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CIVIL EFFECTS EXERCISE

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EXTENDED- AND POINT-SOURCE RADIOMETRIC PROGRAM

F. J. Davis and P. W. Reinhardt, Editors

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CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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EXTENDED- AND POINT-SOURCE RADIOMETRIC PROGRAM

Editors
F. J. Davis and P. W. Reinhardt

Approved by: L. J. DEAL
Acting Chief
Civil Effects Branch

Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee
March 1962

ABSTRACT

An extended-source calibration area was set up in the Nevada Test Site area to encourage a standardization of airborne radiometric instrumentation among several government agencies and private companies. A simulated plane-source array was laid out with positions at 100-ft intervals in the form of a square 2000 ft on a side. For ground measurements a smaller square array of 100 positions at 10-ft intervals was placed in the center of the large array. Two sets of sources were used in the array. Cobalt-60 and cesium-137 sources of 4.5 and 15 mc, respectively, were available for the large array and sources one hundredth of these values in the smaller array. Point sources of Co^{60}, Cs^{137}, and I^{131} of the order of 2 curies each were available for comparison with the area sources. Measurements 3 ft above the area sources indicated 200 μr/hr for Co^{60} and 225 μr/hr for Cs^{137}.

Four government agencies and one private company participated in an intercalibration exercise during November 1960. Various types and sizes of aircraft from a Cessna 172 to a Douglas DC-3 were used. Various instrumentation devices, mostly scintillation type detectors, were tested. Flights ranging from 100- to 1000-ft altitude included background measurements, instrument calibration, intercalibration, proof-testing equipment, comparison of point- and area-source measurements, measurements of air attenuation and buildup of gamma radiation, and gamma-ray spectral measurements.

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Chapter 1

GENERAL INFORMATION

F. J. Davis, P. W. Reinhardt, and R. M. Johnson, Oak Ridge
National Laboratory

1.1 INTRODUCTION

The use of airborne scintillation detectors following the Windscale incident of October 1957 proved to be a rapid method of assessing the radiation contamination and demarcation of hazard areas.[1,2] The use of these detectors in assessing the incident, however, emphasized the need for accurate information regarding natural background activity. The variation in the intensity of radiation from natural background obscures the measurement of radioiodine contamination, and, unless background is known, low-level contamination is very difficult to determine. As a result of experience gained from Windscale, the Division of Biology and Medicine (DBM), U. S. Atomic Energy Commission, has instituted the Aerial Radiological Monitoring System (ARMS) program. The objective of the ARMS program is to obtain background measurements covering 10,000 square miles around each site where a possible incident of the Windscale type could occur. The first of the ARMS surveys have been made utilizing the two aircraft of the U. S. Geological Survey (USGS).

Because many sites involved in nuclear activities exist and more are coming into existence, the need of survey aircraft and equipment has grown beyond the present capability of the USGS. A system analysis of the ARMS program made by Edgerton, Germeshausen & Grier, Inc.,[3] led to the development of miniaturized equipment that could be carried aboard a smaller plane.

Since several AEC installations maintain their own aircraft and equipment for radiation surveys, it became necessary to tie all these various aircraft instruments together to a common calibration.

In May 1960 R. L. Corsbie and L. J. Deal, Civil Effects Test Operations (CETO), and P. W. Reinhardt and F. J. Davis, Oak Ridge National Laboratory (ORNL), held an informal meeting in Oak Ridge, Tenn., to make plans for setting up a calibration area.

The plan for the calibration area was to set up a plane-source field to simulate a fallout area. This field would be constructed to be set up, removed, and reused at will. The sources chosen, Cs^{137} and Co^{60}, have sufficiently long half-lives (30 and 5.3 years, respectively) to last many years and have convenient gamma-ray energies of 0.661 Mev for Cs^{137} and 1.17 and 1.33 Mev for Co^{60}.

Plans were made to include point sources for comparison with the plane sources. The point sources, besides Cs^{137} and Co^{60}, would include I^{131}, which has only an eight-day half-life but is needed as a calibration measurement since the probable contamination to be measured will be I^{131}. Although it would be uneconomical to set up a plane source of I^{131} which could be used only once, it was felt that after the relation between point and plane sources of Cs^{137} and Co^{60} had been determined the relation could be extended to include I^{131}.

During the summer of 1960, the design of the field was completed, and the field layout was surveyed and installed by Reynolds Electrical and Engineering Company (REECO) in the Frenchman Flat area at the Nevada Test Site.

On Nov. 1, 1960, a meeting was held in Las Vegas, Nev., by the various agencies involved in the program. The following laboratories with their project officers participated in the program:

R. L. Corsbie, Director, Civil Effects Test Operations
F. J. Davis, Oak Ridge National Laboratory, Director, Program 60.3
J. L. Meuschke, U. S. Geological Survey, Project 60.3.1
R. F. Merian, Edgerton, Germeshausen & Grier, Inc., Project 60.3.2
D. M. Davis, Oak Ridge National Laboratory, Project 60.3.3
K. K. Brown, Savannah River Operations Office, Project 60.3.4
G. D. Brown, Hanford Operations Office, Project 60.3.5

The following objectives were included in all the projects: (1) background radiation measurements, (2) instrument calibration, (3) intercalibration, (4) proof-testing equipment, and (5) comparison of point- and extended-source measurements. Project 60.3.1 also included gamma-ray spectral measurements.

A schedule of flying was agreed upon among the crews of the five aircraft so that not more than two aircraft were flying over the source area at the same time. The sources were handled by the REECO Rad-Safe Division and were changed after all aircraft had finished with each set of sources. Each aircraft flew at least three times, once for background and once each for the two sets of sources. Because of the weather and instrument difficulties, it took two weeks to complete the flying part of the program.

1.2 DESCRIPTION OF AREA AND SOURCES

The simulated plane-source area consisted of a square array 2000 ft on a side with source stations at 100-ft intervals. In the center of this array, replacing the center station, was a smaller array of 100 stations at 10-ft intervals. In the center square of the small array, strings were stretched to mark off positions at 1-ft intervals. The details are shown in Figs. 1.1 and 1.2. The detail A in Fig. 1.2 shows 11 rows of 11 stations that were laid out due to a misunderstanding; however, one outer row and one outer column were not used. Figure 1.3 shows the location of the point-source positions with respect to the simulated plane-source area. The auto tires shown in Figs. 1.1 and 1.3 were wrapped in red cloth and used as navigational aids by pilots to locate their flight line. The flight pattern usually was a race-track pattern. The position GZ in Fig. 1.3 was the Ground Zero point of an old nuclear detonation and, unfortunately, was still highly radioactive. The detail of the source station is shown in Fig. 1.4. The iron pipes were left permanently in the ground and, when not in use, were covered with a pipe cap. The sources were fixed in the wood dowling rods, which provided a convenient means of handling.

Two arrangements of sources were used. In the first arrangement the sources in the outer array were each 15-mc Cs^{137}, and those in the inner array were 0.15-mc Cs^{137}. Point source A was 1.72-curies Cs^{137}, and point source B was 2.00-curies I^{131}. The second arrangement consisted of 4.5 ± 0.5-mc Co^{60} sources in the outer array, 0.053 ± 0.005-mc Co^{60} sources in the inner array, a 1.2-curie Co^{60} source at point A and a 2.00-curie I^{131} source at point B. The activity of the I^{131} source given was the value as of 1000 EST Nov. 1, 1960. The average value of the source distribution in the first array was 16.15-$\mu c/m^2$ Cs^{137}. In the second array the average value over the whole area was 4.8-$\mu c/m^2$ Co^{60}. Since the Cs^{137} was separated chemically and made up as aliquots, the values should have been uniform, and the large-array sources should have been accurately 100 times the small array sources. The Co^{60} sources, however, were irradiated sources, and the variation of the flux with the position of the pellets in the reactor caused a nonuniformity of activity among the sources. A factor of 100 was attempted in the size of the two arrays of Co^{60} sources, but the values given previously were the results.

1.3 GROUND MEASUREMENTS

The instruments used by ORNL in making ground measurements were

1. A 4-in.-diameter by 2-in.-thick NaI(Tl) crystal with a 256-channel analyzer
2. A hand-carried scintillator, "Scintillac," serial No. 185, with Quality Instruments probe, model 111, containing a $1\frac{1}{2}$-in. by 1-in. NaI(Tl) crystal
3. A hand-carried Geiger counter, "Thyac," model 389c

Measurements made by the Hanford Operations Office (HOO) are described in Chap. 6.

The hand counters, Scintillac and Thyac, were used to take readings at 3 ft above the points marked at 1-ft intervals by the intersection and ends of the strings in the center 10-ft square. Since the points on one side of the diagonal had symmetrical points on the opposite side, only readings in the triangle on one side of the diagonal were made. Actually, because of the symmetry, readings in one-eighth of the square would have been sufficient, but it was felt that the larger number of readings would give a better average reading. The readings above the perimeter points of the triangle were weighted one-half the weight of the points within the triangle since a perimeter point belongs to two adjacent triangles. A simpler method would be to make the readings in the center of the 1-ft squares and allow all readings to have equal weight.

The 4-in. by 2-in.-diameter crystal with the analyzer was set up in the center position only. For dose measurements the integral count of the analyzer was used. The ratio of the average readings of the Scintillac to the reading at the center was used to correct the value of the dose at the center position to the average position. The readings at the center of the Cs^{137} and Co^{60} fields were lower than the average reading over the entire square by 5 and 3.5 per cent, respectively.

Measurements made with and without the central array of Co^{60} sources allowed a correction to be made for the central sources, which were too large. This correction factor is 0.94 and applies only to the ground readings.

The dose at the 3-ft level with the previous corrections applied is shown in Table 1.1. It is felt that the 4-in. by 2-in. crystal measurements are the most dependable since the instrument was calibrated with Cs^{137}, Co^{60}, and radium at a distance that gave a scattering component comparable with that obtained in the field measurements. The calibration dose was determined by the use of the Phil gamma-ray dosimeter;[4] various shields were used to correct for energy dependence. The Scintillac instrument was damaged in transit to the field; thus it was used with a different probe. The instrument was calibrated with a radium source and corrections were used for Cs^{137} and Co^{60}; since a different probe was used, however, it is not known what the low-energy cutoff was. The Thyac Geiger counter was calibrated with Cs^{137} and Co^{60} sources, but the sources were placed close to the instrument and not much scattered gamma radiation was present. These last two instruments indicate the unreliability of some commercially available instruments. The background measurements do not agree with each other, but, since they are all subtracted, the grid measurements should not be affected. The high background measured by the Geiger counter was probably due to beta radiation from fallout.

The usual expression for the variation of intensity I_0 with height h above a point source is

$$I_0 = \frac{k\, S_0\, e^{-\mu h}\, B(\mu h)}{h^2} \tag{1.1}$$

where
μ = the absorption coefficient for air
k = the proportionality constant
S_0 = the source strength
$B(\mu h)$ = the buildup factor due to scattered radiation

The function $B(\mu h)$ can usually be expressed empirically in a power series as

$$B(\mu h) = 1 + a(\mu h) + b(\mu h)^2 + \ldots \tag{1.2}$$

where a, b, etc., are constants depending on the energy of the radiation and the detector-response function. For the purpose of this report, the first two terms are generally sufficient, and, for soft radiation and an altitude above 500 ft, the second term, $a(\mu h)$, alone adequately expresses the buildup. If one integrates Eq. 1.1 using the first two terms of the buildup factor over an infinite plane source of S_A curies per unit area, the intensity relation

$$I_A = 2\pi\, k\, S_A \left[E_1(\mu h) + a e^{-\mu h}\right] \qquad (1.3)$$

is obtained.

With an air density of 1.057 g/liter, calculated from the air pressure and temperature at time of measurements, and the constants given in Table 1.2, the theoretical values given in Table 1.1 are obtained. The values for Cs^{137} compare quite well, but the values for Co^{60} differ by 17 per cent. Since the value of the constant a given in Table 1.2 is for a homogeneous medium and Eq. 1.3 assumes isotropic distribution of gamma rays with no polar angle dependence, the agreement is probably as good as can be expected.

REFERENCES

1. D. Williams and R. S. Cambray, *Environmental Survey from the Air*, British Report AERE-R2954, 1960.
2. A. C. Chamberlain, *Relation Between Measurements of Deposited Activity After the Windscale Accident of October 1957*, British Report AERE HP/R 2606, 1958; A. C. Chamberlain, R. J. Garner, and D. Williams, Reactor Science and Technology, *J. Nuclear Energy*, Parts A and B, 14: 155(1961).
3. R. F. Merian, J. G. Lackey, and J. E. Hand, *Aerial Radiological Monitoring System. I. Theoretical Analysis, Design, and Operation of a Revised System*, USAEC Report CEX-59.4, February 1961.
4. E. B. Wagner and G. S. Hurst, *Health Phys.* 5: 20(1961).
5. W. S. Snyder and J. L. Powell, *Absorption of Gamma Rays*, USAEC Report ORNL-421, Suppl. 2, Oak Ridge National Laboratory, 1950.
6. National Bureau of Standards Handbook 54, *Protection Against Radiation from Radium, Cobalt-60, and Cesium-137*, p.42, 1954.
7. H. Goldstein and J. E. Wilkins, Jr., *Calculation of the Penetration of Gamma Rays*, Report NYO-3075, p.180, 1954.

Table 1.1—DOSE MEASUREMENTS AT 3-FT LEVEL

	Background, μr/hr	16.2 $\mu c/m^2$ Cs^{137} array, μr/hr	4.8 $\mu c/m^2$ Co^{60} array, μr/hr
4- by 2-in. crystal	25	225	200
Scintillac	17	150	126
Thyac	95	122	114
Theoretical		228	234

Table 1.2—CONSTANTS USED IN DETERMINING THEORETICAL DOSE

	Cs^{137}	Co^{60}	Ref.
S_A	16.2 $\mu c/m^2$	4.8 $\mu c/m^2$	
μ	0.077 cm^2/g	0.056 cm^2/g	5
$E_1(\mu h)$	4.32	4.65	
k	0.39 rhm/c*	1.35 rhm/c*	6
a	1.45	1.1	7

* rhm/c = roentgen per hour at one meter per curie.

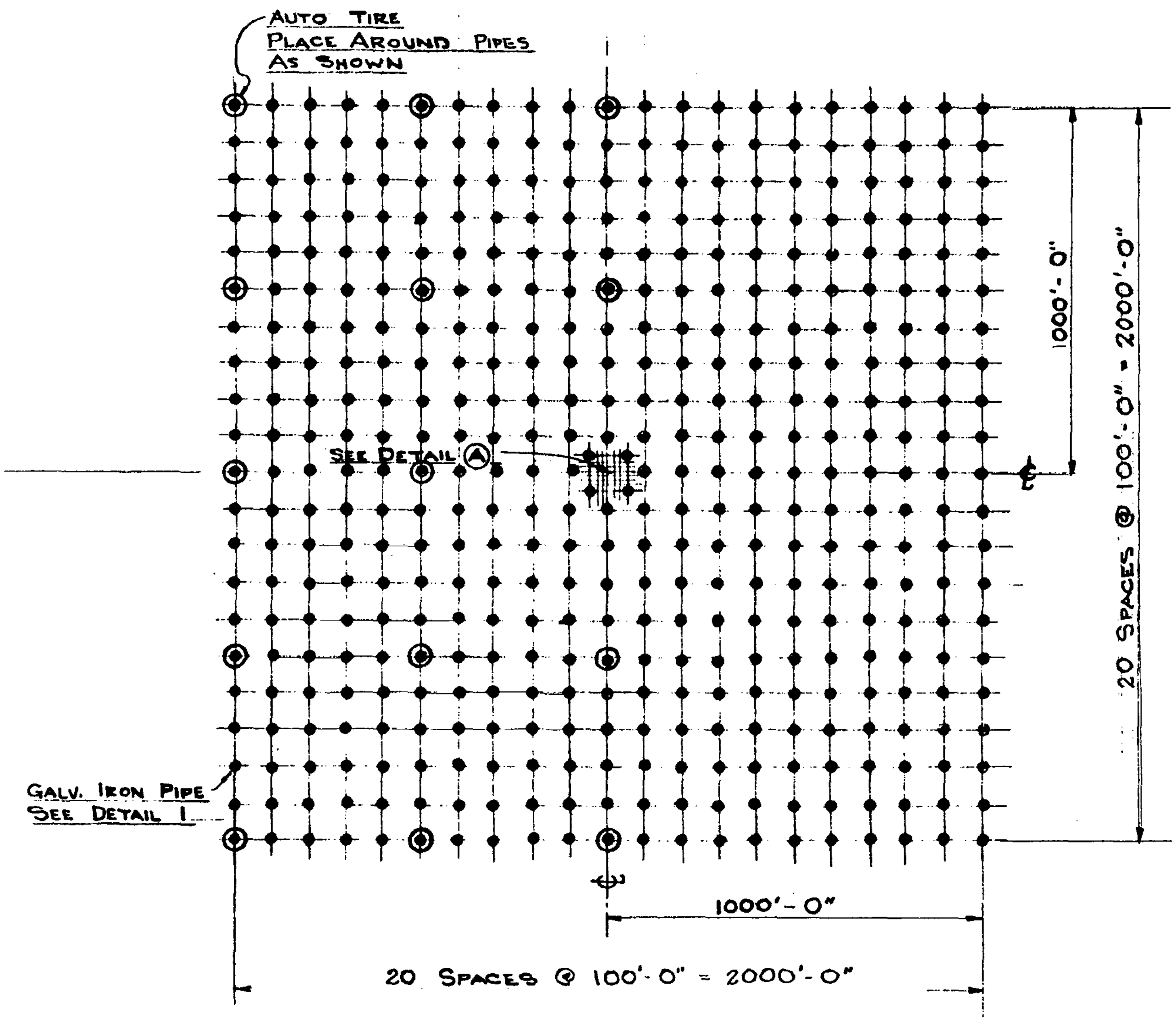

Fig. 1.1—Distribution of sources in the simulated plane-source area.

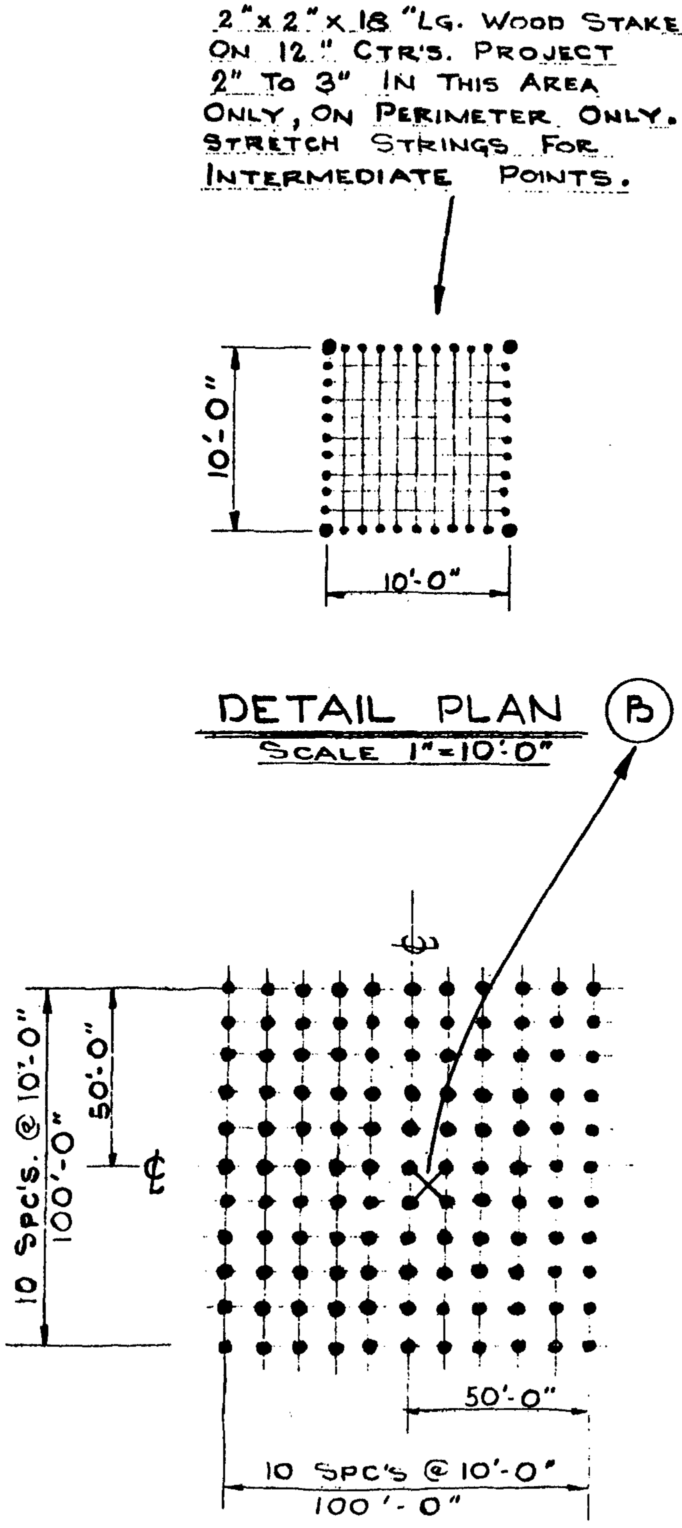

Fig. 1.2—Central detail of sources in the simulated plane-source area.

