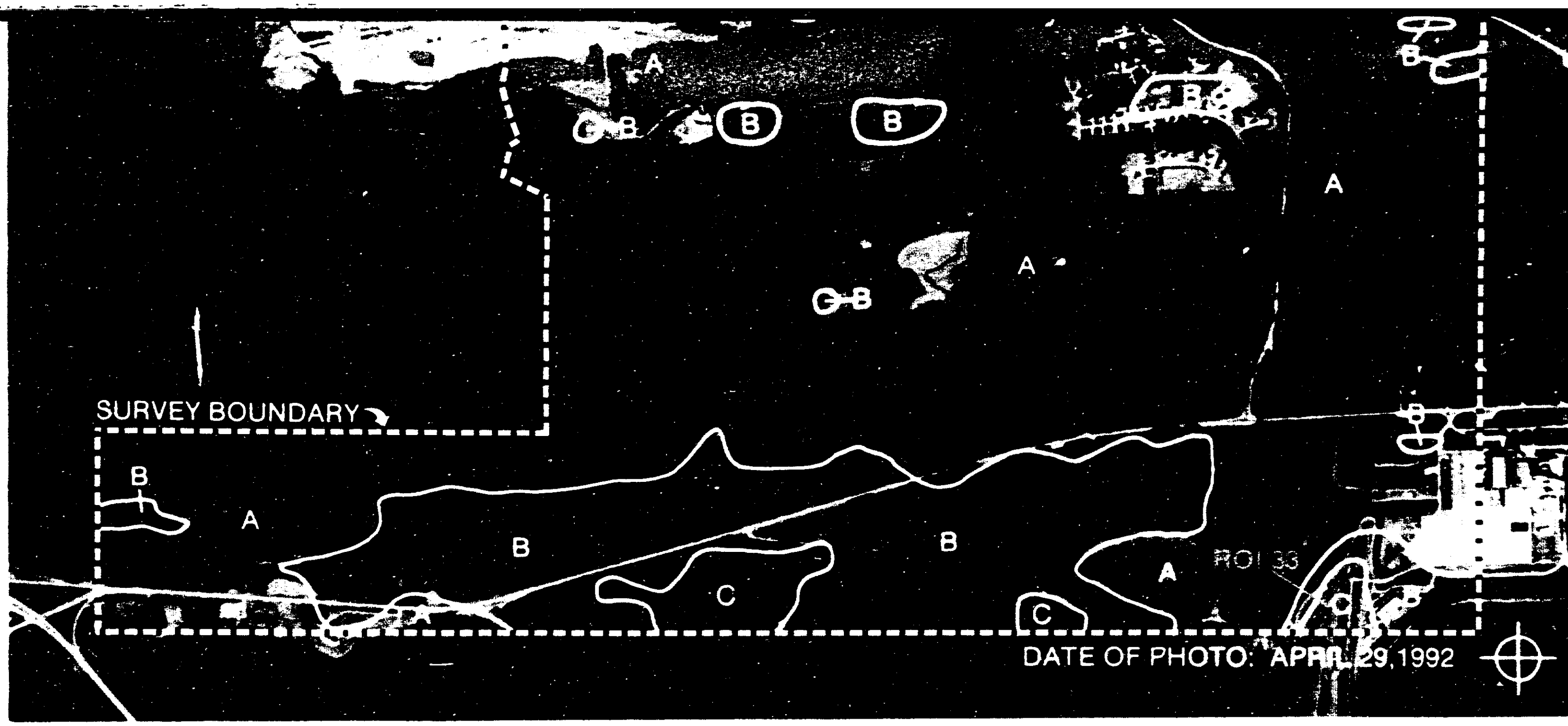


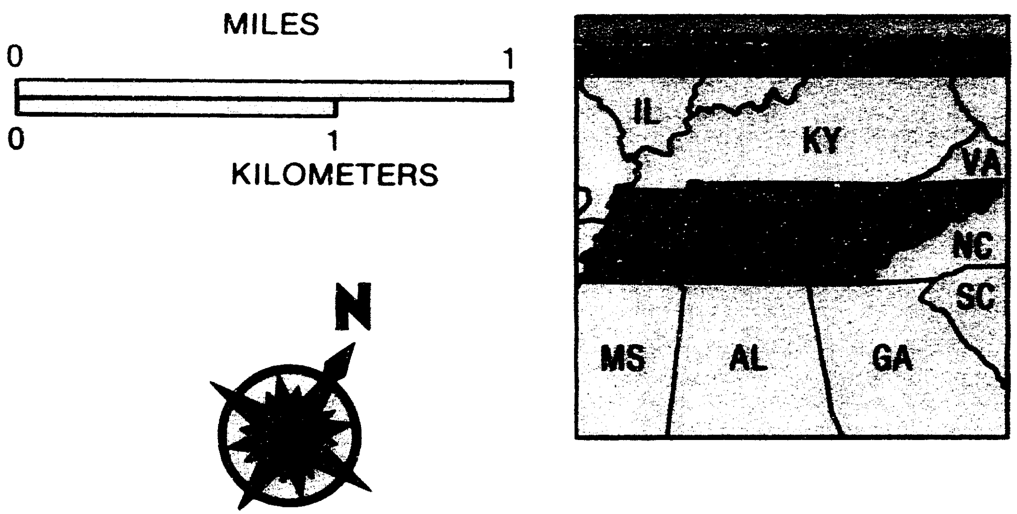
*The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.

LETTER LABEL	MAN-MADE* GROSS COUNT COUNTS PER SECOND
A	< 1,000
B	1,000 - 3,200
C	3,200 - 10,000
D	10,000 - 32,000
E	32,000 - 100,000

