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EG&G
ENERGY MEASUREMENTS GROUP

EG&G Survey Report
NRC-8109
April 1981

AN AERIAL RADIOLOGIC SURVEY OF THE

STEPAN CHEMCIAL COMPANY

AND SURROUNDING AREA

MAYWOOD, NEW JERSEY

DATE OF SURVEY: 26 JANUARY 1981

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ABSTRACT

An aerial radiologic survey to measure terrestrial gamma radiation was performed in Maywood, New Jersey over the Stepan Chemical Company and the surrounding area. This survey was conducted by EG&G for the Nuclear Regulatory Commission (NRC) 26 January 1981.

Gamma-photon data were collected over a four square mile area. Processed data indicated that detected radioisotopes and their associated gamma-photon exposure rates were consistent with those expected from normal background emitters, except directly over and immediately to the west and south of the Stepan Chemical Company. In addition, two other points demonstrated anomalous gamma-photon activity: one north of the plant and another to the southeast, both approximately one-half mile from the center of the plant.

The results are expressed as exposure rate isoradiation contours extrapolated to μR/h at 1 meter above the ground. The background radiation, including cosmic ray contributions, generally ranged from 6 to 7.5 μR/h. Isoradiation contours are also shown for excess radiation from the thorium chain, pinpointing the anomalous areas.

CONTENTS

1.0 SUMMARY

An aerial radiologic survey of the Stepan Chemical Company and the surrounding area in Maywood, New Jersey, was conducted on 26 January 1981 by the Washington Aerial Measurements Department of EG&G, Inc.

Gamma radiation was detected by 20 sodium iodide (thallium activated) crystals, arranged in 2 pods of 10 crystals each mounted on either side of a Messerschmitt-Bolkow-Blohm MBB-105S helicopter. The survey altitude was 61 meters; parallel flight lines were spaced 76 meters apart. The survey covered an area of 4 square statute miles centered on the Stepan Chemical Company.

Gamma-photon data, altitude and all supporting information were recorded each second along the flight lines. An isoradiation contour map, including all sources of gamma radiation, was prepared to show variations in total gamma-photon activity over the site. A second isoradiation map was constructed which shows concentrations of thalium-208, indicating the presence of excess thorium-232.

Areas of higher than normal gamma-photon activity were observed directly over and to the west and south of the plant. Two other areas that showed an increase in thorium concentrations are located (1) near the intersection of Coles Brook and the railroad track, approximately 0.1 mile north of Essex Street; and (2) west of Passaic Street on Latham. Ground surveys at these locations are required to determine the source of these anomalies. Other areas showing radiation levels above the average background, including the Riverside Cemetery, are likely to be variations in the natural radiation levels.

Indicated activity (due to excess thorium-232) directly over the plant was in the range of 40-70 microroentgens per hour (μR/h), compared to 6 to 7.5μR/h typical of background exposure rates for the area.

2.0 INTRODUCTION

The United States Department of Energy (DOE) maintains an aerial surveillance operation called the Aerial Measuring System (AMS). AMS is operated for DOE by EG&G. This continuing nationwide program, started in 1958, involves surveys to monitor radiation in and around facilities producing, utilizing, or storing radioactive materials. The purpose of these surveys is to document, at a given point in time, the location of all areas containing gamma-photon emitting radionuclides (visible at the surface) and to aid DOE pesonnel in evaluating the magnitude and spatial extent of any radioactive contaminants released into the environment. At the request of DOE (or other federal and state agencies), AMS is deployed for various aerial survey operations.

This report is the result of a survey requested by Region 1 of the Nuclear Regulatory Commission. The measurements reported here were made from a base of operations at the Teterboro Airport three miles south of the survey area on 26 January 1981.

Aerial radiation detection systems average the radiation levels due to gamma-photon emitting radionuclides existing over an area of several acres. The systems are capable of detecting anomalous gamma-photon count rates and determining the specific radionuclides causing the anomalies; however, because of area averaging, they tend to underestimate the magnitude of localized sources as compared with ground-based readings.

The results of the survey are reported, where possible, as radiation exposure rates in μR/h at 1 meter above the ground surface. Approximate annual radiation dose levels, expressed as millirem per year (mrem/y), are obtained by multiplying μR/h by 8.76. This conversion number applies only to the external radiation dose component.