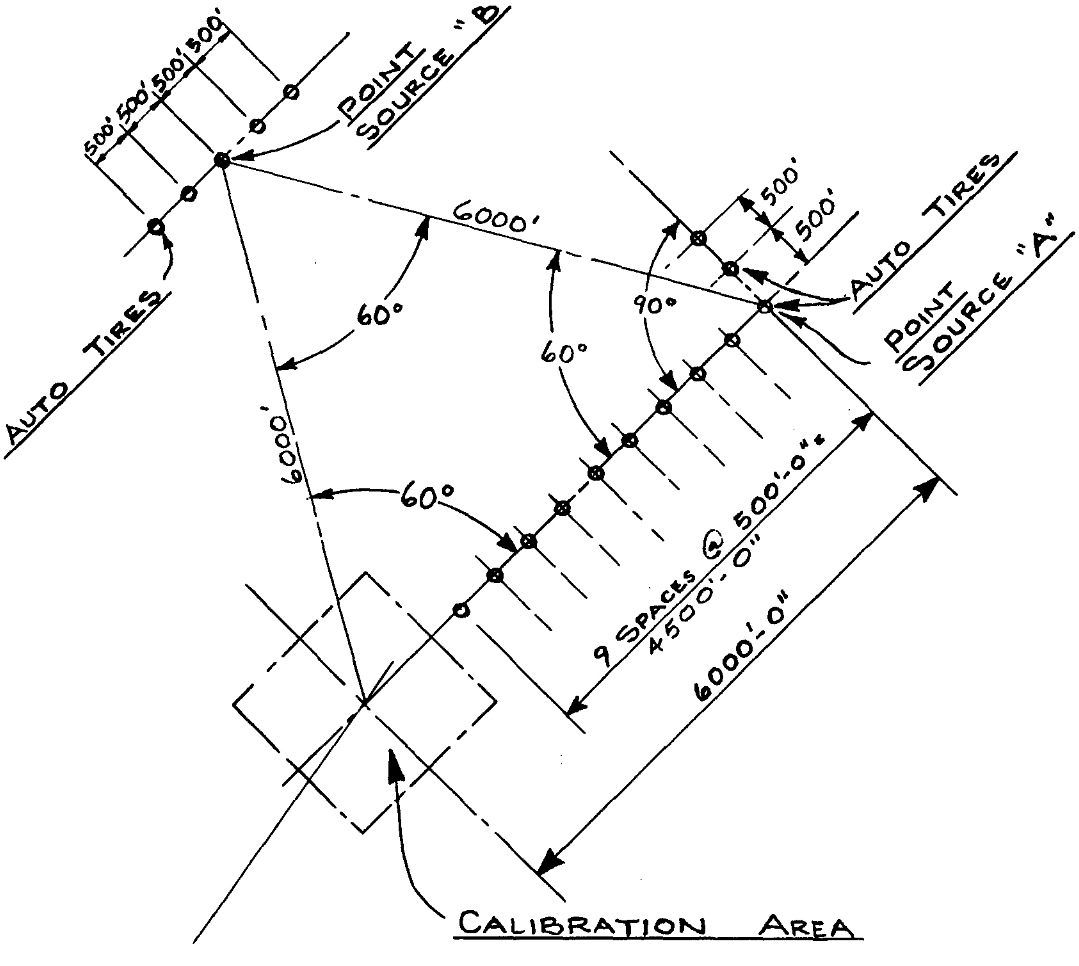

Fig. 1.3—Arrangement of simulated plane source and point sources in the calibration area.

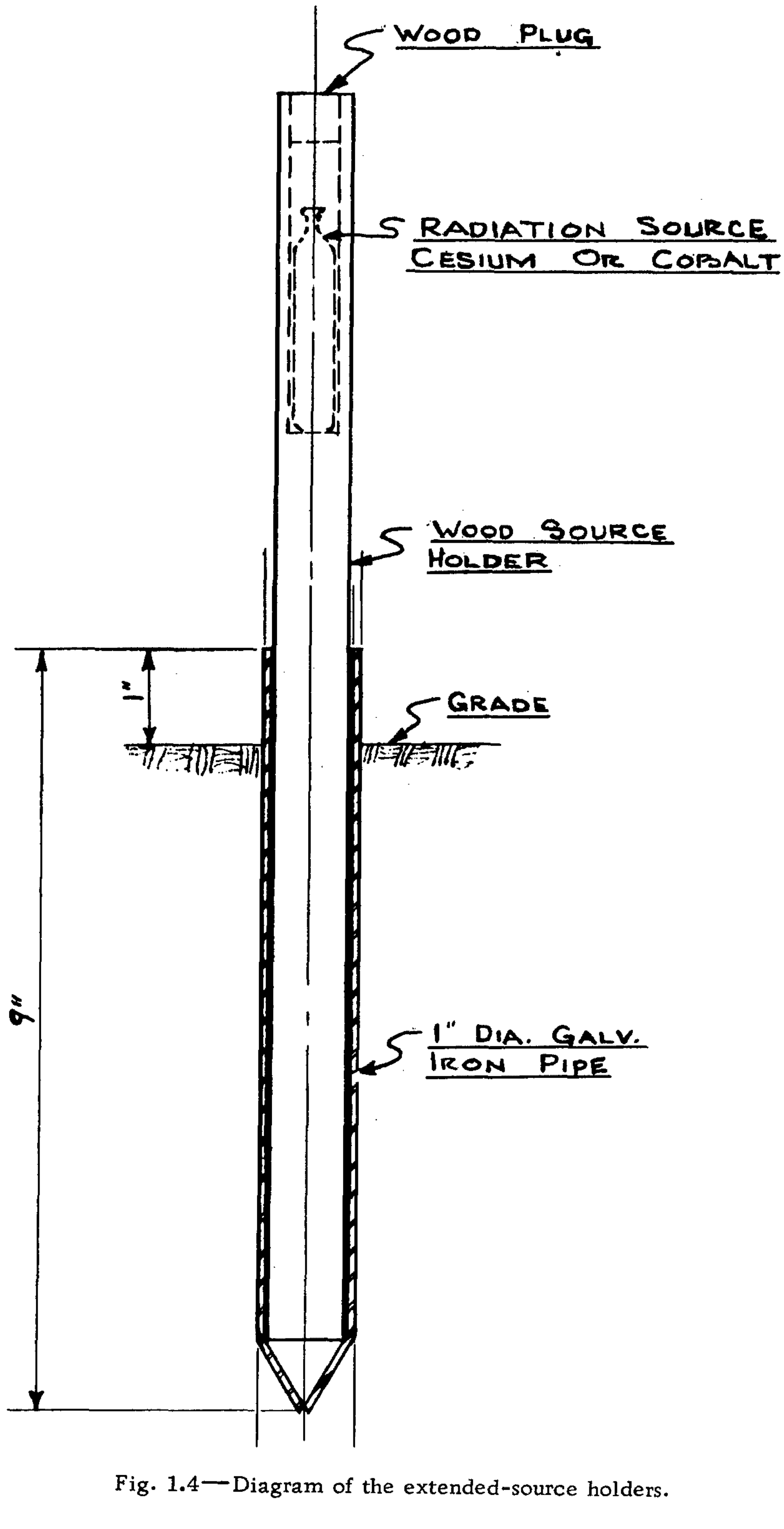

Fig. 1.4—Diagram of the extended-source holders.

Chapter 2

AERIAL MEASUREMENTS–PROJECT 60.3.1

F. J. Davis and P. W. Reinhardt, Oak Ridge National Laboratory
J. L. Meuschke, U. S. Geological Survey

2.1 MEASUREMENTS WITH REGULAR SURVEY EQUIPMENT

2.1.1 Equipment and Flights

The equipment normally used in the USGS DC-3 aircraft is described in Ref. 1. Six NaI(Tl) scintillation detectors are used in parallel, each 4 in. in diameter by 2 in. thick. Lead shielding $\frac{1}{2}$ in. thick is used on the sides and rear of the crystals with 1 in. on the forward side. A single $1\frac{1}{2}$-in.-diameter by 1-in.-thick NaI(Tl) crystal replaces the six large crystals to extend the measurements to higher intensities. The pulses are fed through an amplifier and discriminator to a recording rate meter. The discriminator setting used allows pulses to be counted which are above those originating from 50-kev gamma rays. A radar altimeter is used to record altitude above ground. This altimeter can be coupled into the recording rate meter to compensate automatically for the height of the aircraft and thus give the gamma-radiation intensity on the ground. A continuous strip-film camera is normally used to locate the position of the aircraft. For this calibration, however, only the drift sight was used. The aircraft also carries a magnetometer so that in normal surveying operations both magnetic and radiation data are obtained.

Normal cruising speed of the aircraft is 200 to 220 ft/sec. Flights over the sources included (1) five passes at each 100-ft elevation up to 1000 ft over the center of the sources, (2) 300-, 500-, and 1000-ft elevations over the edge of the source field and 1000 ft to one side of the point source A, and (3) 300- and 500-ft elevations at 500 ft offside the center of the field source and point source A. The flights were made over both sets of sources and background. In the case of the background flights, however, only three instead of five passes were made at each position. Five passes using only the small crystal were made over the cobalt and iodine sources at elevations of 300 and 500 ft.

2.1.2 Point-source Data

In Fig. 2.1 are shown the data obtained from flying over the three point sources. The ordinate is intensity times height plotted on semilog coordinates against height. These coordinates are chosen so that if the data fit a buildup factor proportional to height they will appear as a straight line with slope equal to μ. For I^{131} the data fit the theoretical straight line from 400 ft on up, but, for the harder radiation of Co^{60}, the theoretical straight line fits only above 800 ft. The theoretical half-thicknesses of air given in Fig. 2.1 are calculated from the value of μ given in Table 1.2 and the density of air given above.

The relative experimental buildup factors vs. height determined from flights over the point sources are shown in Fig. 2.2. The straight lines fitted to the points have the indicated equations when normalized to a unity intercept on the ordinate.

The values of a (coefficient of μh in Eq. 1.2) shown on the graph are not values representing dose but values measured with the scintillation detector, which counts all pulses with equal weight. Consequently the value of a for this detector is higher than that of a detector measuring dose.

2.1.3 Extended-source Data

If the second term of the buildup relation is the only one of significance, then Eq. 1.3 becomes simply an exponential variation with height. The data shown in Fig. 2.3 for the Cs^{137} extended sources show a good fit to the theoretical half-thickness of air equal to 280 ft. The points falling below the curve at low altitudes are probably due to the side shielding of the crystals that prevents their effectively seeing an infinite extended source. The Co^{60} extended-source data seem to fit a half-thickness of air of 340 ft better than the theoretical half-thickness of 380 ft. The discrepancy may be due to two causes: (1) the second term in the buildup relation is no longer the controlling term for the harder radiation of Co^{60}, and therefore significant contributions of the $E_1(\mu h)$ term would raise the curve for low altitudes; (2) the high-altitude measurements are too low because of the limited area of the field, as shown later. The count rates at 500 ft equivalent to a ground reading of 1 μr/hr for Cs^{137} and Co^{60} plane sources are 25 and 18 counts/sec, respectively.

The use of the single 4-in. by 2-in. crystal with the 256-channel analyzer was mainly for spectral measurements. The integral of the pulse-height distribution, however, provides a means of comparison with the six-crystal rate meter. The points shown in Fig. 2.4 are the total integrated count minus background of the five passes at each altitude over the extended source. The points shown at 3 ft were measurements made on the ground. Note that the curves rise sharply on the low-altitude end due to the $E_1(\mu h)$ term in Eq. 1.3. Also, no shielding was used on the side of the crystal to cancel this effect. The slope of the curves is steeper, especially for Co^{60}, than the corresponding curves in Fig. 2.3. This may be due to the effect of the time integral of the count, which was started and stopped at the edges of the field.

If I_0 is the intensity over a point source of S_0 curies, then eliminating k in Eqs. 1.1 and 1.3 gives the relation

$$I_A = 2\pi I_0 h^2 \frac{E_1(\mu h) + ae^{-\mu h}}{e^{-\mu h}(1 + a\mu h)} \frac{S_A}{S_0} \tag{2.1}$$

If the second term in the buildup factor is assumed to be the controlling term, this equation reduces to

$$I_A = 2\pi I_0 \frac{h}{\mu} \frac{S_A}{S_0} \tag{2.2}$$

If an instrument is calibrated to give a reading I_0 over a source S_0 with an air absorption constant μ at height h, then the instrument should give a reading I_A over an infinite plane source of S_A per unit area at the same height h. In Table 2.1 are shown the values for the ratio of I_A/I_0 for the three sources, I^{131}, Cs^{137}, and Co^{60}, for an altitude of 500 ft. In other words, at 500 ft an instrument should give the same reading over a 94-mc point source of I^{131} as it does over a field of 1 $\mu c/m^2$ plane source. For the six-crystal rate meter, this would be a count rate of 360 counts/sec above background. The corresponding point sources for Cs^{137} and Co^{60} equivalent to a 1 $\mu c/m^2$ plane source at 500 ft altitude calculated from Eq. 2.1 are 108 and 131 mc, respectively. The corresponding experimental values are 95 and 94 mc, respectively. The radiation-intensity measurements made over the edge of the field averaged 57 per cent for Cs^{137} and 66 per cent for Co^{60} of the corresponding readings over the center line of the field. This would indicate that the field was not large enough and that the readings over the center should be increased by 14 per cent and 33 per cent or more, respectively, to approximate readings over an infinite field. If these corrections are applied to the experimental point sources equivalent to a field of 1 $\mu c/m^2$, the values obtained are 108 μc for Cs^{137} and 125 μc for Co^{60}, which agree much better with the theoretical values given.

If the intensity relation

$$I = \frac{kS_0 e^{-\mu h} B(\mu h)}{h^2}$$

is integrated over a uniformly distributed source of S_m curies per unit mass in a semi-infinite solid and the buildup factor $B(\mu h)$ is assumed to be proportional to the number of mean free paths in the solid and in the air above the solid, the following is the relation for the intensity:

$$I_m = \frac{2\pi k S_m e^{-\mu h}}{\mu \mu_m} \tag{2.3}$$

where μ_m is the mass absorption coefficient of the solid and the other symbols are as defined before. The equation relating the intensity above a point source to that of a semi-infinite solid source corresponding to Eq. 2.2 is then

$$I_m = \frac{2\pi I_0 h S_m}{\mu \mu_m S_0} \tag{2.4}$$

From a previous calibration which gave 8000 counts/sec at 500 ft above a 1-curie radium source, according to Eq. 2.4, 350 counts/sec could be expected at 500 ft above a uniformly distributed source of 10^{-12} curies of radium per gram of soil. This is about the normal concentration of radium in the soil and also about the normal background intensity due to the ground.

A comparison of the sensitivity of the single $1\frac{1}{2}$-in.-diameter by 1-in.-thick crystals gave a ratio of 39.2 over the point sources and a ratio of 30.0 over the extended sources. Presumably the difference is due to the side shielding on the large crystals.

2.2 SINGLE-CRYSTAL SPECTRAL MEASUREMENTS

2.2.1 Laboratory Measurements

Figures 2.5 and 2.6 show the pulse-height distributions for cobalt and cesium sources. The integral count for cesium indicates that 50 per cent of the pulses occur in the photo peak for Cs^{137} and 43 per cent for Co^{60}. The calculated efficiency of the crystal is 78 and 62 per cent for Cs^{137} and Co^{60}, respectively.

2.2.2 Field Measurements

The pulse-height distribution of the gamma rays from the Cs^{137} field is shown in Fig. 2.7. Prominent photo peaks are shown by the experimental points at the lower altitudes, but they nearly fade out at 1000 ft. Figure 2.8 shows the corresponding pulse-height curves obtained from the Co^{60} field.

It is noted in both Figs. 2.7 and 2.8 that the peak due to scattered radiation drifts to lower energies for the higher altitude. Figure 2.9 is a plot of the energy of the scatter peak obtained from the cesium field.

In Fig. 2.10 is plotted the ratio of the height of the scattering-peak height to the photo-peak height of the pulse-height distribution curves. Also shown in Fig. 2.10 is the ratio of the total count rate to the count rate in the photo peak. These are obtained by integrating the pulse-height distribution curves. Note that the curves approach linearity above 100-ft altitude. This is to be expected if the buildup factor is linear with height.

When the count rate of the photo peak is plotted against altitude, the variation of the primary radiation with altitude with no buildup should be obtained. This is shown in Fig. 2.11. Also shown is a plot of $E_1(\mu h)$, which is obtained theoretically when the intensity relation, Eq. 1.1, with unity buildup factor is integrated over a plane source.

2.3 SUMMARY

The 2000-ft array, although sufficiently large to simulate an infinite area source for ground measurements, is inadequate for measurements of 500-ft altitude and above for the harder radiations such as Co^{60}. The measured dose at ground level for Cs^{137} agrees very well with that calculated by Eq. 1.3, but the disagreement of the Co^{60} measurements with this formula indicates that Eq. 1.3 is probably too simplified.

The empirical buildup factor, $1 + a(\mu h)$, for radiation above a point source can be simplified to $a(\mu h)$ for altitudes above 500 ft and primary radiation less than 0.8 Mev. For softer radiation the simplified buildup factor holds to lower altitudes. A rough estimate of the altitude above which $a(\mu h)$ is adequate is $700\sqrt{E}$ ft, where E is the primary gamma-ray energy in Mev.

With the buildup factor $a(\mu h)$, the ratio $I_A/I_0 = 2\pi(S_A/S_0)$ holds for soft radiation such as I^{131}. This indicates that at 500 ft the intensity above a 94-mc point source of I^{131} would be the same as that above a 1 $\mu c/m^2$ plane source.

The spectral measurements show that the energy of the maximum of the scattering peak varies slightly with altitude but is usually about 80 kev. This indicates that for an integral type scintillation detector the low-energy cutoff should be of the order of 50 kev to include the scattering peak.

REFERENCE

1. F. J. Davis and P. W. Reinhardt, *Nuclear Sci. and Eng.*, 2: 713 (1957).

Table 2.1—RATIO OF MEASUREMENTS OVER POINT AND PLANE SOURCES*

Source	$1/\mu$, ft (ρ = 1.057 g/l)	$(I_A/I_0)_{th}$ ($S_A = 10^{-3}\ S_0/m^2$)	$(I_A/I_0)_{exp}$ array	$\frac{2 \times I_{edge}}{I_{center}}$	$(I_A/I_0)_{exp}$ infinite array
I^{131}	334	94			
Cs^{137}	403	108	95	1.14	108
Co^{60}	554	131	94	1.33	125

*Values given are for 500 ft above ground.

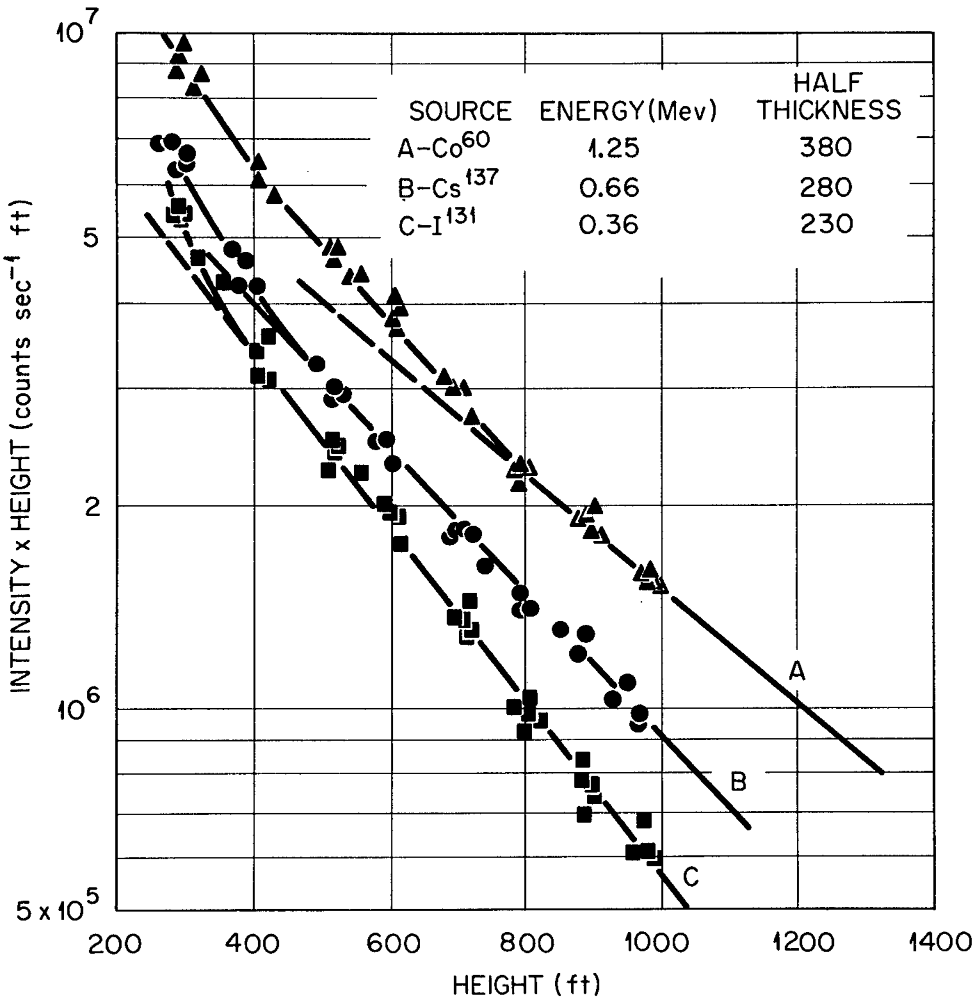

Fig. 2.1—Variation of intensity with height over point sources.