MAP FOR THE Y-12 AND EAST FORK POPLAR CREEK SITES



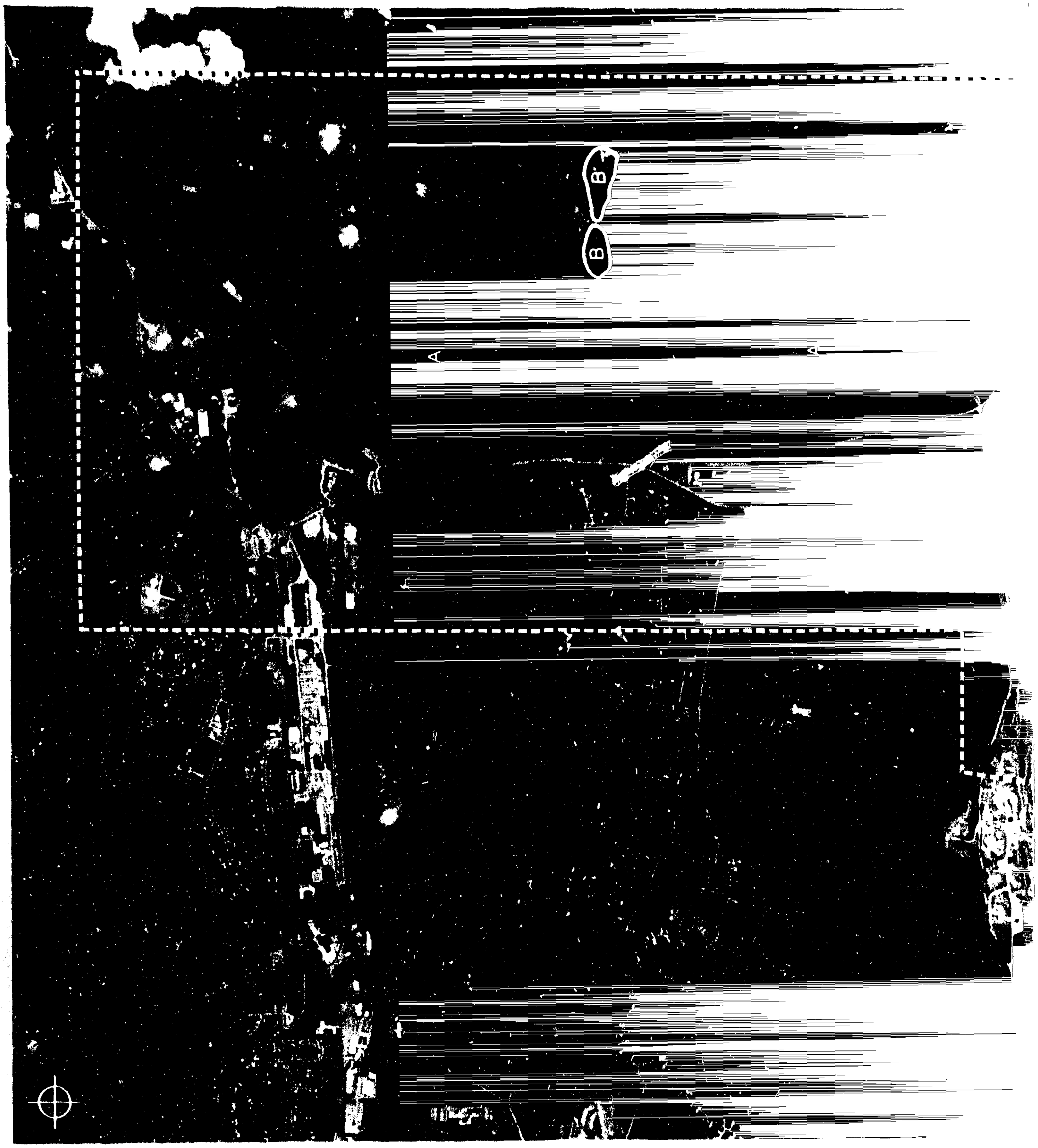


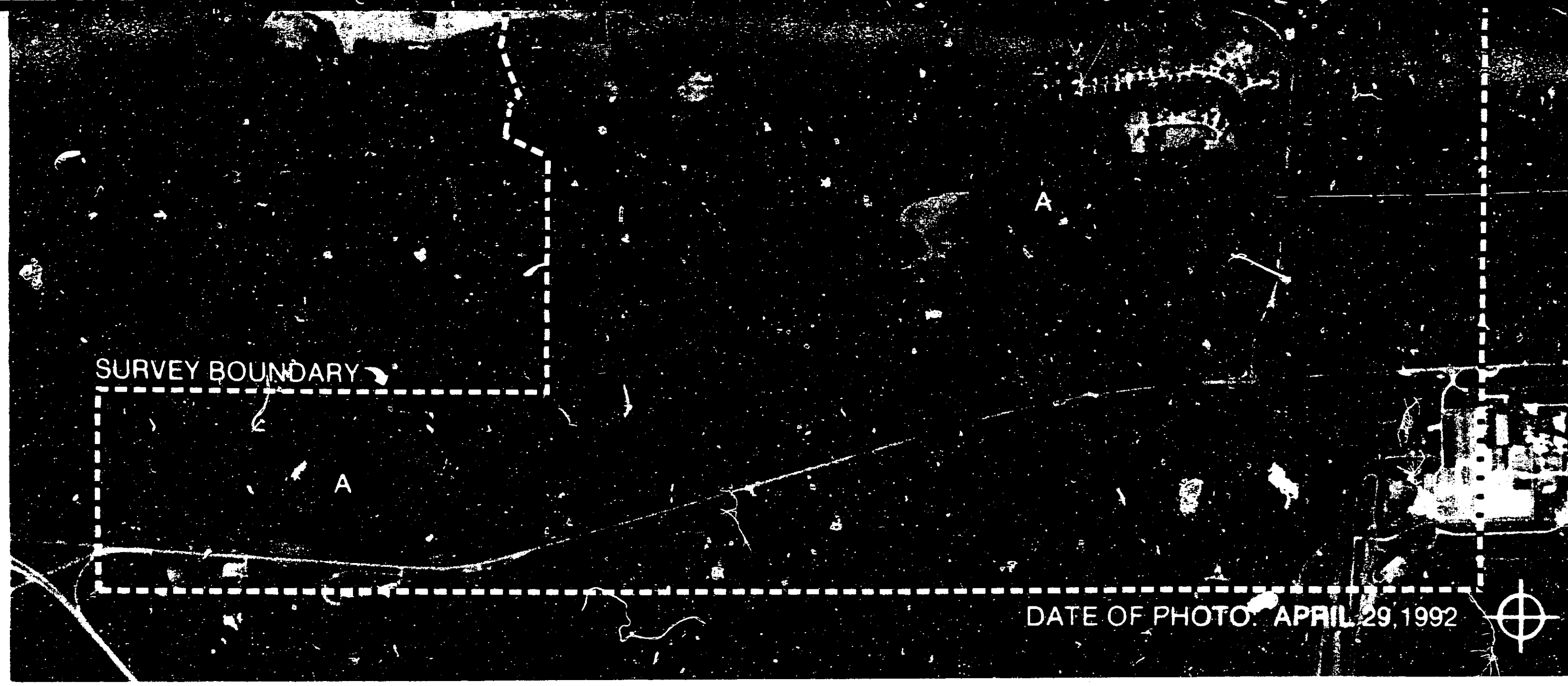


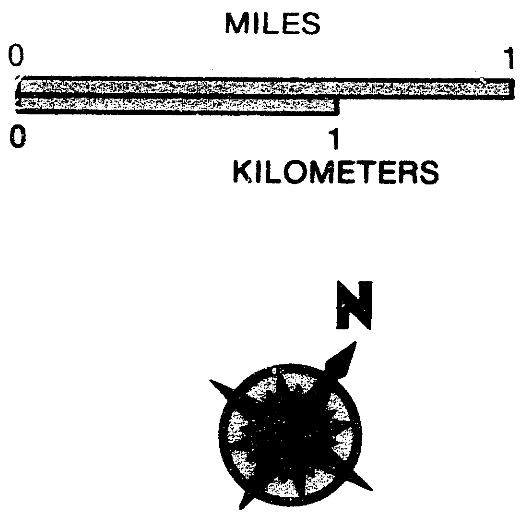
LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER $\mu R/h^*$
A	< 8
B	8 - 10
C	10 - 13

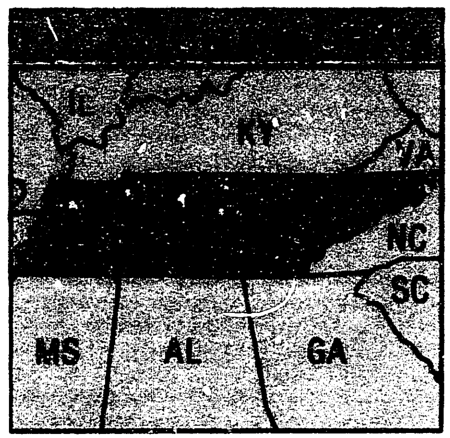
*Values are inferred from aerial data collected at an altitude of 150 feet (46 meters) AGL. Also includes an estimated cosmic ray contribution of 3.8 $\mu R/h$.