3.0 NATURAL BACKGROUND RADIATION

Natural background radiation originates from radioactive elements present in the materials of the earth and cosmic rays entering from space. The terrestrial gamma-photons originate primarily from the uranium and thorium decay chains and radioactive potassium. Local concentrations of these nuclides produce radiation levels at the surface of the earth ranging from 1 to 15 μR/h (or 9 to 130 mrem/y). Some areas with high uranium and thorium concentrations in surface minerals exhibit even higher radiation levels, especially in the western states. (For example, in the Colorado Plateau the average radiation level is above 200 mrem/y).

accumulated and recorded the data are described in detail in previous reports.[3,4]

Data processing was done primarily with a computer based analysis laboratory system in the Remote Sensing Laboratory, located at Andrews Air Force Base, Suitland, Maryland. Frequently, such analyses are carried out with a computer mounted in a mobile van (Figure 2). An extensive collection of software routines was available for data processing. The first data reduction that was accomplished produced gross count isoradiation contours. These contours were constructed from gross count rate numbers, which refer to integral count rates in that portion of the gamma-photon energy spectrum between 0.05 and 3.0 MeV (Figure 3).

A smaller portion of the spectrum was used to separate the fraction of the total activity due to a specific nuclide and to quantify its concentration in the ground. This operation was accomplished by computer processing the data with an algorithm that examined and combined certain regions of the spectrum. A more detailed discussion of the data processing methods typical of most aerial surveys is given in the Appendix.

6.0 RESULTS AND CONCLUSIONS

Shown in Figure 3 are exposure rate isoradiation contours (derived from gross count rates) overlaid on a USGS map. The average natural background in the area is approximately 6 to 7.5μR/h, which includes a cosmic radiation component of 3.7 μR/h. The accuracy of exposure rates computed for areas of elevated thallium-208 activity may have been compromised by difficulties encountered in determination of proper conversion factors (see Appendix).

Shown in Figure 4 are isoradiation levels for excess radiation from the thorium-232 chain inferred from measurement of the thallium-208 photopeak. This refers to quantities of radioactive thallium-208 (2.62 MeV photopeak) over and above that observed in the average natural background of the area. The majority of gamma radiation from the thorium-232 chain is emitted by thallium-208. The technique for determining the exposure rate at 1 meter above ground level is discussed in the Appendix.

Both isoradiation maps show increased levels of activity centered on the Stepan plant, as well as to the west and south. Two detached areas (to the north and southeast of the plant) also show slight increases of thorium concentrations. It is not known whether these increased concentrations are a result of plant activities or natural radiation anomalies. Ground surveys are necessary for this determination. The gross count contour map (Figure 3) shows two additional areas of increased activity not shown in Figure 4. Spectral analysis indicated only an increase in the activity of the natural radioisotopic mix in these areas. Such variations in the natural radiation levels are not unusual. It should also be noted that the levels given in Figures 3 and 4 are normalized to 1 meter above the ground, but only as averages over a large area. Dependent on the nuclides detected and their activity and spatial extent, ground level exposure rates inferred from aerial measurements can differ by large factors from the actual value at a specific point on the ground. A portable radiation detector held 1 meter above the ground will measure activity directly below the detector and in a relatively small circle around it. At 61 meters the helicopter detector system effectively averages the activity from a much larger area. The small source limitation is discussed in the Appendix under the heading, Spatial Resolution Function.

Exposure rate isopleths in Figures 3 and 4 may not agree (after correcting for average natural background exposure rate) for the following reasons.

1. Conversion factors are based on sources of infinite lateral extent, whereas some high activity areas may be of small extent.
2. The excess thallium-208 conversion factor is calculated with the assumptions defined in the Appendix.
3. The gross count conversion factor applies only to typical mixes of natural emitters.

Figure 5 presents a gamma-photon energy spectrum taken over the plant site. A background spectrum has been subtracted from the data presented in Figure 5. Photopeaks characteristic of thallium-208 are prominent in this spectrum.

7.0 EARTH SAMPLE ANALYSIS

The accuracy to which the terrestrial radiologic environment can be determined from airborne

Table 2. Earth Sample Exposure Rate Conversion Factors*	
Uranium-238	0.62 μR/h per ppm radionuclide
Thorium-232	0.31 μR/h per ppm radionuclide
Cesium-137	0.13 μR/h per pCi/g radionuclide
Potassium-40	.179 uR/h per pCi/g radionuclide

*Assumes uniform concentrations both vertically and horizontally.

Table 3. Radionuclide Component Microroentgens/hour

Earth Sample	Uranium-238	Thorium-232	Cesium-137	Potassium-40	Cosmic Ray	Total	Aerial Total
B	1.22	4.52	--	1.79	3.7	11.2	17-25
C	1.29	3.97	.02	1.76	3.7	10.7	17-25
D	.94	2.40	--	1.72	3.7	8.8	17-25