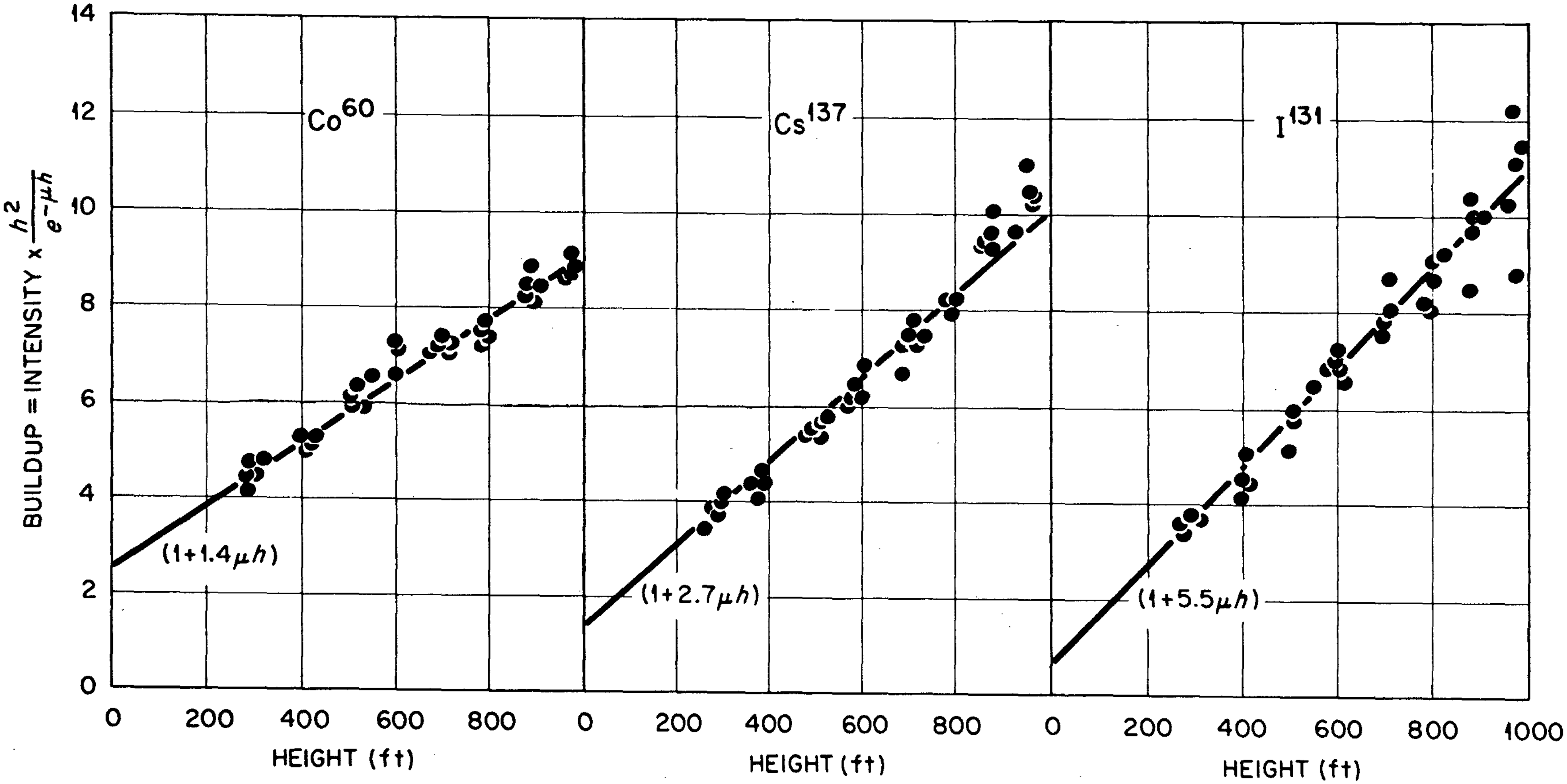

Fig. 2.2—Variation of buildup of radiation with height from point sources.

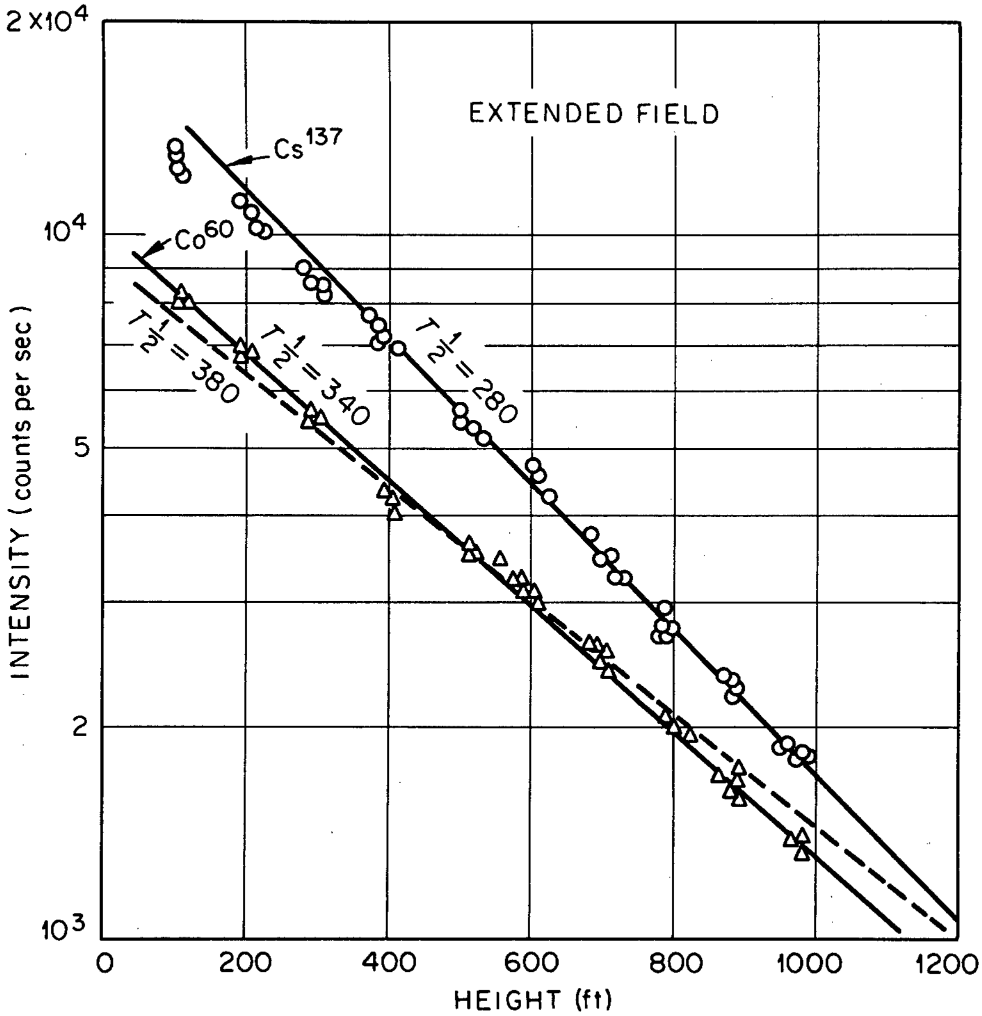

Fig. 2.3—Variation of intensity with height above extended sources (six crystals; side shielded).

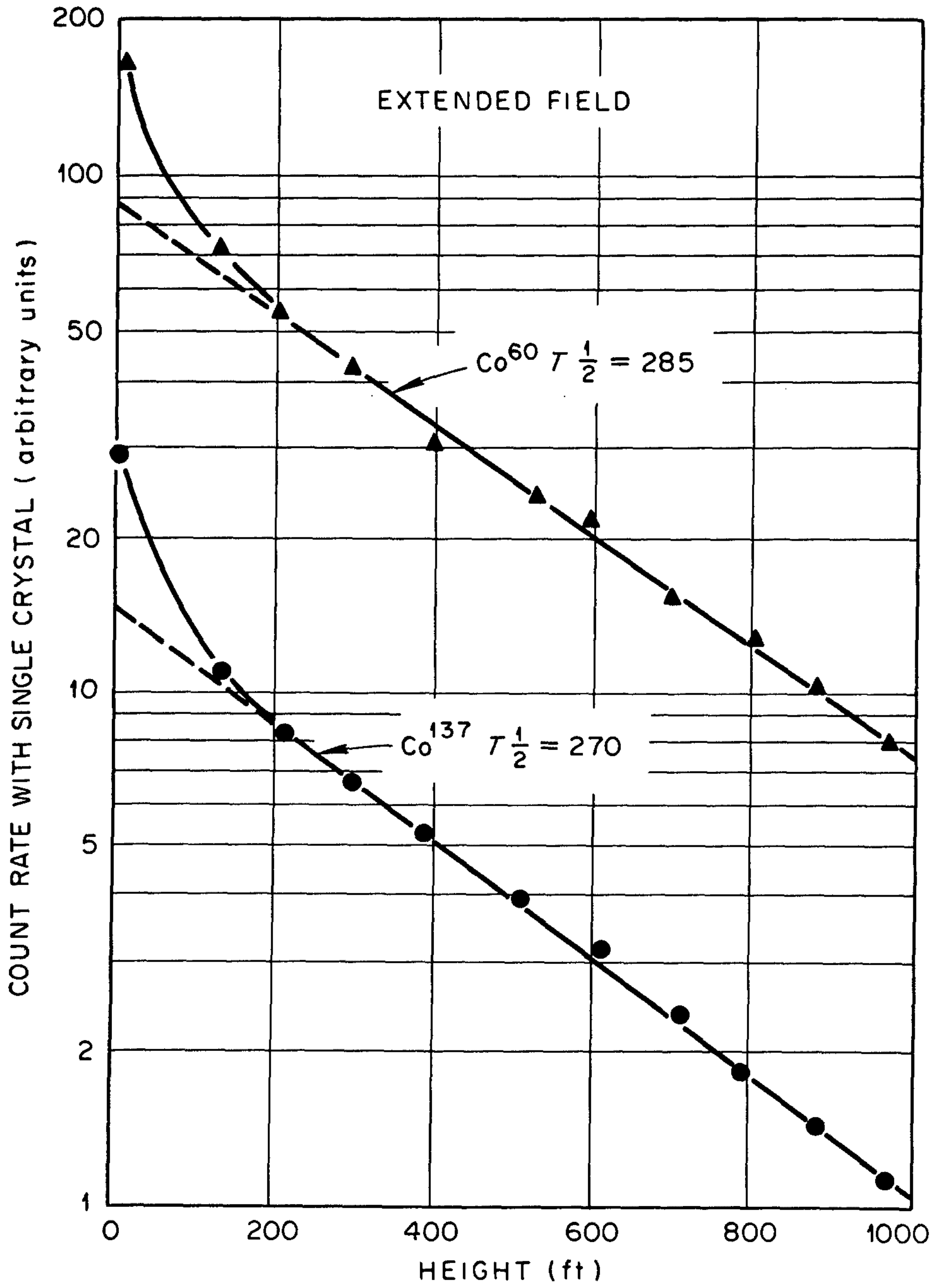

Fig. 2.4—Variation of intensity with height above extended sources (single crystal).

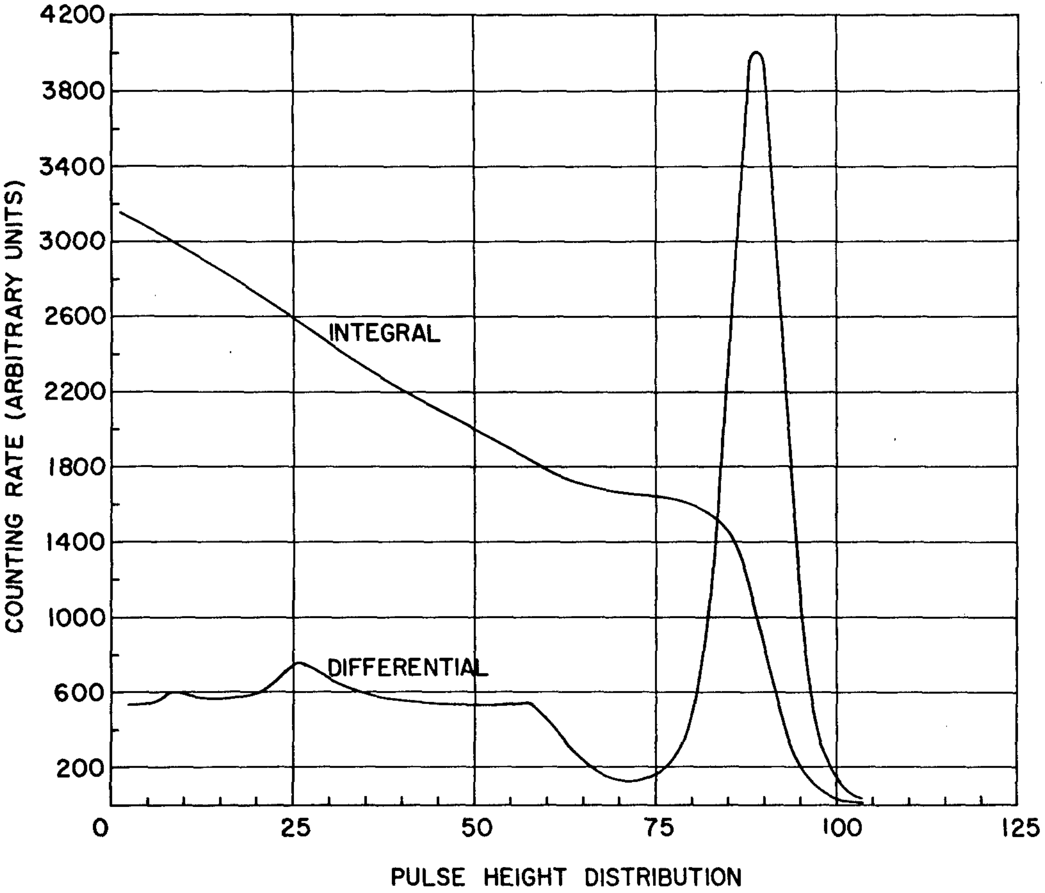

Fig. 2.5—Crystal response to Cs^{137} source.

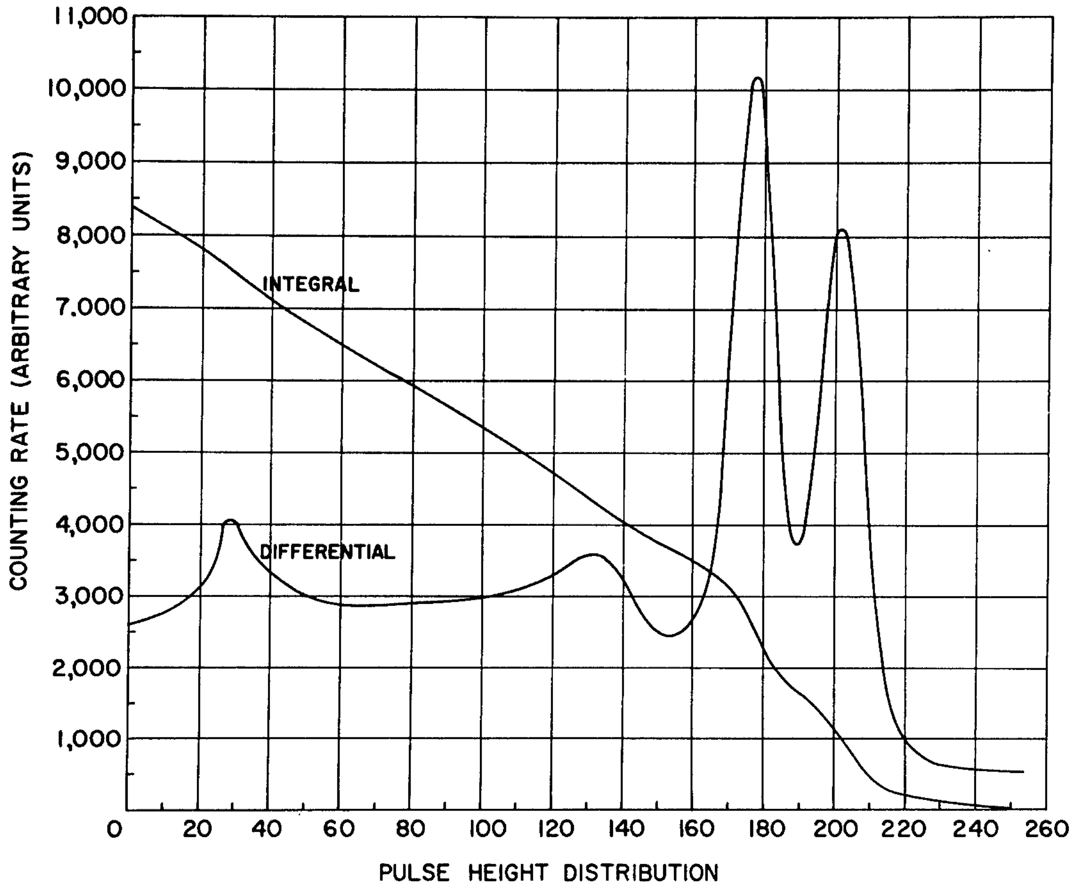

Fig. 2.6—Crystal response to Co^{60} source.

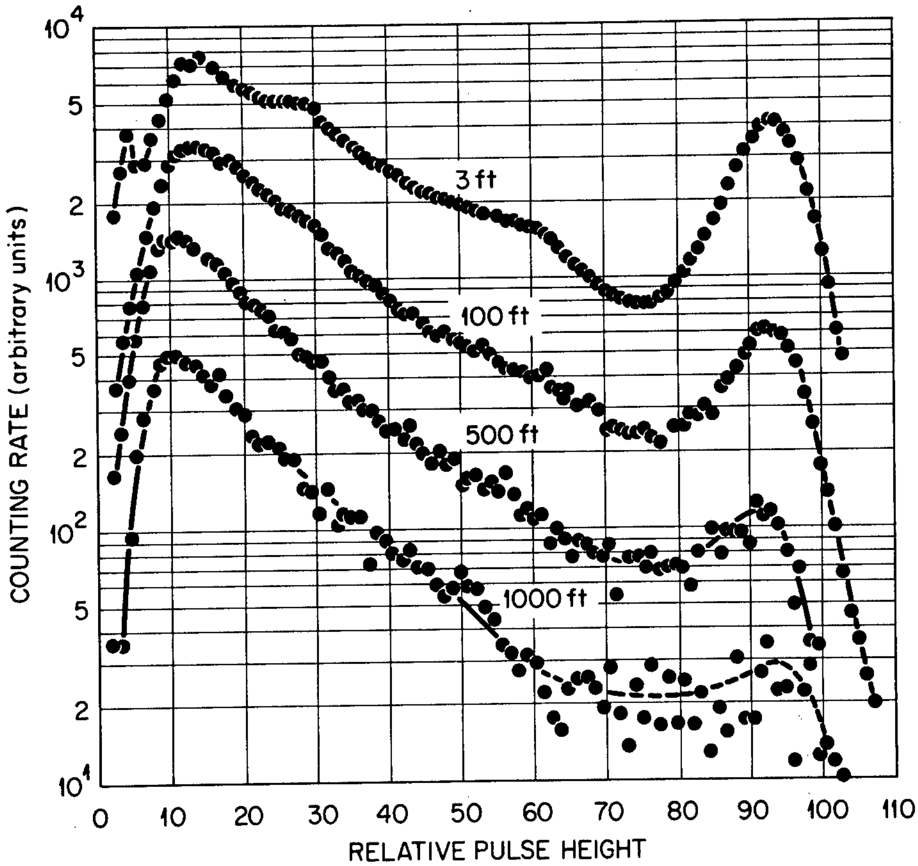

Fig. 2.7—Pulse-height distribution obtained over Cs^{137}-source field.

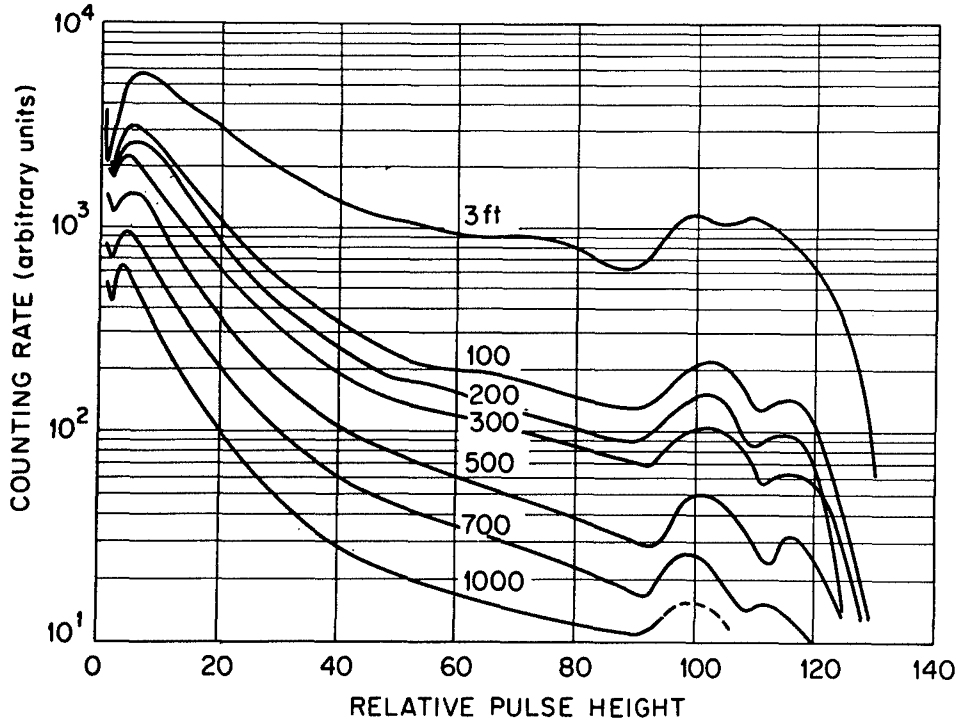

Fig. 2.8 — Pulse-height distribution obtained over Co^{60}-source field.

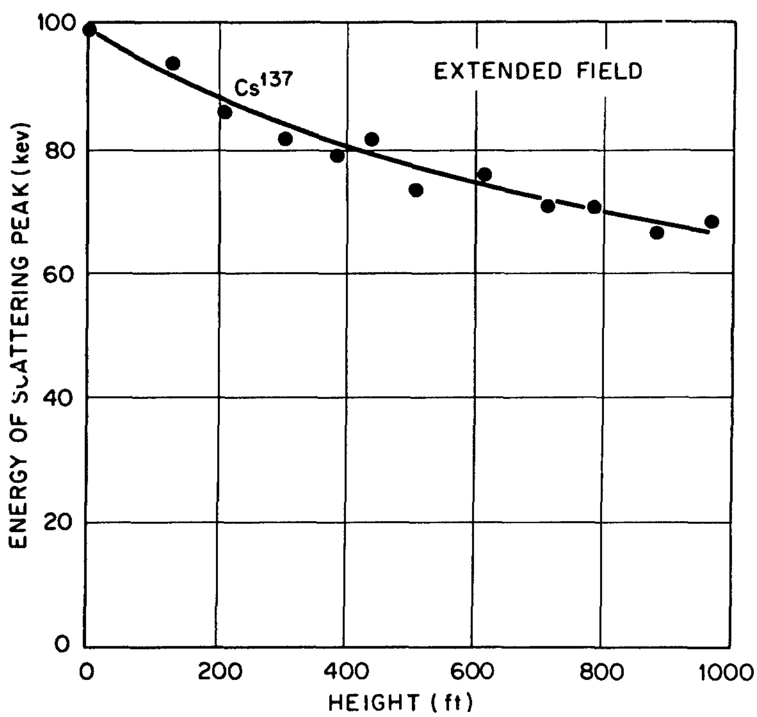

Fig. 2.9 — Variation of the energy of the scattering peak in the pulse-height distribution of Cs^{137}.

