GJBX-126 '79

AERIAL RADIOMETRIC AND MAGNETIC RECONNAISSANCE SURVEY OF PORTIONS OF ARIZONA, IDAHO, MONTANA, NEW MEXICO, SOUTH DAKOTA AND WASHINGTON

FINAL REPORT

VOLUME 1

INSTRUMENTATION AND METHODS

TEXAS INSTRUMENTS INCORPORATED
Dallas, Texas

MARCH 1979

CAUTION
This is a time release report.
Do not release any part of this
publication before

WORK PERFORMED UNDER
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OPERATIONS, GRAND JUNCTION, COLORADO
Subcontract No. 78-184-L and Bendix Contract EY-76-C-13-1664

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
Grand Junction Office
Grand Junction, Colorado 81501

Extra copies of Volumes 1 and/or 2 of this report and copies of all maps or profiles in Volume 2 at full scale (1:250,000) are available for purchase from:

Texas Instruments Incorporated
Airborne Geophysical Services
P.O. Box 225621 Mail Station 975
Dallas, Texas 75265

AERIAL RADIOMETRIC AND MAGNETIC RECONNAISSANCE SURVEY OF PORTIONS OF ARIZONA, IDAHO, MONTANA, NEW MEXICO, SOUTH DAKOTA AND WASHINGTON

FINAL REPORT

VOLUME 1

INSTRUMENTATION AND METHODS

TEXAS INSTRUMENTS INCORPORATED
Dallas, Texas

MARCH 1979

WORK PERFORMED UNDER
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OPERATIONS, GRAND JUNCTION, COLORADO
Subcontract No. 78-184-L and Bendix Contract EY-76-C-13-1664

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
Grand Junction Office
Grand Junction, Colorado 81501

ABSTRACT

Instrumentation and methods described were used for a Department of Energy (DOE) sponsored high-sensitivity, aerial gamma-ray spectrometer and magnetometer survey of the Butte, Choteau, Cut Bank, Great Falls, Havre, Lewistown, Shelby (Montana); Pocatello, Twin Falls (Idaho); Ritzville (Washington); Hot Springs (South Dakota); and St. Johns (Arizona-New Mexico) NTMS, 1:250,000-scale quadrangles. The survey was carried out by Texas Instruments Incorporated under Bendix Field Engineering Corporation Subcontract No. 78-184-L. The objective of the work was to define areas showing surface indications of a generally higher uranium content where detailed exploration for uranium would most likely be successful.

A Sikorsky S-58T helicopter equipped with a high-sensitivity gamma-ray spectrometer and ancillary geophysical and electronic equipment was employed for areas having the ruggedest terrain, including all of Butte and Choteau Quadrangles. A DC-3 aircraft carrying a more sensitive gamma-ray spectrometer system was used in regions of flatter terrain, including all of Shelby and Lewistown Quadrangles. The systems were calibrated using DOE calibration facilities at Grand Junction, Colorado, and Lake Mead, Arizona.

Gamma-ray spectrometric data were processed to correct for variations in atmospheric, flight, and instrument conditions and were statistically evaluated to remove the effects of surface geologic variations. The resulting first-priority uranium anomalies (showing simultaneously valid eU*, eU/eTh*, and eU/K* anomalies) were interpreted to evaluate their origin and significance. Results of the interpretation in the form of a preferred anomaly map, along with significance-factor profile maps, stacked profiles, histograms, and descriptions of the geology and known uranium occurrences are presented in the individual quadrangle volumes of this final report.

---

*eU = Equivalent uranium measured by bismuth-214.
eTh = Equivalent thorium measured by thallium-208.
K = Potassium measured by potassium-40.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD)

APPENDIX A

PRODUCTION SUMMARY AND REDUCED TEST-LINE DATA

ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION

A. GENERAL

1. Objectives

a. National Aerial Radiometric Reconnaissance Survey

Major objectives of the National Uranium Resource Evaluation (NURE) program, sponsored by the Department of Energy (DOE), are to develop an authoritative, comprehensive assessment of the nation's uranium resources and to provide industry with data and technology useful for the timely discovery and exploitation of uranium ores (ERDA, 1976). The National Aerial Radiometric Reconnaissance Survey is a major element of the NURE program.

The major short-term objectives of the aerial survey portion of the NURE program are (Dodd, 1976):

- Rapidly map and evaluate, on a national and regional scale, the distributions of the natural radioelements U, Th, and K and their ratios in the surface geologic units and materials by means of high-sensitivity aerial gamma-ray spectrometers.
- Provide a significant part of the fundamental geochemical-geological sample information needed for preliminary rating of the relative favorability of areas, and, in conjunction with other survey data and geologic modeling criteria, identify areas warranting follow-up investigations and possible exploration by industry.
- Encourage early exploration of new or under-explored geologic environments and minimize redundant reconnaissance surveys by industry.

Longer-term goals include: (1) Synthesize the aerial and other survey data to develop improved concepts of ore genesis to establish refined criteria for favorability and the recognition of subtle clues to possible concealed deposits, and (2) provide timely guides to future sophisticated exploraton and thereby minimize exploration expenditures needed to discover an adequate reserve or probable resource base.

b. Delineation of Uraniferous Provinces

Saunders and Potts (1978) have summarized concepts of uraniferous metallogenic and geochemical provinces and methods for detecting and mapping them using reconnaissance aerial gamma-ray spectrometer data.

Turneaure (1955) pointed out that geologists have long recognized that specific parts of the world are characterized by groups of deposits of certain metals or of geochemically related metals. Such regions are of mining district size, and have been termed as metallogenic, metallogenetic, or metallographic provinces. In addition, certain of these provinces or districts show clear evidence of more than one metallogenic epoch, i.e., similar deposits of different ages are grouped together spatially.

Some groups of related mining districts lie within broader geochemical provinces characterized by general enrichment of the host rocks in those elements making up the groups of ore deposits. Levinson (1974) describes them as relatively large (tens to hundreds of miles), well-defined areas of the earth's crust that have a distinct chemical composition. Geochemical provinces may be considered the largest example of primary geochemical "haloes."

Klepper and Wyant (1957) pointed out that most of the world's important uranium deposits are clustered in a few areas or provinces, and further speculated that perhaps these represent uranium-rich portions of an originally inhomogeneous crust. This is in general accord with the concept of broad geochemical provinces, which is further supported by the additional observation by Klepper and Wyant that uranium-enriched regions appear to persist through long periods of geologic time, with the uranium being moved from one type of deposit to another within each province by normal erosional, sedimentary, and igneous processes. They also observed that such provinces are characterized by uranium-rich rocks and waters and the presence of several types of uranium deposits (see also Darnley, 1973).