Figure 1. *MBB-105S HELICOPTER*

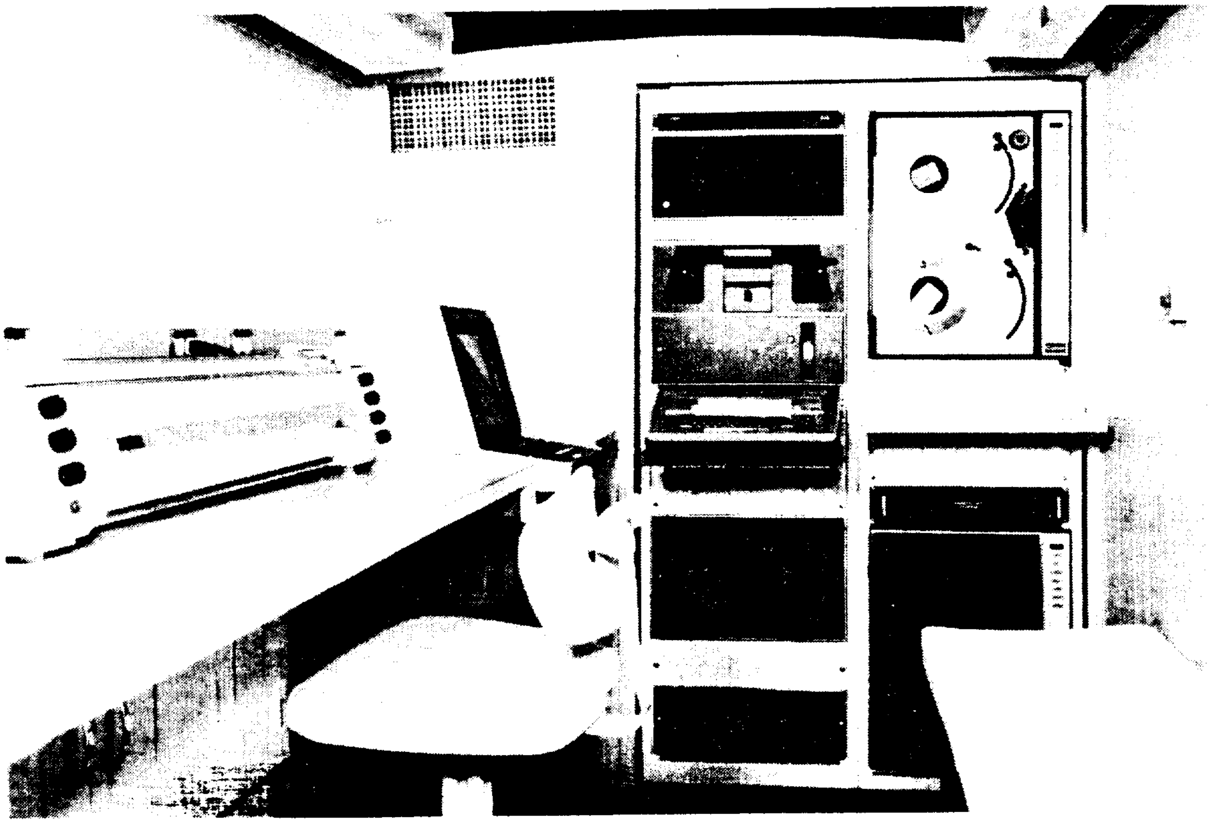
