AERIAL RADIOLOGICAL MONITORING SYSTEM

Part II

PERFORMANCE, CALIBRATION, AND OPERATIONAL
CHECK-OUT OF THE EG&G ARMS-II REVISED
SYSTEM

J. E. Hand, R. B. Guillou, and H. M. Borella

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PART II PERFORMANCE, CALIBRATION, AND OPERATIONAL CHECK-OUT OF THE EG&G ARMS-II REVISED SYSTEM

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ABSTRACT

This report describes in detail the design, installation, and performance of the Edgerton, Germeshausen & Grier, Inc., Aerial Radiological Monitoring System used in Phase II of the Aerial Radiological Monitoring Survey (ARMS-II). The design criteria and specifications of the instrumentation are presented in USAEC Report CEX-59.4 (Pt. I).

The system described is used to perform aerial surveys of ground radioactivity. It supplies both geographical position and radioactivity data in digital form, suitable for use with automatic plotting procedures. Inaccuracies in the geographic positioning data are proportional to the distance flown from a visual ground check point and are, under optimum conditions, a maximum of 750 ft per 30 miles of flight path. Inaccuracies in the maps on which the data are presented are of about the same order of magnitude. The radioactivity units recorded by the system contain a maximum uncertainty of ±0.5 per cent. The performance data satisfy the design specifications, and data compatibility is achieved with the existing U. S. Geological Survey—Oak Ridge National Laboratory system (ARMS-I).

The ARMS-II equipment is installed in a Beech Model 50 Twin Bonanza airplane. A threeman flight crew operates the aircraft and instrumentation during survey flights.

Operational checkout of the system was performed Nov. 13 and 14, 1960, over portions of Frenchman Flat and Yucca Flat, Nevada Test Site. It was concluded that nuclear testing contributed to the surface radioactivity in the northern two-thirds of Yucca Flat and a part of Frenchman Flat but that the natural radioactivity of the surficial materials in the southern third of Yucca Flat and much of the Frenchman Flat area accounts for most of the recorded activity.
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Chapter 1

INTRODUCTION

The Division of Biology and Medicine, U. S. Atomic Energy Commission, has the responsibility for obtaining information concerning the radiation levels existing on the ground in areas surrounding AEC sites which might present potential radiological hazards. Since radioactive aerosols generated and released from these sites can relocate at great distances from the source, the area of interest surrounding each site may be as large as 10,000 square miles.

Edgerton, Germeshausen & Grier, Inc. (EG&G), has developed an aerial measuring system that meets the requirements placed on the AEC. The system is sufficiently versatile to perform the following services:

1. Document ground radiation levels surrounding above-mentioned sites.
2. Periodically resurvey the areas to determine any change in the radiation levels.
3. Provide a capability for rapidly determining hazardous and contaminated areas in the event of a radiation accident.

In the past radiation monitoring services have been provided for the AEC by the U. S. Geological Survey using Oak Ridge National Laboratory equipment installed in a DC-3 aircraft. The ever-increasing number of sites and the expanding requirements placed on the monitoring-system instrumentation, however, demand that the documentation of radiation levels be performed with a system of increased versatility. Therefore the system described here was designed and put into operation. The over-all Aerial Radiological Measuring Survey is divided into two phases: Phase I (ARMS-I) is being conducted by USGS using ORNL equipment and Phase II (ARMS-II) is being conducted by EG&G using the equipment described here.

An acceptable survey system for the ARMS program must survey large land areas rapidly and shortly thereafter present the radiation data in usable form. The radiation information also should be compatible with the existing USGS-ORNL aerial survey data. In addition, it is important that operation of the system be economical. This requirement dictates the need for maximum automation of equipment, the efficient use of manpower, and low-cost aircraft operation. An optimum procedure will be obtained when the collected data are handled by a computer and automatic plotter.

This report outlines the design and installation of the survey system developed by EG&G, as described in an earlier report. The EG&G ARMS-II system has been flown over the extended source range at the Nevada Test Site (NTS) for calibration of the radiation gear and for relating the behavior of the system to the USGS-ORNL system, and over Frenchman and Yucca Flats to determine operational procedures under survey conditions.

The block diagram of Fig. 1.1 presents the functional units of the EG&G ARMS-II installation. The system includes three subsystems:

1. Radiation detection and measurement
2. Aircraft positioning
3. Information print-out

The large and small radiation transducers can record a wide range of radiation intensities. The units consist of thallium-activated sodium iodide crystals properly coupled to photomulti-
Fig. 1.1—Diagram of ARMS-II instrumentation.
plier tubes with the tube outputs feeding into individual preamplifiers located near the tubes. The pulses are then amplified and directed into the radiation arithmetic computer.

The radiation-detection and -measurement subsystem employs digital data-handling techniques. The system samples the incoming radiation pulses for a definite time period. Next, the computer processes the pulses while sampling additional incoming radiation. A signal from a radar altimeter is applied to the sampling-period control circuits so that radiation detected in the altitude range of 300 to 1000 ft above the terrain is normalized to give the equivalent 500-ft value.

The computer also applies a selectable background correction to the gross radiation pulses and sorts the net activity into count-rate channels of a predetermined width. The radiation information is then fed to the information print-out subsystem as a radiation channel number.

The position of the aircraft is determined in flight by its relation to a fixed ground check point. A modified Doppler navigation system utilizing a J-4 compass is used to chart the course of the aircraft along a predetermined flight path from the check point. Heading and ground return signals are fed into a track-navigation computer, which supplies position data to an analog-to-digital converter. Digital information of the position of the plane is then directed to the information print-out subsystem. Upon receiving a print command signal, the information print-out subsystem records the position of the aircraft in relation to the fixed ground check point and the radiation level at that location. The information is recorded decimally by a Clary printer and also as punched binary information on tape to permit automatic reduction and plotting of the data.

REFERENCE

Chapter 2

INSTRUMENTATION

2.1 DETECTOR ASSEMBLY

The detector assembly is a packaged unit consisting of two NaI (thallium activated) crystal–photomultiplier tube combinations. A transistorized preamplifier is mounted on each tube. The large crystal detector (high-sensitivity probe) is 9 in. in diameter by 3 in. thick. The photomultiplier tube for this crystal is an EMI type 9545B 11-stage flat-faced tube, magnetically shielded by a Netic-Conetic layered shield strip-wound over the entire length of the tube. The optical coupling was made with Dow Corning QC-2-0057 silicone grease. The tube–crystal combination mounted in its laboratory support is shown in Fig. 2.1. The second detector (low-sensitivity probe) is a Harshaw Chemical Co. integral assembly consisting of a DuMont 6291 photomultiplier tube coupled to a \( \frac{3}{4} \)- by \( \frac{3}{4} \)-in. NaI(Tl) crystal. Figure 2.2 shows the construction of the solid-state preamplifiers used with the tubes. Figure 2.3 shows the preamplifier in
position on the small tube. The above units, in addition to the two solid-state high-voltage power supplies, are rigidly mounted on a $\frac{1}{4}$-in.-thick aluminum plate. The plate, in turn, is shock-mounted to structural members of the aircraft. Figure 2.4 shows the completed detector assembly, including the quilted fiber glass insulation used to reduce thermal stresses on the photomultiplier tubes.

2.1.1 High-voltage Supply

Each photomultiplier tube is powered by an independent power supply. The output voltages are regulated within 0.01 per cent per degree Fahrenheit over the temperature range of 0 to 120°F. The supplies are completely transistorized and operate on an input voltage of 115 v (a-c), 400 cycles/sec. The maximum output voltage is 1600 v (d-c).

2.1.2 Preamplifier

The transistorized preamplifiers are physically mounted on the base of the photomultiplier tubes (see Fig. 2.3). Each one provides a voltage gain of about 1 on the phototube output pulses and a current gain of about 1500. Power is supplied to the preamplifiers by the power supply in the radiation amplifier.

2.2 RADIATION INSTRUMENTATION

The radiation-instrumentation electronic system consists of the voltage amplifier, energy discriminator, pulse-shaper circuits, and an arithmetic computer. The entire radiation-measuring system utilizes digital circuitry. Interactions in the detectors are sampled and measured over a controllable period of time.
Fig. 2.3—Small photomultiplier tube and preamplifier assembly.

Fig. 2.4—Complete detector assembly.
2.2.1 Amplifier, Discriminator, and Shaper (Figs. 2.5 and 2.6)

This unit performs several functions:

1. Output pulses from the preamplifiers are accepted and further amplified.
2. The discriminator control permits the rejection of pulses below a selectable limit that represents noise and unwanted gamma background.
3. Shaped pulses appear at the output terminals as acceptable signals to the next component.

Fig. 2.5—Radiation amplifier, discriminator, and shaper unit. This unit contains the preamplifier power supply.

Fig. 2.6—Typical plug-in card for the radiation amplifier, discriminator, and shaper unit.

The specifications of the output pulses from this unit are: height, +17 v; rise time, 0.25 µsec; and duration, 0.95 µsec.
The discriminator control is a 10-turn helipot. The numbers on the helipot dial are in a 1 to 1 correspondence with the energy of the gamma rays striking the crystal detectors. This feature permits rapid and accurate calibration of the circuitry with a standardized radioactive source of known energy.

2.2.2 Arithmetic Computer

The shaped output pulses from the radiation amplifier unit are applied to the input of the transistorized arithmetic computer (Figs. 2.7 and 2.8). The unit weighs 35 lb and receives power from a 115-v 400-cycle inverter. Power consumption is approximately 150 watts. The computer is the heart of the radiation system and performs the following functions:

1. Accepts the positive, shaped pulses from the radiation amplifier.
2. Permits cosmic radiation and other undesirable background contributions to be subtracted from the gross crystal interactions detected.
3. Determines the radiation sampling time according to the altitude of the aircraft. (An input signal from the radar altimeter, proportional to the aircraft altitude, provides height information to the computer.)
4. Provides a constant 1-sec sampling period, which is used during calibration of the system.
5. Provides a visual display of the net count at the end of each sampling period for monitoring and calibration purposes.

6. Classifies the count rate (whether gross or net) into digital channels and feeds this information to a printer upon command. Construction of the computer is such that the channel boundaries can be changed to include larger or lesser count rate ranges as the results of preliminary surveying dictate. Table 2.1 lists the channel numbers and the count-rate range associated with each.