Darnley (1972) observed that districts containing uranium deposits in Canada are generally characterized, over tens or hundreds of square miles, by above-average radioactivity relative to their surroundings based on aerial radiometric survey results. Also, uranium is concentrated preferentially over the other naturally occurring radioelements, thorium and potassium, in anomalously radioactive areas considered more favorable for potentially economic uranium deposits. This is supported by other investigators who have pointed out that known uranium deposits tend to be concentrated in areas characterized by generally higher uranium contents in ground waters (Scott and Barker, 1958), igneous rocks (Everhart, 1958), and possible Precambrian source areas for stratiform deposits (Malan, 1972). This, in turn, leads to the concept that new uranium deposits will be found more frequently in such areas than in regions where the uranium content in associated soils, rocks, and ground waters is comparatively low (Brinck, 1974).

Recent studies on aerial gamma-ray spectral data (Texas Instruments, 1977b; Saunders and Potts, 1978; Saunders, 1978) lead to the conclusion that known uraniferous provinces are characterized by:

(1) Higher eU, eTh, and K mean values on a regional basis (due to generally higher radioelement concentrations).

(2) Higher relative standard deviations for eU, eU/eTh and eU/K (reflecting the presence of local uranium enrichments).

(3) Lower regional mean values for eU/eTh and eU/K (showing uranium loss from "average" rocks to form local enrichments).

(4) Relatively large numbers of local anomalies with statistically high eU, eU/eTh and eU/K (indications of local uranium enrichments).

Statistical treatment of the aerial radiometric data allows regions with these characteristics to be defined. These uraniferous provinces constitute the preferred territory for follow-up exploration methods such as detailed aerial or surface radiometric prospecting, geological studies, etc., to define potential prospects for eventual testing by exploration drilling and logging (see Saunders and Potts, 1978).

2. Approach

Aerial gamma-ray spectrometer and magnetmeter data were collected over the following NTMS, 1:250,000-scale quadrangles (Figure 1-1):

Cut Bank	(Montana)	Butte	(Montana)
Shelby	(Montana)	Pocatello	(Idaho)
Havre	(Montana)	Twin Falls	(Idaho)
Choteau	(Montana)	Ritzville	(Washington)
Great Falls	(Montana)	Hot Springs	(South Dakota)
Lewistown	(Montana)	St. Johns	(Arizona-New Mexico)

The program also included processing and interpreting the gamma-ray spectrometer data to indicate potential new uranium prospecting areas.

This constitutes Volume 1 of the final report and includes information on methods and instrumentation common to all the quadrangles. Data and results for each quadrangle are included in individual volumes as follows:

Volume	Quadrangle
2-A	Cut Bank
2-B	Shelby
2-C	Havre
2-D	Choteau
2-E	Great Falls
2-F	Lewistown
2-G	Butte
2-H	Pocatello
2-I	Twin Falls
2-J	Ritzville
2-K	Hot Springs
2-L	St. Johns

Flight-line patterns for this survey are shown on the record location maps of the individual quadrangle volumes. This survey was conducted for the Grand Junction Office of the United States Department of Energy (DOE) under Bendix Field Engineering Corporation (BFEC) Subcontract No. 78-184-L.

All maps and profiles prepared from this survey are presented at 1:500,000 scale, along with histograms of the radiometric data in the individual quadrangle volumes of this final report.

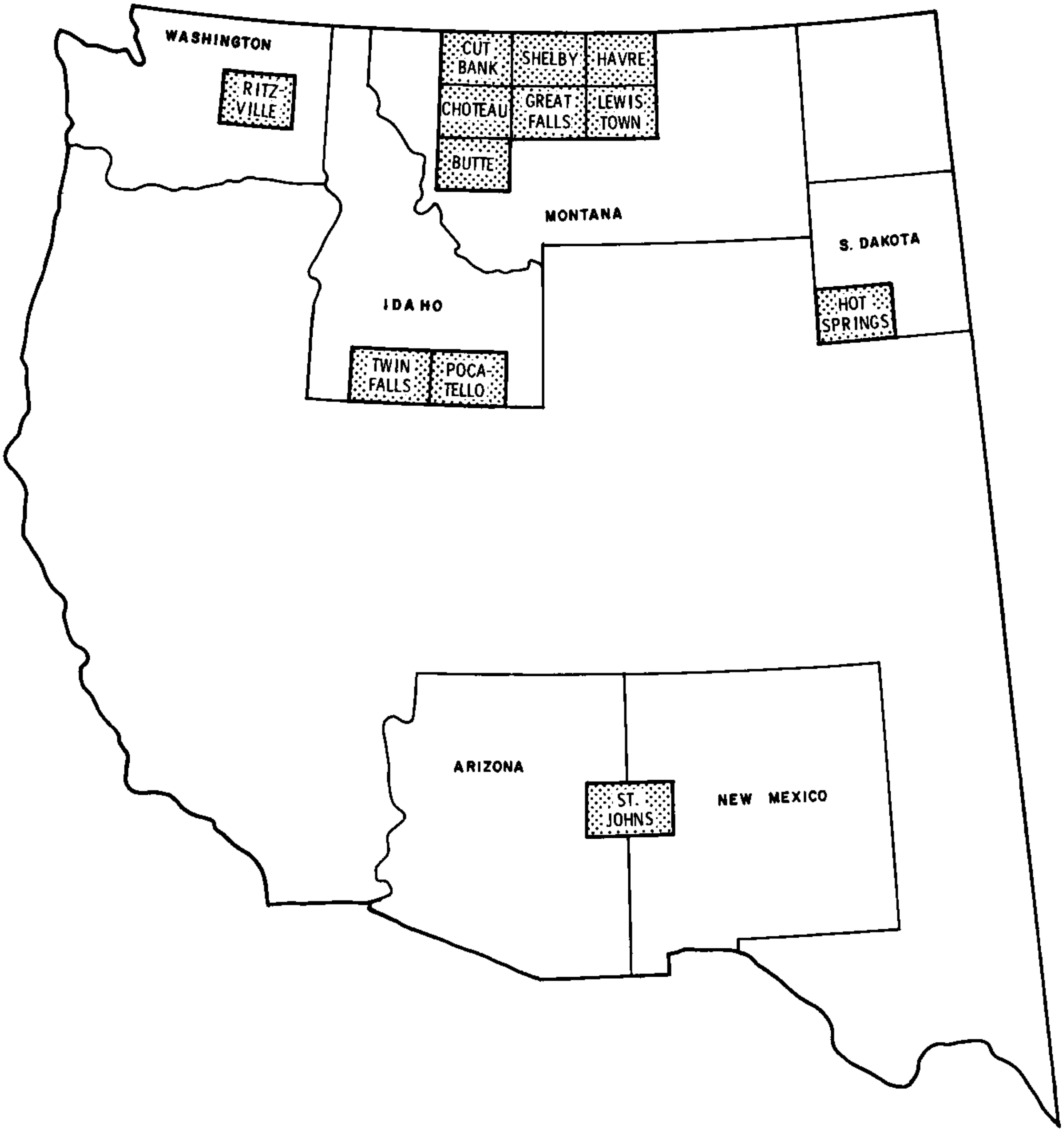

Figure 1-1. Quadrangle Location Map

All data were digitally collected and processed and are presented in the form of computer listings and stacked profiles. Geologic maps at 1:250,000 scale were used as geologic source data in a statistical analysis of the gamma-ray data, which provided a quantitative measure of the anomalousness of each record value. Results of this analysis are presented as statistical tables, a preferred-anomaly map, a record-location map, and profile maps in the individual quadrangle volumes. The record-location and profile maps are printed in composite form with the geologic map. All map sheets conform to the name, scale, and sheet layout of the NTMS, 1:250,000-scale topographic map.