FIGURE 14. *TERRESTRIAL GAMMA EXPOSURE RATE CONTOUR MAP FOR THE ELZA GATE AND PARCEL A SITES*


B'
B







LETTER LABEL	MAN-MADE* GROSS COUNT COUNTS PER SECOND
A	< 1,000
B	1,000 - 3,200

*The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.

FIGURE 15. *MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE ELZA GATE AND PARCEL A SITES*

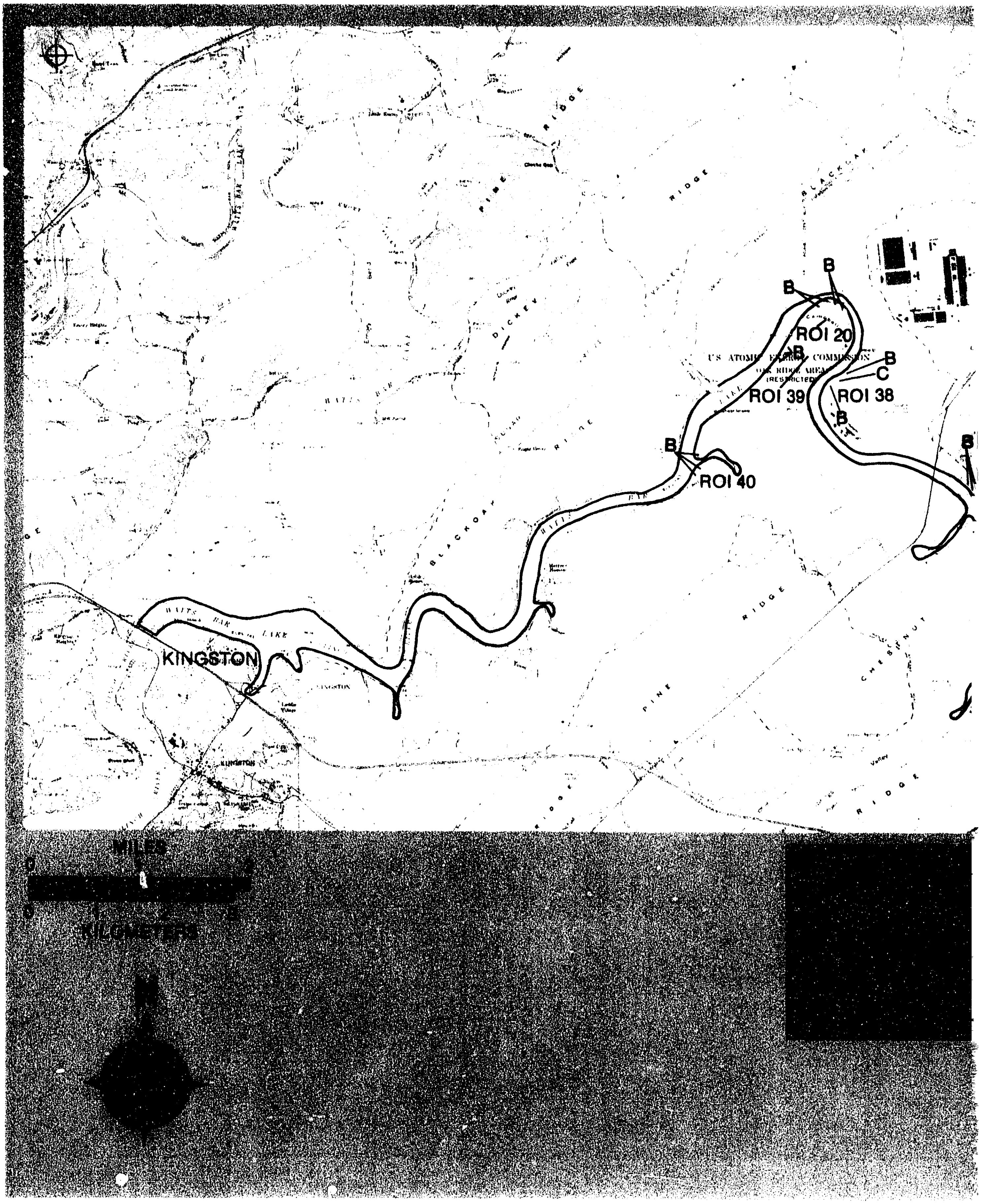
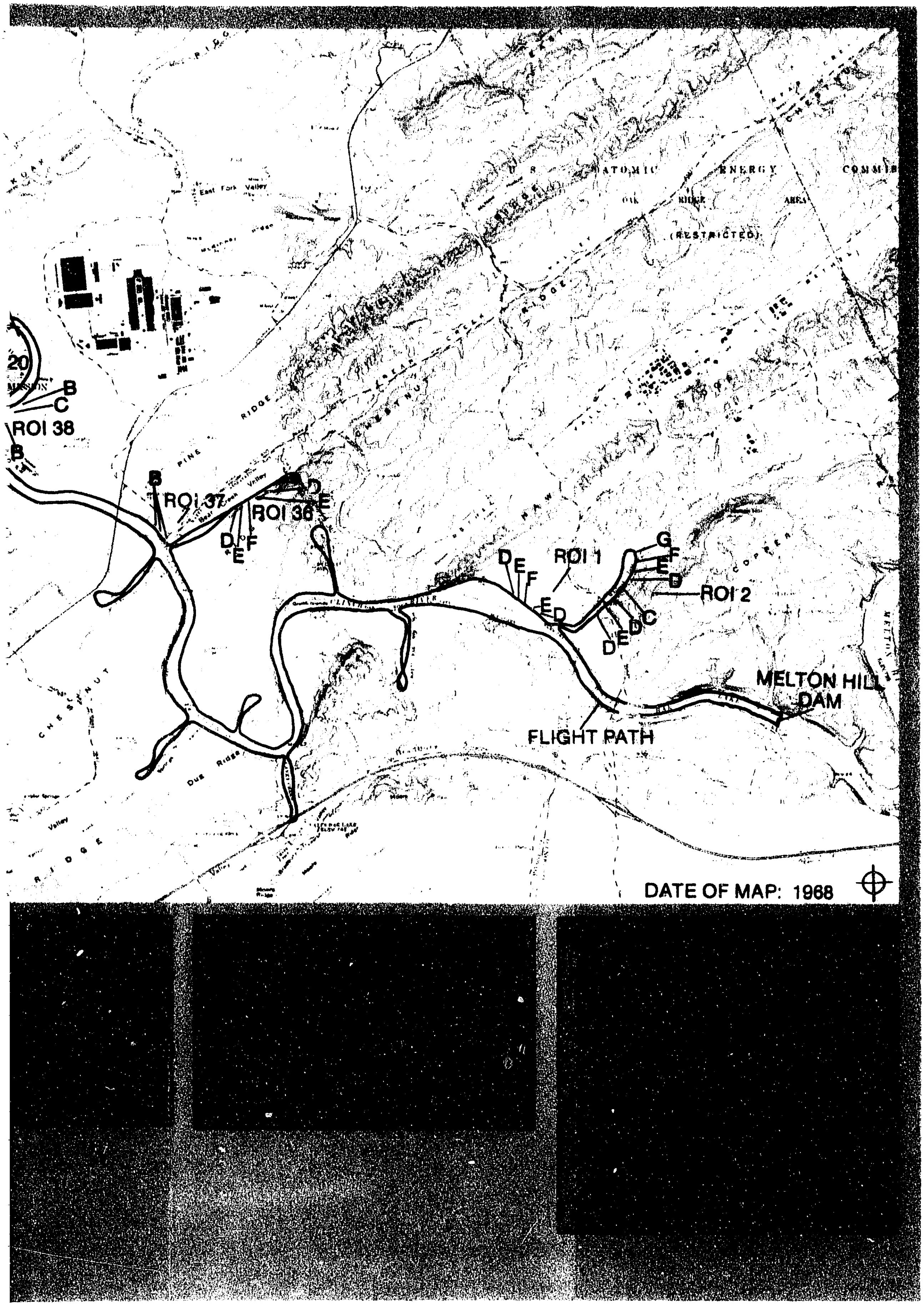