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>Count range, counts/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0–100</td>
</tr>
<tr>
<td>2</td>
<td>100–200</td>
</tr>
<tr>
<td>3</td>
<td>200–300</td>
</tr>
<tr>
<td>4</td>
<td>300–400</td>
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<tr>
<td>5</td>
<td>400–500</td>
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<td>6</td>
<td>500–600</td>
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<tr>
<td>7</td>
<td>600–700</td>
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<tr>
<td>8</td>
<td>700–800</td>
</tr>
<tr>
<td>9</td>
<td>800–1,000</td>
</tr>
<tr>
<td>10</td>
<td>1,000–1,200</td>
</tr>
<tr>
<td>11</td>
<td>1,200–1,400</td>
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<tr>
<td>12</td>
<td>1,400–1,600</td>
</tr>
<tr>
<td>13</td>
<td>1,600–1,800</td>
</tr>
<tr>
<td>14</td>
<td>1,800–2,500</td>
</tr>
<tr>
<td>15</td>
<td>2,500–4,000</td>
</tr>
<tr>
<td>16</td>
<td>4,000–8,000</td>
</tr>
<tr>
<td>17</td>
<td>8,000–15,000</td>
</tr>
<tr>
<td>18</td>
<td>15,000–30,000</td>
</tr>
<tr>
<td>19</td>
<td>30,000–50,000</td>
</tr>
<tr>
<td>20</td>
<td>50,000–100,000</td>
</tr>
</tbody>
</table>

7. Generates command-to-print signals to the printer. The computer provides three methods of obtaining print-command signals: (1) a 3-sec timed interval, (2) radiation-level channel change, and (3) manual (push-button command).

Figure 2.9 is a block diagram of the radiation-detection and -measurement subsystem. The blocks do not necessarily represent separate physical entities, but rather circuit functions performed on the pulses. The top portion of the figure represents units that convert the incoming radiation to shaped electrical pulses. Standard practices are employed for amplification, rejection, and shaping of pulses prior to routing them into the radiation computer. The lower portion represents circuit functions performed on the pulses by the radiation computer. The main functional operations of the computer are controlled by the following internal circuits:

1. The **input gate** is a flip-flop circuit that controls the passage of pulses from the input terminals to the counting circuits. When the gate is closed, the computer does not count pulses. The gating action is controlled by a sample-period gate and a background-correction flip-flop.

2. The **sample-period gate** controls the open and closed condition of the input gate. Analog currents from either the radar altimeter altitude-compensating potentiometer or a 1-sec sampling-period circuit are accepted to control the input gate. The magnitude of these currents determines the sample-period duration of the input gate.

3. The **background-correction**, or subtraction circuit, consists of a variable-frequency oscillator (VFO), in which the frequency of the oscillations is varied by an external control. The rate of the cosmic or undesirable background to be removed is set on the oscillator control indicator. The VFO pulses are then fed into an up–down counter, causing it to count up. This action closes the input gate. If additional oscillator pulses arrive before any radiation pulses are received, the counter continues to count up, keeping the input gate closed. The ar-
Fig. 2.9—Block diagram of radiation-detection and -measurement subsystem.
rival of radiation pulses at the counter causes it to count down. When sufficient pulses have
arrived to return the up-down counter to the zero state, the input gate opens, permitting the
decade-counting circuits to receive incoming pulses. The background-correction circuits are
95 to 100 per cent effective.

4. The 16-bit counter, which registers all input pulses allowed through the input gate, con-
sists of five parallel counting circuits and a dual output. A binary-to-decimal converter on one
output feeds the count-rate information to the decimal display. A parallel output sends binary
information to a decoding matrix, which determines the channel number. Channel number in-
formation is then routed to the comparator.

5. The comparator is a unit in which the decoded count information (channel number) is
stored. The radiation channel number of the subsequent sampling period is compared with the
stored information. Should the subsequent number be different than the number stored, the
comparator replaces the stored number with the new number and a command-to-print signal
is generated, if the print-out selector is in the radiation channel level change position.

6. The display unit consists of five miniature incandescent units containing 10 bulbs each.
Each number to be displayed has a small "grain-of-wheat" type bulb associated with it so that
decimal coding of the count-rate information is fed to individual bulbs of the display. Each
numeral appears on a lenticular glass screen, which requires no lens or focusing system in the
lamp assembly.

7. The print-out selector is a rotary switch for choosing one of four modes of print-
command signals generated by the computer. The command to print can be generated by (1) a
3-sec timed interval, (2) radiation channel level change, and (3) a manual print command. The
fourth mode, which utilizes the manual print-command circuitry, is controlled by the naviga-
tion apparatus. For convenience a selector switch is mounted on the copilot's side of the in-
strument panel as well as on the radiation control panel.

2.2.3 Radiation-detection Control Panel (Fig. 2.10)

All functions performed by the radiation-detection and -measuring system are controlled
from this unit. The controls and indicators located on the panel are as follows:

1. Switch positions are OFF, STANDBY, CALIBRATE, and RUN.
   - OFF: All power is removed from the radiation instrumentation system.
   - STANDBY: Power is applied to the system, but radiation pulses and altimeter currents
     are not fed into the computer.
   - CALIBRATE: The system is powered and a 1-sec sampling period is supplied to the
     computer input gate. Data may be taken at any altitude using the 1-sec sampling
     period. Background correction, energy discrimination, amplifier gain, and print
     selector can all be used. A standard Cs$^{137}$ source can be remotely placed in the
     vicinity of the crystals for periodic calibration of the circuitry against small gain
     changes.
   - RUN: The sampling time of the input gate is controlled by a voltage level obtained from
     a radar-altimeter-controlled potentiometer. The magnitude of the voltage is a func-
     tion of the altitude of the aircraft. All controls are operational with the exception of
     the calibrating source-position control. The source automatically returns to a posi-
     tion shielded from the crystals by a lead brick.

2. Count-rate display: Five-digit display of the net count.

3. Display hold: Push-button control that permits the displayed count to be exhibited
   longer than the normal period.

4. Print-mode selector (four-position rotary switch):
   - OFF: The printer and punch are inoperative.
   - PERIOD: A print-command is sent to the printer every 3 sec.
   - LEVEL: A print-command is sent to the printer whenever the radiation channel level
     changes.
   - TRANSFER: Transferring from one Doppler navigation indicator to the other generates
     a print-command signal.

5. Manual print (push button): Gives a print command regardless of the position of the
print-mode selector.
Fig. 2.10 — Radiation control panel.

Fig. 2.11 — Printer and punch installation.
6. Calibrate mode (two-position rotary switch): This control is operative only when the function selector is in the calibrate position.

   ENERGY POSITION: Powers the Cs\textsuperscript{137} source actuator motor and removes the source from lead shield.

   BACKGROUND POSITION: Returns the source to the shield.

7. Energy cut-off (10-turn digital-read-out helipot): Provides the discriminator action for the amplifier circuitry. The dial reads gamma energy directly in thousand electron volts (kev). Pulses from gamma interactions in the detector of all energies less than that indicated on the dial are rejected by the circuitry.

8. Calibrate adjust: A 360° single-turn helipot graduated from 20 to 200 counts/sec. Operates in conjunction with a range switch having \times 1, OFF, and \times 10 positions as multipliers on the dial graduations. Both the range switch and the helipot are operative in the calibrate and run positions of the function selector.

9. Sensitivity (two-position rotary switch): Selects the output of either the large (high-sensitivity) or small (low-sensitivity) crystal detector.

2.2.4 Calibration Source and Motor

A calibrated source containing 51 \mu C of Cs\textsuperscript{137} is mounted on the traveling nut of a screw-jack type actuator. The position of the source is controlled from the radiation control panel. In either extreme of travel, the drive circuit is opened by limit switches in the actuator unit; the traveling nut will repeat its positioning within 0.015 in. Travel time of the source from the exposed to shielded position is 12 sec. The contribution to the background detected by the large crystal from the source in the shielded position is about 800 counts/sec, which is easily removed by the background-corrector circuitry.

2.3 DOPPLER NAVIGATION SYSTEM

A modified Doppler navigation and J-4 compass system was installed and calibrated by General Precision Inc., at Pleasantville, New York. The system is wholly self-contained aboard the aircraft and requires no ground-operated stations for determining the position of the aircraft. For the ARMS-II installation, a stock unit was modified to read out in hundredths of nautical miles both along and across a predetermined course. The output of the unit was converted to supply both an analog display for visual monitoring and digital information for recording purposes.

Included in the installation at General Precision was a Clary printer—punch combination. Upon receipt of a print command, the radiation and aircraft-position data are printed out decimally by the printer; then the punch records the data on tape in a binary 1248 code. The total time required to record the data serially at a single print command is slightly less than 1.5 sec. The punch can be switched out of the circuit for convenience under various operating requirements, and in this configuration the print-out time of the decimal printer is about 0.6 sec. Figure 2.11 shows the printer—punch combination installed in the equipment rack just aft of the pilot. Figure 2.12 illustrates the decimal-tape record and the corresponding punched-tape record of the data.

A single print-out requires only one line of printing on the decimal tape, or \( \frac{1}{6} \) in., whereas the punch requires \( 1\frac{1}{2} \) in. of tape per print-out. A single roll of each tape is sufficient for 4 hr of recording using the 3-sec print-command mode.

The three left-most digits on the decimal tape illustrated in Fig. 2.12 refer to the survey leg or segment number. The next two digits are the radiation channel numbers. Continuing to the right, the next four digits represent the distance traveled along track from the visual ground check point at which the leg number commenced. Distance is recorded in miles and hundredths of a mile, an unrecorded decimal point being understood. The last three numbers represent the distance across or at right angles to the predetermined track, again with an understood decimal point so that the reading is in miles and hundredths of a mile. The letter on the extreme right indicates whether the cross track position was to the right or left of the desired course. To record which detector sensitivity range was in use, the printer prints
black for the high-sensitivity probe and red for the low-sensitivity probe. The sensitivity information is coded numerically by the tape perforator, as is the across-track direction. The lower entry illustrated in Fig. 2.12 would be read as follows:

Leg No. 13
Radiation channel 05 (400 to 500 counts/sec)
Along-track distance, 20.07 nautical miles
Across-track distance, 0.01 nautical mile
Across-track direction, left of the desired path
Sensitivity, low-sensitivity probe

The colons on the decimal tape have been added for clarity. The punched-tape coding for the across-track direction and sensitivity range is as follows:

1. Direction across track (printed next to last line)
   Right 2
   Left 1
2. Sensitivity (printed last)
   High 6
   Low 5

Early experience has indicated that manual manipulation of the data on the decimal tape proceeds rather rapidly and without difficulty. The punched tape will be used to permit automatic handling of the data by a ground computer and automatic X-Y plotter. Complete specifications covering the computer design criteria are being compiled on the basis of the experience gained from preliminary surveys and manual data reduction.
A block diagram of the aircraft-positioning system is shown in Fig. 2.13. The J-4 compass system was selected because it combines high accuracy with minimum weight. The roll-stabilized model was not required for this application. The compass will permit course information to be held either by a latitude-corrected driven gyro or by a magnetically slaved gyro. The error of the output signal with reference to either of the gyro modes is less than 1°. The free-gyro random drift rate is given as ±3° per hour maximum. In survey operations headings are checked or reset at least every 20 min; so the maximum possible uncertainty induced is ±1°. In the magnetically slaved mode, the effect of local magnetic anomalies and the uncertainty in setting the correct value of the magnetic course into the track navigation computer constitute the largest source of error. Performance specifications of the compass indicate that in a field of 180 milligauss, if the horizontal field strength is varied from 90 to 330 milligauss, the indicated heading will not shift more than ±3/4°. (The order of magnitude of the earth's magnetic field is 330 milligauss.) Consequently the course information fed into the track navigation computer is little affected by intensity variations of the above magnitude in the earth's magnetic field. Changes in the resultant field direction, however, due to local magnetic disturbances are sometimes noticeable. The output signal of the J-4 system is fed into the track-navigation computer (TNC-50) and is used by the computer to determine along- and across-track distance components. The J-4 compass and the RADAN 500 provide heading, ground speed, and drift information, which is fed into the track-navigation computer (TNC-50).