The work was done in accordance with Bendix Field Engineering Corporation (BFEC) Specification No. BFEC-1200-B and the subcontract work statement. The aerial radiometric system was calibrated in accordance with BFEC Specification No. BFEC-1250-A.

SECTION II
DATA ACQUISITION

A. EQUIPMENT

1. Aircraft

Two independent systems were used to collect data. A standard Sikorsky S-58T gas-turbine-powered helicopter equipped with gamma-ray spectrometer system 3 was used in areas of rugged topography. A standard Douglas DC-3 aircraft carrying gamma-ray spectrometer system 1 was used in the remainder of the survey. Quadrangle coverage by rotary-wing (R/W) and fixed-wing (F/W) data collection was as follows:

Rotary-Wing System 3	Fixed-Wing System 1	Mixed R/W and F/W Coverage
Butte	Shelby	Cut Bank
Choteau	Lewistown	Havre
		Great Falls
		Pocatello
		Twin Falls
		Ritzville
		Hot Springs
		St. Johns

All data on maps, profiles, listings, and tapes are identified as R/W or F/W (see Section IV).

Both aircraft systems provided sufficient size, range, carrying capacity, and safety margin for this project. Besides standard equipment, the rotary-wing aircraft was fitted with an inertial navigation system to assist in maintaining straight flight paths. The helicopter was leased from Carson Helicopters. The fixed-wing aircraft was fitted with a Bendix automatic pilot and a Global Navigation Systems GNS-500A VLF system.

2. Airborne Geophysical System 1

The gamma-ray spectrometry system measures the amplitude spectrum of light created on the capture of incident gamma rays by thallium-activated sodium iodide NaI [Tℓ]) crystal. The NaI crystal detectors must be large enough to absorb these incident gamma-ray photons. Several of the crystal detectors are connected in parallel to provide a spectral counting rate that allows adequate statistical measurements within the short measurement periods dictated by an airborne detection system.

Gamma-ray spectrometer surveying involves quantitative measurement of natural gamma radiation of thorium, uranium, and potassium occurring at or near the earth's surface. Thorium and uranium are assumed to be in equilibrium with their respective radiation decay products, thallium-208 and bismuth-214. These two decay products and potassium-40 give pronounced peaks at 2.615, 1.76, and 1.46 MeV respectively in the gamma-ray spectra of naturally occurring radiation and afford the means of measuring the distribution of their source elements (thorium, uranium, and potassium).

A typical gamma-ray spectrum measured in the field consists of discrete photoelectron peaks modified by Compton scattering and other effects caused by naturally occurring radioactive elements and by cosmic radiation and radiation emanating from radionuclides in the atmosphere. All these masking effects can be identified and removed by routine field measurements and data-reduction methods.

Figure 2-1 is a block diagram of Texas Instruments Gamma-Ray System 1 (TIGRS-1). Nine NaI crystal detectors, each 11.5 inches in diameter and 4 inches thick, emit light pulses upon capture of gamma-ray photons. Amplitude of the emitted light is proportional to photon energy. The light pulse (scintillation) created by the capture of each gamma-ray is amplified by photomultiplier tubes coupled to each crystal and converted to an electrical pulse proportional to the amplitude of the light pulse. Each electrical pulse is further amplified and routed by the detector interface unit to the appropriate port of CPU 1 (a TI 990 minicomputer), which converts the amplitude of the pulse to one of 512 digital energy values. By this sequence, the variable energies of the gamma-ray photons are linearly assigned to one of the 512 calibrated energy bands (each approximately 12.05 KeV wide). During each counting period (1.0 second) the sums of the pulses falling in each of the first 255 energy bands, covering the energy range

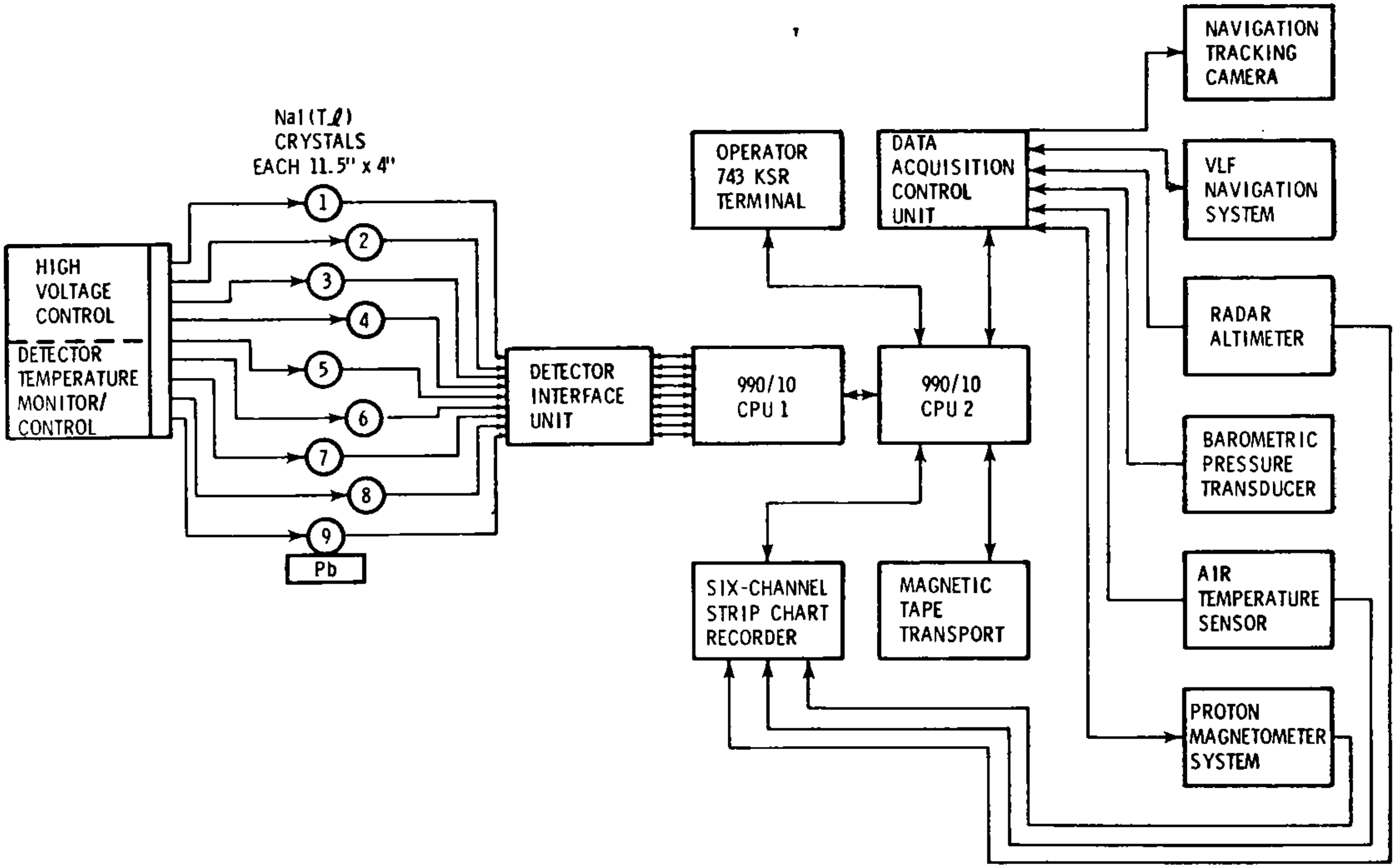

Figure 2-1. Texas Instruments Gamma-Ray System 1 (TIGRS-1)