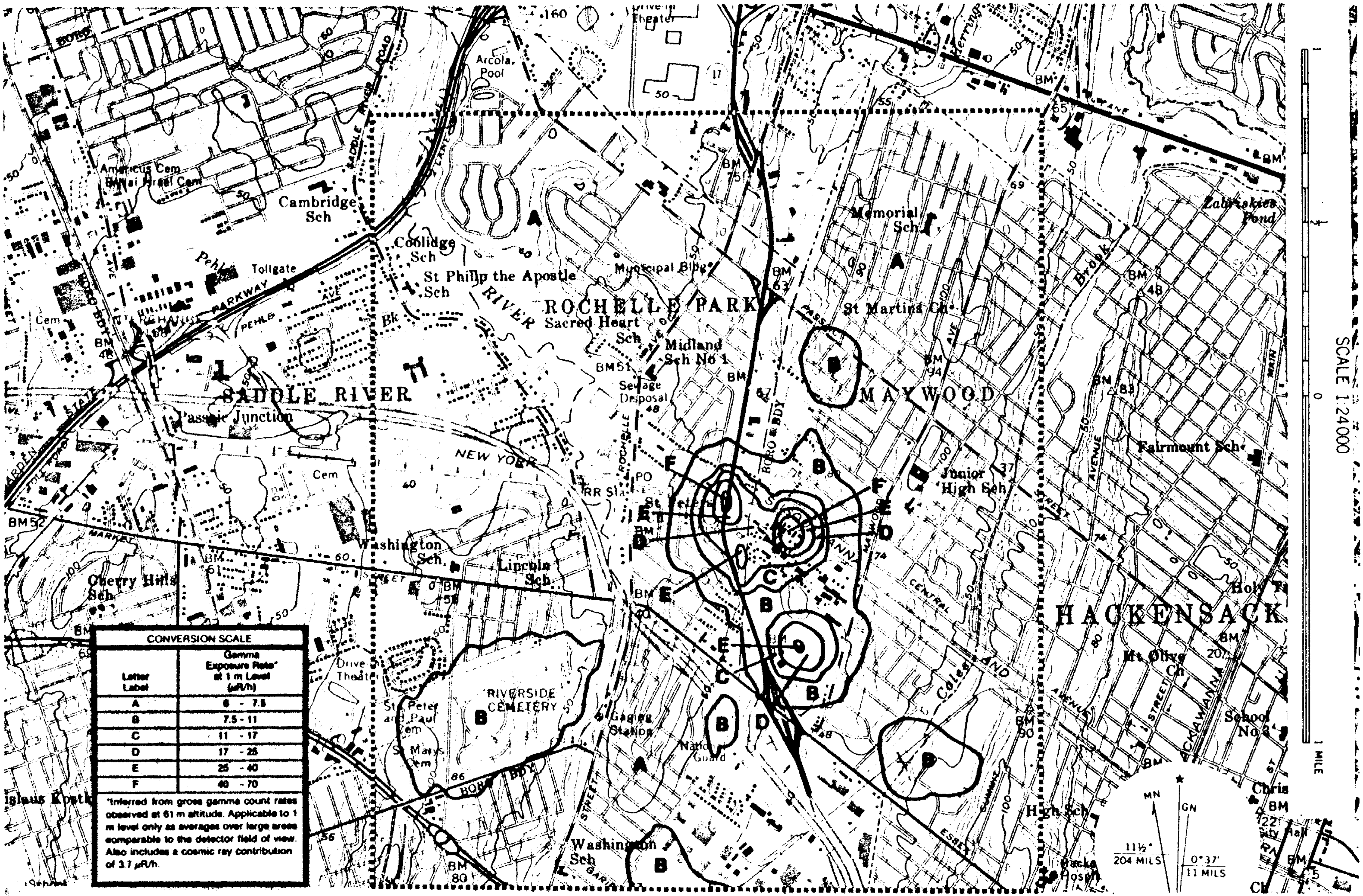