The output signals of the TNC-50 are normally analog currents, but the ARMS-II navigation package utilizes an analog-to-digital converter to permit digital print out of the position information. When a print-command signal is received by the TNC-50, a signal is generated which "freezes" the analog-to-digital converter mechanism. The analog position signals are instantly converted to digital information and fed to the printer. Figure 2.14 shows the TNC-50 controls, which are mounted on the aircraft instrument panel. The TNC-50 control panel contains dual displays both showing "desired track," "nautical miles along track," and "nautical miles off track." In operation one or the other of the indicators is in use, but not both. Controls are present that permit the manual insertion of information into either display and a SET-RUN switch is available for each.

At the start of a flight, the Doppler RADAN 500 is turned on, and the TNC-50 control-panel switch is placed in STANDBY position. The operator then selects either of the displays and inserts the "desired track" and "nautical miles along track" information into it by manual knobs. The SET-RUN switch is placed in the RUN position, and, as the aircraft passes over a predetermined ground reference point, the operator changes the TNC-50 switch from STANDBY to RUN. The display containing the inserted information becomes operative, and, as the aircraft moves along course, the "nautical miles along track" indication increases according to the ground speed and track. If the aircraft stays on course, the "nautical miles off track" indication remains on zero.

At any convenient time during the first flight leg, heading and distance information are set into the alternate, or remaining, display unit covering the second leg. As the aircraft flies over the check point denoting the end of the first leg and the start of the second, the operator normally transfers displays by depressing the SET-RUN switch of the second unit, activating the second unit and stopping the first display. At the same time a print-command signal is generated which prints out the closing information on the first leg. (Upon reaching an indication of 0.00 on the "nautical miles along track," the TNC-50 will automatically transfer itself to the second display unit.) Third-leg information is now inserted into the first display unit, and the procedure is repeated for as many segments as are necessary.

The RADAN 500 transmitter is essentially a conventional radar circuit using a magnetron power oscillator whose pulse-repetition frequency is determined by random voltage pulses from a noise generator. The radio-frequency from the transmitter is fed to the antenna from which two radiation patterns are emitted alternately at half-second intervals. Each pattern consists of two lobes. One is transmitted to the front right and left rear of the aircraft, the other to the front left and right rear. The r-f energy in these lobes strikes the ground at the corners of a rectangular pattern. Thus the echo returned from the ground always contains the reflections of both a front- and rear-pointing lobe with the frequency of the reflected waves shifted according to the velocity of the aircraft (Doppler effect). The electronic circuitry then
Fig. 2.13—Aircraft-positioning subsystem block diagram.
Fig. 2.14—Track-navigation computer (TNC-50) and J-4 compass control panels.
detects the frequency shifts of the reflected signals and converts these deviations into analog currents that are proportional to the along-track and across-track velocity components of the aircraft. These signals are made to indicate aircraft drift angle, ground speed, distance along track, and distance to the right or left of the preset course. Certain of these signals are available for control of an autopilot or a flight director, but they are not used for this purpose in the ARMS-II installation.

The overall navigation-system error, as provided by General Precision, Inc., is based upon results obtained by flying over well-fixed courses. Their maximum values under optimum conditions are as follows:

Cross-track error = ±0.73 per cent of distance flown
Along-track error = ±0.35 per cent of distance flown

The errors inherent in the performance of the ARMS-II installation are discussed in Sec. 3.5. The results quoted therein are also based on flying predetermined lines.

2.4 ASSOCIATED AIRCRAFT SUBSYSTEM

2.4.1 Radar Altimeter

A radar altimeter is used in the ARMS-II installation for two purposes: (1) to provide an accurate altitude-compensation signal to the radiation computer input gate and (2) to give the pilot a more accurate indication of his altitude above terrain than the conventional barometric altimeter will permit.

The radar altimeter used is a Sylvania type AN/APN-117. A stock altimeter was modified to give a linear output from 0 to 1000-ft altitude indication, with an accuracy of ±2 per cent or better. (Results of flight-test calibrations of the indicated altitude by EG&G are discussed in Sec. 3.4.) The vertical radar beam determines an average altitude over a solid angle of 120°, which at 500 ft above terrain, covers a circular area on the ground 1700 ft in diameter at the 50 per cent beam intensity points. This area corresponds roughly to that viewed by the radiation-detection crystal.

A specially wound potentiometer has been attached to the radar-altimeter output servo shaft, which controls the signal to the radiation computer input gate. The potentiometer was wound in an exponential fashion to correspond to the attenuation of terrestrial gamma radiation in the atmosphere as a function of altitude above terrain.

The radar altimeter also has provisions for coupling a signal into the autopilot. However, this feature has not been utilized in the ARMS-II installation.

2.4.2 Aircraft Generators

The standard Beechcraft installation consists of two 50-amp, 28-v d-c generators.

Power for the ARMS-II is supplied by a 100-amp, 28-v d-c generator installed on each engine. Measurements have indicated that the total 28-v d-c current drain due to ARMS-II apparatus operation is 85 amp. With all the aircraft equipment and ARMS-II equipment in operation, the total current drain is 135 amp. Since the total capability of the generators is 200 amp, the maximum rate of power consumption is only about 65 per cent of capability. The increased generator size and the necessary mounting and cabling modifications give a weight increase of 13 lb per unit over the 50-amp generators.

In normal operation the ARMS-II apparatus requires 28-v d-c power; single-phase 400-cycle 115-v a-c power; single-phase 60-cycle 115-v a-c power; and three-phase 400-cycle 115-v a-c power.

The single-phase 400-cycle 115-v a-c power is supplied by a solid-state static inverter, whereas the single-phase 60-cycle 115-v a-c and the three-phase 400-cycle 115-v a-c voltages are provided by 28-v d-c-driven rotary inverters.

2.4.3 Static Inverter

Figure 2.15 shows the 115-v a-c 400-cycle solid-state inverter, which is mounted in the forward baggage compartment. The unit weighs 15 lb and is 5 in. high, 5 in. wide, and 10½ in.
deep. It is capable of delivering 1 kw of power under continuous operation. The inverter is mounted on an aluminum heat sink attached to the skin and frame of the aircraft. A small high-speed blower continuously provides cooling air to the internal circuit components.

The 115-v a-c 400-cycle power requirements of the ARMS-II components are as follows:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Power, watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-4 compass</td>
<td>45</td>
</tr>
<tr>
<td>TNC-50</td>
<td>170</td>
</tr>
<tr>
<td>RADAN 500</td>
<td>280</td>
</tr>
<tr>
<td>Radar altimeter</td>
<td>80</td>
</tr>
<tr>
<td>Radiation equipment</td>
<td>140</td>
</tr>
<tr>
<td>Total</td>
<td>715</td>
</tr>
</tbody>
</table>

An input filter installed in the 28-v d-c supply line to the inverter reduces ripple to an acceptable value. Frequency stability of the inverter is better than ±3 per cent, with the output wave form closely approximating a sine wave (95 per cent). Output-voltage regulation is ±2 per cent or less under load, and the efficiency is about 65 per cent. Since the total current drain of the aircraft and ARMS-II system exceeds the capacity of a single engine generator,

![Fig. 2.15 — Solid-state inverter showing the cooling-air blower and heat-sink plate.](image)

the inverter has been wired in a manner such that if either of the engines fails, or falls below 1400 rpm for any reason, the inverter circuit opens. As a result the remaining generator will have only the normal aircraft load impressed upon it. Sufficient 28-v d-c power is available with a single generator for the pilot to perform all normal aircraft power-consuming functions.

### 2.5 AIRCRAFT

The aircraft selected to carry the ARMS-II equipment was the Beech, Model 50, Twin Bonanza (Fig. 2.16). Features include supercharged engines, an autopilot, communications...
and visual omnirange (VOR) equipment, and two 72-gal auxiliary fuel tanks. With a two-man crew aboard, the full permissible fuel load is 223 gal.

Weight and balance calculations have been run for the aircraft with the ARMS-II gear installed and under conditions of no fuel load and full fuel load. The center of gravity of the aircraft under empty weight plus the ARMS-II instrumentation is at station 118.4. With full fuel tanks and a two-man crew aboard, the center of gravity is located at station 121.2. With a two-man crew and empty fuel tanks, the center of gravity moves to station 118.5. The limits listed in the Federal Aviation Agency (FAA)-approved Flight Manual are from station 118.0 to station 124.6. Under the present arrangement the aircraft is within these bounds whether fully loaded or empty.

The aircraft was flight tested at the General Precision, Inc. Flight Test Center and satisfied FAA requirements regarding the weight and distribution of the equipment being installed. A fuel load of 185 gal was carried and 750 lb of sand ballast was placed aft-most in the cabin. The pilot weighed an additional 200 lb. The plane was taken to about 8000 ft above terrain and put into a shallow dive with a pull-out at 300 mph.

2.6 AIRCRAFT INSTALLATION OF THE ARMS-II EQUIPMENT

Figure 2.17 shows a view looking aft of the pilot—copilot seats with the aft couch type seat removed. The forward wall of the aft baggage compartment has also been removed, providing space for the equipment rack containing the system components. On the left is the remaining seat used by the observer.

2.6.1 Detector Assembly

The crystal—photomultiplier tube detector assembly has been mounted aft of the seat location. Figure 2.18 is an underside view of this point showing the step storage well. The well allows the crystals on the detector assembly to protrude downward. Figure 2.19 shows the detector assembly mounted in position as viewed through the aft baggage-compartment door. The assembly is shock-mounted to structural members of the fuselage. Thermal insulation protects the photomultiplier tube and also surrounds the crystals in the well. The entire well is filled with 1-in.-thick layers of spun glass insulation. A 1/16-in.-thick fiber glass board is used as fairing over the well opening, rather than aluminum, to minimize absorption and scattering of incident gamma rays.