from 0.0 to 3.0720 MeV, are accumulated as the first 255 channel sums of the spectrum. Pulses falling in energy bands 256 to 512 (3.0720 to 6.0000 MeV) are accumulated as the 256th channel sum.

The spectra accumulated during one counting period for eight of the detectors are identical and represent the gamma-ray flux captured by these detectors from sources anywhere in the 4-pi steradian space around the detectors. The last detector is shielded from gamma rays originating below the aircraft by three inches of lead. The accumulated spectrum from this detector is used to measure the radioactivity of Bi-214 in the atmosphere. This detector is thus said to have 2-pi geometry and its spectral information is treated separately.

Each crystal is protected from thermal and mechanical shock and from thermally induced gain shifts in the spectra by a combination of thick polymeric insulation and automatically controlled internal heaters.

At the end of each counting period the location for storing spectral information in CPU 1 is switched, and the accumulated spectra, plus other data (average radar-altimeter reading, air pressure, air temperature, magnetometer reading, record number, line number, day of year, time of day, etc.), are transferred to magnetic tape. This procedure, which permits no loss of spectral information between counting periods, is accomplished by CPU 2, which additionally performs multiple data quality control, data displays, arithmetic, and operator communication functions.

System control is maintained by the data acquisition control unit. This unit sequences all operations during each counting period and acquires data from the peripheral sensors and the navigation system computer for inclusion by CPU 2 on magnetic tape. Its crystal-controlled clock provides timing information for the operator-selected counting period and for triggering the magnetometer reading and the 35-mm tracking camera at the midpoint of the counting period. It measures average terrain clearance by digitally sampling the output of the radar altimeter continuously during the counting period.

The following describes the several units making up Gamma-Ray System 1:

Unit	Function
High-voltage control	Permits matching the gain of each photomultiplier tube in each detector
Detector temperature monitor/control	Displays and automatically controls the temperature of each detector package
NaI crystals	Gamma-ray scintillation detectors each 11.5 inches in diameter by 4 inches thick coupled to multiple photomultiplier tubes and housed in thick polymeric insulation. One detector is shielded from the ground by 3 inches of lead
Detector interface unit	Amplifies pulses from the NaI detectors and routes the pulses for computer storage. Computer feedback meters and gain controls on this unit provide for spectral gain calibration
CPU 1	Dedicated TI 990 minicomputer that digitizes and stores pulses from the individual detectors according to one of 512 energy bands determined by spectral gain settings
CPU 2	Multifunction TI 990 minicomputer that operates on the spectral data in the memory of CPU 1; provides strip-chart, CRT, and meter data displays; performs several QC and arithmetic funcitons on the spectral data; communicates with the equipment operator; and formats and writes all data on magnetic tape
Data acquisition control unit	Controls the sequence of operations during a sample period and acquires all ancillary data for inclusion on magnetic tape
Magnetic tape transport	Records all data in nine-track, mixed binary and BCD form with unformatted PE encoding at 1600 bpi. The tapes are compatible with transports on large computers used for data processing
Operator terminal	Provides equipment operator link to CPU 2 for system control, paper and CRT data display, and quality assurance monitoring

Proton-magnetometer system	Measures total magnetic field to nearest 0.25 gamma. Uses proton precession sensor towed at the end of a 100-foot cable. Digital output from the console is recorded with the other collected data, and an analog output is recorded at two scales on the strip-chart recorder
Pressure transducer	Measures ambient barometric pressure during each gamma-ray measurement interval using an absolute magnetic reluctance sensor
Air-temperature sensor	Measures flight-line air temperature during each gamma-ray interval using a conductivity-measuring thermometer
Radar altimeter	Measures aircraft terrain clearance. The output from the altimeter is continuously averaged during each gamma-ray measurement interval
Tracking camera	35-mm framing camera with wide-angle lens for recording the flight-path image. The camera is triggered at the midpoint of each gamma-ray measurement interval. Seven-segment LEDs in an attached data box, expose the current record number on each film frame
VLF navigation system	GNS 500-A system measures aircraft position relative to worldwide network of VLF and Omega stations. Data on ground speed, latitude, and longitude are obtained from the navigation computer for inclusion on magnetic tape
Strip-chart recorder	Six-channel analog recorder used for real-time display of raw uranium counts (4-pi and 2-pi), magnetic field reading (two scales), average terrain clearance, and air temeprature. Fiducial marks indicate the completion of each sampling period.

3. Airborne Geophysical System 3

Figure 2-2 is a block-diagram of Texas Instruments Gamma-Ray System 3 (TIGRS-3). Fourteen rectangular NaI crystal detectors, each 16 inches long and 4 inches by 4 inches in cross section, emit light pulses upon capture of gamma-ray photons, with light amplitude being proportional to photon energy. The light pulse (scintillation) created by the capture of