Figure 2. *MOBILE COMPUTER PROCESSING LABORATORY*

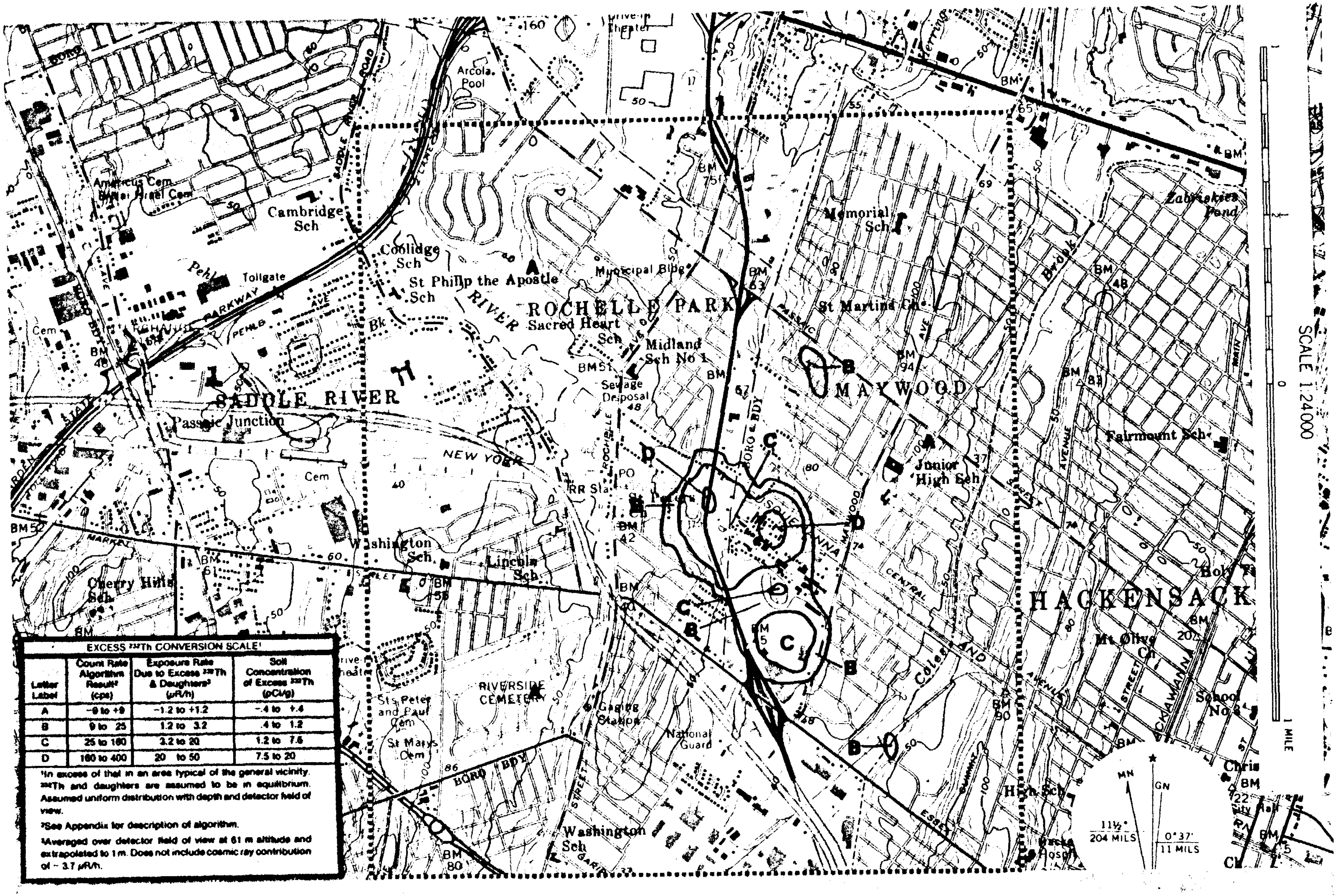


CONVERSION SCALE

Letter Label	Gamma Exposure Rate* at 1 m Level (μR/h)
A	6 - 7.5
B	7.5 - 11
C	11 - 17
D	17 - 25
E	25 - 40
F	40 - 70

*Inferred from gross gamma count rates observed at 61 m altitude. Applicable to 1 m level only as averages over large areas comparable to the detector field of view. Also includes a cosmic ray contribution of 3.7 μR/h.

Figure 3. *EXPOSURE RATE ISORADIATION CONTOURS*



EXCESS ^{232}Th CONVERSION SCALE[1]			
Letter Label	Count Rate Algorithm Result[2] (cps)	Exposure Rate Due to Excess ^{232}Th & Daughters[3] (μR/h)	Soil Concentration of Excess ^{232}Th (pCi/g)
A	−9 to +9	−1.2 to +1.2	−.4 to +.4
B	9 to 25	1.2 to 3.2	.4 to 1.2
C	25 to 160	3.2 to 20	1.2 to 7.5
D	160 to 400	20 to 50	7.5 to 20

[1] In excess of that in an area typical of the general vicinity. ^{232}Th and daughters are assumed to be in equilibrium. Assumed uniform distribution with depth and detector field of view.

[2] See Appendix for description of algorithm.

[3] Averaged over detector field of view at 61 m altitude and extrapolated to 1 m. Does not include cosmic ray contribution of ~ 3.7 μR/h.

Figure 4. *ISORADIATION CONTOURS FOR EXCESS RADIATION FROM THE THORIUM-232 CHAIN, INFERRED FROM MEASUREMENT OF THE THALLIUM-208 PHOTOPEAK (2.62 MeV)*