2.6.2 Equipment Rack and Electronic Packages

Figure 2.20 is a view of the cabin space aft of the pilot—copilot seats, showing the completed installation. The equipment rack, designed by General Precision, Inc., to withstand 5-g vertical and horizontal loadings, is attached to structural members of the fuselage and wing root with wedjit mounts. The printer is on a sliding tray to facilitate replacement of the decimal tape. All units are properly shock-mounted and have sufficient sway clearance. The rack plus equipment weighs about 338 lb. Figure 2.21 shows the room available for a rear-seat operator near the radiation control panel.

2.6.3 Radar—altimeter Transmitter—Receiver

The radar—altimeter transmitter—receiver is rigidly mounted on the floor of the fuselage rear. Figure 2.22 shows the external view of the receiving—transmitting antennas flush with the fuselage.

2.6.4 Doppler Antenna

The Doppler antenna is mounted just aft of the detector assembly. The transmitting—receiving antennas are below the fuselage skin. Figure 2.23 shows the protective housing for the antenna, which is attached to aircraft structural members by fairing screws. The window of the antenna housing is a fiber glass plate 1/16 in. thick. The thickness is governed by the
Fig. 2.16 — Front quarter view of ARMS-II aircraft.

Fig. 2.17 — Empty cabin view aft of pilot seat showing observer’s seat in position.
Fig. 2.18 — Underside view of step well with the large-crystal clearance hole shown.

Fig. 2.19 — Detector assembly as seen through aft baggage-compartment door.
Fig. 2.20 — Inside cabin aft of pilot—copilot seats. Complete installation of ARMS-II apparatus.

Fig. 2.21 — Complete installation with operator’s seat in position.
Fig. 2.22 — Radar-altimeter transceiver installation.

Fig. 2.23 — Doppler-antenna installation housing.
Fig. 2.24 — Completed pilot's instrument panel.

Fig. 2.25 — Interior of forward baggage compartment showing the single-phase 400-cycle 115-v solid-state inverter installation.
electromagnetic transparency characteristics of the material as seen by the transmitted r-f energy.

2.6.5 Instrument Panel

Figure 2.24 shows the modified instrument panel with the Doppler, compass, and TNC-50 controls on the center section and right side. Instruments added to the standard panel are:

1. Radar-altimeter indicator (extreme left, center row)
2. ID 249 off-course indicator (extreme left, bottom row)
3. J-4 compass indicator (to right of manifold-pressure gauge)
4. Drift-angle and ground-speed indicator (to left of print-mode selector)

None of the instruments, controls, or equipment have radium-worked dials.

2.6.6 Forward Baggage Compartment

The solid-state inverter and filter are visible in the foreground of Fig. 2.25. Not shown in the figure is a small 3-phase 115-v 400-cycle rotary inverter mounted to the right of the solid-state inverter used to drive the J-4 compass gyro. In the far rear are the radio communications and VOR electronics. Just to the rear of the filter box is a rotary 115-v 60-cycle inverter, which provides power to the printer-punch combination. This inverter is supplied from 28 v direct current with the ON-OFF control switch located on the far left of the pilot's instrument panel.
Chapter 3

LABORATORY CALIBRATIONS AND SYSTEM PERFORMANCE

All components comprising the ARMS-II installation were designed and constructed to give the highest degree of performance obtainable under the present state of the art. The effects of temperature variation, input-voltage fluctuations, load changes, and other variables upon the behavior of each unit have been taken into account so that system performance will be comparable to that given by laboratory apparatus.

3.1 HIGH-VOLTAGE POWER SUPPLY

Each of the high-voltage power supplies was subjected to the following tests and measurements:

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage fluctuation, no load</td>
<td>Less than 0.01 per cent</td>
</tr>
<tr>
<td>Input voltage variation</td>
<td>Less than ±0.01 per cent</td>
</tr>
<tr>
<td>115 v ± 10.0 per cent and 400 cycles ± 3 per cent</td>
<td>output voltage change</td>
</tr>
<tr>
<td>Output change for load change of 0 to 1 ma</td>
<td>Less than ±0.01 per cent</td>
</tr>
</tbody>
</table>

Manufacturers specifications indicate a temperature dependence of ±0.01 per cent per degree Fahrenheit per volt from 0 to 120°F on the output voltage of each supply.

3.2 THE 115-V 400-CYCLE INVERTER

The following tests and measurements were taken on the 115-v 400-cycle inverter:

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency at steady-state conditions, full load</td>
<td>395 cycles</td>
</tr>
<tr>
<td>Ripple on 28 v d-c input</td>
<td>Less than 0.4 v peak-to-peak, 400 cycles/sec</td>
</tr>
<tr>
<td>Wave form</td>
<td>About 95 per cent sine wave</td>
</tr>
<tr>
<td>Full-load temperature rise</td>
<td>120°F</td>
</tr>
<tr>
<td>Efficiency under full load</td>
<td>65 per cent</td>
</tr>
</tbody>
</table>

3.3 DETECTOR ASSEMBLY AND SOLID-STATE RADIATION ELECTRONICS

The EMI 9545B photomultiplier tube was made in England. Operating characteristics and voltages required on the focusing electrodes and multiplier stages were determined experi-
mentally for the ARMS-II installation. A Victoreen discriminator—shaper and a Baird-Atomic amplifier, scaler, and timer were used on the output of a unity-gain vacuum-tube preamplifier fed from the photomultiplier tube in tests. A Cs$^{137}$ source, having a photopeak energy of 662 kev, provided the count rate. Voltages on the focusing electrodes and first dynode were set to optimize the gain, resolution, and stability of the tube. Also, the operating voltage was selected to put the photomultiplier tube gain in range of the solid-state amplifier—discriminator and shaper-circuit adjustments so that a 1 to 1 correspondence could be obtained between the kev value of the incident-gamma-ray energies and the discriminator control dial. Potentials of 330 v (direct current) on the first dynode, 230 v on the focusing electrodes, and an over-all tube voltage of 1180 v satisfied the above conditions. Figures 3.1 to 3.3 show some of the measured electrical characteristics of the 9545B photomultiplier tube. The resolution is defined as the discriminator spread at half-maximum peak value divided by the peak discriminator value, with the result taken as a percentage. The tube—crystal combination exhibits a resolution of about 15.8 per cent. Figure 3.2 shows that the low fluctuations present in the output of the high-voltage power supplies will not visibly shift the Cs$^{137}$ peak position. Since, in practice, the system is periodically calibrated according to the discriminator position of the Cs$^{137}$ peak, Fig. 3.3 shows that for a given constant Cs$^{137}$ source intensity, the count rate associated with the desired peak position is unique. Hence, to standardize the apparatus, one needs only to obtain a predetermined count rate at the Cs$^{137}$ energy position of the discriminator by adjustment of the amplifier gain.

Figure 3.4 shows the extent of the fine-gain range in terms of equivalent high-voltage-power-supply output-voltage change. For this curve the high-voltage on the tube was changed in increments of 10 v, and the change in fine gain required to return the Cs$^{137}$ peak to a 662 discriminator setting was recorded. Sufficient control is available to compensate for the degree of instrument drift to be expected in survey work.

The uniformity of response of the crystal—tube assembly was determined by placing a small Cs$^{137}$ source in symmetrical positions about the crystal detector. Slight effects due to scattering of the gammas were to be expected in this measurement since the assembly is not symmetrically constructed. Measurements across the crystal face and around the periphery showed less than a 1 per cent variation in the recorded count rate. Hence during survey operations directional effects of the detector are negligible.
Fig. 3.2 — Gain vs. applied voltage.

Fig. 3.3 — Counting rate at Cs$^{137}$ photopeak vs. peak position.
Fig. 3.4—Change in fine-gain setting ($\Delta G$) required to return Cs\textsuperscript{137} photopeak position to discriminator setting of 662 as a function of high-voltage change ($\Delta V$) on the photomultiplier tube.
Figure 3.5 shows the results of measuring the relative energy response of the large-crystal detector. Calibrated sources of Ba$^{133}$, Cs$^{137}$, and Co$^{60}$ were used in identical geometries. The curve compares favorably with those published by the Harshaw Chemical Co. for NaI(Tl) crystals of smaller dimensions.

Since the Victoreen discriminator unit contained an adjustable "window" control, this apparatus was used to determine the operating potential to be applied to the phototube. The voltage was varied until the Cs$^{137}$ photopeak occurred at a discriminator setting of 662, giving a 1 to 1 correspondence of the reading with the Cs$^{137}$–Ba$^{133}$ gamma energy. The vacuum-tube electronics were then replaced with the ARMS-II transistorized radiation electronics, and adjustments were made on the amplifier and discriminator circuits so that the Cs$^{137}$ photopeak occurred at a reading of 662 on the dial of the discriminator control. Figure 3.6 shows the results obtained with this technique. Curve 1 shows the differential spectral curve obtained with the vacuum-tube circuitry in the vicinity of the Cs$^{137}$ photopeak using the 0.2-v window. Curve 2 was taken with the complete ARMS-II solid-state radiation-measuring system. The ARMS-II apparatus contains only base-line discrimination; so the shape of the two curves is necessarily different. The point of inflection of curve 2 occurs at essentially the same discriminator setting as does the center of the photopeak of curve 1, indicating that the two electronics systems were well matched in their performance.

Figure 3.7 illustrates the linearity of the discriminator circuitry. The apparatus was adjusted so that the Cs$^{137}$ photopeak occurred at a discriminator setting of 662. The Co$^{60}$ and Ba$^{133}$ photopeaks were then located experimentally and plotted against their known energies. A very slight and acceptable departure from linearity can be seen at energies above 900 kev.

The system was found to perform equally well with a square-wave or a sine-wave input to the amplifier, although most of the laboratory tests requiring an oscillator input to the amplifier were conducted with a square-wave generator. Some of the square-wave input tests performed are as follows:
1. The square-wave generator input to the amplifier–discriminator circuit was used to determine display-light sequencing. The numbers were found to light consecutively from 00000 to 99999. A print-command pulse was generated at the predetermined channel edges.

2. At constant input rates of 50,000, 20,000, 10,000, 5000, 1000, and 100 cycles/sec, the computer-display system was stable, giving exact reproduction through 20,000 cycles/sec and ±1 cycle at 50,000 cycles/sec.

3. The variable-frequency-oscillator background-correction control was positioned and calibrated. On both high- and low-range settings, the circuit will remove at least 95 per cent of the count indicated on the control knob.

4. With the square-wave generator input, the computer and amplifier–discriminator circuitry counted to 99,999 cycles/sec without difficulty. With a radioactive source providing the input signal, the system exhibits a linear response as a function of radiation intensity to an average counting rate of $5 \times 10^4$ counts/sec.