FIGURE 16. *MAN-MADE GROSS COUNT RATE POSITION PLOT FO*



E POSITION PLOT FOR THE CLINCH RIVER

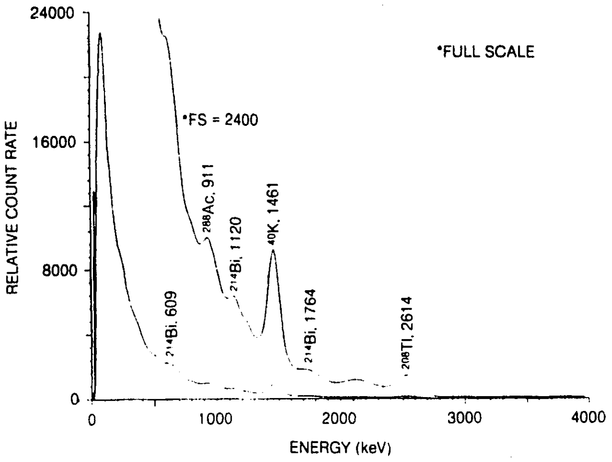


FIGURE 17. ***TYPICAL NATURAL BACKGROUND GAMMA SPECTRUM FOR THE OAK RIDGE AREA***

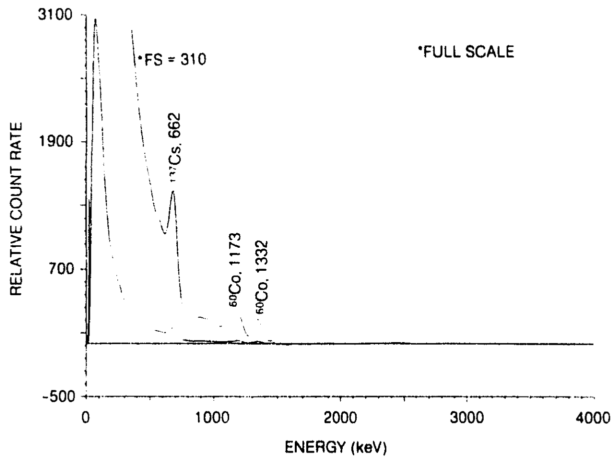


FIGURE 20. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 3***

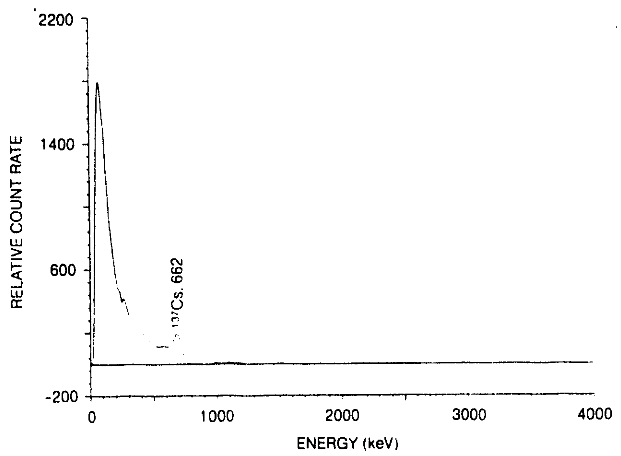


FIGURE 18. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 1***

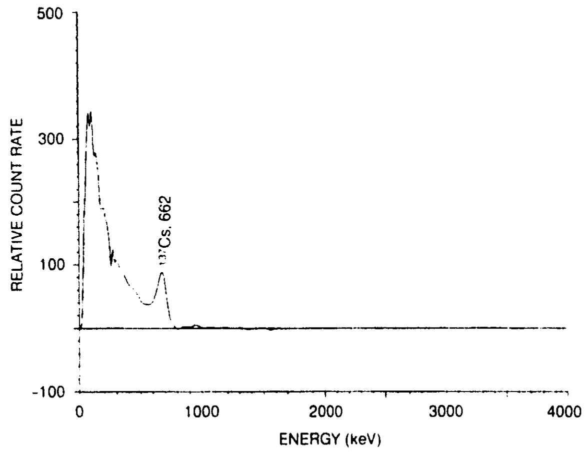


FIGURE 21. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 4***

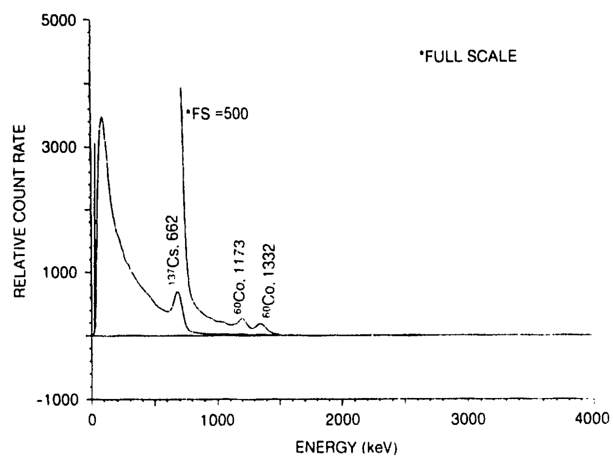


FIGURE 19. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 2***

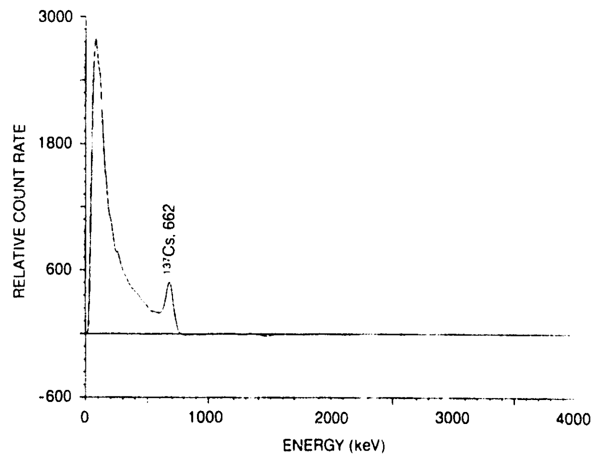


FIGURE 22. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 5***

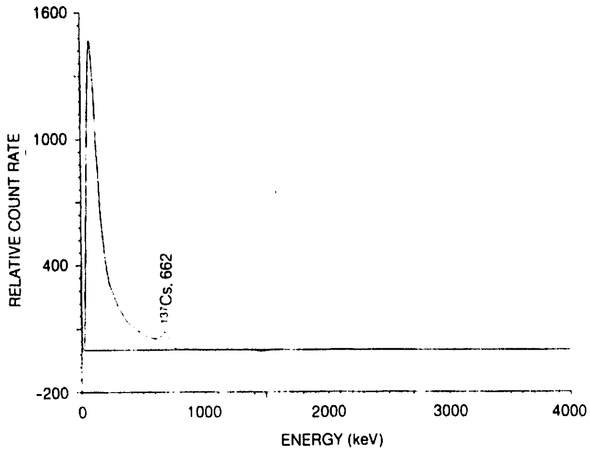


FIGURE 23. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 6***

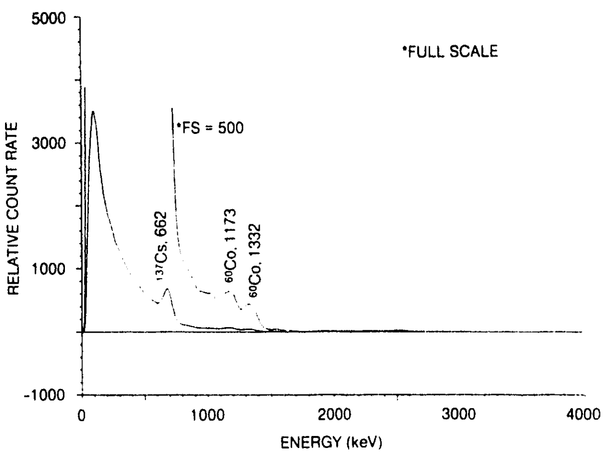


FIGURE 24. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 7***

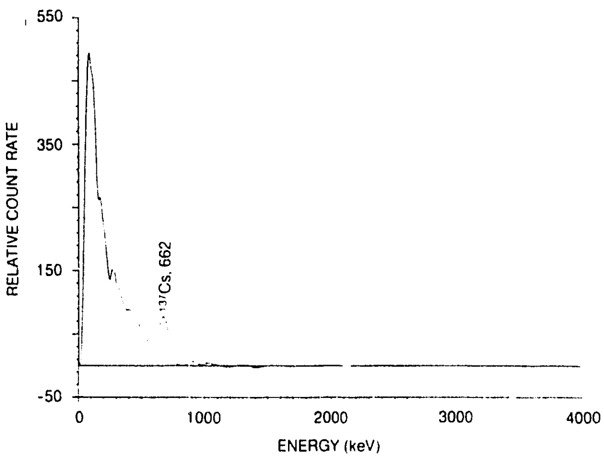


FIGURE 25. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 8***

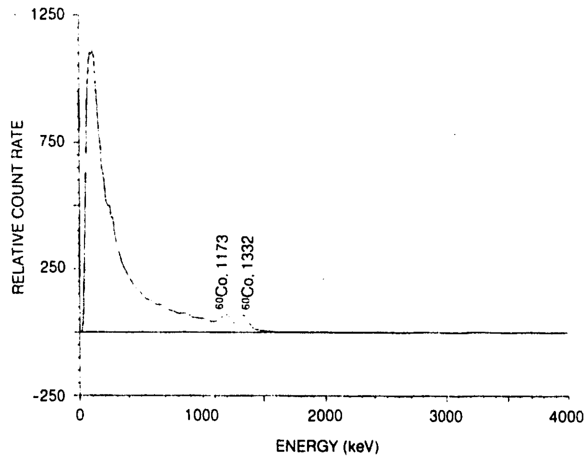


FIGURE 26. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 9***

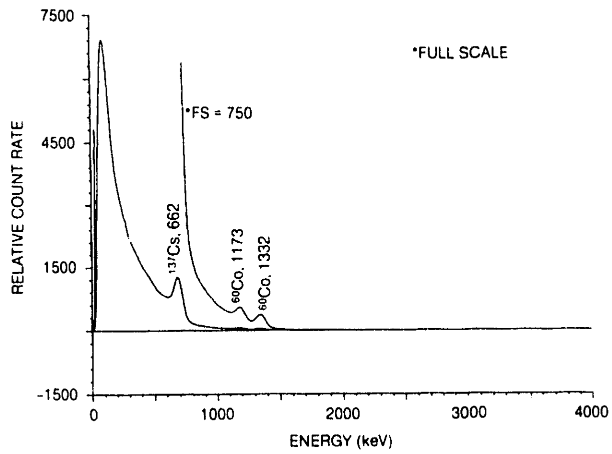


FIGURE 27. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 10***

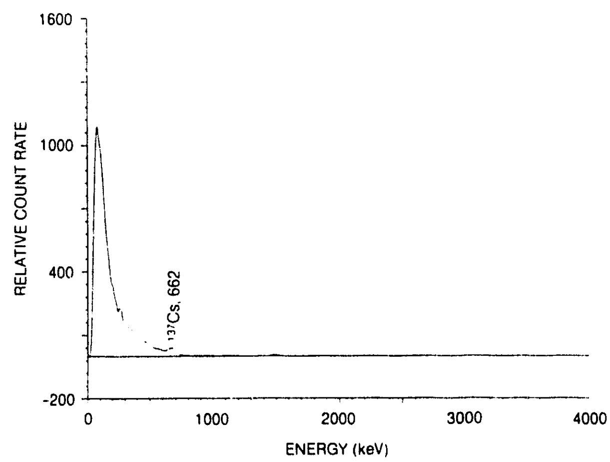


FIGURE 28. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 11***

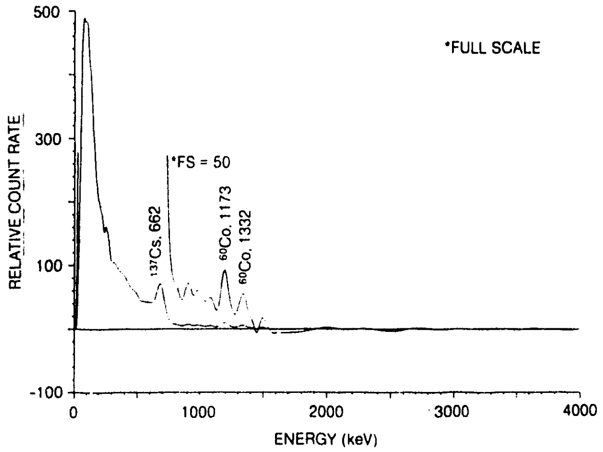


FIGURE 29. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 12***

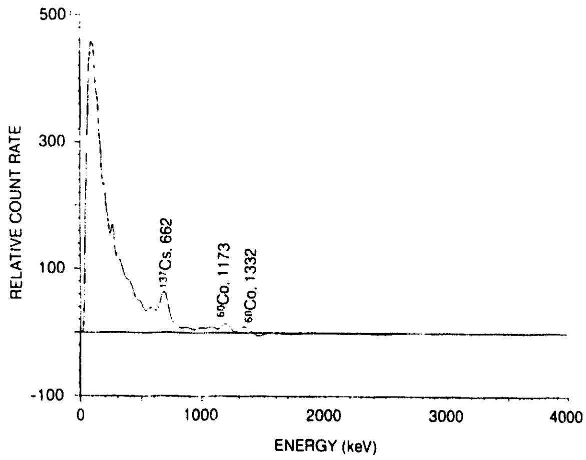


FIGURE 32. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 15***

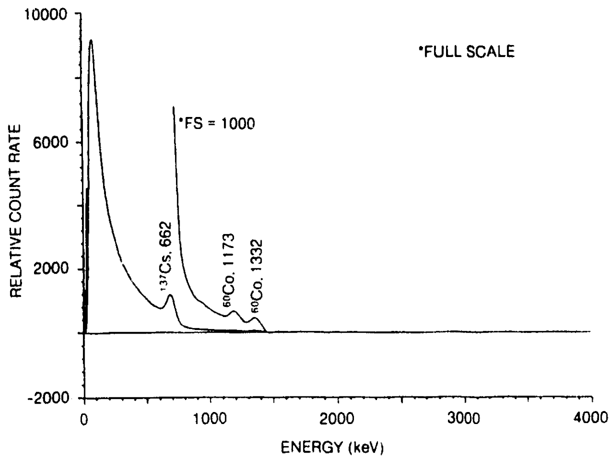


FIGURE 30. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 13***

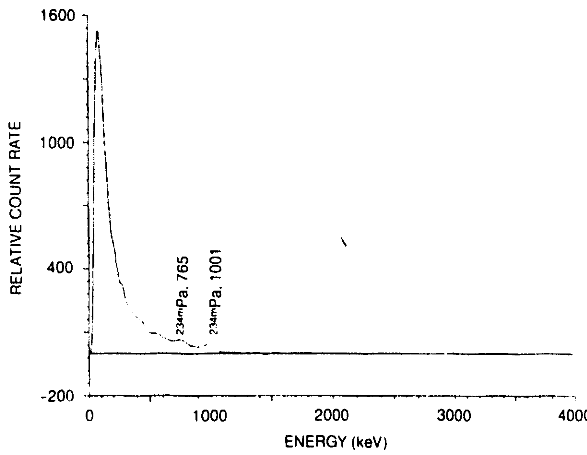


FIGURE 33. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 16***

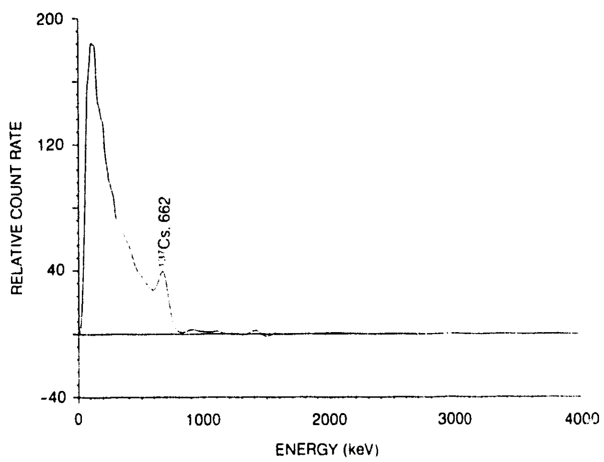


FIGURE 31. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 14***