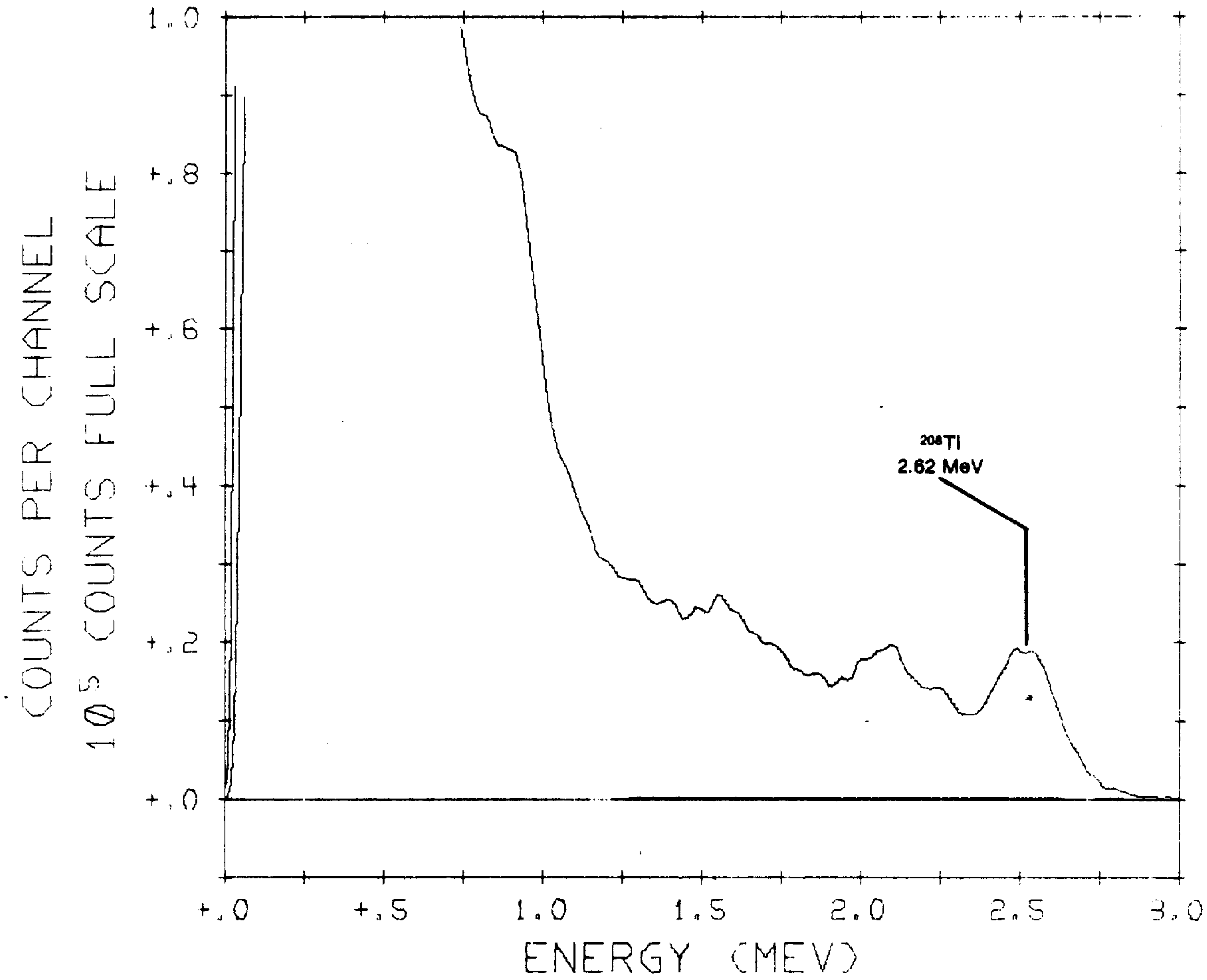


Figure 5. *NET GAMMA-PHOTON SPECTRUM OVER ANOMALOUS AREA*

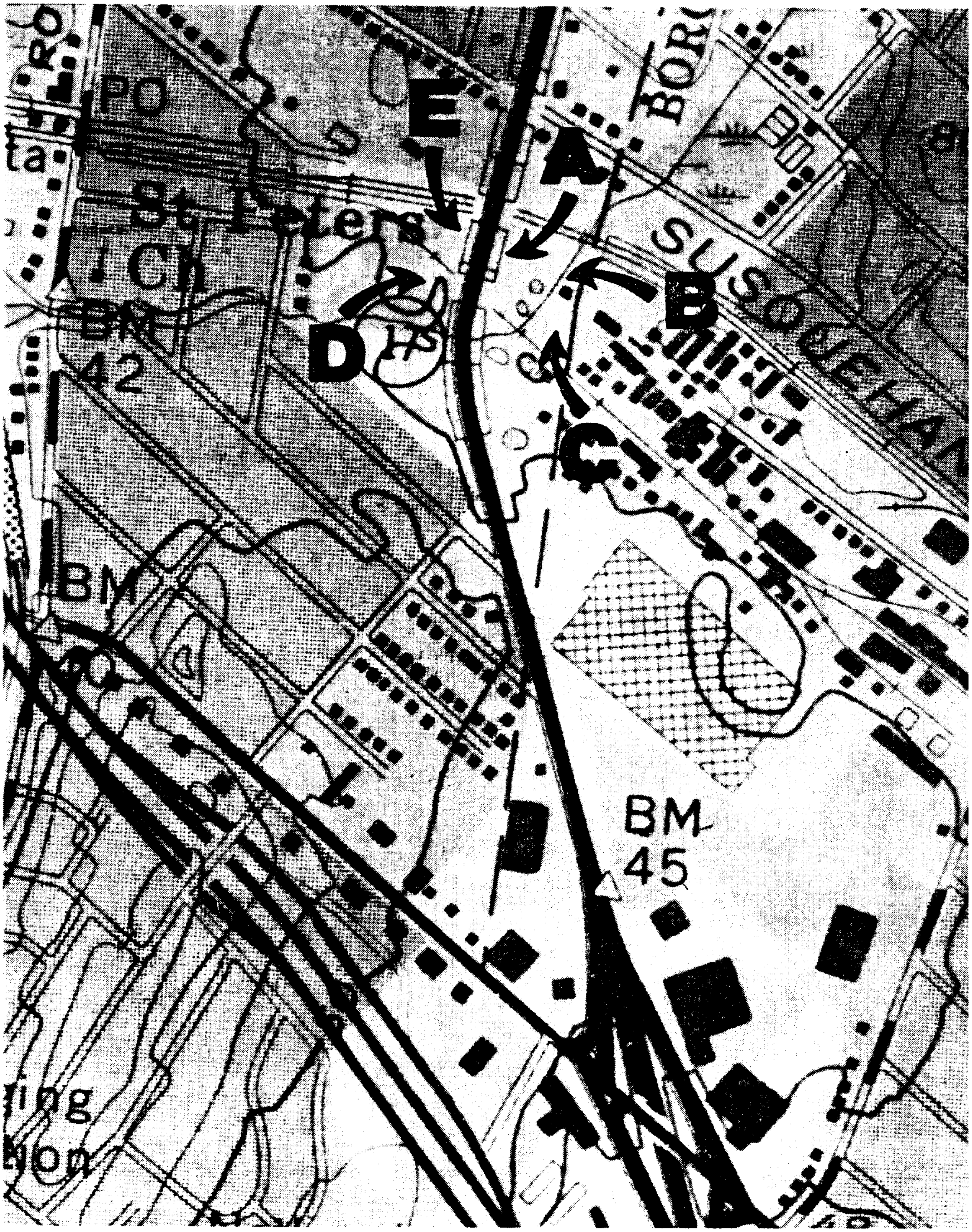


Figure 6. *LOCATIONS OF SOIL SAMPLES TAKEN FOR ANALYSIS*

APPENDIX
CALIBRATION PROCEDURES AND CONVERSION FACTORS

GROSS COUNTS

Gross counts refer to the sum of counts in that portion of the gamma-photon energy spectrum between 0.05 and 3.0 MeV. The detectors are calibrated by flying over a selected area of land near a body of water. The terrestrial component of the gross count rate is obtained from the land data by subtracting the water data, consisting only of those counts due to aircraft background, airborne radon daughter components and cosmic rays. The gross count conversion factor is established by comparing this land-water difference with exposure rates measured on the ground after they are similarly corrected for radon and cosmic ray contributions. The ratio of exposure rate to the land-water difference of the gross count rate is the factor that converts the measured gross count rate of terrestrial origin to the corresponding exposure rate of terrestrial origin. The conversion factor used for this survey was 1120 counts per second at 61 m altitude equals 1 μR/h at 1 m.

The terrain in the calibration area contained a typical mix of naturally occurring radionuclides, consisting of potassium-40 and members of the uranium and thorium chains. A different mix will modify the shape of the spectrum over the energy interval covered by gross counts. Since the gross count conversion factor is dependent on spectral shape, the established conversion factor will not apply precisely to areas where the mix is atypical or where extraneous radionuclides are present.

THORIUM-232 ISOPLETHS

Since spectral extractions revealed anomalous concentrations of thallium-208 and ancestors, the magnetic tape data were processed to isolate effects from this natural chain. For this purpose, an energy window centered on the prominent 2.62 MeV gamma photon from thallium-208 was monitored.