Calibrations were performed in the laboratory on the sampling time of the altitude-controlled sampling gate. Prior to installation of the APN-117 radar altimeter in the airplane, the unit was placed in the sampling circuit while the apparatus was mocked-up on the laboratory bench. The radar-altimeter circuitry is not electrically coupled to the computer.

<table>
<thead>
<tr>
<th>Altitude, ft</th>
<th>Gate-open time</th>
<th>Servo-potentiometer current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical, sec</td>
<td>Experimental, sec</td>
</tr>
<tr>
<td>300</td>
<td>0.645</td>
<td>0.685</td>
</tr>
<tr>
<td>400</td>
<td>0.828</td>
<td>0.868</td>
</tr>
<tr>
<td>500</td>
<td>1.000</td>
<td>1.068</td>
</tr>
<tr>
<td>600</td>
<td>1.240</td>
<td>1.336</td>
</tr>
<tr>
<td>700</td>
<td>1.540</td>
<td>1.653</td>
</tr>
<tr>
<td>800</td>
<td>1.920</td>
<td>2.021</td>
</tr>
<tr>
<td>900</td>
<td>2.390</td>
<td>2.521</td>
</tr>
<tr>
<td>1000</td>
<td>2.960</td>
<td>3.122</td>
</tr>
</tbody>
</table>

*Mean per cent error = 6.2 per cent.*

The variable-frequency-oscillator background-correction control was positioned and calibrated. On both high- and low-range settings, the circuit will remove at least 95 per cent of the count indicated on the control knob.

Calibrations were performed in the laboratory on the sampling time of the altitude-controlled sampling gate. Prior to installation of the APN-117 radar altimeter in the airplane, the unit was placed in the sampling circuit while the apparatus was mocked-up on the laboratory bench. The radar-altimeter circuitry is not electrically coupled to the computer.

<p>| Table 3.1—EXPERIMENTAL AND THEORETICAL SERVO-SHAFT POTENTIOMETER CURRENTS* |
|-----------------------------|-----------------------------|-----------------------------|</p>
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</tr>
<tr>
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*Mean per cent error = 6.2 per cent.*

The variable-frequency-oscillator background-correction control was positioned and calibrated. On both high- and low-range settings, the circuit will remove at least 95 per cent of the count indicated on the control knob.

Calibrations were performed in the laboratory on the sampling time of the altitude-controlled sampling gate. Prior to installation of the APN-117 radar altimeter in the airplane, the unit was placed in the sampling circuit while the apparatus was mocked-up on the laboratory bench. The radar-altimeter circuitry is not electrically coupled to the computer.

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<td>3.122</td>
</tr>
</tbody>
</table>

*Mean per cent error = 6.2 per cent.*

The variable-frequency-oscillator background-correction control was positioned and calibrated. On both high- and low-range settings, the circuit will remove at least 95 per cent of the count indicated on the control knob.

Calibrations were performed in the laboratory on the sampling time of the altitude-controlled sampling gate. Prior to installation of the APN-117 radar altimeter in the airplane, the unit was placed in the sampling circuit while the apparatus was mocked-up on the laboratory bench. The radar-altimeter circuitry is not electrically coupled to the computer.

Table 3.1 lists the theoretical and experimental values of the current out of the special servo-shaft potentiometer. The measured current values are corrected for the resistance of the measuring meter.

Table 3.1 illustrates the mean error shown by the "gate-open time" data. The experimental values of the gate time are consistently higher than the desired times. The measured values of the current, as compared to the theoretical values, show that the long gate times are due to a high value of the gating current. The nature of the gating circuitry does not permit closer adjustment to the theoretical time values than those shown in Table 3.1; however, Fig. 3.8 shows that the correct gate-opening time can be made to occur at the correct aircraft altitude by adjusting the radar altimeter. This adjustment will be discussed in Sec. 3.4.
Fig. 3.6—Vacuum-tube response vs. solid-state discriminator. Curve 1, vacuum-tube electronics. Curve 2, solid-state electronics.

Fig. 3.7—Discriminator linearity curve of ARMS-II radiation-detection equipment.
Fig. 3.8—Gate time vs. altitude.

UPPER CURVE = EXPERIMENTAL
LOWER CURVE = THEORETICAL
3.4 FLIGHT-TEST CALIBRATIONS

Installation of the Doppler system and J-4 compass was made by General Precision, Inc., personnel. Since it was the responsibility of GPI to provide the printer—punch combination, the units were first assembled and operated at the GPI laboratory. Compatibility of the units was obtained throughout the entire system.

The aircraft, with the complete ARMS-II installation, has been approved as airworthy and is licensed in the Standard Category.

The aircraft was test flown over the Doppler—compass course used by GPI in New York. The Doppler—compass system performance was well within the manufacturer's specifications. Doppler courses were calculated and laid out for a cross-country flight from New York to Las Vegas, Nev. The average closing error tabulated on each of the flight legs was about 0.6 per cent.

3.4.1 Doppler Navigation Equipment

Six Doppler courses were calculated and laid out in the vicinity of Las Vegas so that by flying them in the forward and reverse directions, compass headings covering every 30° of the quadrant were obtained. The length of the legs was between 38 and 45 miles (Fig. 3.9).
Table 3.2 lists course information along with the number of flights conducted over each leg. The closing-error spread, taken in terms of percentage of distance flown, gives preliminary results within the manufacturer's specifications. Whether or not the Doppler system records the "surface" distance or a smooth geoid contour is yet to be determined. Further information is needed, also, to determine the closure errors obtained by flying a curved or off-course path and then closing on the end point, as compared to the errors involved in flying the calculated course along a straight line.

Experiments were conducted to determine the error introduced into the data by the aircraft's making turns. In some instances at the end of a grid line, it may be necessary for the survey pilot to determine the neighboring survey grid line by making a 180° turn and using the across-track indicator to position the plane 1 mile from his original flight line. The effect of these maneuvers was documented by making a series of turns starting over a visual ground check point. Turns of 180, 270, and 360° were executed with the Doppler unit recording-position data. The turns were made at banking angles up to 60°. At the end of each turn, the pilot repositioned the aircraft over the ground check point, and the closing error was recorded by the Doppler gear. The average values of the errors encountered during 23 turns were as follows:

Across-track error, ±0.02 nautical miles
Along-track error, ±0.03 nautical miles

Above banking angles of 60°, the Doppler gear went into the memory mode. The errors listed above are of the same order of magnitude as the instrumental uncertainties inherent in setting data into the Doppler reader. Hence the errors introduced into the position data by making turns up to a 60° banking angle are considered negligible.

To obtain information on the across-track distances obtained during 180° turns as a function of banking angle and aircraft speed, the All Weather Flight Manual distributed by the FAA Bureau of Flight Standards was used. Figures 3.10 to 3.12 summarize the turn data obtained. Figure 3.10 illustrates the across-track distances covered during a 180° turn as a function of the banking angle at several aircraft speeds. Since the survey grid lines will be laid out on 1-mile centers, the banking angle and aircraft speed combination that would put the pilot on a 1-mile spacing upon completion of a 180° turn was investigated (Fig. 3.11). The data in Fig. 3.12 were obtained to determine whether the execution of turns under the conditions indicated

Table 3.2—ARMS-II DOPPLER NAVIGATION-SYSTEM CALIBRATION*

<table>
<thead>
<tr>
<th>Leg</th>
<th>Magnetic course, deg</th>
<th>Length of leg, nautical miles</th>
<th>No. of runs</th>
<th>Along-track error</th>
<th>Cross-track error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spread in recorded error, nautical miles</td>
<td>% of distance flown</td>
</tr>
<tr>
<td>F-G</td>
<td>6.52</td>
<td>41.23</td>
<td>2</td>
<td>0.16 ±0.08</td>
<td>±0.1</td>
</tr>
<tr>
<td>C-D</td>
<td>41.36</td>
<td>41.22</td>
<td>2</td>
<td>0.32 ±0.16</td>
<td>±0.4</td>
</tr>
<tr>
<td>F-E</td>
<td>76.04</td>
<td>43.99</td>
<td>1</td>
<td>0.24 ±0.12</td>
<td>±0.3</td>
</tr>
<tr>
<td>B-A</td>
<td>102.39</td>
<td>38.45</td>
<td>5</td>
<td>0.46 ±0.23</td>
<td>±0.5</td>
</tr>
<tr>
<td>G-H</td>
<td>134.91</td>
<td>45.78</td>
<td>2</td>
<td>0.59 ±0.30</td>
<td>±0.6</td>
</tr>
<tr>
<td>C-E</td>
<td>163.55</td>
<td>49.45</td>
<td>5</td>
<td>0.23 ±0.12</td>
<td>±0.3</td>
</tr>
<tr>
<td>G-F</td>
<td>186.52</td>
<td>41.23</td>
<td>1</td>
<td>0.20 ±0.10</td>
<td>±0.2</td>
</tr>
<tr>
<td>D-C</td>
<td>221.36</td>
<td>41.22</td>
<td>2</td>
<td>0.10 ±0.05</td>
<td>±0.1</td>
</tr>
<tr>
<td>E-F</td>
<td>256.04</td>
<td>43.99</td>
<td>2</td>
<td>0.27 ±0.14</td>
<td>±0.3</td>
</tr>
<tr>
<td>A-B</td>
<td>282.39</td>
<td>38.45</td>
<td>2</td>
<td>0.20 ±0.10</td>
<td>±0.2</td>
</tr>
<tr>
<td>H-G</td>
<td>314.91</td>
<td>45.78</td>
<td>1</td>
<td>0.10 ±0.05</td>
<td>±0.1</td>
</tr>
<tr>
<td>E-C</td>
<td>343.55</td>
<td>49.45</td>
<td>4</td>
<td>0.27 ±0.14</td>
<td>±0.3</td>
</tr>
</tbody>
</table>

n = 29 Av. 0.28 ±0.14 ±0.33 0.32 ±0.16 ±0.35

Fig. 3.10 — Bank angle vs. distance across track required to make 180° change in direction.

Fig. 3.11 — Speed vs. bank angle to provide 1-mile displacement across track for 180° change of direction.
would seriously affect the structural loading of the aircraft. The normal aircraft speed used during survey flights varies from about 140 to 160 mph. With 150 mph as the average, a banking angle of approximately 35° will reposition the aircraft to the desired 1-mile spacing for the return grid line. Assuming that no gust loading is superimposed on the turn loading, the equipment and plane are well within the safe-load region. Banking angles of 50 to 60° also lie in a safe region if no additional loading factors occur. However, high banking angles are not recommended for two reasons: (1) If an unexpected gust occurs, instantaneous loading can become dangerously high, as indicated by the steep slope at the upper regions of the curve in Fig. 3.12. (2) Needless loadings of 2 g's or more on the structural members supporting the equipment rack and on the rack itself will tend to shorten the trouble-free operation time of the aircraft and instrumentation.