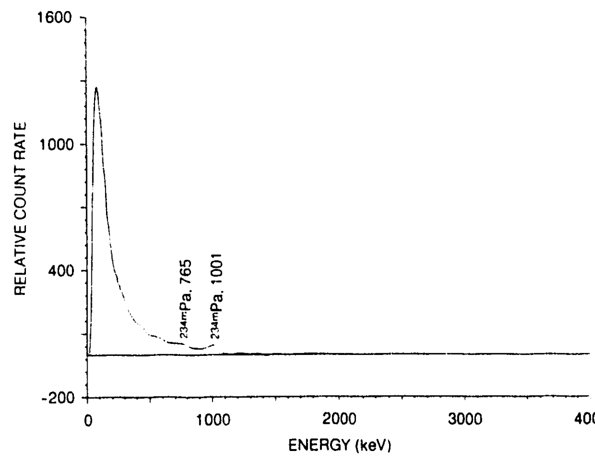


FIGURE 34. ***NET GAMMA SPECTRUM FOR REGION OF INTEREST 17***

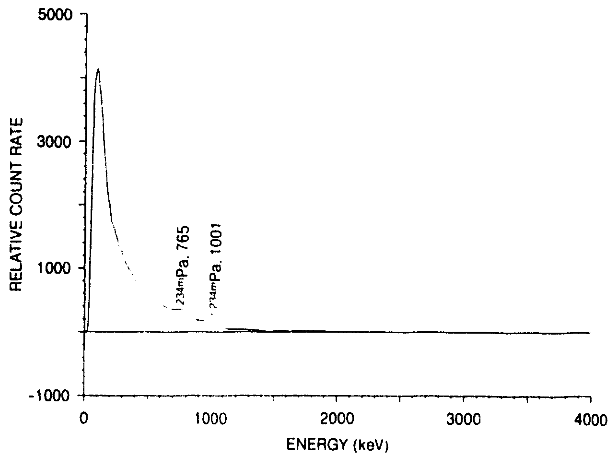


FIGURE 35. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 18*

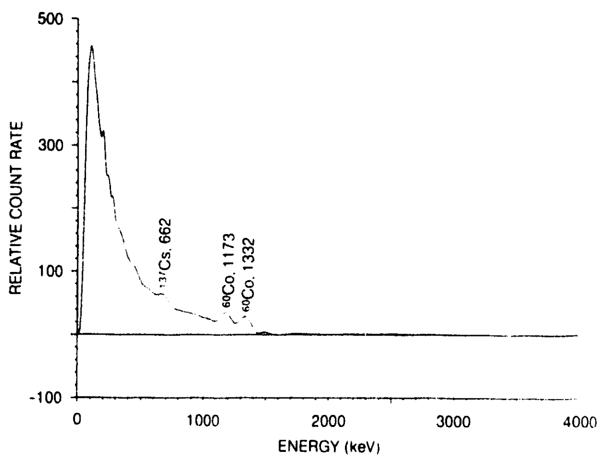


FIGURE 36. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 19*

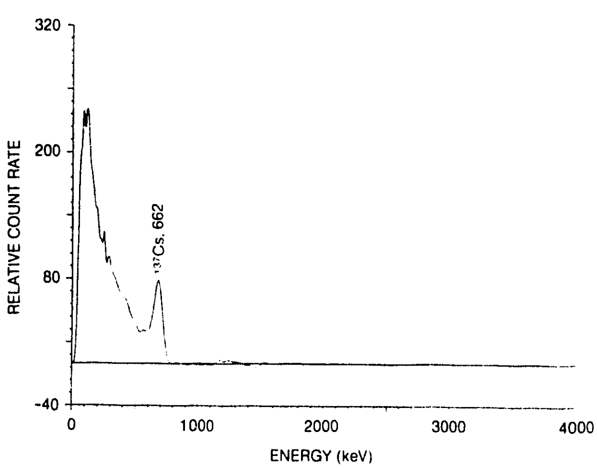


FIGURE 37. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 20*

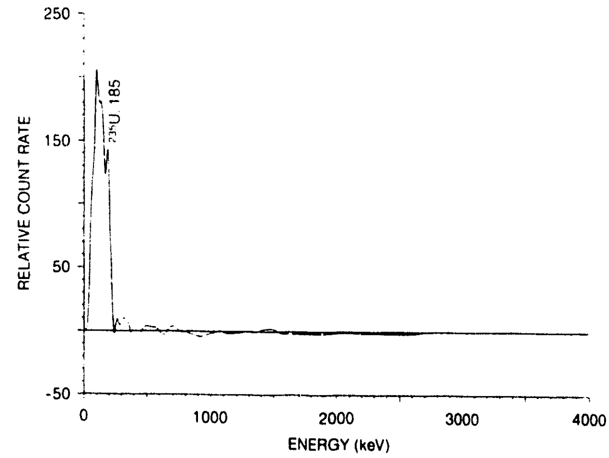


FIGURE 38. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 21*

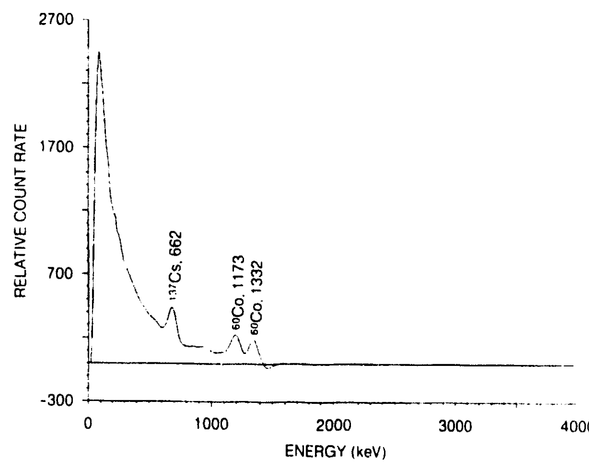


FIGURE 39. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 22*

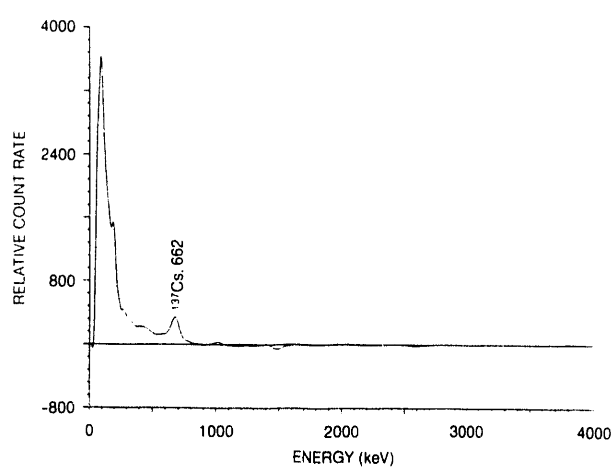


FIGURE 40. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 23*

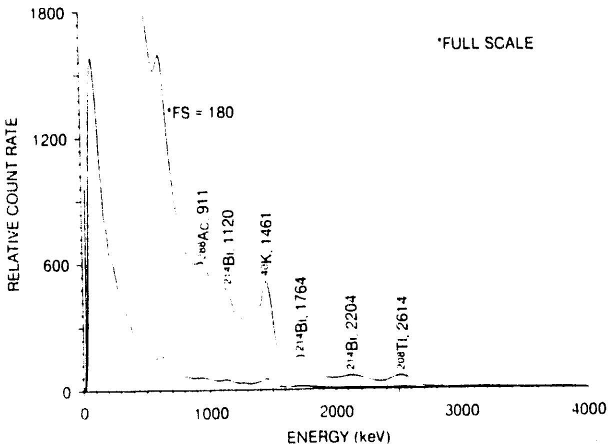


FIGURE 41. *GAMMA SPECTRUM FOR REGION OF INTEREST 24*

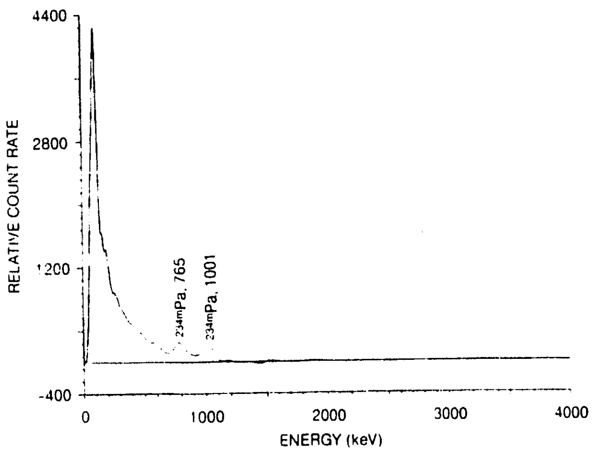


FIGURE 42. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 25*

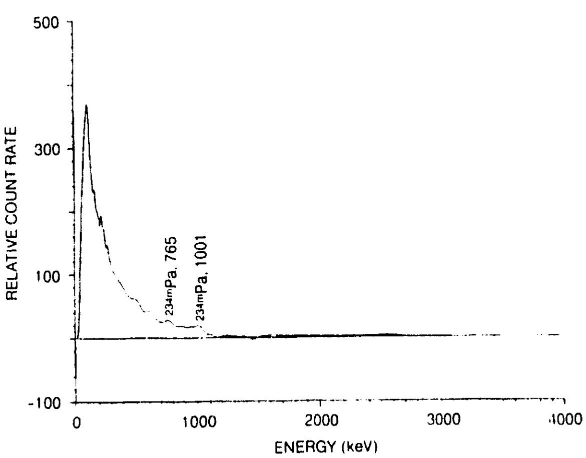


FIGURE 43. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 26*

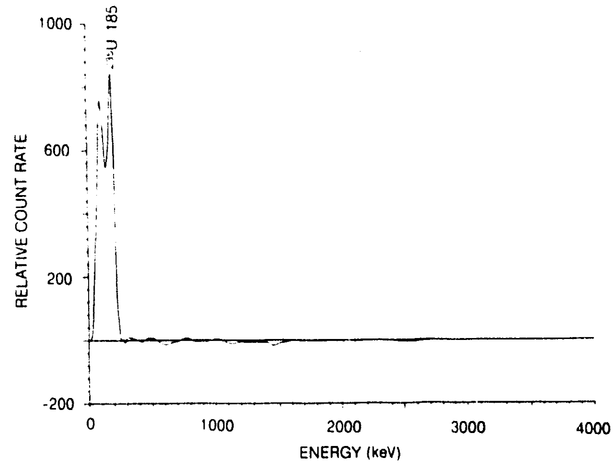


FIGURE 44. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 27*

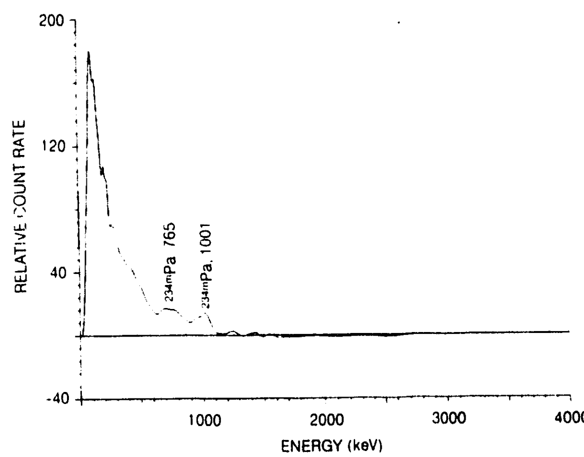


FIGURE 45. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 28*

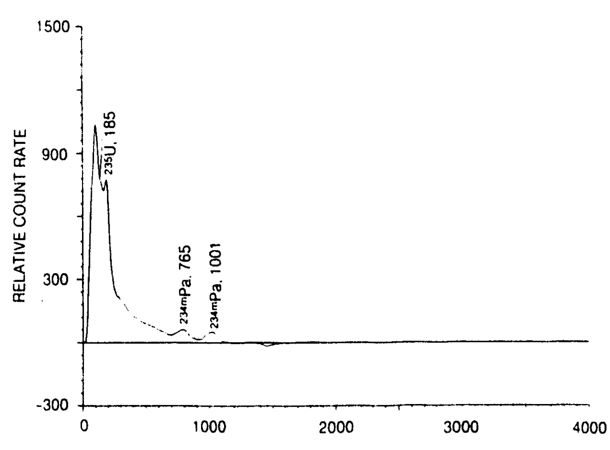


FIGURE 46. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 29*

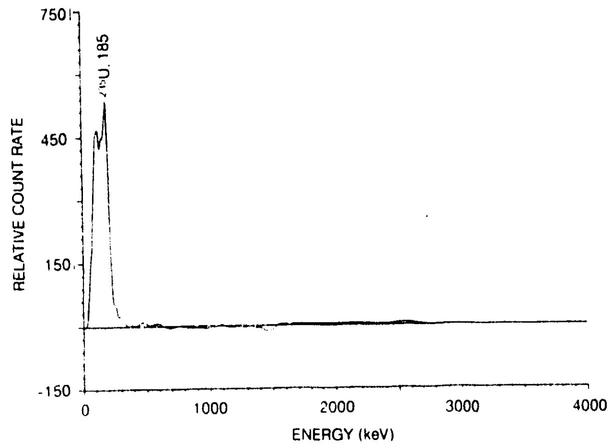


FIGURE 47. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 30*

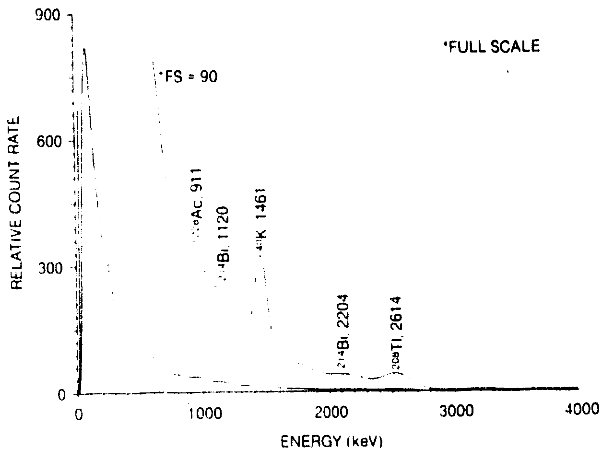


FIGURE 50. *GAMMA SPECTRUM FOR REGION OF INTEREST 33*

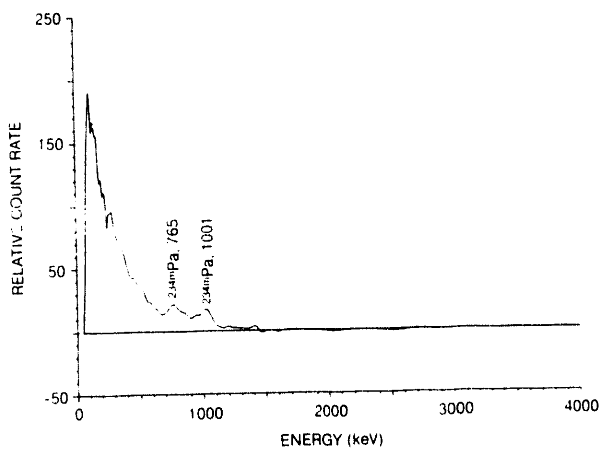


FIGURE 48. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 31*

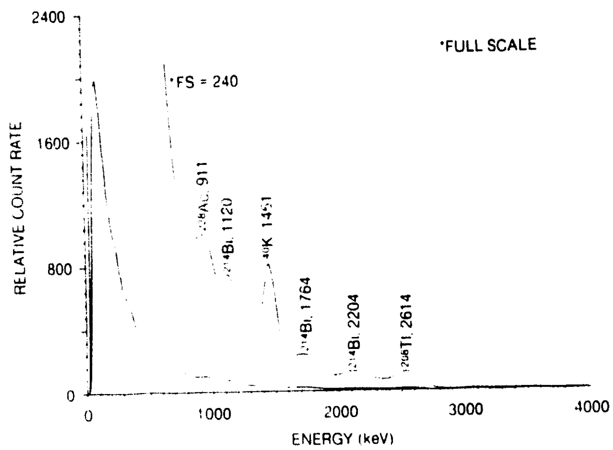


FIGURE 51. *GAMMA SPECTRUM FOR REGION OF INTEREST 34*

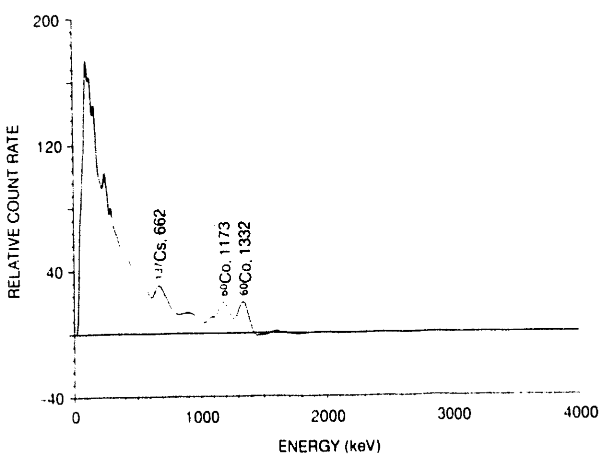


FIGURE 49. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 32*

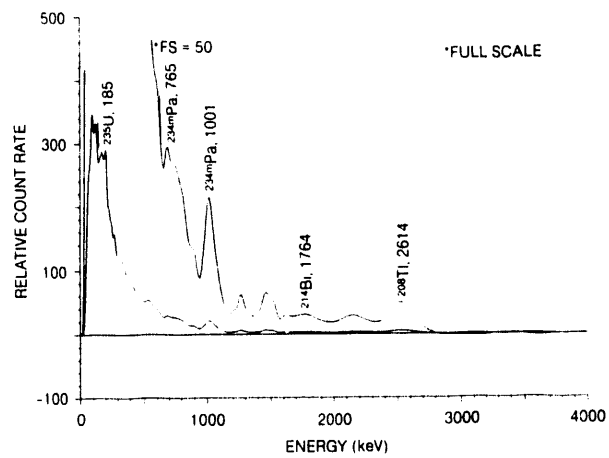