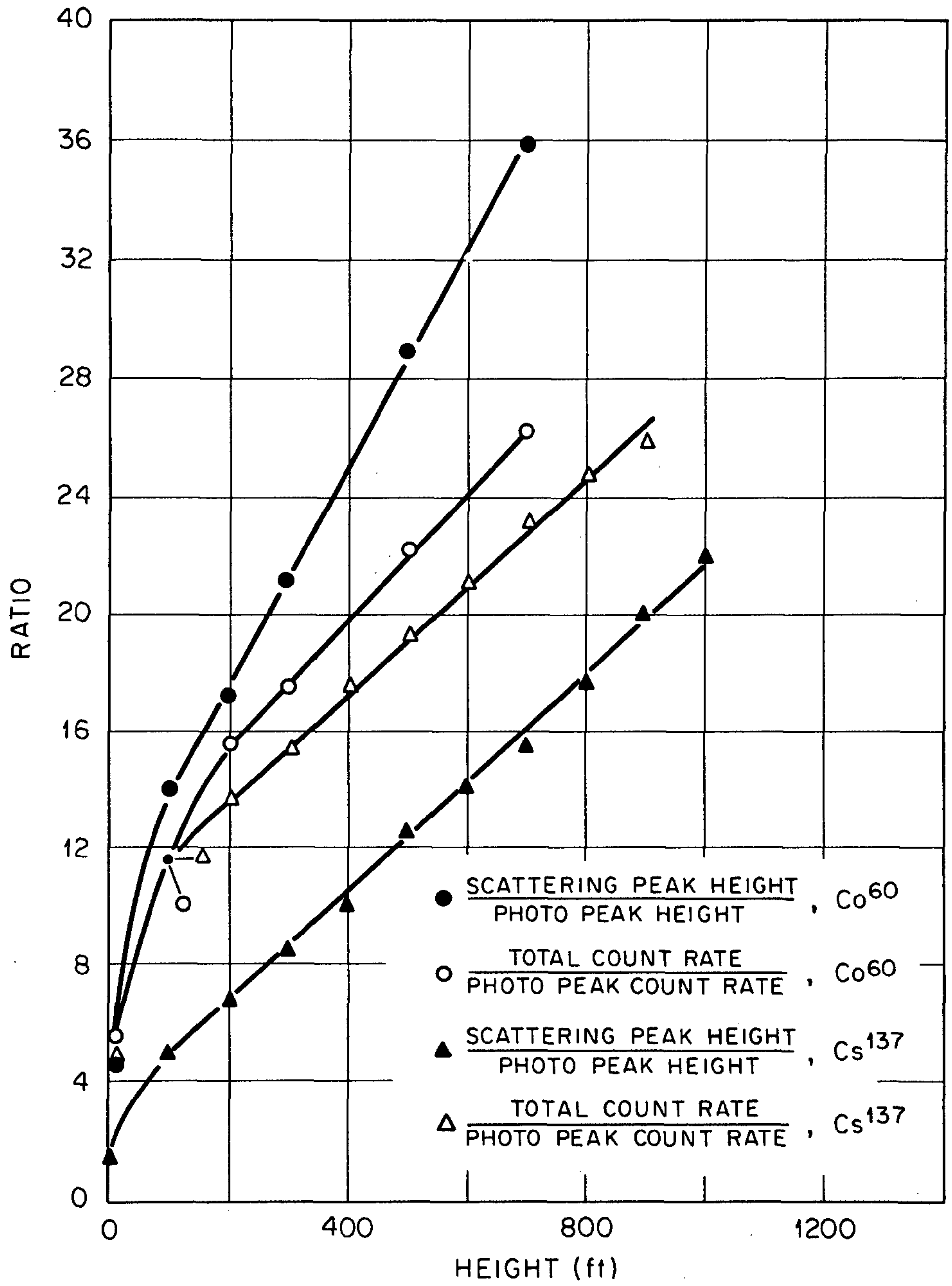

Fig. 2.10—Ratio of the scattering peak to photo peaks.

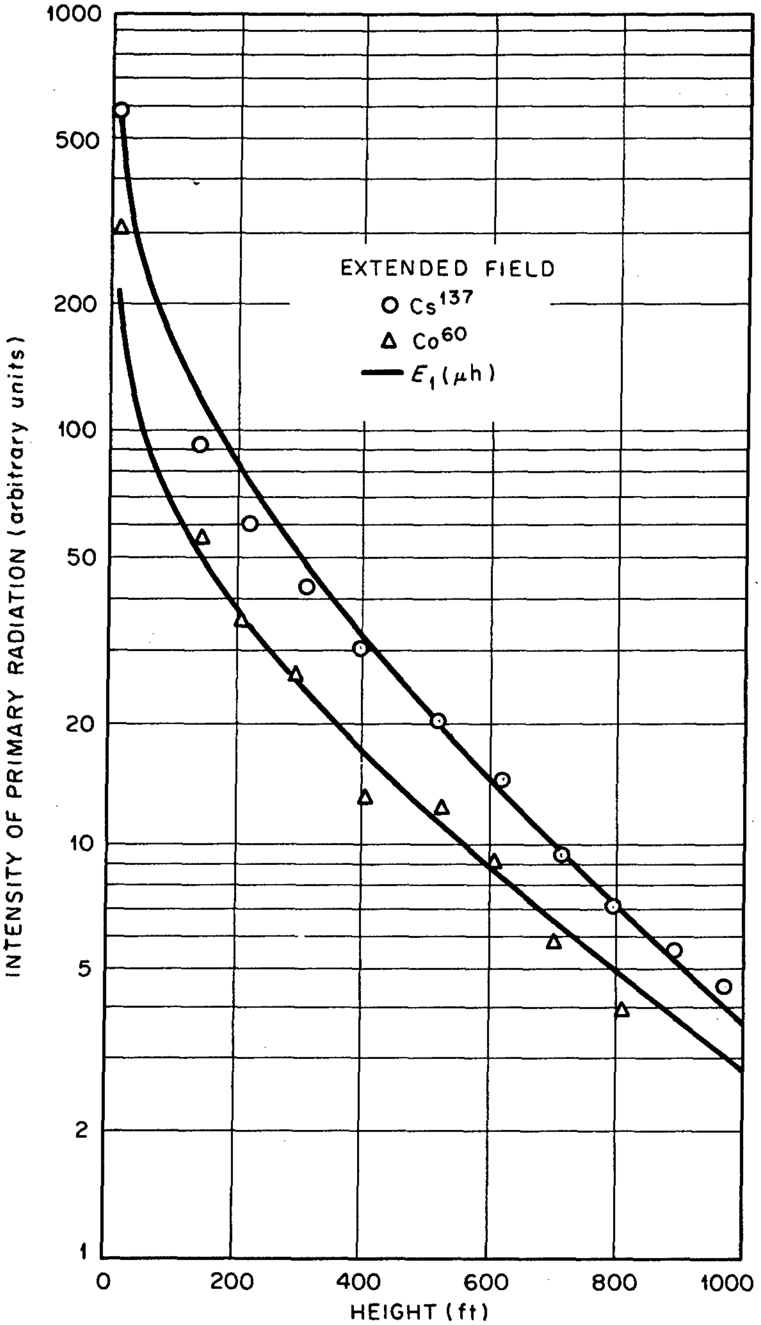

Fig. 2.11—Variation of primary radiation with height above extended-source field.

Chapter 3

AERIAL MEASUREMENTS–PROJECT 60.3.2

J. E. Hand, Edgerton, Germeshausen & Grier, Inc.

3.1 GENERAL

The equipment carried in the ARMS Beech model 50 Twin-Bonanza aircraft is described in Ref. 1. Two NaI(Tl) crystals 9 in. in diameter by 3 in. thick (high sensitivity) and 1 in. in diameter by 3 in. long (low sensitivity) coupled to suitable photomultiplier tubes are used as radiation detectors. The electronic circuitry necessary to convert the photomultiplier-tube output into usable data consists of compact transistorized modules. The radiation level is electronically correlated with the space position of the aircraft, and the result is automatically recorded in flight by a dual printout system. A punched-tape printer and a decimal printer are used simultaneously to record the data. The decimal printer provides a means whereby rapid presentation of the data is immediately available, whereas the punched-tape printer output is used subsequently with a computer and recorder to yield automatic data processing.

The ARMS aircraft made a total of 150 passes over the array and point-source locations. Although the Co^{60} and Cs^{137} sources were easily detected, no activity was found at the indicated I^{131} location. Possible explanations are that ground personnel neglected to place this source correctly or that its true location was misunderstood by the pilot. Data were taken in both "Calibrate" and "Run" positions of the radiation system control, giving 1-sec and altitude-corrected gating times, and in both high and low sensitivity range positions. In addition, 30 passes were made at various altitudes over the area with all sources removed so that the background could be recorded.

3.2 ARRAY AND POINT-SOURCE RESULTS

In normal operation the radiation system records the activity detected in terms of channel numbers. So that increased accuracy could be provided during the source-area calibration runs, the count rate displayed on the radiation control panel was read and manually recorded. With the 1-sec sampling period, about seven readings were obtained on each pass over the array. The tens and unit digits were not recorded so that manual recording could keep pace with the rate of change of the displayed count. Table 3.1 summarizes the data taken over the center line of the array and point-source location. Each of the counting-rate and total-count figures is the mean of 9 to 10 individual readings. These figures are uncorrected for background contributions. Approximately 800 counts/sec of the count rate recorded is due to the calibration Cs^{137} source installed abroad the aircraft.

Figures 3.1 through 3.7 depict the system behavior of the ARMS radiation equipment as functions of altitude, gamma energy, intensity, etc. Wherever possible, the collected data were compared to theoretical or previously published experimental results. Also, the altitude corrections have been applied to the data points. The altitudes, as listed in Table 3.1, are the altimeter indicator readings; the actual aircraft altitude is 6 per cent higher in each case. The detected radiation intensities have not been corrected for the background content. The strength of the Co^{60} point source was 1.2 curies, and that of the Cs^{137} was 1.72 curies.

Figures 3.1 and 3.2 show the normalized count rate over the array for Co^{60} and Cs^{137}, respectively. The solid line in each figure represents the theoretical results provided by the Project Services Group at the Santa Barbara Laboratory of EG&G; the data points are those taken with the ARMS apparatus over the source arrays. The experimental results of Fig. 3.1 show good agreement with the predicted curve. The data points of Fig. 3.2, however, indicate a slightly different slope than that of the calculated curve.

Figure 3.3 illustrates the count rate as a function of altitude over the point sources. The solid curve in each case has been placed as the best-fitting curve represented by the data. Figure 3.4 is again obtained from the point-source data. The normalized count rate multiplied by the altitude is plotted against the altitude so that the slopes exhibited by the curves are proportional to the gamma absorption coefficients for the Cs^{137} and Co^{60} gamma energies. The solid curves are those published by Davis and Reinhardt[2] from experimental data, and the slope has been corrected for the difference in air density between Oak Ridge and Las Vegas. Acceptable agreement is seen to exist between the results of the two independent series of measurements.

Figure 3.5 shows the experimentally determined sampling times required to give an equivalent 500-ft altitude count rate. Ratios of the 1-sec count data at each altitude to the 1-sec count rate at 500 ft were used to obtain these data. The solid curve is again the best-fitting curve represented by the data. In Fig. 3.6 the solid curve is the sampling times required to give the 500-ft equivalent readings as derived from the published data of Davis and Reinhardt.[2] The data points in this figure were obtained from the ARMS radiation measurement results over the source array. They are simply the count ratios obtained from the "Run" to "Calibrate" sampling positions. Figure 3.7 shows the agreement between the experimentally determined gating times required (Fig. 3.5) and the gating times actually measured (data points of Fig. 3.6). It is concluded from the data presented in these figures that the radiation sampling times exhibited by the altitude-compensating control circuitry are as required, as determined from two independent sets of experimental measurements.

3.3 AREA RESULTS

The radiation measurements obtained in flying over the point sources were used to gain information concerning the ground area "seen" by the crystal detector. As the aircraft approached the point source, the count rate began increasing, reaching a maximum when the plane was directly overhead and decreasing as the source became farther away from the rear of the aircraft. The resulting radiation-intensity curve vs. distance is bell shaped and symmetrically positioned about the source. Since a series of such curves was obtained at various altitudes, it was possible to plot the radiation intensity at different ground distances from the source as a percentage of the maximum intensity directly overhead as a function of altitude above terrain. From this information the extent of the ground coverage of the detector was determined in terms of the fractional contribution to the total intensity recorded and as a function of altitude. The ground distances give a measure of the coverage on each side of the aircraft as well as fore and aft. Figure 3.8 shows the results of this study; the diameter of the circular area seen and integrated by the radar altimeter beam has been superimposed on the figure. The curves of Fig. 3.8 are to be interpreted as showing the diameter of the ground circle viewed by the crystal for the corresponding percentage contribution to the total count recorded. This, of course, assumes that a flat, homogeneous infinite plane gives 100 per cent of the detected count. At the 500-ft survey altitude, Fig. 3.8 shows that the area integrated by the radar altimeter to provide sampling-gate control nearly corresponds to the ground area that provides 90 per cent of the recorded radiation level.

3.4 CRYSTAL-SENSITIVITY RATIO

Runs over the array and point-source locations were performed with both the high-sensitivity and low-sensitivity crystals. Data with the small crystal were taken at altitudes of 100, 300, 500, and 700 ft. With these data corrected for background content, the ratio of the detection sensitivities was calculated. A total of 65 pieces of data was used; the resulting ratio of the large crystal response to the small crystal response was 190 ± 3 to 1. The standard deviation represents an uncertainty of ±1.6 per cent of the ratio value. In terms of the actual count-rate range of the system, the large-crystal count-rate equivalent extends from 50 to approximately 10^7 counts/sec.

3.5 DETECTION SENSITIVITY

So that the count recorded in the aircraft could be converted to information concerning ground contamination levels, the activity from the small radiation sources was considered to be homogeneously distributed over the entire array in such a way that the total curie strength remained unchanged. Since Fig. 3.8 indicates that from the center of the array the source field appears to be an infinite plane to the aircraft detector at 500 ft above the ground, the error introduced by the above assumption is small. In the case of the Co^{60}, therefore, the detector is essentially viewing an infinite homogeneous plane of radiation whose intensity is 0.45 μc/sq ft; that of the Cs^{137} appears to be 1.5 μc/sq ft. The average maximum count rates at 500-ft over the center of the array were 4400 counts/sec for the Co^{60} and 5600 counts/sec for the Cs^{137}.

If 50 counts/sec is arbitrarily selected as the lower limit of detection of the apparatus, the minimum ground concentrations measurable are 0.0051 μc/sq ft of Co^{60} and 0.0137 μc/sq ft of Cs^{137}. Similarly, with the aid of the data presented by R. M. Johnson earlier for his 4-in. by 2-in. detector, a Co^{60} dose rate of 1 mr/hr at the 3-ft level would correspond to a count rate in the EG&G apparatus of 2.2×10^4 counts/sec at 500 ft and a count rate of 2.5×10^4 counts/sec for a ground-level dose rate of 1 mr/hr due to Cs^{137} gamma rays.

REFERENCES

1. *Aerial Radiological Monitoring System, Phase IIIA,* Edgerton, Germeshausen & Grier Report No. S-26, Jan. 25, 1961.
2. F. J. Davis and P. W. Reinhardt, *Nuclear Sci. and Eng.,* 2: 713 (1957).

Table 3.1—COUNT-RATE SUMMARY OF NTS SOURCE-CALIBRATION RANGE

Altitude, ft	Count rate: 1-sec gate, counts/sec	Count rate: Altitude-compensated gate (total count)	Background count rate (1-sec sample time), counts/sec
	Co^{60} Array		
200	10,700		2,200
300	9,000	6,000	1,600
400	7,300	6,200	1,470
500	6,000	6,000	1,400
600	4,900	6,500	1,370
700	4,200	6,600	1,300
800	3,400	7,100	1,200
900	3,000	7,700	1,200
	Co^{60} Point Source		
200	40,000		1,700
300	24,000	19,000	1,500
400	17,000	14,500	1,400
500	10,000	10,500	1,300
600	8,000	10,000	1,200
700	5,500	7,900	1,100
800	4,100	8,000	1,100
900	3,300	8,400	1,100
	Cs^{137} Array		
200	13,600		2,200
300	10,500	7,500	1,600
400	8,800	7,500	1,470
500	7,200	7,300	1,400
600	5,100	7,200	1,370
700	4,300	6,900	1,300
800	3,600	7,500	1,200
900	3,100	7,800	1,200
	Cs^{137} Point Source		
200	32,600		1,700
300	18,000	16,000	1,500
400	10,200	8,800	1,400
500	6,600	7,000	1,300
600	4,750	5,800	1,200
700	3,300	5,200	1,100
800	2,700	5,300	1,100
900	2,200	5,400	1,100

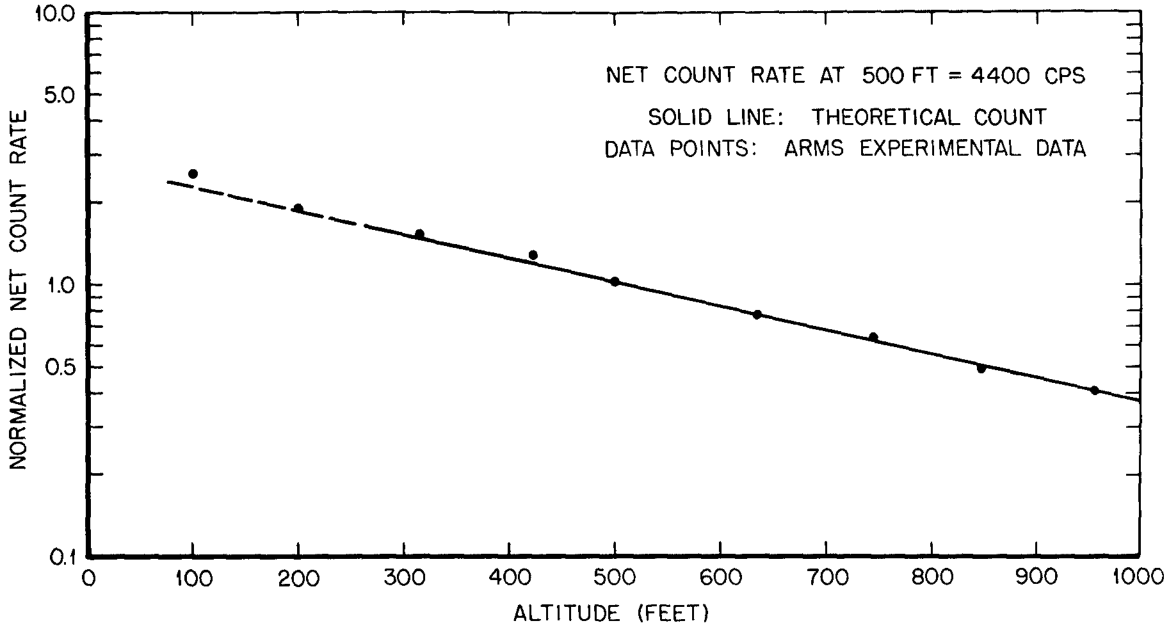

Fig. 3.1 — Co^{60}-array normalized count rate vs. altitude.

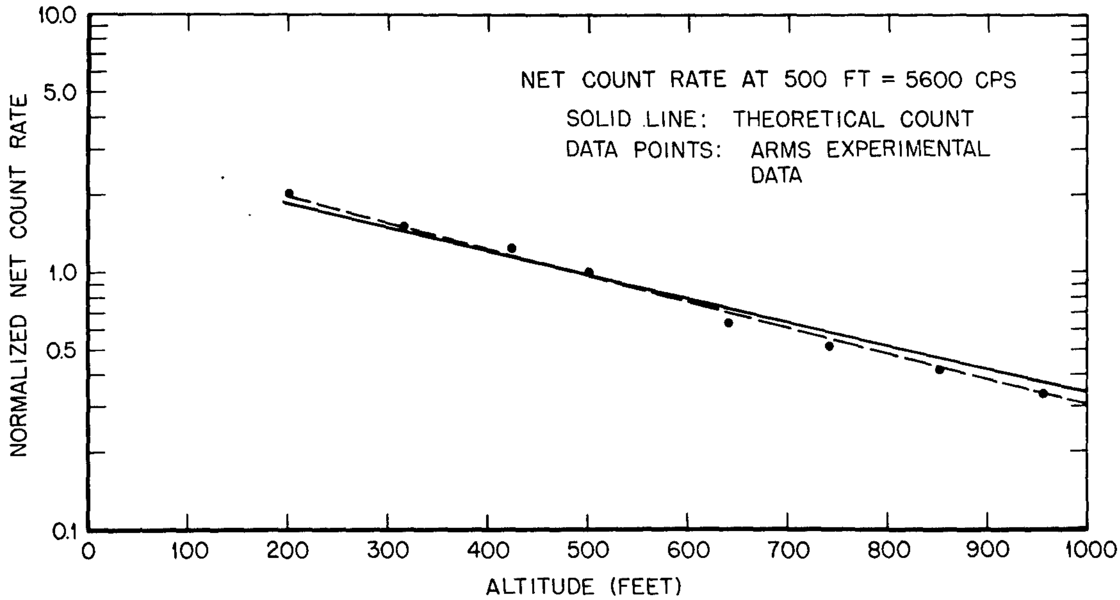

Fig. 3.2 — Cs^{137}-array normalized count rate vs. altitude.