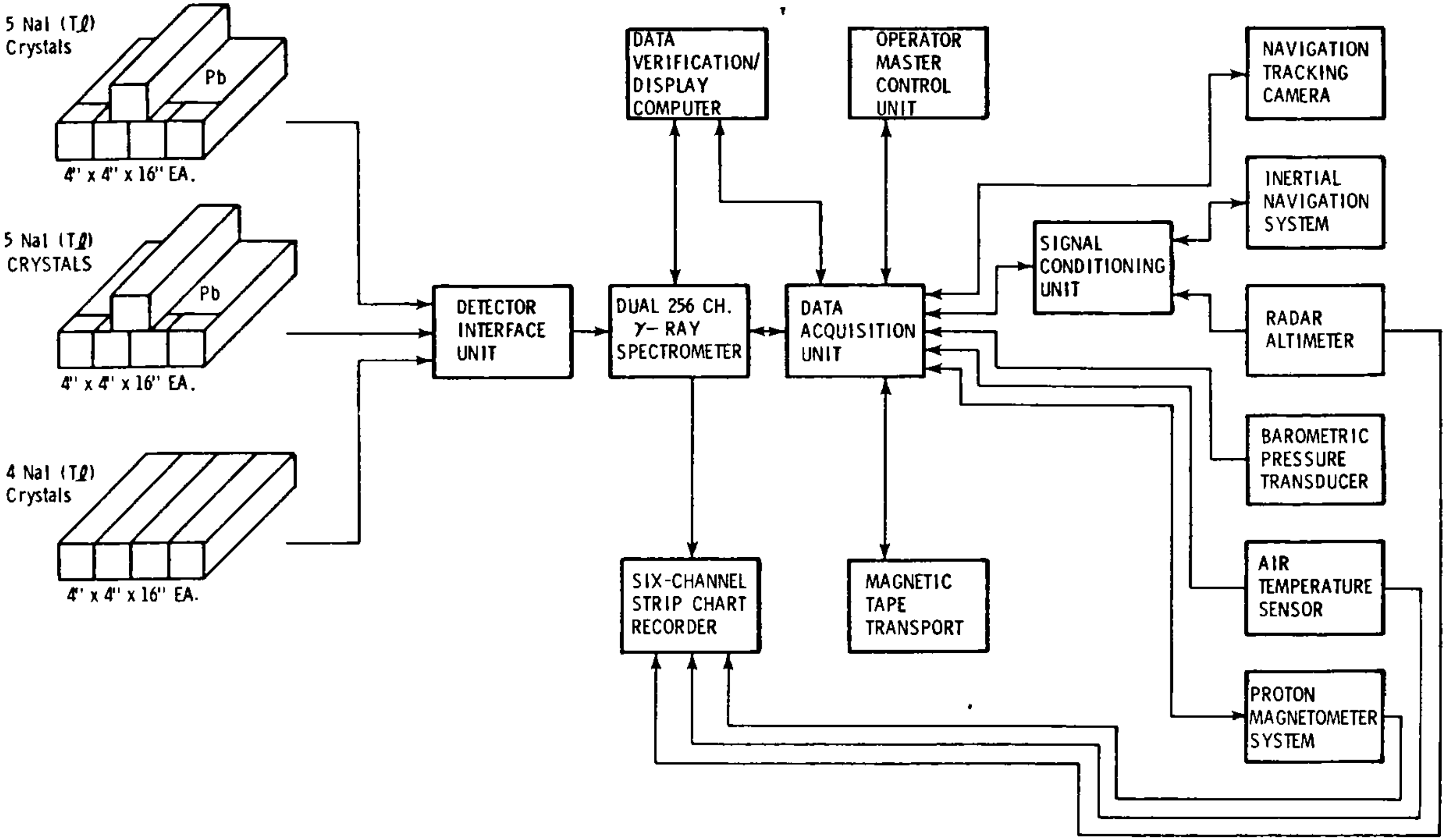

Figure 2-2. Texas Instruments Gamma-Ray System 3 (TIGRS-3)

each gamma-ray is amplified by a photomultiplier tube coupled to each crystal and converted to an electrical pulse proportional to the amplitude of the light pulse. Each electrical pulse is further amplified and routed by the detector interface unit to the gamma-ray spectrometer, which converts the amplitude of the pulse to one of 512 digital energy values. By this sequence, the variable energies of the gamma-ray photons are lineraly assigned to one of the 512 calibrated energy bands (each approximately 12.05 KeV wide). During each counting period (1.0 second) the sum of the pulses falling in each of the first 255 energy bands, covering the energy range from 0.0 to 3.0720 MeV, are accumulated as the first 255 channel sums of the spectrum. Pulses falling in energy bands 256 to 512 (3.070 to 6.0000 MeV) are accumulated as the 256th channel sum.

Two of the 14 detectors are shielded from gamma-rays originating below the aircraft by their position over a combination of four NaI crystals, each 4 inches thick, and 0.75 inch of lead. Analog signals from these two detectors are mixed and the composite spectrum is used to measure the radioactivity of Bi-214 in the atmosphere. The other 12 detectors are essentially unshielded from ground radiation. Analog signals from these detectors are similarly mixed, and their composite spectrum represents the gamma-ray flux captured by these detectors from sources on the ground and in the atmosphere. The spectral information from the shielded detectors when corrected for relative sensitivity and geometry can be used to remove the atmospheric component from the unshielded detectors spectra.

Each crystal is protected from thermal and mechanical shock and from thermally induced gain shifts in the spectra by the combination of thick polymeric insulation and automatically controlled internal heaters.

At the end of each counting period the location for storing spectral information is switched to the other half of the spectrometer, and the accumulated spectra, together with other data (average radar-altimeter reading, air pressure, air temperature, magnetometer reading, record number, line number, day of year, time of day, etc.), are transferred to magnetic tape. This procedure prevents loss of spectral information between counting periods.

System control is maintained by the data acquisition control unit. This unit sequences all operations during each counting period and acquires data from the gamma-ray spectrometer, the peripheral sensors, and the navigation system computer for inclusion on magnetic tape. Its crystal-controlled clock provides timing information for the operator-selected counting period and for triggering the magnetometer reading and the 35-mm tracking camera. It measures average terrain clearance by digitally sampling the output of the radar altimeter continuously during the counting period.

The following describes the several units making up the Texas Instruments Gamma-Ray System 3:

Unit	Function
NaI crystals	Gamma-ray scintillation detectors each 16 inches long and 4 inches by 4 inches in cross section coupled to a photomultiplier tube. Two detectors are shielded from the ground by the combination of other crystals and 0.75 inch of lead
Detector interface unit	Provides high-voltage and temperature control for detectors, spectral gain calibration controls, and separate mixing of signals from the shielded and unshielded detectors
Gamma-ray spectrometer	Digitizes and stores spectral sums of pulses from the shielded and unshielded detectors and provides raw spectral sums for analog or digital display
Data acquisition unit	Controls the sequence of operations during a sample period and acquires all spectral and ancillary data for inclusion on magnetic tape; formats and performs quality checks on data as written magnetic tape
Magnetic-tape transport	Records all data in nine-track, mixed binary and BCD form with unformatted NRZI encoding at 800 bpi. The tapes are compatible with transports on large computers used for data processing

Data verification/ display computer	Displays all collected data in several analog or character formats; permits real-time visual verification and numerical analysis of spectral data from spectrometer or data acquisition unit and of all ancillary data
Operator master control unit	Provides operator control of system and remote displays of fiducial and navigation information
Signal conditioning unit	Interfaces inertial navigation system and radar altimeter with data acquisition unit
Proton-magnetometer system	Measures total magnetic field to nearest 0.25 gamma. Uses proton precession sensor towed at the end of a 100-foot cable. Digital output from the console is recorded with the other collected data, and an analog output is recorded at two scales on the strip-chart recorder
Pressure transducer	Measures ambient barometric pressure during each gamma-ray measurement interval using an absolute magnetic reluctance sensor
Air-temperature sensor	Measures flight-line air temperature during each gamma-ray interval using a conductivity-measuring thermometer
Radar altimeter	Measures aircraft terrain clearance. The output from the altimeter is continuously averaged during each gamma-ray measurement interval
Tracking camera	35-mm framing camera with wide-angle lens for recording the flight-path image. The camera is triggered at the midpoint of each gamma-ray measurement interval. Seven-segment LEDs in an attached data box, expose the current record number and flight-line number on each film frame
Inertial navigation system	Delco Carousel IV-A system measures aircraft position relative to waypoints and geodetic grid
Strip-chart recorder	Six-channel analog recorder for real-time display of raw uranium counts (shielded detectors and unshielded detectors), ratio of raw uranium counts to total counts minus uranium counts, average terrain clearance, magnetic field reading, and air temperature. Fiducial marks indicate completion of each sampling period.