FIGURE 52. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 35*

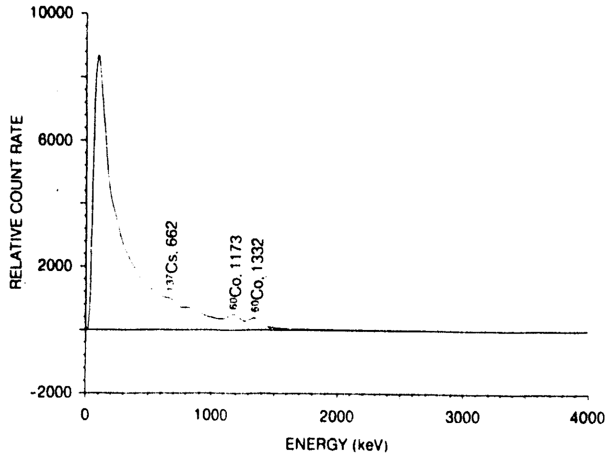


FIGURE 53. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 36*

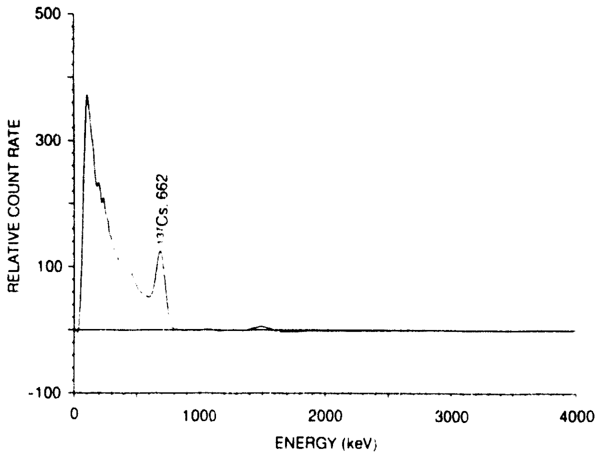


FIGURE 54. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 37*

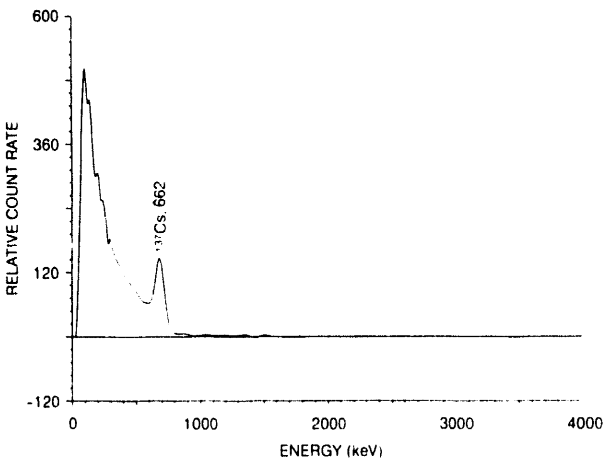


FIGURE 55. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 38*

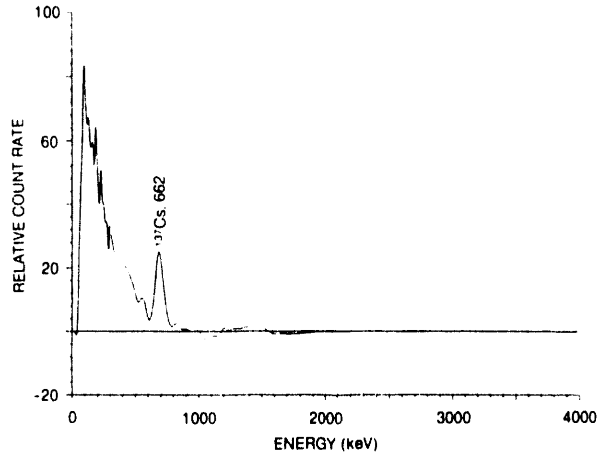


FIGURE 56. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 39*

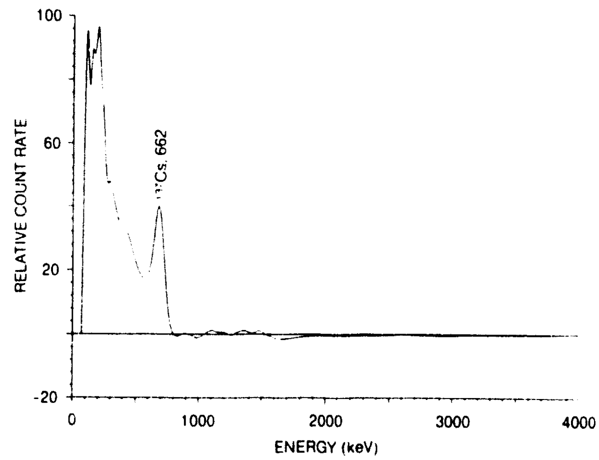


FIGURE 57. *NET GAMMA SPECTRUM FOR REGION OF INTEREST 40*

(pCi/g). The radium-226 (^{226}Ra) radionuclide exists in nature in equilibrium with ^{238}U, and therefore, provides a direct measurement of the natural ^{238}U concentration in the soil sample. The ^{137}Cs concentrations measured in the Oak Ridge area were found to be typical of those measured in the eastern United States.[6]

7.0 DISCUSSION OF RESULTS

In the following section, a discussion of the results of the aerial radiological survey will be presented. The results will be compared to data obtained in previous surveys conducted in 1987 and 1989. The 1987 aerial survey of the White Oak Creek Floodplain (X-10 site) was conducted at the same altitude as the present survey, *i.e.*, 150 feet (46 meters). The 1989 survey encompassed the entire Oak Ridge reservation and was conducted at an altitude of 300 feet (91 meters). By reducing the survey altitude to 150 feet (46 meters), a factor of two improvement in spatial resolution for point sources is obtained, which provides a more detailed data set for use in environmental restoration and waste characterization projects.

The X-10 site is the location of the Oak Ridge National Laboratory and the White Oak Creek Floodplain. The X-10 site was found to contain several areas which exhibit anomalous radiation levels as shown in the MMGC contour map in Figure 5. The gamma spectra for the anomalous radiation areas, labelled ROIs 1-15 