Figure 4 shows the isopleths relating to this window after naturally occurring concentrations have been suppressed by subtracting a constant equal to the window count rate over "natural" areas in the vicinity of the anomalous areas.

These window count rates arise from "excess" thallium-208 photons that reach the detector without interacting in the air or soil. Since uncollided photons of this type behave in a mathematically predictable way, the window count rates can be related to soil concentration through the survey and detector system geometry.[6,7] A uniform distribution with depth has been assumed in order to generate column 4 from column 2 in the conversion scale of Figure 4. In addition, the angular response of the detector has been assumed to be an average between the two extremes of isotropic and cosine. The data of Beck et al.[8] have been used to generate column 3 from column 4 in this conversion scale.

It should be noted that the values given in the conversion scales in Figure 4 are given to two significant figures. These theoretical values are correct within the context of the assumptions; however, this does not imply that the isopleth values are accurate to these significant figures. Due to the uncertainty in determinations of many of the parameters that relate to the air-to-ground conversion factors, the exposure rate values given in Figures 3 and 4 may be uncertain by ±25% for values relating to the natural radiation level, up to about 20 μR/h. For those areas containing elevated radiation levels, the exposure rate values are expected to be within a factor of 2 if the radiation levels at 1 m are averaged over at least several acres.

SPATIAL RESOLUTION FUNCTION

A useful way of viewing the small source limitation is through the concept of spatial resolution function. This function is the relative count rate, measured at survey altitude, versus lateral distance from a point source on the ground. Count rates that are recorded during a survey are the result of mathematically "folding" the true ground distribution with this resolution function. This folding process can be performed easily. The reverse process, the one of interest, is lengthy and inaccurate; it has not, therefore, been attempted.