![Fig. 3.12 — Load factor vs. bank angle.](image)

Turns made at a banking angle of 35° at 150 mph will place the aircraft in position for proceeding along the next grid line without the introduction of Doppler error and with no undue loading on the aircraft.

The extent of the error introduced by the survey pilot as he starts the Doppler navigator while flying over a visual ground check point was determined by providing the pilot with information on his position relative to the check point at the instant he activated the Doppler apparatus. Two-way radio communication was set up with the pilot from a ground check point. Several runs were conducted over the point in which a signal was radioed to the pilot by the
ground observer the instant the plane passed overhead. To work out an operational procedure, the pilot made trial runs during which he began a countdown along his approach the instant the ground station passed from view under the nose of the aircraft. Upon receiving a ground signal, he stopped counting. From these trial runs an average count was obtained, and the data runs were begun. At a signal from the pilot the instant he thought he was directly overhead, the aircraft was photographed with a vertically directed ground camera. Visual aid from objects off to the side of the check point was not used.

Table 3.3 gives the pilot's position relative to the ground station the instant he thought he was directly overhead.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Run direction</th>
<th>Along track from Ground Zero, ft</th>
<th>Across track from Ground Zero, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
<td>32.2 short</td>
<td>23.2 pilot's left</td>
</tr>
<tr>
<td>2</td>
<td>S</td>
<td>73.7 short</td>
<td>24.6 pilot's left</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>126.0 long</td>
<td>66.4 pilot's left</td>
</tr>
<tr>
<td>4</td>
<td>S</td>
<td>21.2 long</td>
<td>59.1 pilot's right</td>
</tr>
<tr>
<td>5</td>
<td>N</td>
<td>15.2 short</td>
<td>7.0 pilot's right</td>
</tr>
</tbody>
</table>

Slight winds and turbulence were present at the time; so the pilot was kept busy trying to maintain 500 ft altitude as well as course direction. Average countdown time was about 17 sec.

The data show that all points except one fall within a 75-ft-radius circle of Ground Zero. The pilot felt that by using side objects from the check point, as is done in actual practice, much better results could have been achieved. On the basis of this experiment, it is felt that the error introduced into the aircraft position data as a result of pilot uncertainty over the check point is negligible.

The APN-117 radar altimeter was calibrated using a photographic technique over the Yucca Lake Area of NTS. The lake bed was selected because it is a large flat area over which a constant relative altitude could be maintained. A vertically pointing camera was oriented to within 1° of the zenith on the dry lake bed, and the aircraft was flown over the camera station at an altitude of 500 ft, as shown on the radar-altimeter indicator. By means of two-way radio communication with personnel at the ground camera station, the altimeter reading was recorded at the same time the aircraft was photographed. Markings at measured distances were placed on the underside of the aircraft wings, permitting altitude calculations to be made from the photographs. Twenty-one determinations of the true vs. indicated altitude were made. Although the radar altimeter was bench-calibrated by Sylvania personnel prior to installation, the experiment revealed that a constant error of 15 ± 1.5 ft was present in the altimeter indication at the 500-ft-above-terrain position. The error was such that at an indicated altitude of 515 ft the aircraft was at a true altitude of 500 ft.

A second experiment showed that the correct sampling gate time vs. altitude curve could be obtained by reducing the indicated altitude by 6 per cent. Both corrections were set into the altimeter during a subsequent flight.

3.4.2 Radiation Equipment

(a) Laboratory Calibrations. Nearly all the laboratory calibrations performed on the radiation-detection and -measuring system were repeated after the equipment had been installed in the airplane and minor voltage adjustments had been made. Figure 3.13 shows a typical discriminator count-rate curve obtained with the aircraft installation using the calibrating Cs\textsuperscript{137} source installed near the crystal. This curve was obtained during flight with an amplifier-gain setting near the center of the adjustment range, demonstrating that large instrumental drifts during survey operations can be accommodated.

Although the small Cs\textsuperscript{137} source used for calibration purposes is mounted behind 2\textfrac{1}{4} in. of lead shielding, its proximity is detected by the crystal. The background-correction control is
used to remove this contribution to the total count rate. The actual magnitude of the Cs$^{137}$ contribution to the entire background detected by the system was measured during several flights over land (Fig. 3.14) with no calibrating source installed in the aircraft, and 1 to 2 miles off shore over the ocean (Fig. 3.15) with the Cs$^{137}$ source installed in the plane. The gamma-ray contribution from the earth is clearly evident from a comparison of Figs. 3.14 and 3.15. The sharp upswing in the curve at the lower altitudes over land is not present in the data collected over the ocean. Radiation from the Cs$^{137}$ source contributed about 800 counts/sec to the total count rate, and cosmic radiation amounted to about 220 counts/sec. Although the airborne radon concentration was not measured, the low-altitude rise in intensity in Fig. 3.15 was probably due to an inversion that increased the effect of airborne radon and its daughters.

(b) Extended-source Results. An extended range of standard sources was prepared at Frenchman Flat, NTS, by AEC and ORNL personnel (Fig. 3.16). Source positions were laid out on 100-ft centers to cover an area 2000 by 2000 ft. Small sources of Cs$^{137}$ (15 mc) and Co$^{60}$ (4.46 mc) were positioned so that flights could be made over a simulated constant-intensity field for two different average energies. Two point-source locations were also laid out forming an equilateral triangle with the center of the source array. The sides measured 6000 ft. The small source in the center of the array geometry was replaced with 100 smaller ones on 10-ft centers. The total intensity of these sources was approximately equal to the intensity of the larger source which they replaced.

The ARMS-II aircraft made a total of 150 passes over the array and point-source locations. 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.
Fig. 3.14 — Cosmic count rate vs. altitude over land with no calibrating source in aircraft.

Fig. 3.15 — Cosmic count rate vs. altitude over ocean with calibrating source in aircraft.
(c) **Array and Point-source Results.** In normal operation the radiation system records
the activity detected in terms of channel numbers. For increased accuracy 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. So that the recorder could keep pace with the rate of change of the
displayed count, the tens and unit digits were not recorded. Table 3.4 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 or 10 individual readings. These figures are uncor-
rected for background radiations. A constant contribution of about 800 counts/sec from the
calibration source is contained in the background values.

The illustrations on the following pages depict the system behavior of the ARMS-II radia-
tion equipment as a function of altitude, gamma energy, intensity, etc. Wherever possible col-
lected data were compared with theoretical or previously published experimental results. The
detected radiation intensities have been corrected for the background content. The strength of
the Co\textsuperscript{60} point source was 1.2 curies, and that of the Cs\textsuperscript{137} source was 1.72 curies.

Figures 3.17 and 3.18 show the count rate normalized to the 500-ft value over the array
for Co\textsuperscript{60} and Cs\textsuperscript{137}, respectively. The experimental results of Fig. 3.17 show good agreement
with the predicted curve. However, the data points of Fig. 3.18 indicate a slightly different
slope than that of the calculated curve.
Table 3.4 — NTS SOURCE CALIBRATION RANGE COUNT-RATE SUMMARY

<table>
<thead>
<tr>
<th>Alt., ft</th>
<th>Gross count rates</th>
<th>Altitude-compensated gate, total count</th>
<th>Background count rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-sec gate, counts/sec</td>
<td>(1-sec gate), counts/sec</td>
<td></td>
</tr>
<tr>
<td>Co(^{60}) Array</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>10,700</td>
<td>2,240</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>9,000</td>
<td>2,240</td>
<td>1,950</td>
</tr>
<tr>
<td>400</td>
<td>7,300</td>
<td>2,240</td>
<td>1,730</td>
</tr>
<tr>
<td>500</td>
<td>6,000</td>
<td>2,240</td>
<td>1,600</td>
</tr>
<tr>
<td>600</td>
<td>4,900</td>
<td>2,240</td>
<td>1,440</td>
</tr>
<tr>
<td>700</td>
<td>4,200</td>
<td>2,240</td>
<td>1,350</td>
</tr>
<tr>
<td>800</td>
<td>3,400</td>
<td>2,240</td>
<td>1,260</td>
</tr>
<tr>
<td>900</td>
<td>3,000</td>
<td>2,240</td>
<td>1,200</td>
</tr>
<tr>
<td>Cs(^{137}) Array</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>13,600</td>
<td>2,240</td>
<td>1,950</td>
</tr>
<tr>
<td>300</td>
<td>10,500</td>
<td>2,240</td>
<td>1,730</td>
</tr>
<tr>
<td>400</td>
<td>8,800</td>
<td>2,240</td>
<td>1,600</td>
</tr>
<tr>
<td>500</td>
<td>7,200</td>
<td>2,240</td>
<td>1,440</td>
</tr>
<tr>
<td>600</td>
<td>5,100</td>
<td>2,240</td>
<td>1,350</td>
</tr>
<tr>
<td>700</td>
<td>4,300</td>
<td>2,240</td>
<td>1,260</td>
</tr>
<tr>
<td>800</td>
<td>3,600</td>
<td>2,240</td>
<td>1,200</td>
</tr>
<tr>
<td>900</td>
<td>3,100</td>
<td>2,240</td>
<td>1,100</td>
</tr>
</tbody>
</table>

| Co\(^{60}\) Point Source | | | |
| 40,000 | 40,000 | 1,700 |
| 24,000 | 19,000 | 1,500 |
| 17,000 | 14,500 | 1,400 |
| 10,000 | 10,500 | 1,300 |
| 8,000 | 10,000 | 1,200 |
| 5,500 | 7,900 | 1,100 |
| 4,100 | 8,000 | 1,100 |
| 3,300 | 8,400 | 1,100 |

| Cs\(^{137}\) Point Source | | | |
| 32,600 | 32,600 | 1,700 |
| 18,000 | 16,000 | 1,500 |
| 10,200 | 8,800 | 1,400 |
| 6,600 | 7,000 | 1,300 |
| 4,750 | 5,800 | 1,200 |
| 3,300 | 5,200 | 1,100 |
| 2,700 | 5,300 | 1,100 |
| 2,200 | 5,400 | 1,100 |

Figure 3.19 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 3.20 is also 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. Acceptable agreement exists between the two measurements illustrated.

Figure 3.21 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 data at 500 ft were used. The solid curve is again a best-fit curve represented by the data. Figure 3.22 illustrates gate-open time vs. altitude, comparing experimental to theoretical points. Figure 3.23 shows the agreement between the experimentally determined gating times required (Fig. 3.21) and the experimentally measured gating times actually obtained (data points of Fig. 3.22). To summarize, the radiation sampling times exhibited by the altitude-compensating control circuitry are satisfactory.