in Figure 5, are presented in Figures 18-32. The spectra exhibit the characteristic photopeaks for ^{137}Cs (662 keV) and ^{60}Co (1,173 and 1,332 keV). A comparison of the ^{137}Cs contour maps from 1987 and 1989 and the present survey show only subtle changes. The ^{60}Co contour map shows activity primarily in the lower portion of the White Oak Creek Floodplain and at ORNL, as opposed to the 1989 data, which shows ^{60}Co activity extending from ORNL to the White Oak Creek Floodplain. In early 1992, the ^{60}Co was removed from the graphite reactor storage canal and stored underground. However, low-level ^{60}Co activity is still detected at the ORNL facilities, as indicated in Figure 7.

The K-25 site was found to contain eight anomalous radiation areas denoted as ROIs 16-21 in Figure 9, and ROIs 34 and 35 in Figure 8. The ROIs 16-18 were identified in the 1989 survey as storage yards for cylinders of uranium hexafluoride. The gamma spectra for ROIs 16-18 are shown in Figures 33-35, respectively, and exhibit the characteristic photopeaks at 765 and 1,001 keV for ^{234m}Pa, a decay product of ^{238}U. In 1989, the anomalous radiation levels detected at ROI 19 were attributed to ORNL heat exchangers stored at the K-25 contaminated metal scrap yard. The gamma spectrum from ROI 19 (Figure 36) shows the characteristic photopeaks for ^{60}Co and a trace of ^{137}Cs. Two anomalous radiation areas,

Table 1. Exposure Rates from Aerial and Ground-Based Measurements

Site Number	One Meter Gamma Exposure Rates (μR/h)		
	Aerial Survey	Soil Analysis[1]	Ion Chamber[2]
1 (K-25)	8.2 ± 1.2	9 ± 2	9.2 ± 0.5
2 (K-25)	10.3 ± 1.5	not available	9.2 ± 0.5
3 (Y-12)	9.0 ± 1.4	13 ± 1	12.4 ± 0.6
4 (Y-12)	8.0 ± 1.2	9 ± 1	9.2 ± 0.5
5 (X-10)	7.1 ± 1.1	9 ± 2	9.0 ± 0.5
6 (FBA/ORISE)	9.9 ± 1.5	10.9 ± 0.9	11.7 ± 0.6
7 (FBA/ORISE)	8.9 ± 1.3	11 ± 1	10.4 ± 0.5

[1] Calculation includes cosmic ray contribution of 3.8 μR/h and a moisture correction of the form 1/(1+m)
[2] Reuter-Stokes PIC Model #RSS-111, Serial #R-3588.