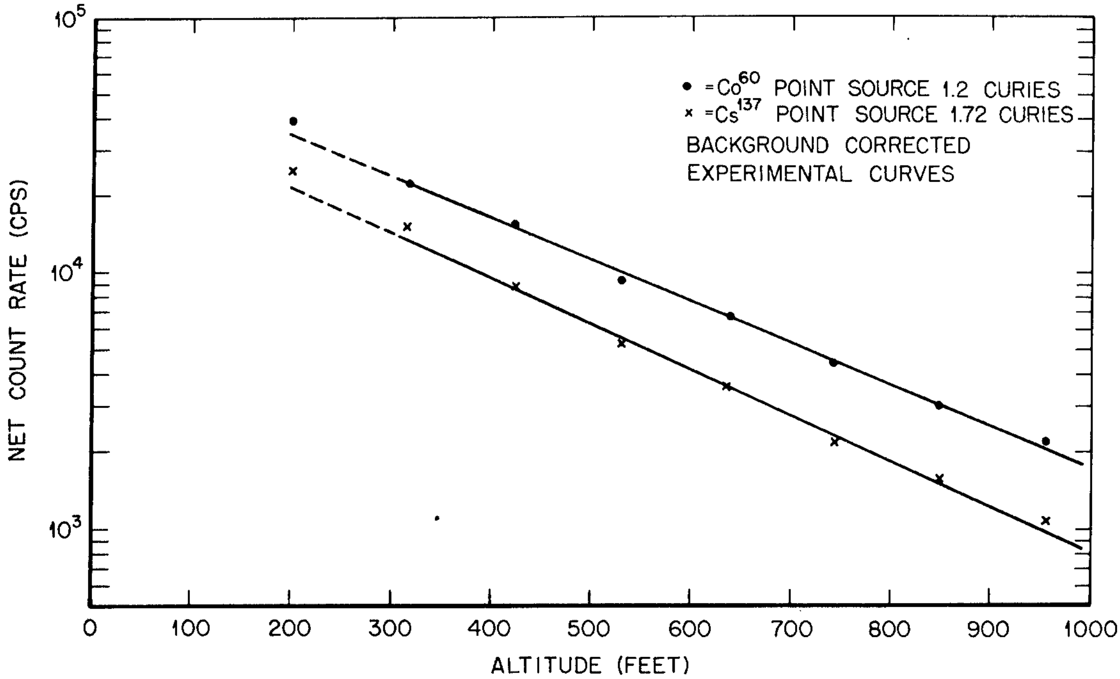

Fig. 3.3 — Count rate vs. altitude for point sources.

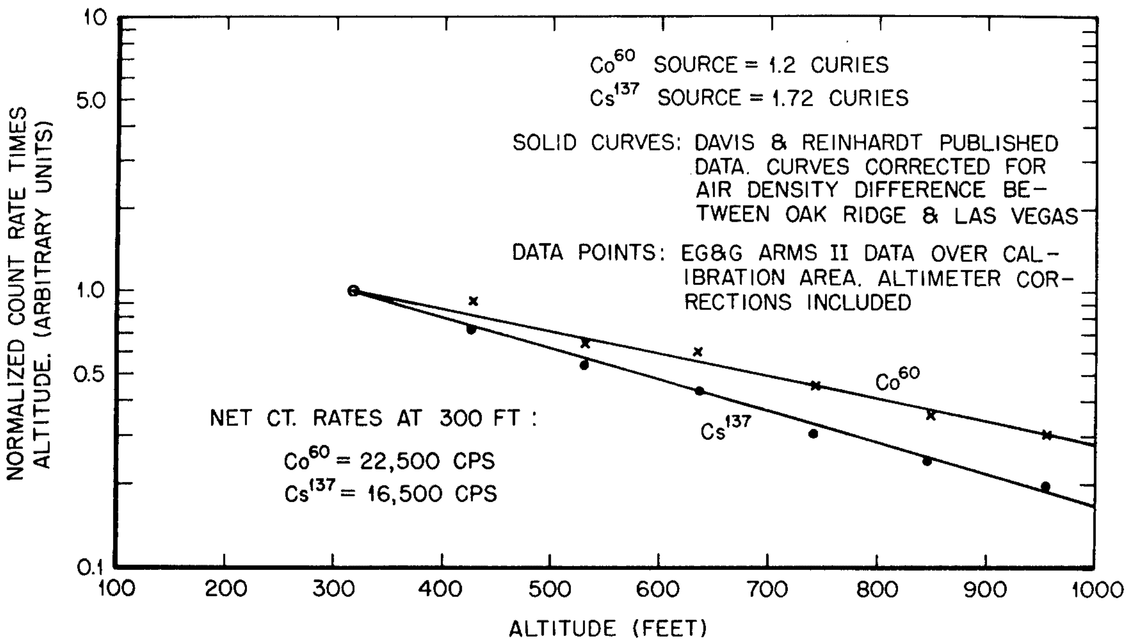

Fig. 3.4 — Point-source radiation vs. altitude.

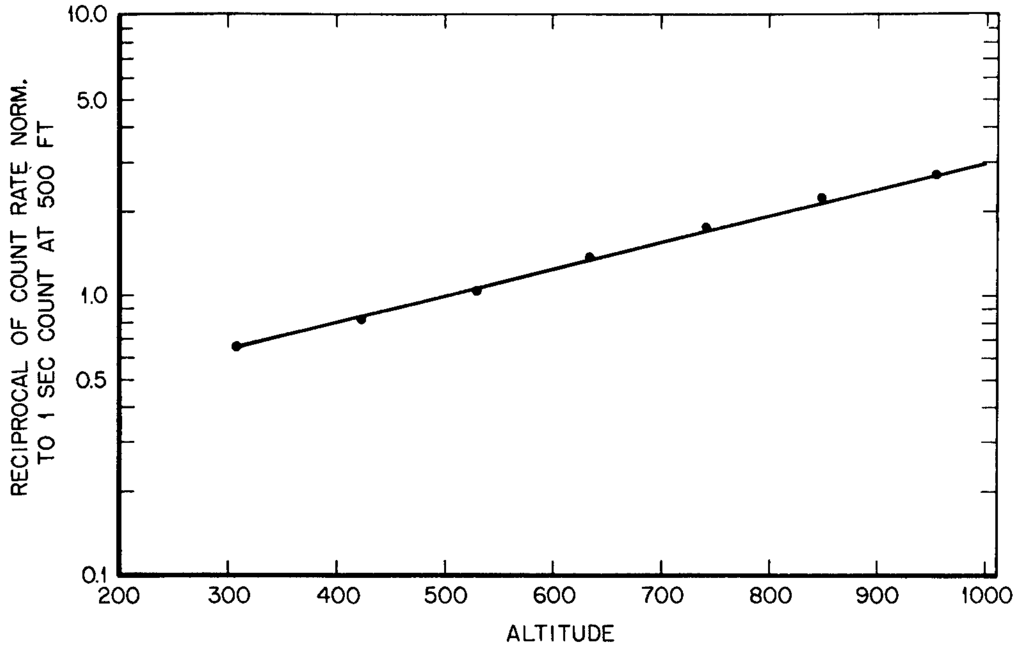

Fig. 3.5 — Experimentally determined gate-open times required to give equivalent 500-ft-level counts.

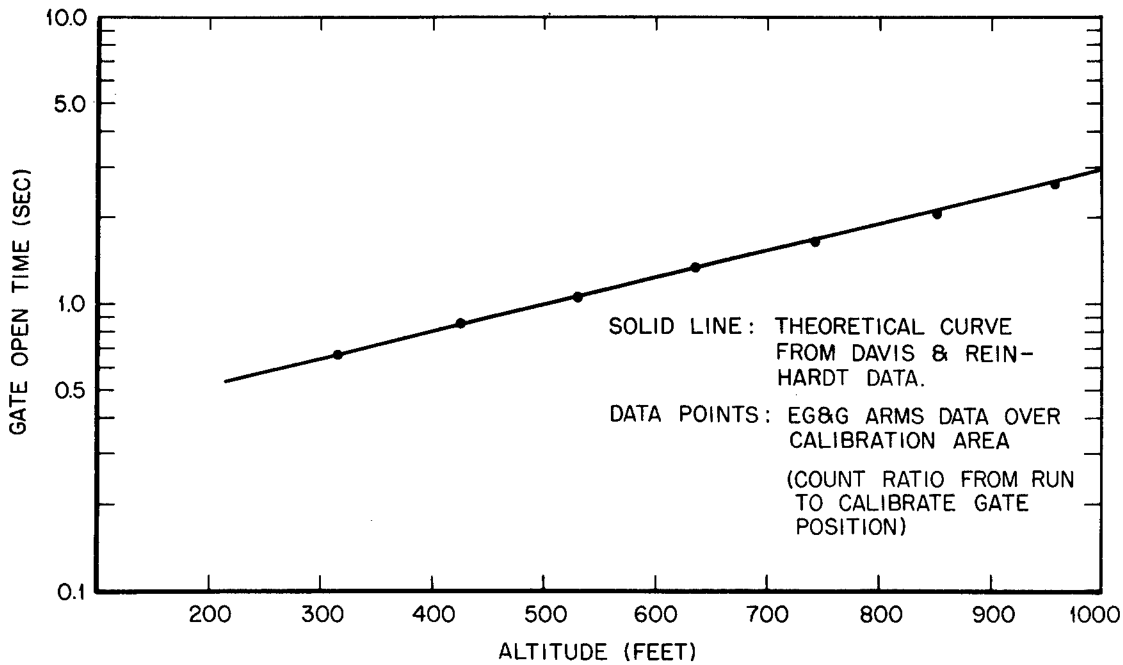

Fig. 3.6 — Gate-open time vs. altitude. (Comparison of experimental points to theoretical.)

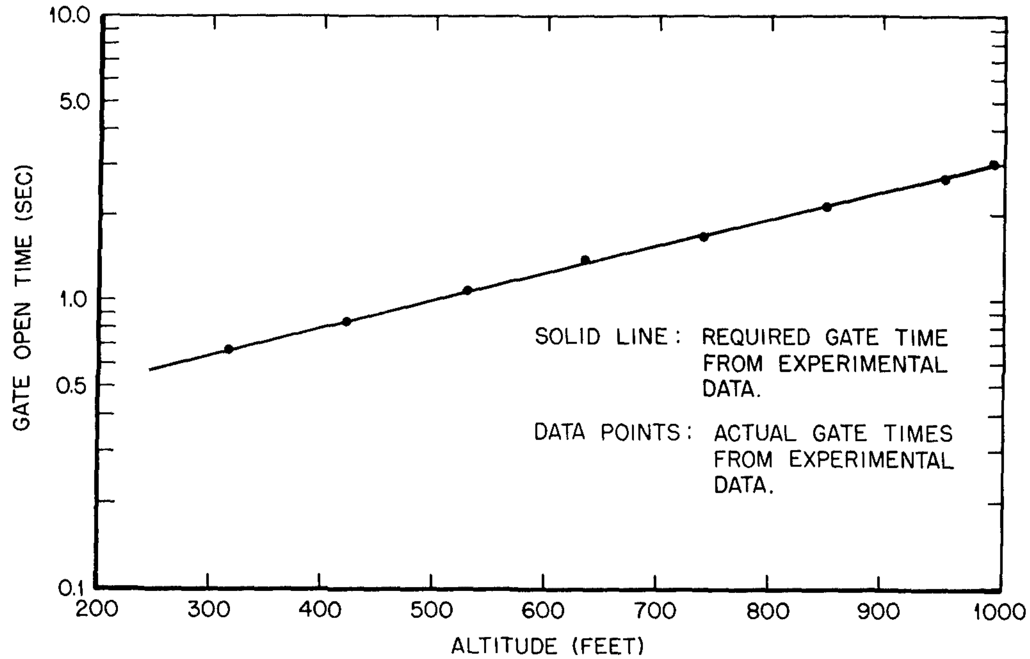

Fig. 3.7—Gate-open time vs. altitude.

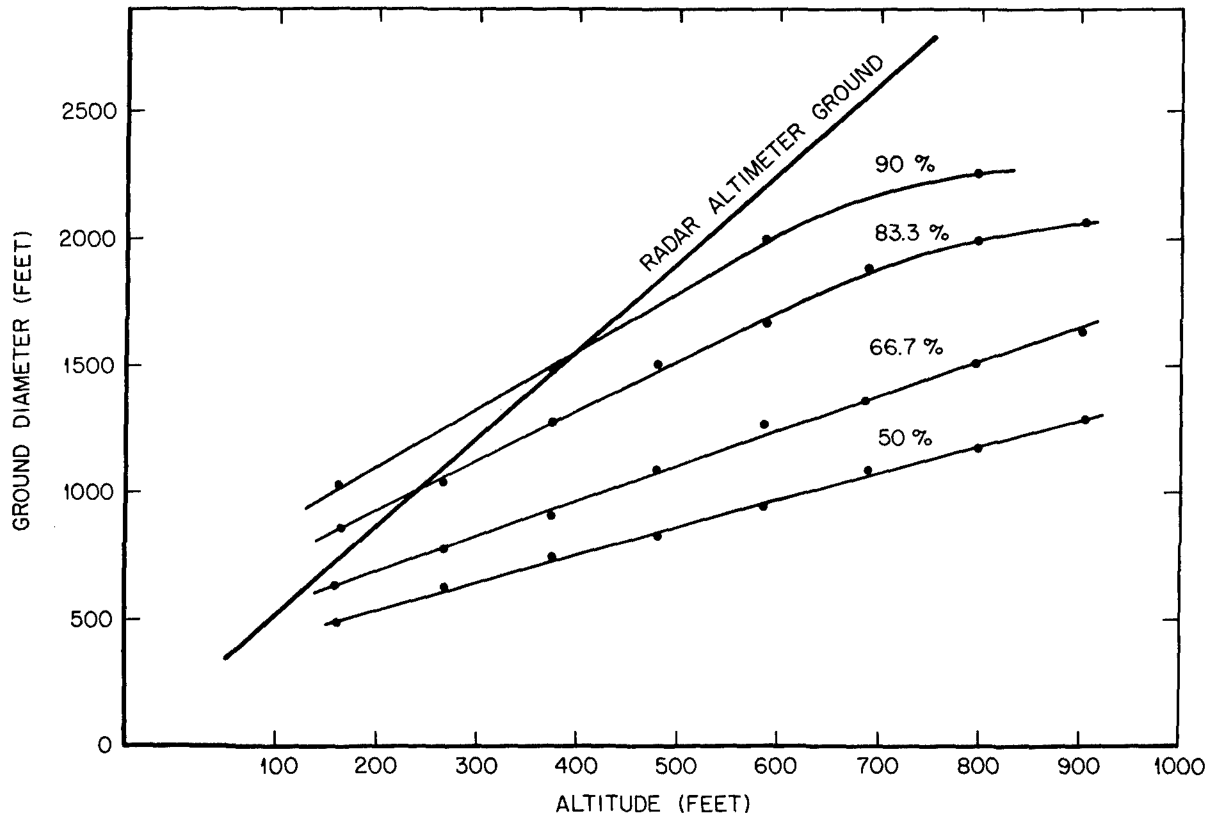

Fig. 3.8—Altitude vs. area "seen" by large crystal on ground.

Chapter 4

AERIAL MEASUREMENTS–PROJECT 60.3.3

D. M. Davis and H. H. Abee, Oak Ridge National Laboratory

4.1 INTRODUCTION

The basic purposes of ORNL Applied Health Physics participation in Project 60.3 were (1) to test current aerial survey instruments for operation under field conditions, (2) to determine the relation of point-source readings to readings from an extended source, and (3) to determine the most feasible altitude for aerial survey work with reference to instruments available.

To a degree the above purposes were accomplished. However, because of instrument battery failure (an item of major concern since this is an emergency instrument), some unfavorable weather, and the location of the array of sources near high background areas, some additional local tests are probably desirable to establish the best values for emergency purposes.

4.2 INSTRUMENTATION

The basic instrument used in the ORNL Applied Health Physics phase of the program is shown in Fig. 4.1; its circuit diagram is shown in Fig. 4.2. Major design objectives for the instrument were to provide (1) analyses of 0.25- to 1.0-Mev gamma fields of low intensity, (2) portability and compactness, (3) simplicity of circuit design for easy adjustment and servicing, (4) capability for driving a portable 1-ma recorder, and (5) capability of operation in temperatures ranging from 0 to 45°C. The instrument features include (1) completely transistorized circuitry, (2) power for rechargeable nickel–cadmium cells, (3) 2- by 3-in. NaI-crystal detector, (4) 14-stage photomultiplier tube, and (5) upper and lower pulse-level discriminator. The instrument is, therefore, a portable recording single-channel gamma analyzer. Its weight, less recorder, is 10 lb.

Two nonrecording type portable instruments were checked, but data from these instruments were of little value.

4.3 AIRCRAFT

The aircraft used was a single engine Cessna 172. It was rented from the Alamo Airways Corporation, Las Vegas, Nev., and no modifications were made to the aircraft for this aerial survey work. The altitude was known by a barometric altimeter only. Because the altimeter was set from data available at the Las Vegas airport, the estimated height above the sources may be off by several feet. The cruising speed of the aircraft was about 115 mph.

4.4 DATA

Nonrecording GM survey type instruments proved to be of minimum value for precise aerial surveys. Instruments of this type may prove of some value in locating high-intensity point sources, but for general ground contamination more sensitive instruments (recording instruments) are required.

Measurements over the sources, point and array, are shown in Figs. 4.3 through 4.5. Typical charts from flights over the source are shown in Figs. 4.6 and 4.7.

4.5 DISCUSSION

According to calculations from the data plotted for cobalt with the instrument in the integrated position, at about 300 ft a 0.48-curie cobalt source is equivalent to 0.5 μc of Co^{60}/sq ft, or a 1-curie source of Co^{60} is equivalent to an array of about 1 μc/sq ft.

According to the calculations from the data plotted for cesium with the instrument in the differential position, at 300 ft a 0.6-curie Cs^{137} source is equivalent to 1.65 μc/sq ft, or a 1.0-curie Cs^{137} source is equivalent to an array of about 2.75 μc/sq ft.

An extrapolation from the relation of mass absorption coefficients for Co^{60} and I^{131} makes it appear that at about 500 ft, 1 curie of iodine is equivalent to 1 μc/sq ft of iodide. According to the reports from the Windscale incident, in terms of tolerance a point source of 100 mc of I^{131} would be equivalent in reading at 500 ft above the ground to a maximum permissible amount of iodine over a large area.

4.6 CONCLUSIONS

The following conclusions have been drawn from these preliminary data:

(1) For precise aerial surveys an instrument similar to the one in Fig. 4.1 is desirable.

(2) Aerial surveys should normally be made between a minimum altitude of 300 ft and a maximum of 500 ft.

(3) For general survey purposes the instrument should be used in the integrating position.

(4) Routine background survey should continue; at least one flight per quarter should be made.

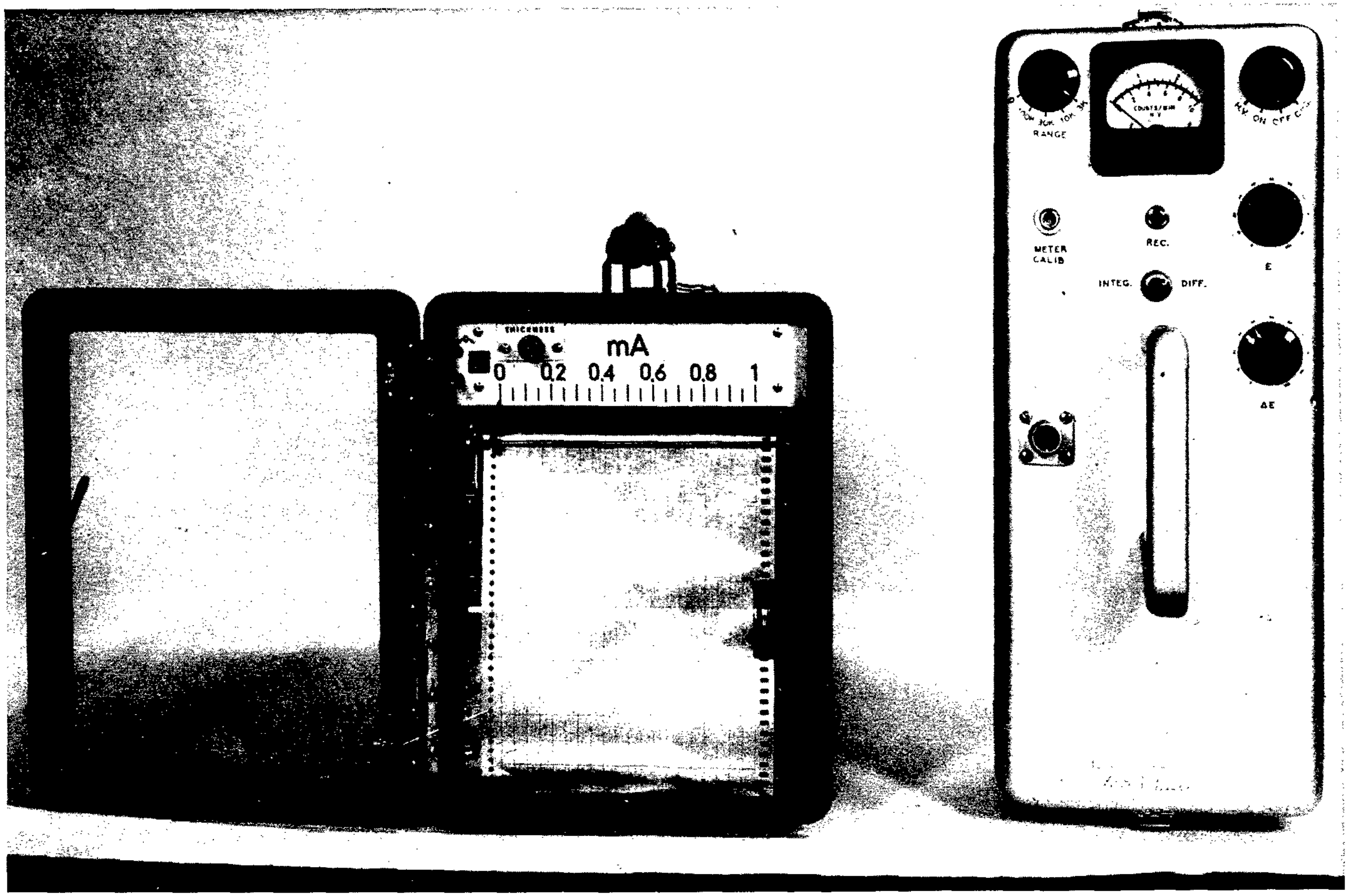

Fig. 4.1— Portable single-channel gamma monitor.