4. Base-Station Magnetometer

A base-station, proton precession magnetometer and digital recording system are used to monitor diurnal variations in the earth's total magnetic field. The system measures and records total intensity magnetic field data of 0.25-gamma resolution every 4 seconds. The system displays data with a six-digit illuminated display and analog strip-chart recorder with time fiducial markers. Data are recorded with the Julian date and time of day on a digital magnetic-tape transport.

B. PROCEDURES

1. Airborne

Flight operations were conducted during the period 13 July 1978 through 16 December 1978. Appendix A in each Volume 2 contains a production summary for that quadrangle as a supplement to the overall production summary data in Appendix A of this volume. The airports at Butte, Great Falls, Missoula, Kalispell, Havre, Lewistown, Pocatello, and Twin Falls were bases of operation for Montana and Idaho quadrangles. The bases for Ritzville were Spokane and Deer Park airports; the base for Hot Springs was Rapid City, and Albuquerque and White River were bases for the St. Johns Quadrangle.

Traverse lines were flown in an east-west direction at intervals of 3 or 6 miles, and tie lines were flown north-south at intervals of 12, 18, or 24 miles.

The systems were calibrated on the following dates according to BFEC Specification 1250-A, and the results were reported separately:

	F/W (System 1)	R/W (System 3)
High-altitude flights	31 August 1978	20 July 1978
Lake Mead test strip	1 September 1978	28 June 1978
Walker Field pads	9 September 1978	24 June 1978

The aircraft navigation system and a prepared set of topographic maps were used to maintain correct aircraft heading. Simultaneously, a second copy of the topographic maps was marked by the flight-path spotter to record the aircraft position. This navigation technique allowed immediate detection of off-line flying, which was corrected by breaking off the flight line and picking it up again with sufficient overlap to maintain continuity of data. The tracking camera provided a photographic record of the aircraft's location at the center of each recording interval.

Required terrain clearance was maintained by the pilot through monitoring the radar altimeter. Flight path and terrain clearance were maintained within contract specifications except where local flight regulations or considerations of flight safety dictated otherwise.

Nominal terrain clearance, aircraft speed, and sampling time were 400 feet, 150 mph, and 1.0 second respectively for the fixed-wing survey and 400 feet, 120 mph, and 1.0 second for the rotary-wing survey. These survey configurations meant that an approximate 220-foot strip of terrain along the flight path was sampled with each record during the fixed-wing survey and a 180-foot strip for the rotary-wing survey.

During flight, the equipment operator monitored system performance with the digital CRT (System 3) and analog recorder displays (systems 1 and 3) incorporated into the collection system. When an actual or potential malfunction in any component's operation was detected, the flight line was immediately broken off until the problem was eliminated or its impact was determined to be negligible. At the beginning and end of each flight line, the gain of each detector was checked and adjusted as necessary.

To minimize variations caused by variable ground moisture and equipment drift, a ground test line was established near the base of operation. Whenever possible, this line was flown under survey flight configuration at the beginning and end of each flight. The primary requirement was that the raw data be reproducible to within 20 percent from flight to flight. An additional test line was flown over a large body of water. The significance of this is discussed in subsection III.A.6. A summary of the data is presented in Appendix A.

2. Ground Procedures

Before each flight, each detector was calibrated and an appropriate gain was set using standard radioactive sources. Reproducibility was checked prior to each takeoff with the aircraft positioned over a marked spot on the apron at each base of operation. At the conclusion of each data-collection flight, data quality was checked by inspecting the airborne analog records and by field processing a test strip from each roll of 35-mm tracking film. The latter check ensured proper operation of the flight-path tracking camera. Flight lines or portions of flight lines containing data failing to meet contract specifications were scheduled for reflights.

Detailed daily records of survey progress were kept, and at convenient intervals flight magnetic tapes and films were dispatched to the data processing center at Dallas, Texas, for quality checks to further ensure consistent data quality.

SECTION III

DATA REDUCTION AND ANALYSIS

A. GAMMA-RAY DATA REDUCTION PROCEDURES

1. General

Figure 3-1 shows the major steps of the data processing sequence used in fixed- and rotary-wing surveys. Gamma-ray data reduction consisted of three main stages:

Stage I — Program TIGRRED. Raw data on the field tapes were edited and transferred to direct-access-disk intermediate storage. Two passes were made at the data stored on the disk. The first pass made an energy-to-channel calibration for the pulse-height analyzer outputs for the shielded and unshielded recording systems. The second pass reduced the data by carrying out various corrections for spectral unfolding, live-time normalization, terrain clearance, and atmospheric radiation. The output was in the form of intermediate magnetic tape with on-line printer listings for monitoring purposes.

Stage II — Programs GAMMIT and SORTLL. Flight-line navigation data were merged with the digital records; any required additional data corrections were made; and all data were sorted into individual NTMS quadrangles, averaged, and transferred to final data tapes.

Stage III — Normalization and Merging of Data. Survey operations related to establishing fixed-wing/rotary-wing continuity included flying 1-mile overlaps into adjacent fixed-wing/rotary-wing flight lines. The normalization multiplication factors were established from these overlaps on an individual quadrangle basis. The fixed-wing averaged data were then normalized to equivalent rotary-wing response and integrated to provide statistical evaluation of all data on a quadrangle basis. Reduced single-record data and raw data were not normalized. The normalization factors for each quadrangle as well as the tabulated average data from the overlaps are included in the individual quadrangle reports.