Table 2. Radionuclide Assay of Soil Samples (pCi/g)					
Site No.	% Moisture	^{226}Ra	^{232}Th	^{137}Cs	^{40}K
1 (K-25)	22 ± 4	1.0 ± 0.2	1.1 ± 0.2	0.3 ± 0.3	11 ± 7
2 (K-25)	10 ± 5	0.3 ± 0.9	0.1 ± 1.1	0.3 ± 0.1	3 ± 22
3 (Y-12)	20 ± 2	0.9 ± 0.1	1.7 ± 0.2	trace	29 ± 4
4 (Y-12)	15 ± 2	1.3 ± 0.1	1.1 ± 0.3	0.1 ± 0.08	4 ± 1
5 (X-10)	19 ± 2	0.8 ± 0.1	0.8 ± 0.2	0.5 ± 0.3	8 ± 6
6 (FBA)	20 ± 2	1.1 ± 0.2	1.3 ± 0.1	0.3 ± 0.1	14 ± 2
7 (FBA)	23 ± 4	0.9 ± 0.1	1.4 ± 0.1	0.2 ± 0.2	18 ± 3

ROIs 34 and 35, are also denoted on the terrestrial gamma exposure rate contour map in Figure 8. The ROI 34 has been identified as a fly ash pile left over from the operation of the old steam power plant. The gamma spectrum for ROI 34 (Figure 51) shows evidence for only naturally-occurring radionuclides. The elevated activity levels may be attributed to high residual natural radioactivity. The gamma spectrum from ROI 35 (Figure 52) shows distinct photopeaks for ^{234m}Pa and ^{235}U (185 keV). The spectrum also shows evidence for bismuth-214 (^{214}Bi) and thallium-208 (^{208}Tl) photopeaks which are decay products of ^{232}Th and ^{238}U. The gamma activity detected at ROI 35 has been attributed to a uranium cylinder storage area.

Two additional radiation areas were detected at the K-25 site which were not detected in previous surveys. These areas are denoted as ROIs 20 and 21 in Figure 9. The ROI 20 is located near Campbell Bend along the Clinch River. The gamma spectrum from ROI 20 (Figure 37) shows a distinct photopeak for ^{137}Cs. The gamma spectrum from ROI 21 (Figure 38) shows the characteristic photopeak at 185 keV for ^{235}U. The ROI 21 has been identified as the location of Building K-1420, which is the Oil Decontamination and Recovery Facility used in the past for the treatment and decontamination of lubricating oil from the uranium enrichment process.

The FBA/ORISE site was found to contain only one anomalous radiation area, as indicated by ROI 22 in Figure 11. Identified in 1989, ROI 22 is a sludge application area for the city of Oak Ridge. The gamma spectrum for ROI 22 is presented in Figure 39 and shows evidence for both ^{137}Cs and ^{60}Co activity.

The 100-year floodplain of the East Fork Poplar Creek from Y-12 to K-25 was also surveyed in the present study. The East Fork Poplar Creek follows a course northwest from the Y-12 plant along Illinois Avenue through the city of Oak Ridge, then southwest along the Oak Ridge Turnpike to the K-25 plant. The MMGC contour map in Figure 13 shows no evidence of man-made radioactivity within the 100-year floodplain of the East Fork Poplar Creek.

The MMGC contour map, however, does show evidence for two anomalous radiation areas, denoted ROIs 23 and 24. The ROI 23 is attributed to the White Wing Scrap Yard, a former aboveground storage area for radioactive materials which has been cleaned up except for unknown amounts of rubble, metal, plastic, and other materials which were buried. The gamma spectrum for ROI 23 (Figure 40) shows evidence of ^{137}Cs. The gamma spectrum for ROI 24 (Figure 41) exhibits no evidence of man-made radioactivity and is similar to the background spectrum in Figure 17. The source of the elevated activity has been attributed to an outcropping of Chattanooga shale.

The Y-12 site was the location of seven anomalous radiation areas denoted as ROIs 25-31 in Figure 13. The ROI 25, identified in 1989, is a shallow burial ground for uranium metal chips and turnings located on Bear Creek Road due west of the Y-12 plant. The gamma spectrum for ROI 25 (Figure 42) shows photopeaks for ^{234m}Pa, indicating the presence of ^{238}U. The ROIs 26-31 are collocated inside the Y-12 plant fenced boundary. The gamma spectra for ROIs

26, 28, and 31 (Figures 43, 45 and 48, respectively) show evidence for ^{234m}Pa. The ROI 31 was the only anomalous radiation site at the Y-12 plant that was not detected in the 1989 survey. The gamma spectra for ROIs 27 and 30 (Figure 44 and 47, respectively) show the characteristic photopeak at 185 keV for ^{235}U. The gamma spectrum for ROI 29 (Figure 46) shows evidence for both ^{234m}Pa and ^{235}U.

The Elza Gate site, located in the Melton Lake Industrial Park in the city of Oak Ridge, was previously a storage area for pitchblende (uranium ore). In 1972, the Elza Gate storage area was decontaminated. The MMGC contour map in Figure 15 shows no evidence for uranium activity at the Elza Gate site. In the course of the Elza Gate survey, one anomalous radiation area on the east side of the Clinch River, denoted ROI 32 in Figure 15, was detected. The man-made radioactivity is attributed to ^{137}Cs and ^{60}Co contamination resulting from a former commercial encapsulation facility operated in the 1970s. The gamma spectrum for ROI 32 (Figure 49) shows the characteristic photopeaks for ^{137}Cs and ^{60}Co.

The Parcel A site is located on the easternmost section of the Oak Ridge Reservation. The MMGC contour map for the Parcel A site, presented in Figure 15, shows no evidence for man-made radioactivity. The gross count rate contour map in Figure 14 shows a slightly elevated activity level at ROI 33, which is a coal ash disposal area used by the TVA Bull Run Steam Plant. The gamma spectrum for ROI 33 (Figure 50) shows no evidence for man-made radioactivity. The elevated activity level may be attributed to a high residual ^{40}K concentration in the coal ash.

The Clinch River was radiologically surveyed from the Melton Hill Dam to the city of Kingston, a distance of approximately 20 miles (32 kilometers). With the water level at its yearly low, the intent was to survey the exposed river banks for man-made radioactivity. The survey consisted of a single pass over the river banks of the Clinch River and its major tributaries. The MMGC map presented in Figure 16 shows the locations of eight anomalous radiation areas. The ROIs 1 and 2 (Figures 18 and 19, respectively) are located in the White Oak Creek Floodplain and were previously identified as containing ^{137}Cs and ^{60}Co in the X-10 survey. The ROI 20 was also previously identified in the K-25 survey and found to contain ^{137}Cs (Figure 37).

Five additional anomalous radiation areas were detected along the Clinch River. The ROI 36, detected in 1989, was attributed to a commercial, low-level waste processing, compaction, and incineration facility located near the Grassy Creek Tributary on Bear Creek Road. The gamma spectrum (Figure 53) shows the characteristic photopeaks for ^{137}Cs and ^{60}Co. The ROI 37 is located at the intersection of the Grassy Creek Tributary and the Clinch River and shows evidence of ^{137}Cs (Figure 54). Further north on the Clinch River, three additional anomalous radiation areas, denoted as ROIs 38-40 were identified. The gamma spectra for ROIs 38-40 (Figures 55-57) each show a distinct photopeak of ^{137}Cs.

The CSX Railroad Tracks from the Y-12 plant to the city of Oak Ridge were previously surveyed in 1989 using a helicopter AMS system. The survey consisted of several passes over the railroad tracks at 125 feet (38 meters) AGL. The three anomalous radiation areas which were detected in 1989 were also detected in the present survey. The anomalous radiation areas are denoted A-C in Figure 1. Site A is attributed to the Quadrex Recycle Center, a commercial decontamination facility located on Flint Road in the city of Oak Ridge. The radiation source at the Quadrex plant is ^{60}Co. Sites B and C are located near Warehouse Road in the city of Oak Ridge. The radiation source has been attributed to ^{137}Cs which is embedded in the railroad bed.

8.0 SUMMARY

A radiological survey of the Oak Ridge Reservation and surrounding area was conducted during the period March 30 to April 14, 1992. The survey was conducted at an altitude of 150 feet (46 meters) above ground level over several sites which encompassed an area of approximately 55 square miles (141 square kilometers). The survey sites included X-10 (Oak Ridge National Laboratory), K-25 (former Gaseous Diffusion Plant), Y-12 (Weapons Production Plant), the Freels Bend Area and Oak Ridge Institute for Science and Education, the East Fork Poplar Creek (100-year floodplain extending from K-25 to Y-12), Elza Gate (former uranium ore storage site located in the city of Oak Ridge), Parcel A, the Clinch River (river banks extending from Melton Hill Dam to the city of Kingston), and the CSX Railroad Tracks (extending from Y-12 to the city of Oak Ridge). The terrestrial exposure rates at 1 meter were found to vary from 8 to 13 μR/h. The man-made radionuclides, ^{137}Cs and ^{60}Co, and the man-concentrated radionuclides, ^{235}U and ^{238}U, were detected at several sites on the Oak Ridge Reservation.

APPENDIX A

SURVEY PARAMETERS

Survey Site:	Oak Ridge Reservation Oak Ridge, Tennessee
Survey Coverage:	55 mi^2 (141 km^2)
Survey Date:	March 30 to April 14, 1992
Survey Altitude:	150 ft (46 m)
Aircraft Speed:	70 knots (36 m/s)
Line Spacing:	250 ft (76 m)
Line Direction:	East-West
Detector Array:	Eight 2-in $\times$ 4-in $\times$ 16-in NaI(Tℓ) detectors
Acquisition System:	REDAR IV
Conversion Factor:	917 cps/(μR/h) at 150 ft (46 m)
Air Attenuation Coefficient:	0.0020 ft^{-1}
Aircraft:	MBB BO-105 Helicopter
Survey Crew:	R. Maurer, L. Ruff, E. Smith, J. Holzclaw, J. Walker, T. Stampahar, L. Komich, C. Ward, R. Rea, R. Fratrick

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