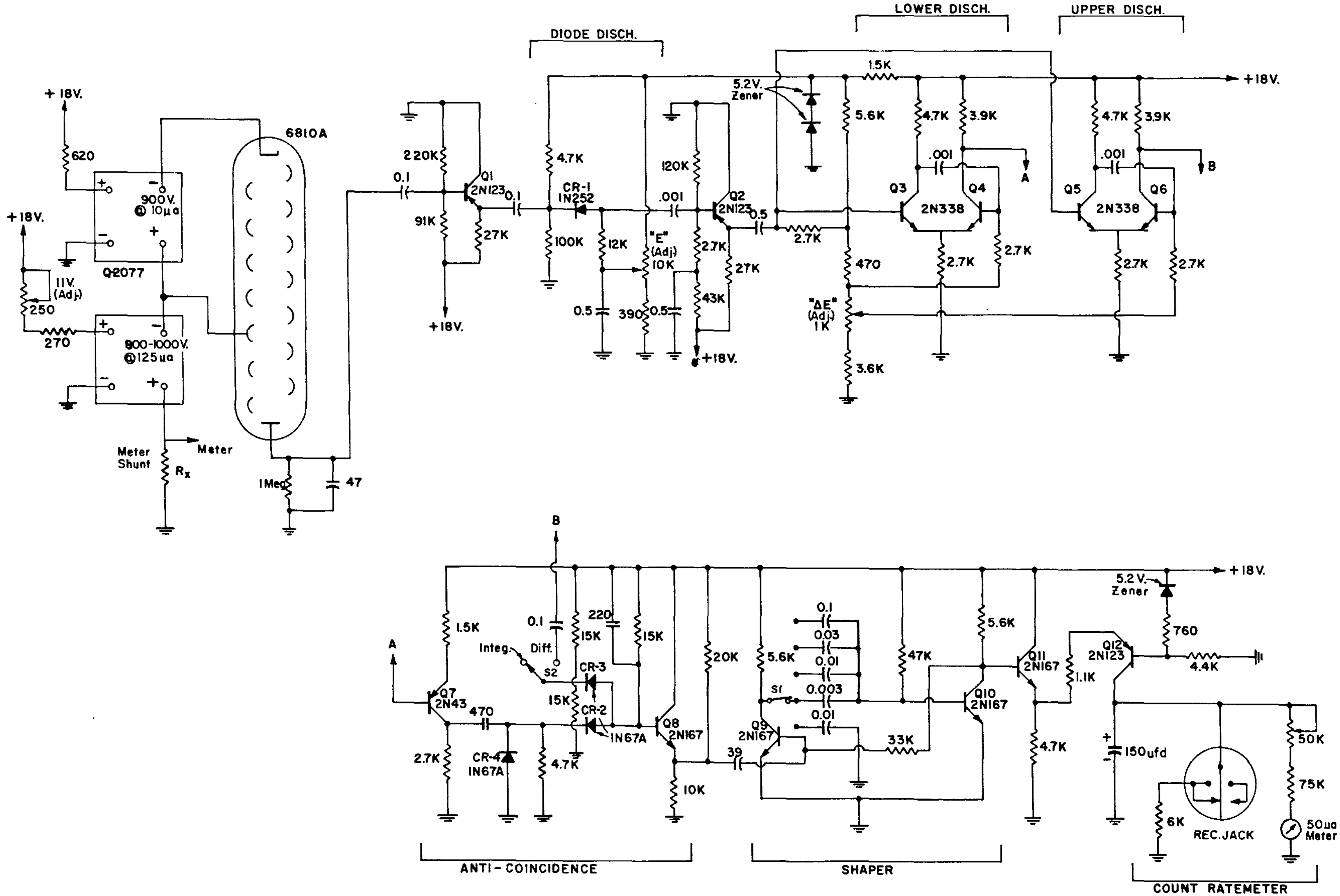

Fig. 4.2—Circuit diagram of portable single-channel gamma monitor.

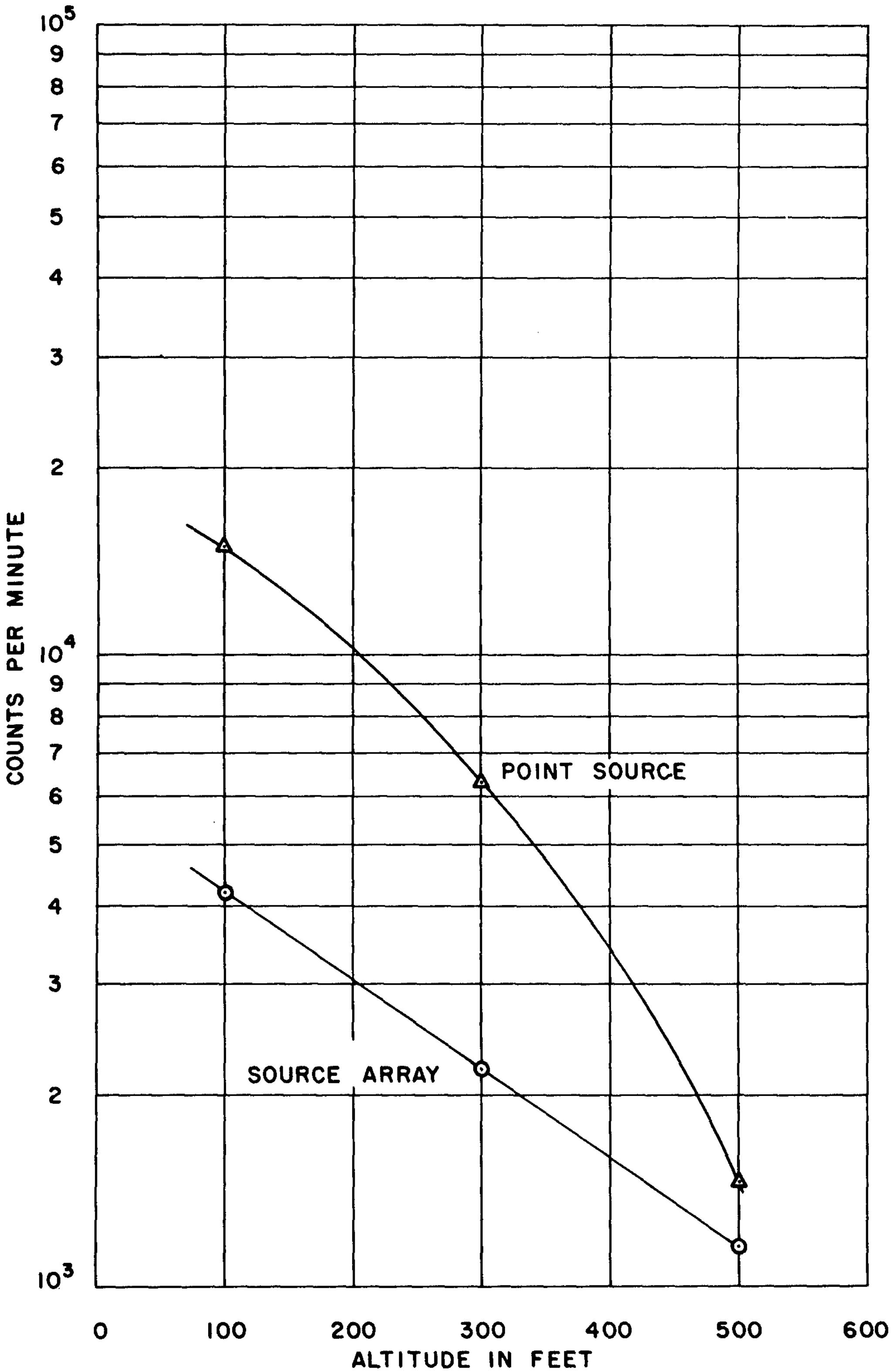

Fig. 4.3—Differential reading of Cs^{137} run Nov. 3, 1960.

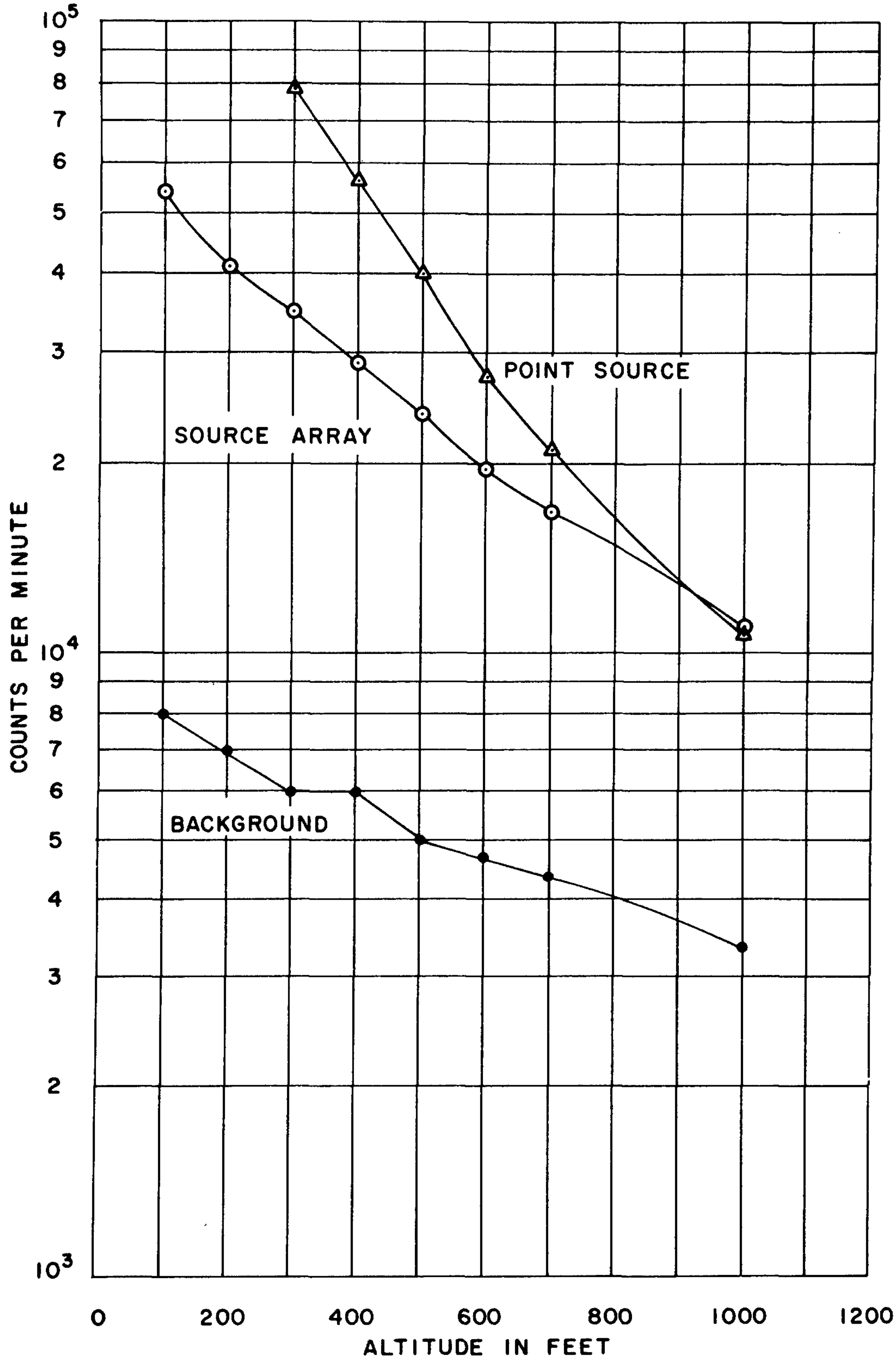

Fig. 4.4—Integrated reading of Co^{60} run Nov. 4, 1960.

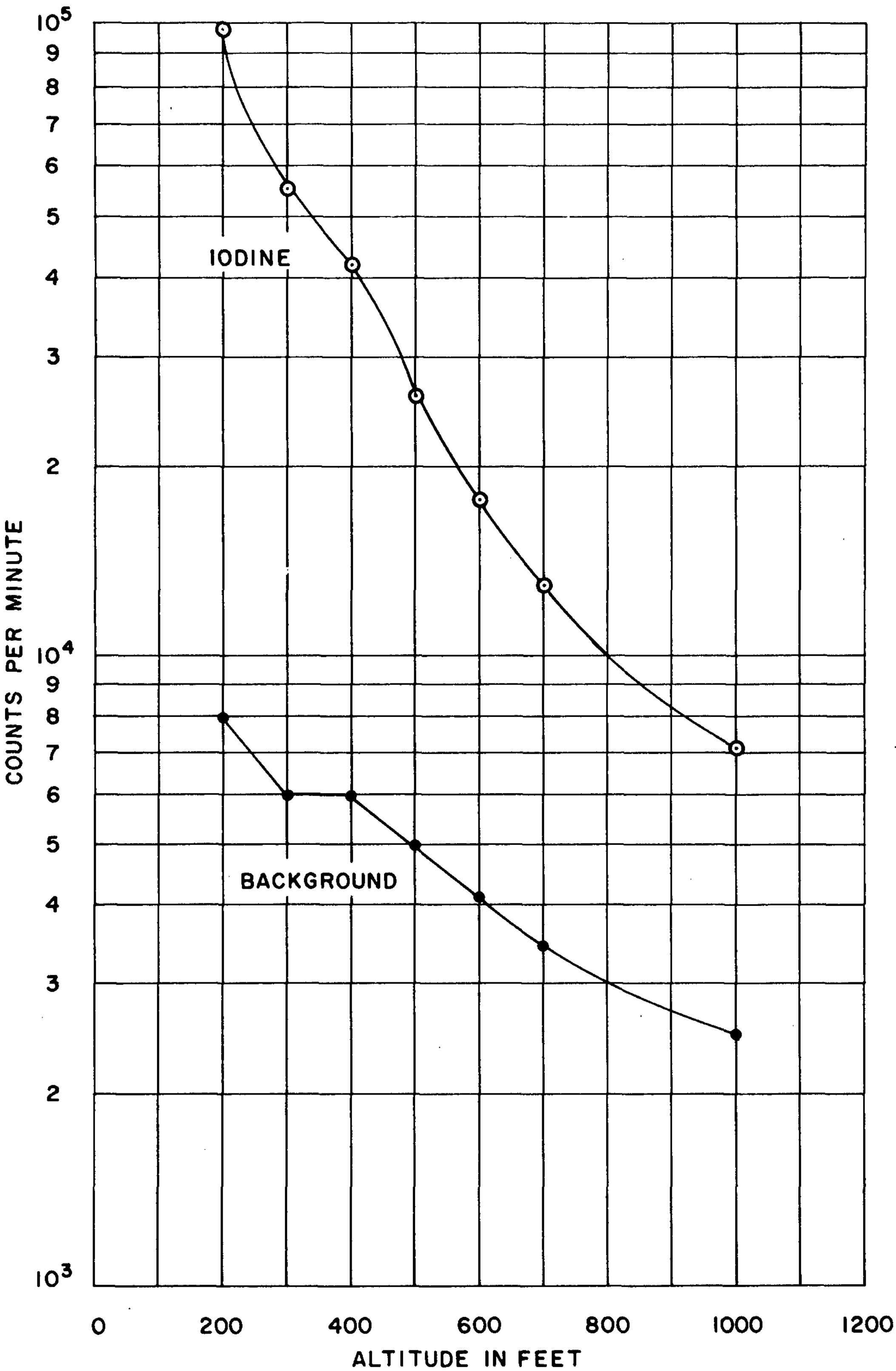

Fig. 4.5—Integrated reading of I^{131} run Nov. 4, 1960.

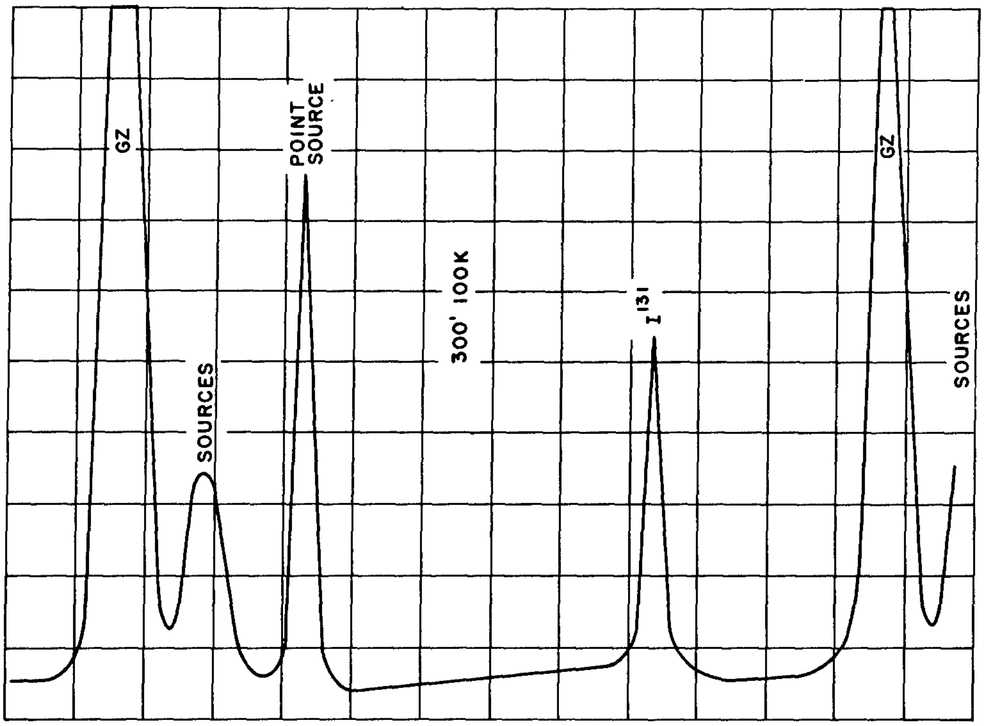

Fig. 4.6 — Typical flight over Co^{60} source.

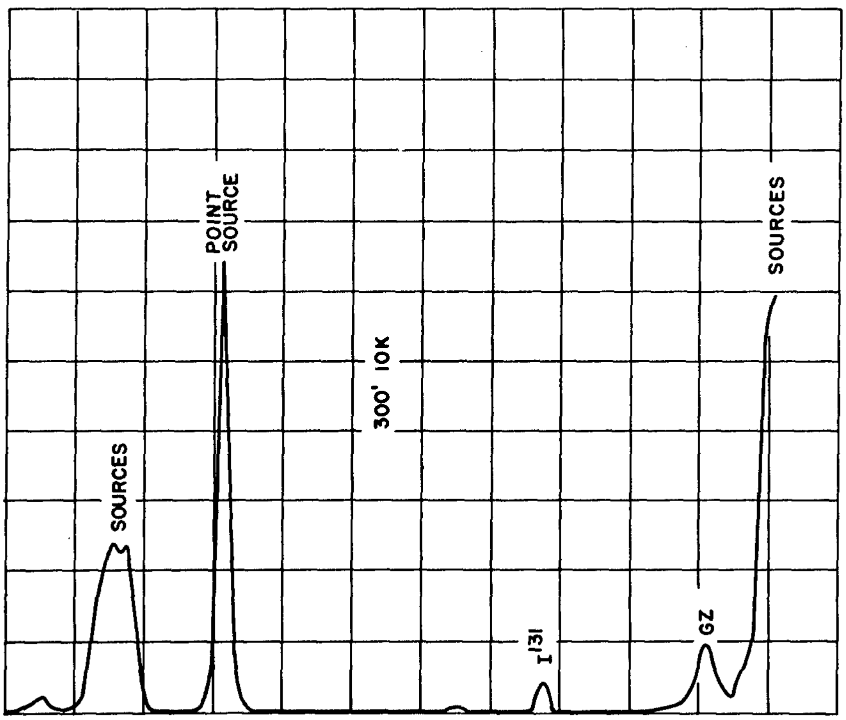

Fig. 4.7 — Typical flight over Cs^{137} source.

Chapter 5

AERIAL MEASUREMENTS–PROJECT 60.3.4

John A. Harper and R. V. Studley, Savannah River Plant
K. K. Brown, Savannah River Operations Office

5.1 PURPOSE

The goal of Savannah River effort was to calibrate a sensitive mobile gamma scintillometer for use in aerial survey.

5.2 SUMMARY

Curves for use in the aerial survey of large land areas in cases of contamination were developed. The instrument was limited in the detection of radioiodine contamination of less than 1 $\mu c/m^2$ in the background range of 400 to 600 counts/sec. In the case of a major release of radioactivity, however, the deposition will contain a number of other detectable gamma emitters. If the release were from a reactor, much would depend on the irradiation history of the fuel. In such a case, because of the many higher energy emitters, an aerial survey with this instrument would provide a fast means of delineating problem areas for better direction of ground survey teams.

5.3 DISCUSSION

The mobile gamma scintillometer is a specially designed instrument for environmental monitoring. It is sensitive to low levels of gamma radiation and is usable in a car, boat, or light plane. It makes use of a 5-in.-diameter by 4-in.-thick NaI(Tl) crystal, a 5-in. photomultiplier tube, and transistorized electronics. The readout is an Esterline-Angus recorder. The time constant for the system, a function of the recorder response, is 0.625 sec. No shielding is employed in the instrument.

The calibration procedure consisted of a number of flights, or passes, over the area at various altitudes to establish background. Flights were then carried out over the different isotopes in turn. For each calibration point the flight plan called for at least three acceptable passes at altitudes of 100, 300, 500, and 1000 ft at a ground speed of 140 mph. In this plan time over the array was 10 sec, and the array approximated an infinite source. The altitudes were measured above the 3100-ft elevation of the sources by the aircraft's altimeter (and pilot's judgment) and are approximated to be ±40 ft.