(d) Area Results. The curves of Fig. 3.24 show the diameter of the ground circle viewed by the crystal for the corresponding percentage contribution to the total count recorded (assuming that a flat, homogeneous infinite plane gives 100 per cent of the detected count). Figure 3.24 shows that at 500 ft the ground area integrated by the radar altimeter beam to provide sampling-gate control corresponds nearly to the ground area that provides 90 per cent of the recorded radiation level. Figure 3.25 shows the relative effectiveness or percentage contribution of concentric areas immediately below the aircraft at the 500-ft survey elevation.

(e) 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. From these data, corrected for background content, the ratio of the detection sensitivities was calculated. Sixty-five pieces of data were used, giving a ratio of the large-crystal response to the small-crystal response of 190 ± 3 to 1. The standard deviation represents an uncertainty of 1.6 per cent on the ratio value. In terms

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Fig. 3.17—The Co$^{60}$-array normalized count rate vs. altitude.

Fig. 3.18—The Cs$^{137}$-array normalized count rate vs. altitude.
Fig. 3.19—Count rate vs. altitude for point sources.

Fig. 3.20—Point-source radiation vs. altitude.
Fig. 3.21—Experimentally determined gate-open times required to give equivalent 500-ft-level counts.

Fig. 3.22—Gate-open time vs. altitude. Comparison of experimental points with theoretical.
Fig. 3.23 — Gate-open time vs. altitude.

Fig. 3.24 — Altitude vs. area seen by large crystal on ground.
of actual count-rate range of the system, the large-crystal count-rate equivalent extends from 50 to approximately $10^7$ counts/sec.

(1) Detection Sensitivity. So that the count recorded in the aircraft could be converted into 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 manner that the total curie strength remained unchanged. Since Figs. 3.24 and 3.25 indicate that, from the center of the array, the source field is nearly an infinite plane to the aircraft detector at 500 ft above the ground, the error introduced by the above assumption is small. Hence in the case of the Co$^{60}$, the detector viewed a homogeneous plane of radiation whose average intensity was 4.8 $\mu$C/m$^2$; that of the Cs$^{137}$ appeared to be 16.15 $\mu$C/m$^2$. The average maximum count rates at the 500-ft altitude over the center of the array were 4400 counts/sec for the Co$^{60}$ and 5600 counts/sec for the Cs$^{137}$. Combining these quantities gives the following results:

$$\begin{align*}
\text{Co}^{60}: & \quad \frac{916 \text{ counts/sec}}{\mu\text{C/m}^2} \\
\text{Cs}^{137}: & \quad \frac{347 \text{ counts/sec}}{\mu\text{C/m}^2}
\end{align*}$$

If the energy of the radiation to be normally detected is considered to be due chiefly to radium and its daughters in the soil, then approximately 0.1 $\mu$C/m$^2$ represents the lower limit of detection (50 counts/sec) when surveying at 500 ft. In the case of freshly deposited fission products, this value of the ground concentration would be reduced slightly. With the aid of the data presented by Davis and Reinhardt$^3$ of ground measurements made over the array, a Co$^{60}$ dose rate of 1 $\mu$R/hr at the 3-ft level corresponds to a count rate in the ARMS-II apparatus of 22 counts/sec at 500 ft above terrain, and a count rate of 25 counts/sec for a ground-level dose rate of 1 $\mu$R/hr due to Cs$^{137}$ gammas. (These figures compare with 25 and 18 counts/sec for Cs$^{137}$ and Co$^{60}$, respectively, for the USGS ARMS-I equipment.)

3.5 SYSTEM UNCERTAINTIES

The uncertainties contained in the data generated by the ARMS-II equipment can be divided into two categories, each of which affects the other to some extent: (1) aircraft positioning errors and (2) uncertainties contained in the recorded radiation data. If the data are being
recorded periodically (period print command), the combined data point information of radiation level and aircraft position will contain a time uncertainty equal to one sampling period; so the indicated location will be in error according to the aircraft velocity. This is not a serious effect, but is nevertheless present.

3.5.1 Aircraft-positioning Uncertainties

Most of the error present in the recorded position of the aircraft is introduced by the following three sources: (1) pilot positioning error, (2) sampling time, and (3) along-track and across-track instrumental errors.

Observational results indicate that a pilot positioning uncertainty exceeding ±50 ft at each end of a traverse leg is unlikely.

Table 3.5 — MAXIMUM POSITIONING UNCERTAINTIES

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot position</td>
<td>±100 ft</td>
</tr>
<tr>
<td>Sampling period</td>
<td>±110 ft</td>
</tr>
<tr>
<td>Instrumental error</td>
<td></td>
</tr>
<tr>
<td>Along track (30-mile leg)</td>
<td>±554 ft</td>
</tr>
<tr>
<td>Across track (10 miles)</td>
<td>±385 ft</td>
</tr>
<tr>
<td>Total error = (100^2 + 110^2 + 554^2 + 385^2)(^{1/2})</td>
<td>±685 ft</td>
</tr>
<tr>
<td></td>
<td>±0.11 nautical mile</td>
</tr>
</tbody>
</table>

The maximum uncertainty of associating a radiation level with a geographic position is one sampling period. At an altitude of 500 ft, this corresponds to 1 sec, or about 220 ft of ground distance at an aircraft speed of 150 mph. If the survey altitude is higher than 500 ft, the error is increased according to the sampling gate time.

The instrumental errors associated with the along- and across-track indications have not as yet been fully determined experimentally. Preliminary data, however, indicate that the system will perform within manufacturer's specifications. For the present purpose the manufacturer's figures will be used. The along-track error is given as 0.35 per cent of the distance flown, and the across-track error is 0.73 per cent. Table 3.5 summarizes the maximum error to be expected in the positioning data at a nominal survey altitude of 500 ft.

On the USGS quadrangle maps (4 miles = 1 in.), the ±0.11 nautical mile amounts to an uncertainty of ±0.037 in. Investigation of the inherent accuracies of these maps indicates that the maximum positioning error in the ARMS-II data is smaller than that associated with the cultural features of the map. Hence, when a data point is located on a map in relation to some fixed ground check point, the error contained in the map will be superposed on that given in Table 3.5, and an uncertainty of at least ±0.16 nautical mile will be encountered when associating a data point on the map with the actual ground location.

3.5.2 Radiation-level Uncertainties

The total uncertainty present in the recorded radiation channel level varies with channel number since this uncertainty is largely composed of the statistical fluctuations inherent in the behavior of radioactive sources. The largest uncertainties are present in the lower channel numbers, decreasing as the radiation level increases because of decreased statistical error and channel widening at the higher count rates. Other than the statistical radiation fluctuations, the error consists of uncertainties introduced from instrumental, meteorological, and gating-time variations. Curves are presented in USAEC Report CEX-59.4(Pt.I), the ARMS-II, Phase I report, which show the effect introduced into the recorded radiation data over a wide range of meteorological parameters. The effect on the radiation data discussed here will be based on the magnitude of the meteorological changes observed during the calibration and survey flights at NTS.

The largest effect that meteorological changes impose on the passage of gamma rays from the earth to the detector is the change that occurs in the density of the air column be-
between the aircraft and the ground. The most important factor here, of course, is that of temperature variations, although the effect of other parameters is also noticeable. During the flights at NTS, the maximum free-air temperature variations recorded were \( \pm 4^\circ F \) over flight periods of 4 hr duration. However, temperature variations of \( \pm 10^\circ F \) might occur in flight which are not accompanied by moving frontal conditions that would prevent further survey activity. Temperature deviations of this magnitude would create a maximum variation in the count rate of \( \pm 3.0 \) per cent.

The effect of air-pressure variations on the uncertainty in the data is of smaller consequence than the temperature, mainly because over a normal survey area pressure gradients are either small or absent entirely. A maximum value for the pressure variations is about \( \pm 8 \) mm Hg. An error of only 0.15 per cent in the count rate is introduced from this effect.

The third meteorological parameter to be considered is relative humidity and its effect on gamma attenuation. Although relative humidity can change rapidly and over a wide range, the effect on the measurements is small. For example, if survey operations are proceeding at \( 80^\circ F \) at 500 ft and the relative humidity is 50 per cent, the error that a change of \( \pm 50 \) per cent in the relative humidity will introduce into the data is about 0.9 per cent.

The maximum changes in the meteorological conditions to be expected during a survey operation and their effect on the radiation uncertainty can be summarized as follows:

\[
\begin{align*}
\pm 10^\circ \Delta T &= \pm 3.0 \text{ per cent count-rate variation} \\
\pm 8 \text{ mm Hg } \Delta P &= \pm 0.15 \text{ per cent count-rate variation} \\
0 \text{ to } 100 \text{ rel. humidity} &= \pm 0.45 \text{ per cent count-rate variation} \\
\sigma \text{ met.} &= \pm (3.0^2 + 0.15^2 + 0.45^2)^{\frac{1}{2}} \\
\sigma \text{ met.} &= \pm 3.04 \text{ per cent}
\end{align*}
\]

The altimeter-controlled sampling gate time has been calibrated and found experimentally to coincide nearly exactly with the desired times. However, in flight some gustiness and turbulence are always encountered; thus, during any particular radiation sampling period, the altimeter can vary the gating time. If it is assumed that a maximum rate of altitude change occurring during any sampling period is \( \pm 1000 \) ft/min, or about 17 ft/sec, then (coupled with the uncertainty of the photographic calibration) a total error of \( \pm 3.4 \) per cent is introduced into the radiation data.

The effect of instrumental variations on the count rate can be made negligible by periodic calibrations of the system using the Cs\(^{137}\) source mounted near the crystal. If the calibration is performed every 15 to 20 min, the effects of instrumental drift will be kept negligible.

Figure 3.26 illustrates the time–gain drift of the apparatus. After a 30-min operational period, the gain change required to maintain calibration of the apparatus is small. In practice the survey area is generally 20 to 40 min flying time from the take-off point; therefore, if a
calibration is performed when the area is reached, the subsequent drift rate should be small. Experimental evaluations of the drift rate have shown that, if the calibrations are performed no oftener than once an hour, the count-rate error introduced is no larger than 5.6 per cent.

The statistical error inherent in the detected radiation will be due chiefly to three sources of radiation: (1) earth radiation, (2) cosmic plus airborne radiation, and (3) Cs\textsuperscript{137} source leakage through the shield.

The average background rate determined from many readings at 3000 ft above terrain is about 1030 counts/sec, which includes cosmic, source, and extraneous background radiation. Although the background-correction control removes the average rate of this activity, the total statistical fluctuation is present on the net earth radiation. Hence, if the net count from the ground is 500 counts/sec, the standard deviation amounts of ±39 counts/sec, or ±7.8 per cent.

All the above discussed errors are present in the recorded radiation data. Table 3.6 summarizes these effects.