2. Channel-Energy Calibration

Despite calibration at the beginning of each flight, the correspondence of channel number to energy level must be checked throughout the recording process. Slight variations in high-voltage supply, photomultiplier response, or amplifier gain can be corrected in this way, thereby increasing

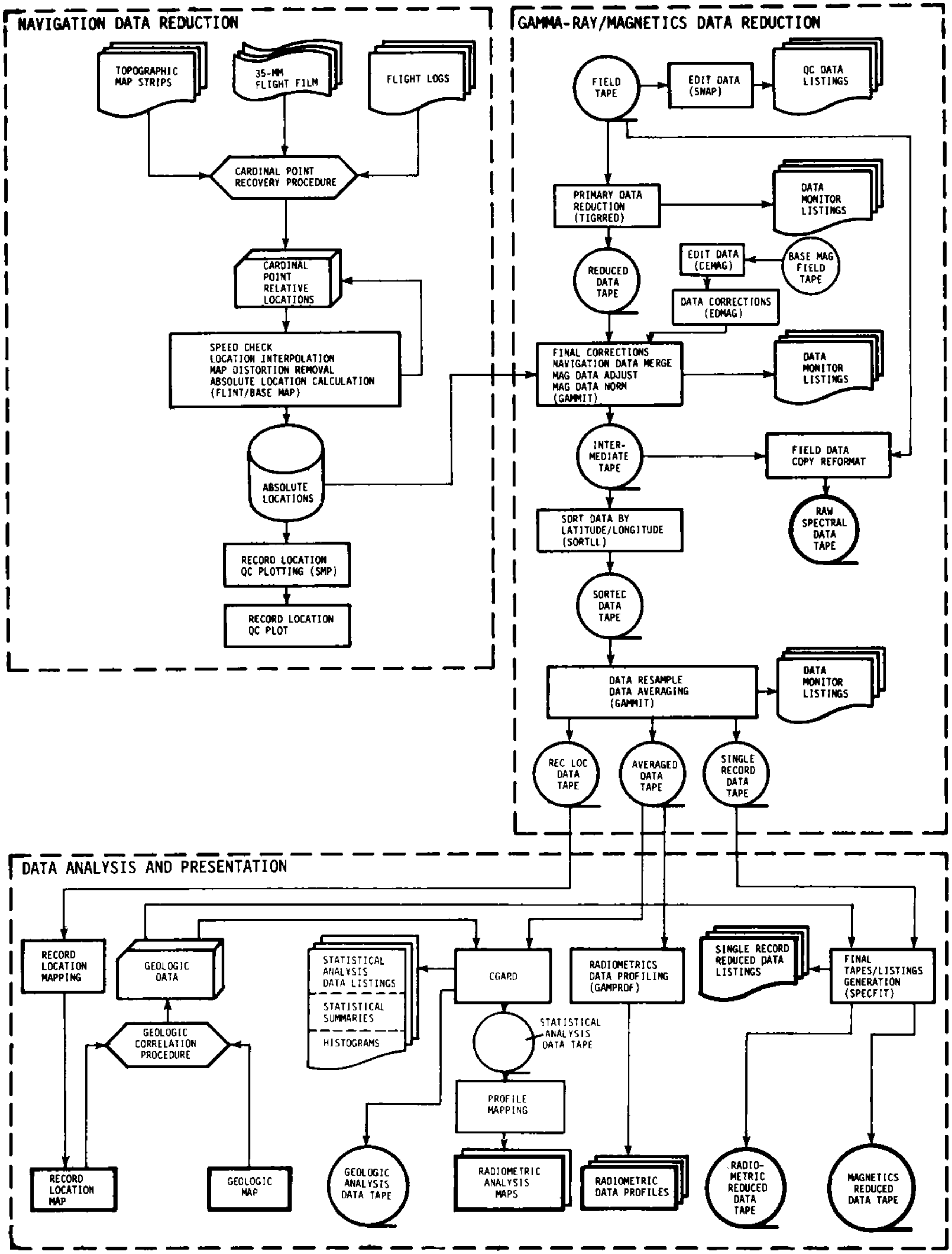

Figure 3-1. Steps in Processing Fixed-Wing and Rotary-Wing Survey Data

the system's overall resolution. In addition, because this process depends on the shape of the recorded spectra, any major changes in spectral shape because of instrument failures or other cause can be quickly and automatically detected. Channel calibration for both shielded and unshielded detector systems consists of the following steps:

- Sum sufficient individual spectra to obtain well-defined photoenergy peaks.
- Determine the exact channel location of the 2.615-MeV and 1.460-MeV photoenergy peaks.
- Calculate the zero-energy channel position and the energy per channel to obtain the required precise channel-to-energy calibration.

3. Matrix-Reduction Correction

Each field spectrum is assumed to be a composite formed by summing the spectra of decay products of naturally occurring potassium, uranium, and thorium, together with cosmic radiation. The quantitative separation (or unfolding) of the sum of the different gamma-radiation sources is performed using matrix reduction methods. The matrix, which is used to multiply the vector formed by the field-recorded spectra, was obtained by inverting the normalized matrix of standard calibration spectra for each of the major contributing sources. Because the standard calibration spectra were obtained using airborne measurements with the current operations system and crystals, and because the technique is normalized to 400 feet above the terrain, there is no need to identify separately and to correct for effects such as Compton scattering, backscattering in the crystals, crystal geometries, and spectral deformation caused by differential attenuation in the atmosphere between the ground and recording system. The basic asumptions, therefore, are:

- Field and standard spectra must be taken in the same experimental geometry.
- Field and standard spectra must be identically energy-calibrated.
- Any gamma-emitting nuclide in the field spectrum that is not represented by a standard must be present in relatively small quantities.

4. Live-Time Normalization

"Live time" is the actual time in which the gamma-ray detection system is not processing a gamma-ray pulse (and therefore can accept a gamma-ray pulse from any detector). This variable is strongly dependent on the counting rate, implying that the spectra recorded (and parts thereof) are reduced in proportion to the ratio of live time to total record time.

The total dead time incurred during the acquisition of one recorded spectrum is calculated from the total number of gamma-ray pulses in the spectrum times the fixed time per pulse necessary for conversion and storage.

5. Cosmic-Radiation Correction

The volume of the crystal detectors employed in the Texas Instruments gamma-ray spectrometer system is such that cosmic radiation has a measurable effect on the observed radiation; therefore, a correction for this is made.

Pulses in the energy range 3.0-6.0 MeV are automatically summed in the data acquisition computer and recorded as a tag word during each record. These values give a direct measure of incident cosmic radiation, since no naturally occurring terrestrial sources emit significant gamma radiation in this energy range. Inasmuch as the standard shape of the cosmic radiation spectrum is included in the reduction matrix, the effects of this radiation on the lower-energy photopeaks are removed.

6. Onboard Background-Radiation Corrections

Despite measures to eliminate all radioactive sources in the aircraft, there is always residual or background radiation. It is measured by recording spectra from the individual detectors while the aircraft is at altitudes greater than 6000 feet over the ocean with wind blowing toward land. The high altitude and wind direction make airborne radiation sources negligible. After correction for cosmic radiation and live-time normalization, the residual spectra thus measured in the survey area were subtracted from all subsequent spectral counts.

7. Terrain-Clearance Correction

To eliminate observed variations in counting rate as the distance between the aircraft and ground changes, all radiometric counts are normalized to a constant 400-foot vertical terrain clearance at standard temperature and pressure ($0^{o}C$ and 1 atmosphere). This normalization is achieved using a function of average terrain clearance, air temperature, air pressure, and empirically determined total attentuation coefficients for the respective energy windows.

8. Atmospheric-Radiation Correction

Radon-222 gas, with a half-life of 3.8 days, escapes from the ground into the atmosphere in significant amounts and decays to gamma-emitting bismuth-214. The bismuth-214 radionuclides in the atmosphere contribute a significant and variable portion of the bismuth-214 counts measured by the airborne system. Atmospheric conditions, air turbulence, and air-temperature inversion layers affect the distribution of radon, and consequently of bismuth-214, in the atmosphere. Failure to account for bismuth-214 radiation coming from airborne radionuclides could result in almost meaningless uranium estimations.