During initial use and in the collection of background data, variances were observed in recorded values between scales on the instrument. A checkout of the electronics of the equipment confirmed some variation between scales, and a correction of observed count rate to absolute count rate as plotted in Fig. 5.1 was required. On later analysis of data, however, it was necessary to apply an additional correction factor to readings on the 2500 counts/sec scale. This factor was obtained by correlation between scales where data overlapped during the calibration. The background of the area was variable because the GZ of a weapons test in 1958 was located approximately 4000 ft from the array, and this affected readings (Fig. 1.3). See the background data in Table 5.1; the difference between the array (averaged across array) and point-source locations should be noted.

Calibration data for the various sources are summarized in Tables 5.2 and 5.3 and plotted in Figs. 5.2 and 5.3. The iodine response in Fig. 5.2 was obtained from the ratios of the I/Cs and I/Co (counts/sec/curie) point sources applied to extended-source response (counts/sec/ $\mu c/m^2$).

The precision of these measurements depends on the statistics of the count rate, background level, and aircraft altitude. Since the results are based on the average of a number of passes, in most cases only the standard deviation of the count rate is considered, $\pm$ (count rate/2 $\times$ time constant)$^{1/2}$. If the recorder trace is averaged, an increase of four times the standard deviation on the 1000 counts/sec scale should be detectable. If the altitude remains constant at 500 ft, the $\mu c/m^2$ (infinite plane source) detectable above background is shown in Fig. 5.4 as a function of background. This relation may also be applied to localized or point sources as shown in Fig. 5.5. The percentage of error of this measurement may be taken as

$$\frac{100\sqrt{\text{total count rate} + \text{background}}}{\sqrt{2 \times \text{time constant}}\,(\text{total count rate} - \text{background})}$$

and would amount to ± 35 per cent for extended sources in the background range of 400 to 600 counts/sec. Fluctuations in aircraft altitude would cause an additional error of +7 to 10 per cent at 500 ft for ± 40 ft.

Data were also collected for the Victoreen Scintillac during the calibration runs and are shown in Table 5.4. The Scintillac responded to the calibration sources with perceptible readings (above background) up to an elevation of 1000 ft. The instrument appears to be more energy dependent than the mobile gamma scintillometer, although sensitivity to the extended sources was in ratio to that of the gamma scintillometer by size of crystals. Because of the time constant, the instrument is so erratic that it can be considered indicative only.

Table 5.1—BACKGROUND DATA

Elevation, ft	Scale	Instrument reading, %	Corrected response, counts/sec
		Extended Source or Array	
100	1000	84 (av.)*	720
300	1000	82 (av.)	700
500	1000	72†	620
1000	1000	35 (av.)	300
		Point Source	
300	1000	52 (av.)*	440
500	1000	44†	370
1000	1000	29 (av.)	240

*Average of acceptable passes.

† Only one acceptable pass on 1000 counts/sec scale, others being on 2500.

Table 5.2 — EXTENDED-SOURCE DATA

Elevation, ft	Scale	Instrument reading, %	Background, counts/sec	Corrected response, counts/sec	Counts/sec per $\mu c/m^2$
		Co^{60} (1.96 curies, 5.3 $\mu c/m^2$)			
100	10,000	79	720	5,780	1090
300	10,000	45	700	2,900	550
	2,500	63 (av.)	Gives a scale C.F. of 3		
500	2,500	45 (av.)	620	1,960	370
1,000	1,000	83 (av.)	300	420	80
		Cs^{137} (6.2 curies, 16.75 $\mu c/m^2$)			
100	10,000	78 (av.)	720	5,680	340
300	10,000	46	700	2,950	175
	2,500	105	Gives a scale C.F. of 2		
500	2,500	69 (av.)	620	1,980	120
1,000	1,000	92 (av.)	300	500	30
1,500	1,000	34	15%	140	8.4
2,000	250	74	55%	45	2.7
2,000	1,000	20	14%	50	3

Table 5.3 — POINT-SOURCE DATA

Elevation, ft	Scale	Instrument reading, %	Background, counts/sec	Corrected response, counts/sec	Counts/sec per curie
		Co^{60} (1.2 curies)			
100		Off scale			
300		Off scale			
500	2,500	76 (av.)	370	4,130	3,400
1,000	1,000	91 (av.)	240	540	450
		Cs^{137} (1.72 curies)			
100		Off scale			
300	10,000	89 (av.)	440	6,900	4,000
500	2,500	73 (av.)	370	2,430	1,400
1,000	1,000	62 (av.)	240	300	170
1,500	1,000	25	15%	80	46
2,000	1,000	16	12%	30	17
		I^{131} (2 curies as of 10:00 a.m., Nov. 1, 1960)			
100		Off scale			
300	10,000	62	440	4,560	2,800
500	2,500	54 (av.)	370	1,630	990
1,000	1,000	46 (av.)	240	150	96

Table 5.4 — DATA USING VICTOREEN SCINTILLAC*

	Point sources†				Extended sources‡		
Elevation, ft	1.72 curies cesium, counts/min	1.2 curies cobalt, counts/min	1.65 curies iodine, counts/min	1.56 curies iodine, counts/min	16.75 $\mu c/m^2$ cesium, counts/min	5.3 $\mu c/min^2$ cobalt, counts/min	Background, counts/min
100	Off scale	Off scale		40,000	30,000	25,000	1,000–1,500
300	25,000	30,000		9,000§	20,000	8,000§	1,500–2,000
500	8,000	8,000	4,500	4,000	5,000§	7,000	1,500–2,000
1000	2,500	3,000			3,500	2,500	1,000–1,500

* Model 645 with a 587J probe, using a $1\frac{1}{4}$- by $1\frac{1}{2}$-in. NaI(Tl) crystal. Readings were taken at altitudes noted at a ground speed of 140 mph with the instrument on time constant 0.5.

† Maximum instantaneous reading recorded, which may be low due to slow time response of instrument.

‡ Instrument response erratic because of time constant; maximum deflection recorded.

§ Data do not appear to fit expected response.

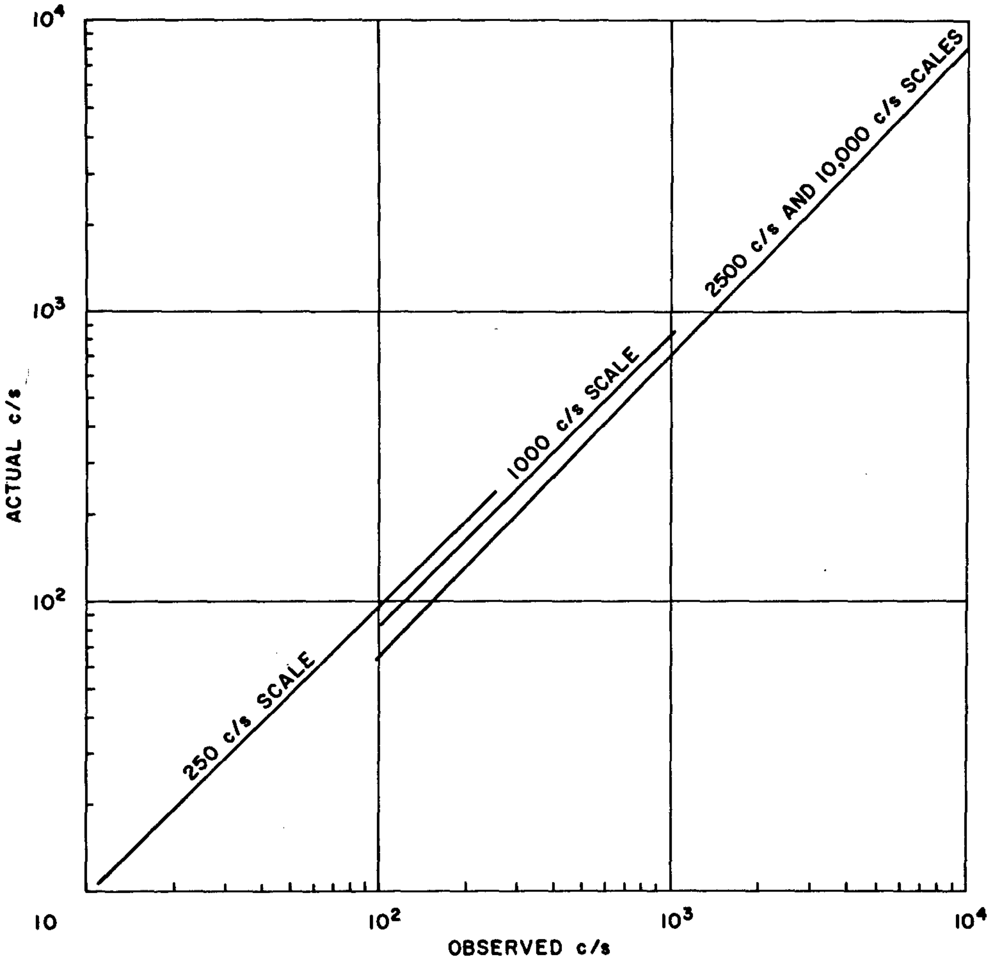

Fig. 5.1 — Absolute calibration of mobile gamma scintillometer.

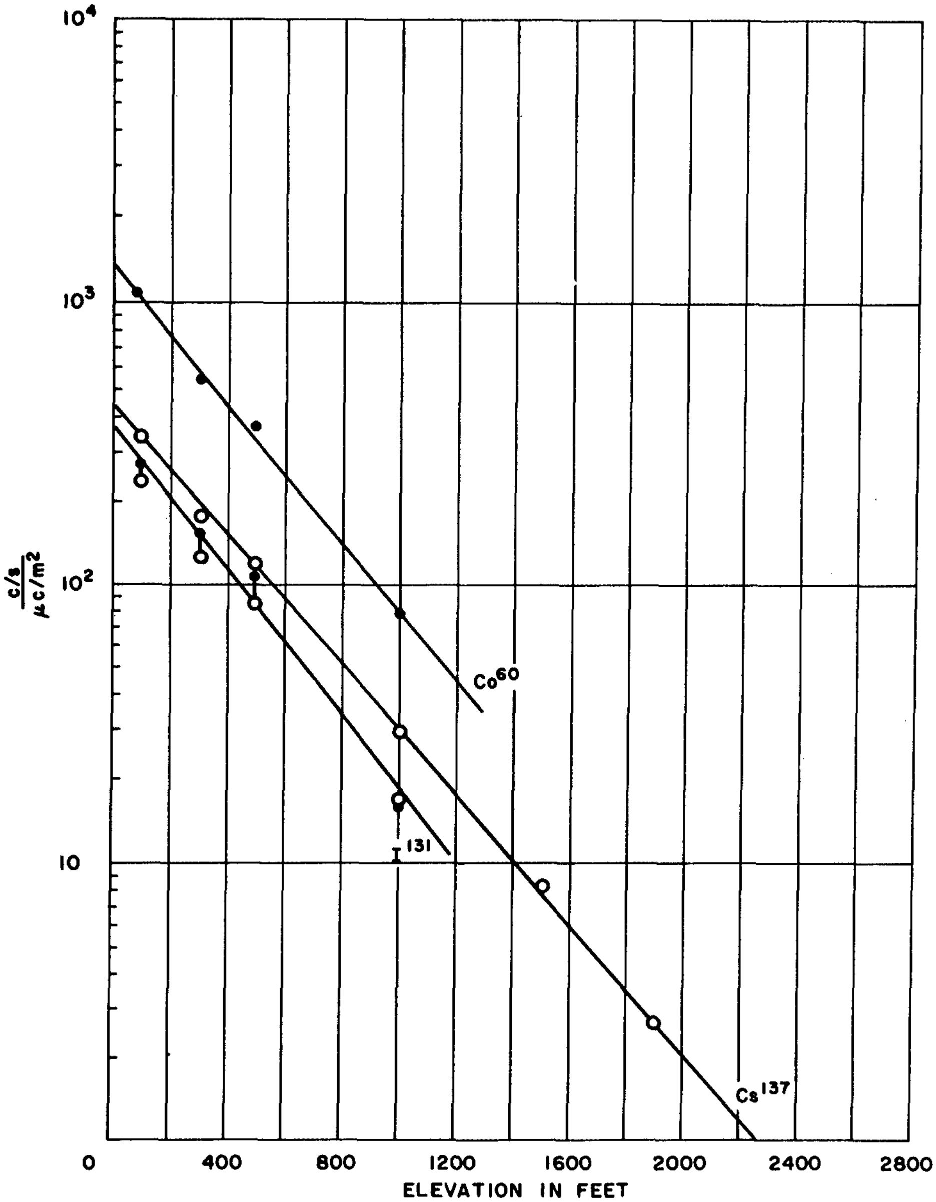

Fig. 5.2 — Mobile gamma-scintillometer calibration for extended sources.

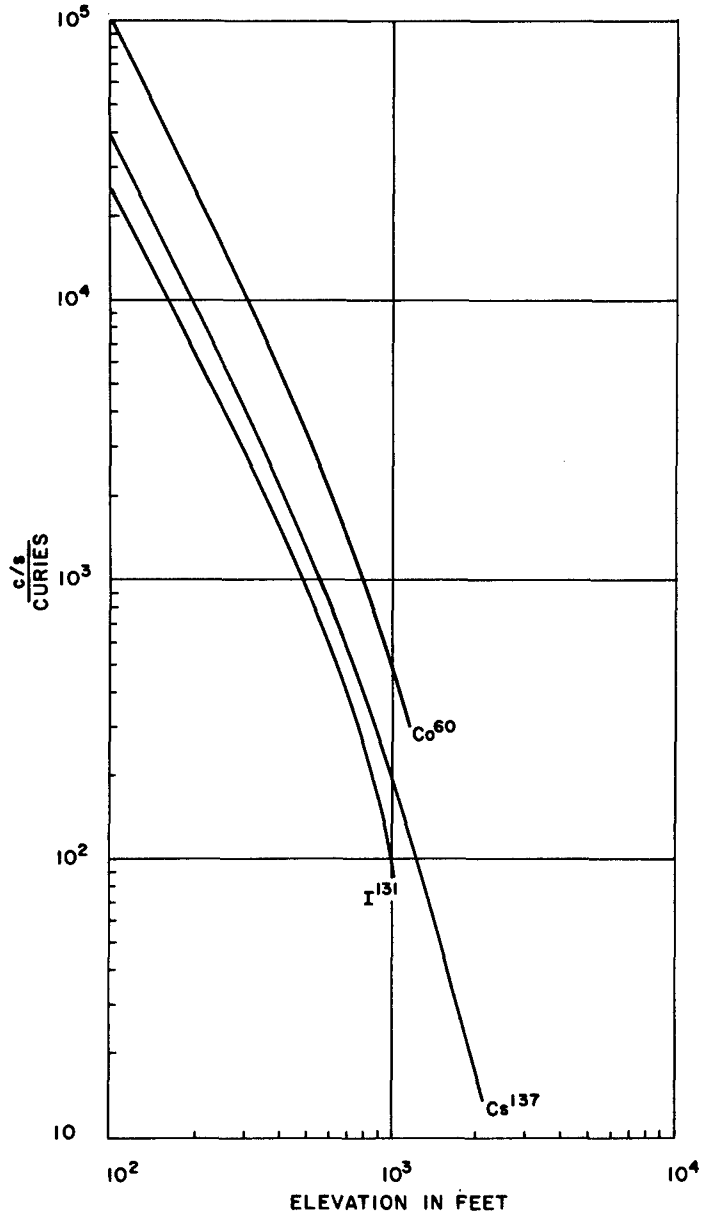

Fig. 5.3 — Mobile gamma-scintillometer calibration for point sources.

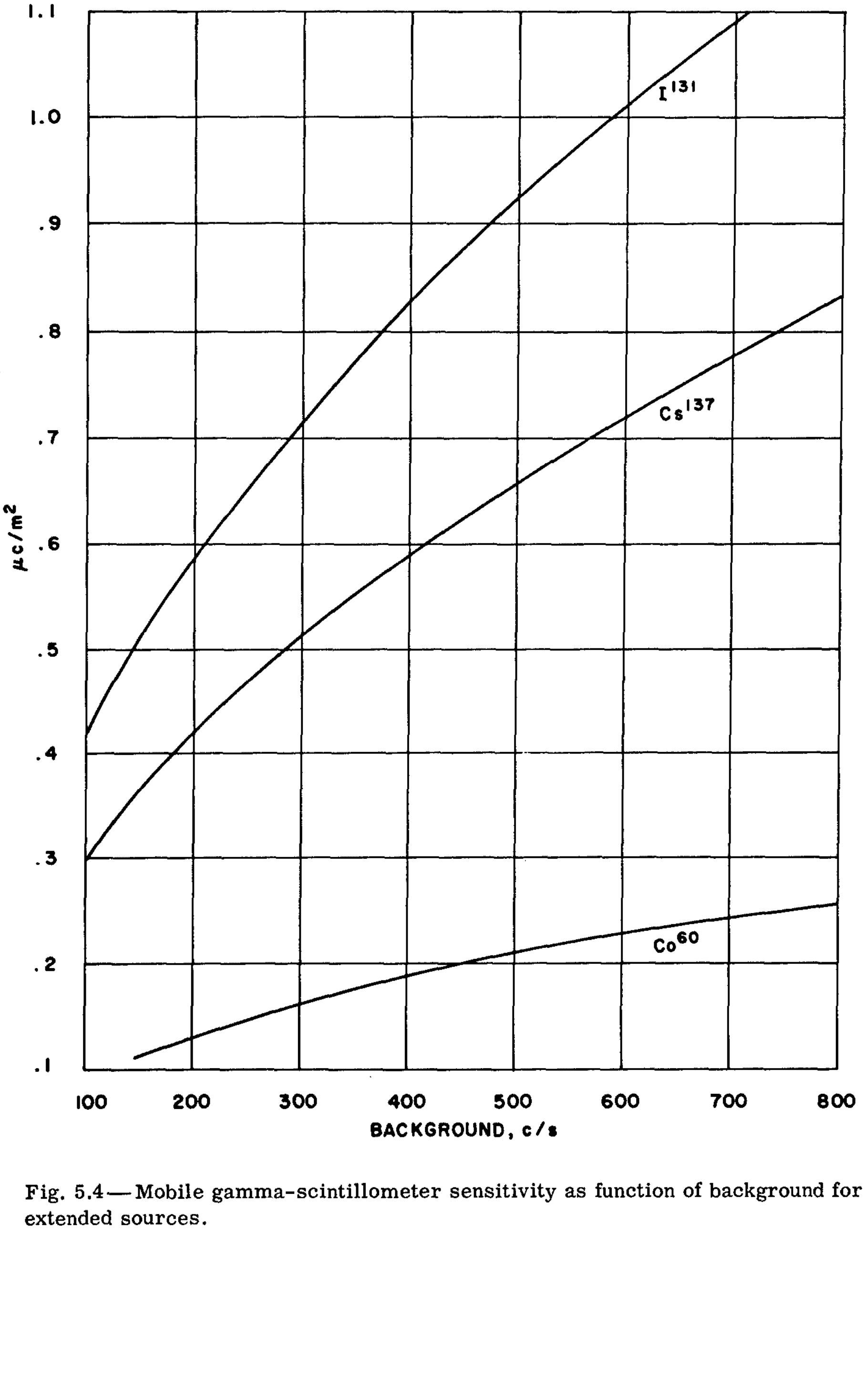

Fig. 5.4—Mobile gamma-scintillometer sensitivity as function of background for extended sources.

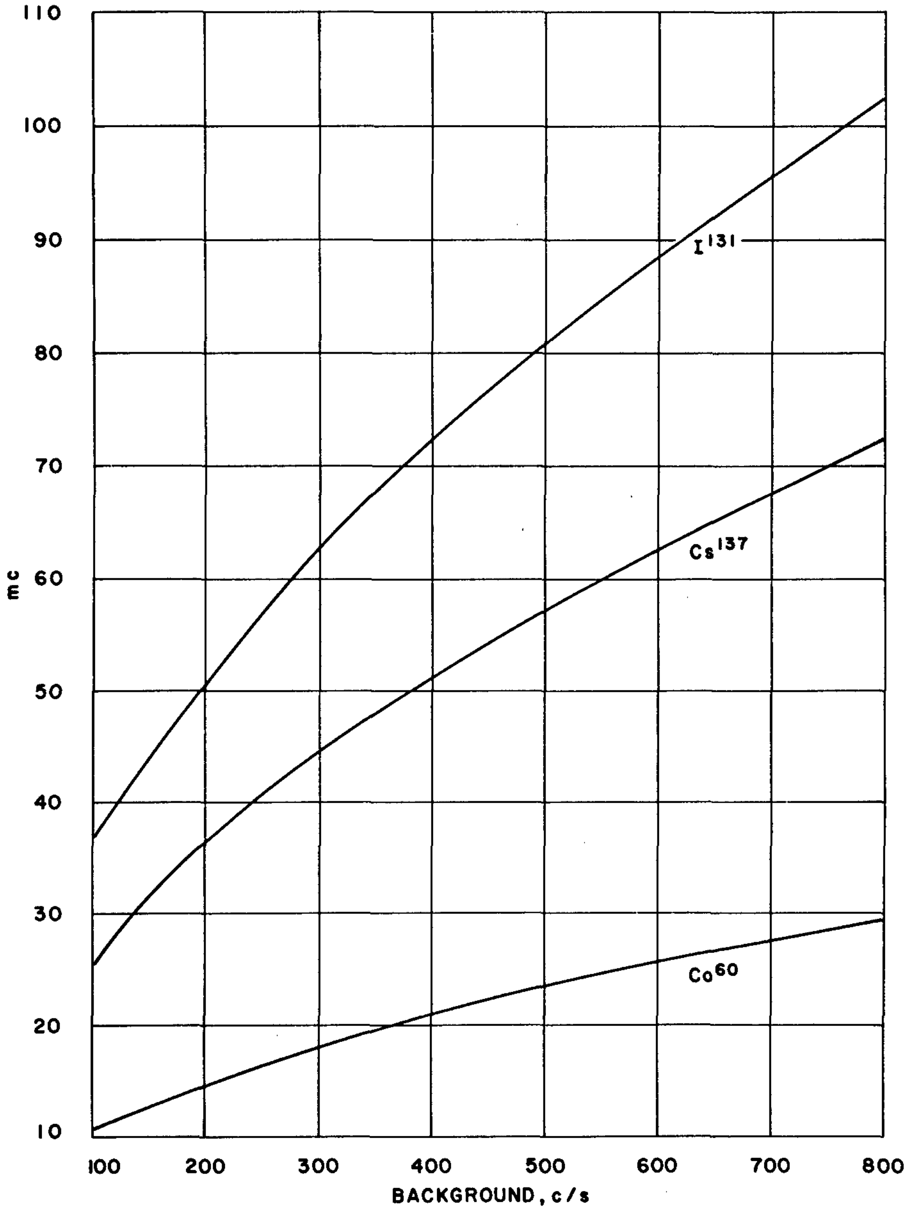

Fig. 5.5—Mobile gamma-scintillometer sensitivity as function of background for point sources.