<table>
<thead>
<tr>
<th>Table 3.6—RADIATION DATA MAXIMUM UNCERTAINTIES</th>
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<td>Meteorological effects</td>
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\[ \sigma = \pm (3.0^2 + 3.4^2 + 2.8^2 = 7.8^2) \]

\[ \sigma = \pm 9.5 \text{ per cent} \]

If the net radiation being recorded averages 550 counts/sec, the recorded data will average channel number 6. Since the channel widths are 100 counts/sec wide at this position, the uncertainty of ±9.5 per cent in Table 3.6 means that channel variations from channels 4 through 6 will be normal as a result of the uncertainties present. Preliminary survey data show that this channel spread is a little high. However, maximum error conditions are represented by the above calculations.

The magnitude of the uncertainties summarized in Table 3.6 applies to data taken during a single survey day at one site. To match data between days of widely different meteorological conditions, one must apply the proper corrections.

REFERENCES

Chapter 4

OPERATIONAL CHECK-OUT FLIGHTS

4.1 FLIGHT PROCEDURE

Following calibration of the radiation-detection apparatus, about 75 square miles of Yucca Flat (Fig. 4.1) and 80 square miles of Frenchman Flat (Fig. 4.2) were surveyed. The flight paths covered about 150 and 180 traverse miles, respectively, at a nominal altitude of 500 ft.

The flight lines generally were north and south. Distinguishable ground check points were not available at the ends of the survey lines and deviations from parallel flight lines were made to allow flight over usable ground check points. In so doing, the error accumulation in the Doppler apparatus could be documented from the ground check points. The data presented in Figs. 4.1 and 4.2 have been proportionately corrected for the closure errors.

During the Yucca Flat survey, radiation and aircraft-position data were recorded every 3 sec. Since the average aircraft speed was 150 mph, data were collected at approximately 600-ft intervals, furnishing about 1300 data points.

For the Frenchman Flat area, the radiation-detection and -measurement subsystem was set so that print-command signals would occur whenever the radiation computer sensed a change in the activity level. About 1900 radiation level changes were recorded. Owing to the heterogeneity of the ground radiation pattern, the distance between print outs varied from about 200 to 5000 ft.

4.2 COMPILATION OF DATA

The compilation of the radioactivity and position data recorded during the surveys of the Yucca Flat and Frenchman Flat areas was accomplished in four stages. The procedure was as follows:

1. Scanning the decimal tape and selecting significant data points.
2. Proportionately correcting the location of the data points according to the recorded Doppler error.
3. Plotting the data points on a map of the area.
4. Delineation of the radioactivity values into narrow-range count-rate groupings or aeroradioactivity units.

About 230 of the 1300 data points recorded over the Yucca Flat area were considered to indicate significant changes in the radiation level. Over the Frenchman Flat area, about 290 of the 1900 data points obtained were so interpreted. These are the points that were selected in step 1 above.

The proportionate positioning correction was applied graphically to each data point. The uncorrected position of the point was plotted on tracing paper. Then, the position of the point was corrected by graphically proportioning the along-track and across-track closure errors. The most severe closing errors recorded were 0.55 mile along track and 0.65 mile across track. These figures represent an error of less than 0.7 per cent of the distance flown, which
Fig. 4.1 — Aeroradioactivity map of the Yucca Flat survey area, NTS. Radioactivity levels in counts per second determined at a nominal altitude of 500 ft above the ground. Surveyed by EG&G, Nov. 13 and 14, 1960. Aircraft N702B. Data compensated for deviations from nominal altitude.
Fig. 4.2—Aeroradioactivity map of the Frenchman Flat survey area, NTS. Radioactivity levels in counts per second determined at a nominal altitude of 500 ft above the ground. Surveyed by EG&G. Nov. 14, 1960. Aircraft N702B. Data compensated for deviations from nominal altitude.
is the order of magnitude to be expected. When the proportionate correction was applied to the
data points, any remaining uncertainty present in each would probably be due to local magnetic
anomalies or uncertainties in the map itself.

The data points were plotted on U. S. Geological Survey topographic maps, scale \(\frac{1}{62500}\).
The Yucca Flat area is on parts of the Cane Spring, Frenchman Lake, Papoose Lake, and
Tippipah Spring quadrangles. The Frenchman Flat area is on parts of the Cane Spring, French-
man Lake, and Mercury quadrangles.

The radioactivity data have been grouped into regions of similar count rate or aeroradio-
activity units. Because a range in count-rate values is usually recorded on any segment of a
flight line, the aeroradioactivity unit is assigned a range in count instead of a definite value.
The upper limit of one unit may be the lower limit of an adjacent unit or the range of one unit
may overlap the range of the adjacent unit. The overlapping of ranges is especially common
in areas of low (100 to 800 counts/sec) count rate.

In delineating the aeroradioactivity units, account is taken of the fact that radioactivity
data recorded at 500 ft above terrain pertain to a strip of ground about \(\frac{1}{4}\) mile wide (\(\frac{1}{4}\) in. at
a map scale of \(\frac{1}{62500}\)) along each flight line. Where flight lines are more than \(\frac{1}{4}\) mile apart, it
was assumed that the radioactivity between the flight lines was similar to that along the flight
lines if similar count rates were recorded on several adjacent lines. At locations where dis-
similar count rates were recorded on adjacent lines, the boundary between the two aeroradio-
activity units represents an interpolated position. Hence, it is clear that dissimilar count
rates on adjacent lines, as well as fluctuations along a flight line, contribute to the width of
the range of count for a particular aeroradioactivity unit.

4.3 AERORADIOACTIVITY MAP OF YUCCA FLAT SURVEY AREA

The aeroradioactivity map of the Yucca Flat Survey Area is shown in Fig. 4.1. The most
striking features of this map are the areas of relatively high radioactivity resulting from nu-
clear test activities in Areas 1, 4, 2, 7, and 3. Fairly well defined areas of low radioactivity
were found in the southern one-third of the area.

A maximum reading of 30,000 to 50,000 counts/sec was recorded over Area 1. Two activ-
ity peaks were recorded in Area 4, one of 30,000 to 50,000 counts/sec, the other of 8000 to
15,000 counts/sec. Maximum readings of 8000 to 15,000 were recorded in Areas 2 and 7. A
large portion of Area 3 indicated an average count rate greater than 2000 with two anomalies
in the range of 30,000 to 50,000 counts/sec being recorded.

The nuclear weapons testing activities undertaken in this region are undoubtedly the con-
trolling factor in the distribution of radioactivity units in the northern two-thirds of the Yucca
Flat survey area.

Radioactivity resulting from test activities, although certainly present, is not the dominant
factor in the southern one-third of the Yucca Flat area. The natural radioactivity of the sur-
ficial soils and rocks accounts for some, if not all, the aeroradioactivity units in this part of
the area. An indication of this is the coincidence of aeroradioactivity-unit boundaries and
surface-drainage lines. The areas of 100 to 300 and 300 to 500 counts/sec north and west of
the check point probably reflect a high percentage of weakly radioactive carbonate rock frag-
ments in the soil. The area of 400 to 700 counts/sec could reflect an increased content of
volcanic rock fragments of the moderately radioactive Oak Spring formation in the soil.

4.4 AERORADIOACTIVITY MAP OF THE FRENCHMAN FLAT SURVEY AREA

The aeroradioactivity map of the Frenchman Flat survey area is shown in Fig. 4.2. A
prominent anomaly, with a peak reading of 15,000 to 30,000 counts/sec, occurs over weapons
test Ground Zero. The activity is less than 1000 counts/sec in the rest of the area except for
four small anomalies, one of which has a peak value of 4000 to 8000. Excluding the anomalous
areas, the controlling factor in the distribution of the surface radioactivity is probably the
natural radiation of the soils and rocks. The published geological literature of the alluvial
area of Frenchman Flat is not sufficiently detailed to permit a correlation of the recorded radioactivity and areal geology to be made.

4.5 DISCUSSION AND CONCLUSIONS

The aeroradioactivity maps, Figs. 4.1 and 4.2, are to be considered as being representative of the type of survey data presentation proposed by EG&G. In conformity with requirements placed on the Division of Biology and Medicine, USAEC, the delineation of aeroradioactivity units provides a method of data presentation that will be intelligible to scientist and layman alike. In reporting on actual survey operations, the finished survey map will consist of a base map, containing drainage and cultural information for orientation purposes, upon which the aeroradioactivity unit lines will be superposed. The base map information will be subdued so that the radioactivity information will stand out.

The radioactivity data taken during these initial surveys indicate that a flight-line spacing of ¼ mile is necessary to obtain an adequate picture of the activity levels over a complex radiation field and that presentation on a map having a scale of 1:62,500 is adequate. One-mile spacing is acceptable in areas where the radioactivity units are fairly broad and the controlling factor in the distribution of the units is the natural radioactivity of the surficial soils and rocks. If these data are presented on 1:250,000 scale maps, 1-mile survey-line spacing will provide sufficient resolution of the activity for any user to grasp the over-all radiation patterns of the area.

Based on the experience gained during these actual survey operations, an initial appraisal of the system indicates that the accuracy of the Doppler positioning data in areas containing clearly defined check points is, in general, comparable to that obtained with photographic techniques. Over regions in which distinct ground points are nonexistent, the Doppler system provides a greater accuracy than the photographic method. Although a high degree of accuracy is inherent in the corrected positioning data, the delineation of aeroradioactivity units must be based upon human interpretation of the radiation data. The positions of the sharp radioactivity boundary lines as shown in Figs. 4.1 and 4.2 are therefore open to interpretation.
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 The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960. ($0.75)

CEX-58.1 Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. C. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959. ($2.75)

CEX-58.2 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. ($0.75)

CEX-58.7 AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960. ($0.50)

CEX-58.8 Comparative Nuclear Effects of Biomedical Interest, Clayton S. White, I. Gerald Bowen, Donald R. Richmond, and Robert L. Corsbie, January 1961. ($1.00)

CEX-58.9 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. ($1.25)

CEX-59.1 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. Clashe, January 1960. ($0.60)


CEX-59.7C Methods and Techniques of Fallout Studies Using a Particulate Simulant, William Lee and Henry Borella, February 1962. ($0.50)

CEX-59.13 Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960. ($0.50)


CEX-60.1 Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Buson, and J. Jacovitch, February 1961. ($1.75)

CEX-60.3 Extended- and Point-source Radiometric Program, F. J. Davis and P. W. Reinhardt, August 1962. ($1.50)

CEX-60.6 Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Z. Buson and H. Borella, February 1962. ($1.00)

CEX-62.01 Technical Concept—Operation Bren, J. A. Auxier, F. W. Sanders, F. F. Haywood, J. H. Thorogate, and J. S. Cheka, January 1962. ($0.50)