It is, however, often instructive to compare the resolution function contours with contours measured over certain areas to gain some insight into the lateral extent of the ground activity. If the resolution function isopleths are similar to the measured isopleths, the source is probably highly localized relative to dimensions comparable to the survey altitude.

The point source (or resolution function) contours are generated from a calculated resolution function, which depends on gamma-photon energy, depth distribution of the source in the soil, and the angular response of the detector system. The resolution function for gross counts cannot be calculated due to the lack of energy definition. The resolution function for gamma-photon energy window counts can be calculated, but the result still suffers from uncertainties in depth distribution and angular response of the detectors. In practice, two calulations are performed to bracket the true resolution function for the energy window data.

Figure A-1 shows bracketing contours for the thallium energy window counts. The radius of the D levels were chosen to match the nearly circular D levels in Figure 4. The radii of contours of lower levels surrounding the two D levels are similar to these in Figure A-1. Therefore, these sources are probably localized relative to dimensions of a few hundred feet. The lack of a D level, coupled with the large C level radius in the third active area in Figure 4, suggests that this source has some spatial extent.

The width of the spatial resolution is a measure of how far equal activity point sources must be separated on the ground in order to appear as separate sources in the overflight data. This width is, therefore, a measure of the distances through which point sources can exert their influence. It is obvious that this distance will depend on the point source activity, since the vertical resolution function scale is relative. In practice, the resolution function is reduced to about half its maximum value at lateral distances from the source equal to the survey altitude.

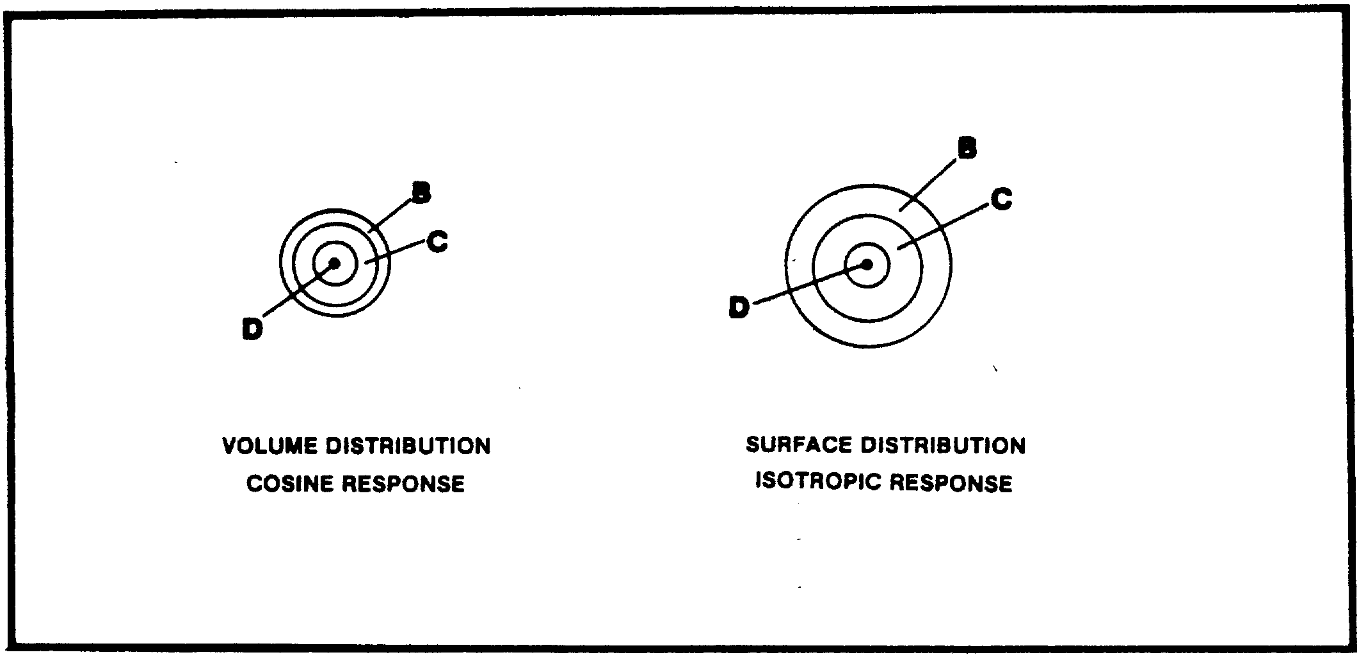


Figure A-1. *POINT SOURCE ISOPLETHS FOR ENERGY WINDOW 2.52 TO 2.72 MeV AT 61 METERS ALTITUDE*

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