Chapter 6

AERIAL MEASUREMENTS–PROJECT 60.3.5

I. C. Nelson, Hanford Laboratories

6.1 GENERAL

The aerial-survey equipment carried aboard the Hanford aircraft consisted of an NaI scintillator, bioplastic scintillator, and a 40-liter ionization chamber.

The aircraft employed was a twin-engine Beechcraft D18S, owned and operated by the Atomic Energy Commission at Hanford. No modifications to the aircraft are made in its routine use for aerial-survey work. Knowledge of altitude is obtained from a barometric altimeter. The normal cruising and survey speed is about 200 ft/sec.

The NaI scintillator employed a 5-in.-diameter by 3-in.-thick NaI crystal viewed by a 5-in. photomultiplier. Associated electronic equipment, including power supply, amplifier, and count rate, was transistorized portable equipment designed and fabricated at Hanford. The bioplastic instrument consisted of a 5-in.-diameter by 5-in.-thick plastic phosphor viewed by a 5-in. photomultiplier and associated electronics similar to that used with the NaI instrument. Information from these instruments was displayed on Esterline-Angus spring driven 1-ma chart recorders.

One index of instrument sensitivity is the count rate for 1 μr/hr radium gamma. For the bioplastic detector 500 counts/min corresponded to 1 μr/hr radium gamma. The sensitivity of the instrument was about 700 counts/min/μr/hr radium gamma. Later experiments indicated that a sensitivity of about 2000 counts/min/μr/hr radium gamma would have been a preferable sensitivity.

The 40-liter ionization chamber was designed for low-intensity ground-level dose measurements. The instrument consisted of a welded aluminum cylinder. The center electrode, a length of copper wire, was attached to a 30-volt chamber battery. The opposite end of the battery was connected through the chamber to a Keithly model 600 portable battery-powered electrometer. The 0.1-volt output of the electrometer was displayed on a Varian G-11 recorder. The ionization-chamber–electrometer system was calibrated with radium gamma and had a useful range of 3.5 μr/hr to over 15 mr/hr.

6.2 MEASUREMENTS AND RESULTS

Initial measurements were made to determine the background radiation of the area. Flights at 100, 300, 500, 700, 1000, and 2000 ft above the array and point-source locations were made. At least three flights were made at each altitude, excluding the 2000-ft altitude, over the source arrays and point sources.

Measurements made over the Cs^{137} point source and array are shown in Fig. 6.1, as made with the NaI detector. Also shown are the background measurements.

Of interest is the low-altitude peak in the data. This is believed to be due to angular response and to instrument response time. Factors were developed to adjust the data for these influences; the method was not sensitive enough, however, at low altitudes to permit a reliable conclusion. The present Hanford aerial-survey electronics are being modified to permit a choice of several response times as a means of obtaining better small-source resolution.

The point at which the curve for source-array measurements and the curve for the point-source configuration crosses is of interest. This amounts, according to the data, to saying that at about 500-ft altitude a Cs^{137} array of about 1.65 μc/sq ft appears equivalent to a point source of 1.7 curies of Cs^{137}.

Measurements of the Cs^{137} point source or array with the bioplastic detector were made with confidence only at 100-ft altitude. At 300 ft the results were highly questionable, and at higher altitudes the source was undetectable.

Measurements on the Co^{60} point source and array as taken with the bioplastic detector are shown in Fig. 6.2. Also shown are background measurements made with the instrument. The point source–array equivalent point for Co^{60}, 1.2 curies and 0.5 μc/sq ft, respectively, occurred at about 900 ft.

Data taken over the I^{131} point source, together with background data, are shown in Fig. 6.3. On the day the I^{131} source was flown, it was estimated that 1-curie of I^{131} remained. The results were not illuminating since the iodine source was scarcely detectable even at 300-ft.

Data taken with the 40-liter ionization chamber were no less erratic than the scintillation data. The correlation between measurements made with the two types of instruments was poor. The most useful measurements made with the 40-liter chamber were on-the-ground background determinations. The data taken on the background levels are presented in Fig. 6.4. Illustrated is the unusually high and quite variable ground radiation levels, which are presumably due to radioactivity remaining from an old nuclear detonation.

Inclusion of other data taken with the 40-liter ionization chamber was not judged to be of general interest.

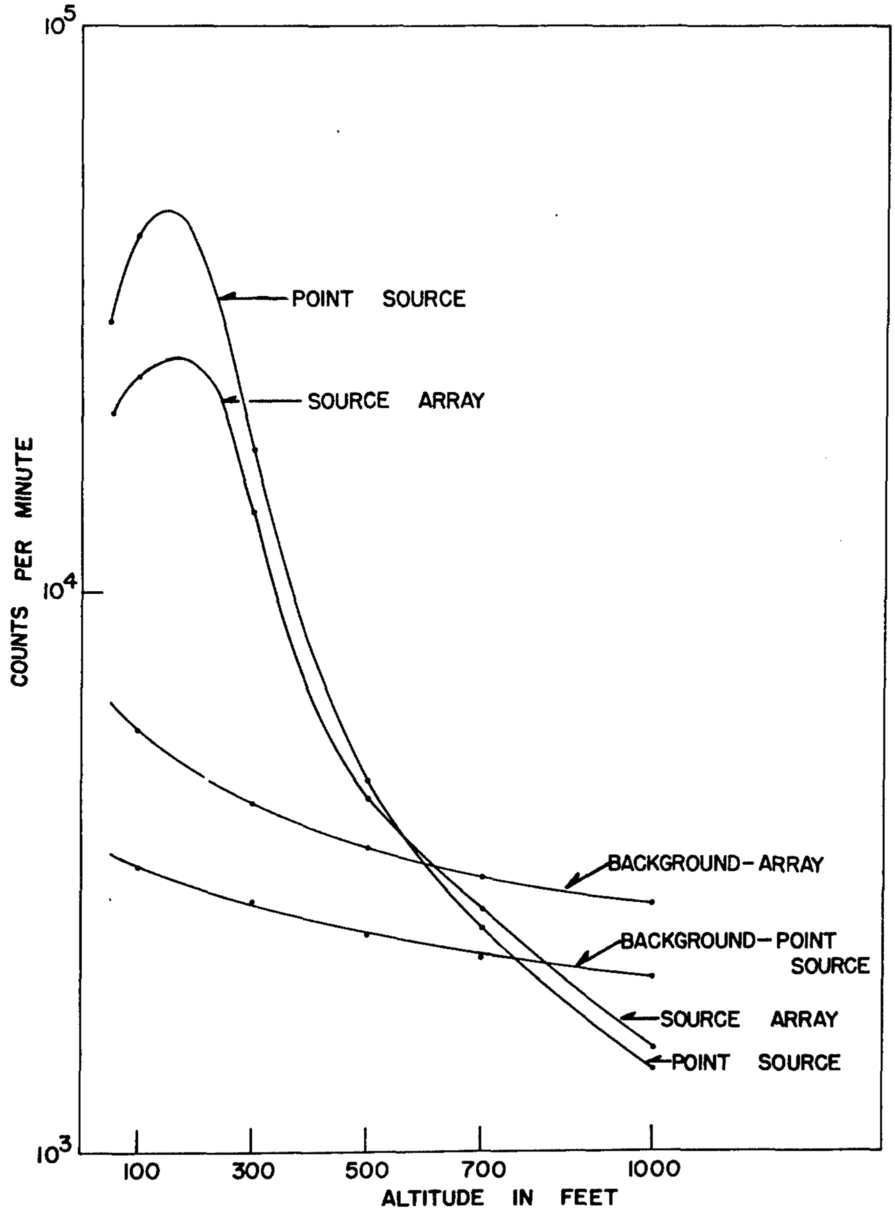

Fig. 6.1—Aerial radiometric measurements of Cs^{137} sources made with NaI detector.

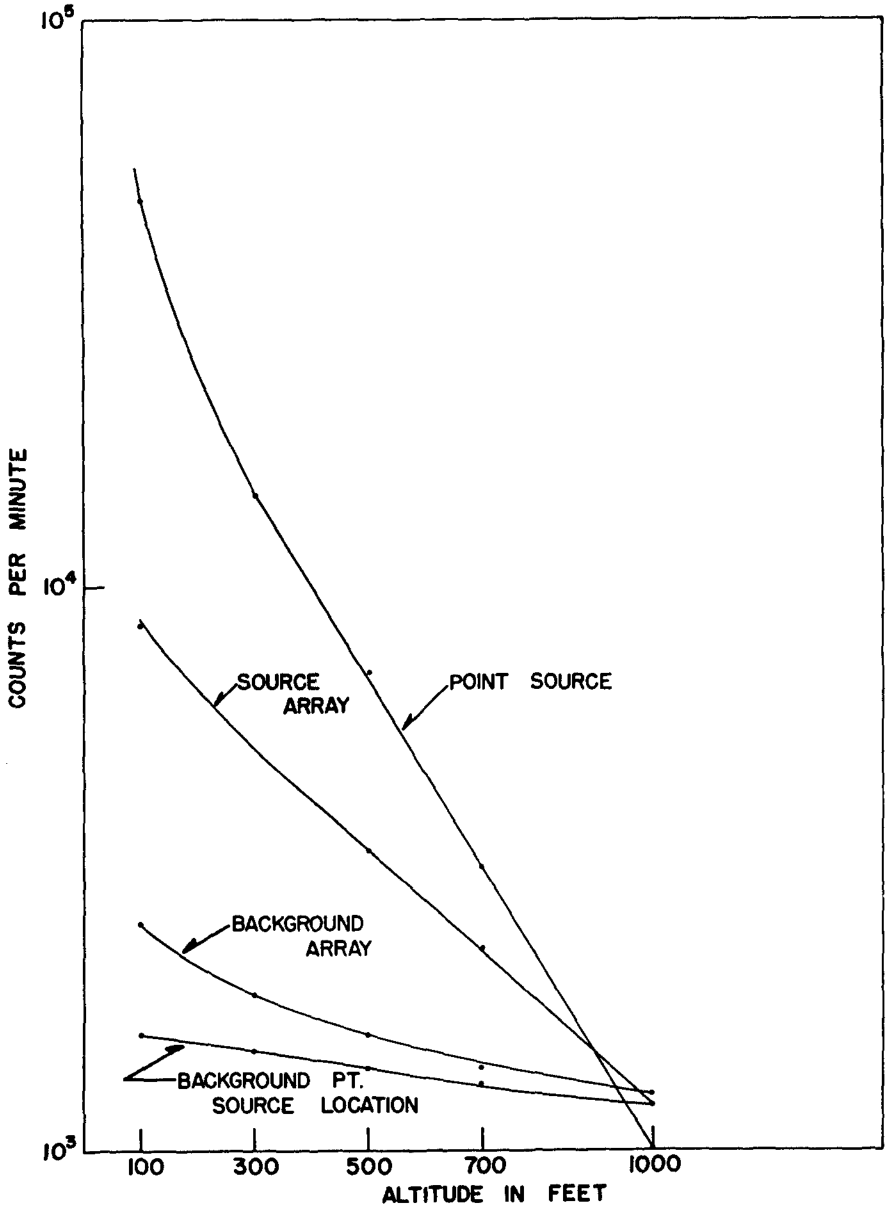

Fig. 6.2—Aerial radiometric measurements of Co^{60} sources made with bio-plastic detector.

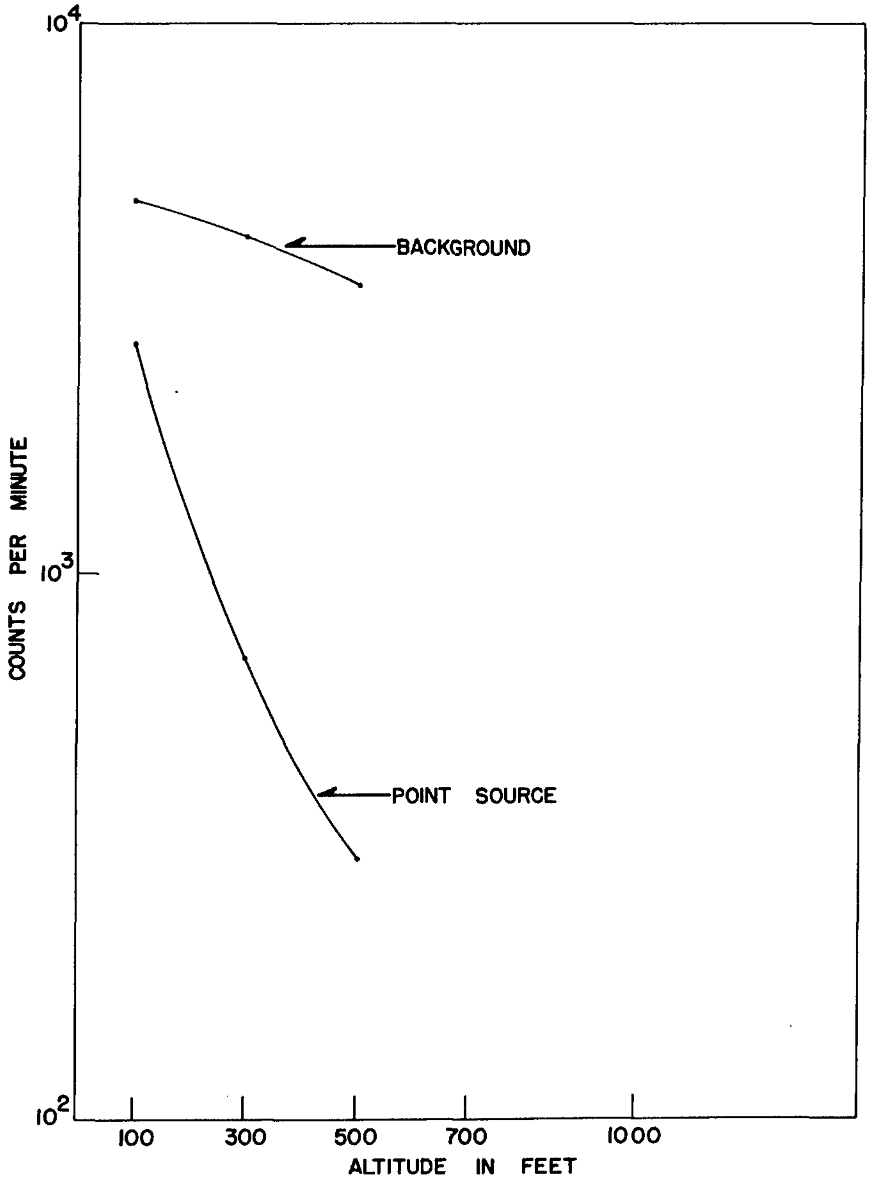

Fig. 6.3 — Aerial radiometric measurements of I^{131} source made with NaI detector.

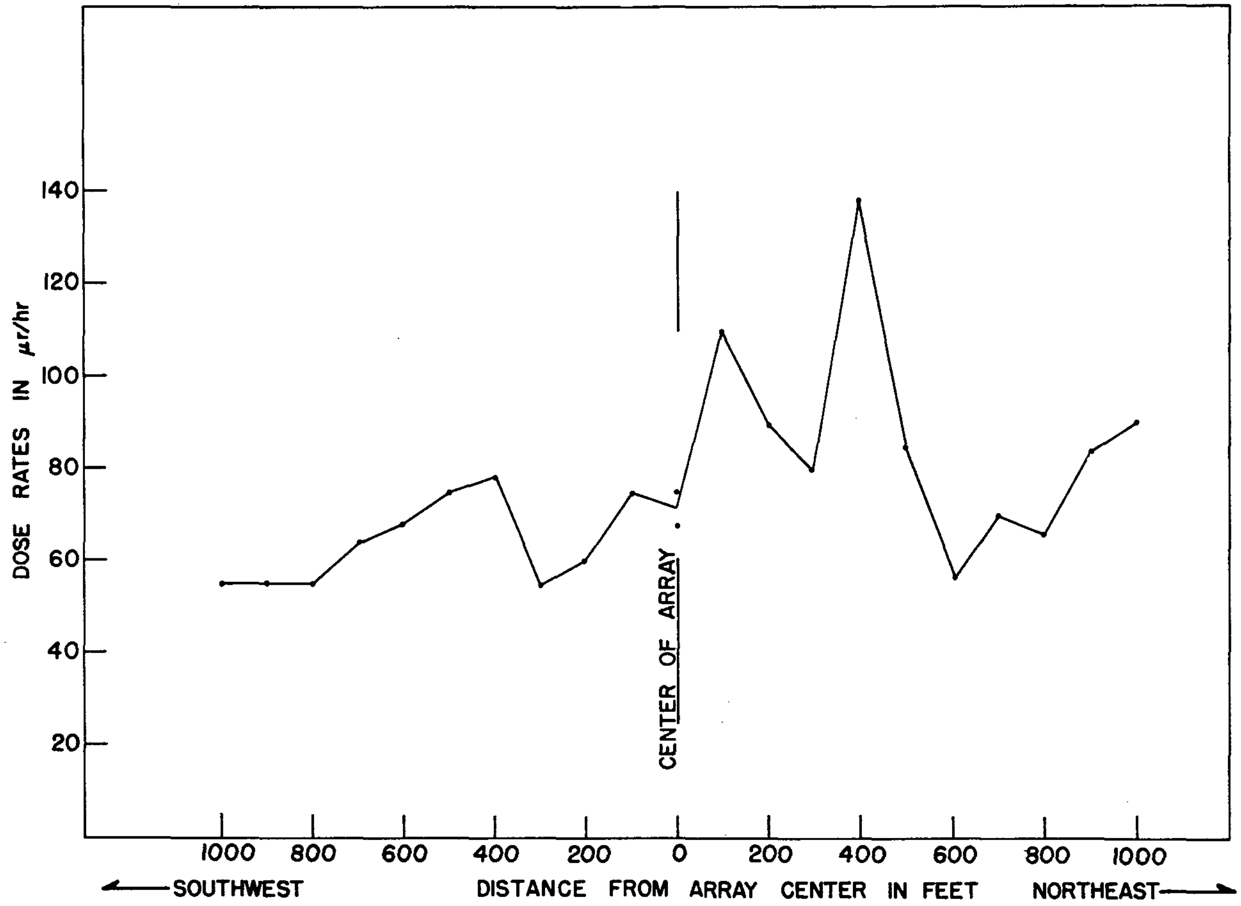

Fig. 6.4—Dose rates taken at 100-ft intervals down center of array at ground level.

Chapter 7

SUMMARY

F. J. Davis, Oak Ridge National Laboratory

Four government agencies and one private company participated in an aircraft instrument intercalibration exercise during November 1960. Flights ranging from 100 to 1000 ft over point sources of Cs^{137} and Co^{60} gave pertinent information on the sensitivity and reliability of the instruments carried aboard the various aircraft. All participants reported successful missions and gained information for redesign or improvement of instrumentation. Measurements made of air attenuation and buildup of gamma radiation as well as gamma-ray spectra gave information for better interpretation of fallout data. Relationships established between point and plane sources allow interpretation of plane-source measurements using calibrations with point sources.

When the 1500-ft BREN tower is erected in the Yucca Flat area at NTS, it would seem advantageous to move the source field so that one corner is at the base of the tower. This would give an equivalent field with four times the area. Measurements could be made with long time intervals so that time constants would not be a consideration. Other measurements could include: (1) spectral measurements, (2) scattering due to ground and air, (3) angular measurements, and (4) surface measurements, that is, sources directly on the ground vs. those a few inches above the ground. Some measurements would also be needed to determine the effect of the tower. A greater variety of point sources would be desirable to give a wider spread of gamma-ray energies.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-57.1 ($0.75)	The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960.
CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960.
CEX-58.8 ($1.00)	Comparative Nuclear Effects of Biomedical Interest, Clayton S. White, I. Gerald Bowen, Donald R. Richmond, and Robert L. Corsbie, January 1961.
CEX-58.9 ($1.25)	A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I. Gerald Bowen, Ray W. Albright, E. Royce Fletcher, and Clayton S. White, June 1961.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
CEX-59.4 ($1.25)	Aerial Radiological Monitoring System. I. Theoretical Analysis, Design, and Operation of a Revised System, R. F. Merian, J. G. Lackey, and J. E. Hand, February 1961.
CEX-59.7C ($0.50)	Methods and Techniques of Fallout Studies Using a Particulate Simulant, William Lee and Henry Borella, February 1962.
CEX-59.13 ($0.50)	Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960.
CEX-59.14 ($1.75)	Determinations of Aerodynamic-drag Parameters of Small Irregular Objects by Means of Drop Tests, E. P. Fletcher, R. W. Albright, V. C. Goldizen, and I. G. Bowen, October 1961.
CEX-60.1 ($1.75)	Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Burson, and J. Jacovitch, February 1961.
CEX-60.5 ($0.50)	Experimental Evaluation of the Fallout-radiation Protection Afforded by a Southwestern Residence, Z. Burson, D. Parry, and H. Borella, February 1962.
CEX-60.6 ($1.00)	Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Z. Burson and H. Borella, February 1962.
CEX-62.01 ($0.50)	Technical Concept—Operation Bren, J. A. Auxier, F. W. Sanders, F. F. Haywood, J. H. Thorngate, and J. S. Cheka, January 1962.
CEX-62.02 ($2.25)	Operation Plan and Hazards Report—Operation Bren, F. W. Sanders, F. F. Haywood, M. I. Lundin, L. W. Gilley, J. S. Cheka, and D. R. Ward, April 1962.