A similar gaseous decay product, radon-220 in the thorium radioactive decay series, has a half-life of only 54.5 seconds and therefore is not considered significant in the measurement of thorium distribution by detection of thallium-208.

Radiation due to atmospheric bismuth-14 is measured during the survey by shielded-detector spectra. These "upward-looking" spectra are calibrated and reduced in the same manner as the normal spectra, except that attenuation due to ground clearance is omitted. Under the assumption that atmospheric bismuth-214 is homogeneously distributed in the atmosphere surrounding the aircraft, the normalized bismuth-214 counts obtained from the shielded detector afford a correction factor, which is subtracted from the final bismuth-214 count obtained from the unshielded detectors.

9. Correction Factors

Below is a list of the correction factors used to correct the data. These factors were determined from the Walker Field pads and the Lake Mead Test Range sites.

- Detector energy bandwidths (for fixed- and rotary-wing data):

uranium (4-pi and 2-pi) = 1.6504 - 1.8673 MeV
thorium (4-pi and 2-pi) = 2.4094 - 2.8311 MeV
potassium (4-pi and 2-pi) = 1.3493 - 1.5661 MeV

- Stripping ratios:

	Fixed Wing	Rotary Wing
α(Th in U)	= 0.282701	0.305869
β(U in K)	= 0.388678	0.446012
γ(Th in K)	= 0.918818	0.864923
b(U in Th)	= 0.0554	0.052659

- Cosmic correction factors:

	Fixed Wing		Rotary Wing	
	4 pi	2 pi	4 pi	2 pi
Thorium window	0.134	0.145	0.144	0.158
Uranium window	0.113	0.129	0.109	0.122
Potassium window	0.140	0.159	0.133	0.156
Gross window	2.331	2.695	2.145	2.678

- Background correction factors (cps):

	Fixed Wing		Rotary Wing	
	4 pi	2 pi	4π	2π
Thorium window	5.826	0.941	8.061	0.885
Uranium window	15.257	1.501	11.068	1.697
Potassium window	32.824	3.883	39.440	5.170
Gross window	301.840	34.921	292.528	43.523

10. Statistical Significance Test

As a result of the above corrections and normalizations, the reduced counting-rate values for uranium (eU), thorium (eTh), potassium (K), and gross (0.4 to 3.0 MeV) and the ratios eU/eTh, eU/K, and eTh/K are obtained. However, since some samples are collected over water-saturated ground, some over areas with low radioelement content, and some at high terrain clearance, the measured counting rates may be so low that the reduced data are statistically meaningless. To eliminate such data, the statistical adequacy of each eU, eTh, and K value is analyzed using the ideas presented by Currie (1968). As applied here, a statistic is calculated for each eU, eTh, and K value that defines whether the value equals or exceeds a particular probability threshold (cutoff level). This statistic consists of the ratio of the cutoff level in counts per second (cps) to the observed net counting rate in cps. As taken from Currie (1968), the cutoff levels are defined on the basis of the observed background. Since the observed background in each energy window (onboard radioactivity, airborne radioactivity, and scattering from other sources) varies from record to record, the cutoff level for this statistic must be calculated on a record-by-record basis. Calculating the statistic in this manner (as a ratio analogous to a noise-to-signal ratio) allows the statistic to be recalculated for the averaged records to take into account the improved noise-to-signal ratio obtained by averaging (paragraph 3.A.11). Taking the detection-level cutoff as the limit, any values falling below this limit are excluded from the subsequent anomaly analysis procedure (subsection 3.C).

11. Averaging

For subsequent anomaly analysis and radiometric stacked-profile presentations, the following averages are calculated for successive groups of samples: eTh, eU, K, eU/K, eU/eTh, eTh/K, gross counting rates, and average terrain clearance. Each record is an average of a group of seven successive records, with the averaged record being the centroid of each group. A residual total magnetic-field value is also included in each averaged record but is not averaged.

To provide additional noise suppression for data of marginal quality, the following procedures were followed in the averaging:

- Include in the averages data collected at altitudes in excess of the 1,000-foot terrain-clearance limit and retest for excessive average terrain clearance.
- Include observed values of negative counting rates in the averaging.
- Include record values regardless of whether they pass the statistical adequacy test and recalculate the Currie statistic after the averaging.
- Reject any records of poor quality not included in the above. Calculate the average eU/eTh, eU/K, and eTh/K values from the average eU, eTh, and K values and not from the average of the single-record ratios.

Each of these procedures can be shown to enhance the data and to allow more records with marginal signal-to-noise ratios to pass the statistical adequacy test.

B. NAVIGATION DATA PROCESSING

The procedure for navigation data processing is shown in the block diagram of the data-processing sequence (Figure 3-1). The flight path of the aircraft was recovered from the combined information available from the navigator's topographic map strips, the flight logs, and the 35-mm tracking film. The image on the film is compared with the corresponding image on the maps to locate the position of the aircraft precisely at intervals of 10 miles, except when terrain characteristics warranted picking points at closer intervals. The intermediate locations are determined by automatic interpolation. Whenever possible, every line-intersection position is recovered by this same method. The recovered points (designated as cardinal points) are posted to the 1:250,000-scale maps and digitized by means of an X-Y coordinate digitizer. The digitized cardinal-point locations are then edited for proper position and identification. A proprietary computer program, BASEMAP, is used to correct for map sheet distortion and to convert the X-Y cardinal locations to latitude and longitude. The output of this procedure is used both for mapping purposes and for merging with the gamma-ray data.

C. DATA ANALYSIS PROCEDURES

The averaged data is analyzed statistically by means of a software package, Computerized Geological Analysis of Radioactivity Data (CGARD), developed by Texas Instruments. This software package relates gamma-ray data to surface geologic map units, calculates estimates of the statistical parameters for the distribution of each element and ratio in each map unit sampled, and determines the statistical significance of each value relative to all other samples of that particular map unit.

The objective of this data analysis is to evaluate gamma-ray data by identifying variations in record values caused by geochemical differences between map units, identifying record values that are statistically significant relative to other samples of the map unit in which they occur, and calculating the magnitude (significance) of the deviation of such records from the mean.

Analyzing data within each geologic cell consists of the following steps:

(1) Record-location maps are superimposed on the geologic map for each NTMS quadrangle. Tabulations are prepared relating every individual averaged record to geologic map units.

(2) These tabulations, in thoroughly edited card form, are used as the input to the search/sort function of CGARD to separate the data according to geologic map unit and to provide the necessary preliminary calculations. Only error-free data passing the statistical adequacy test (subsection III.A.10) are used in this analysis, which accounts for differing numbers of samples of eU, eTh, and K and their ratios for the same map unit. Data collected over land and open water are analyzed separately.

(3) Based on these calculations, the distributions of data in each geologic map unit are tested for normality/log-normality using a modified chi-squared statistical test.

(4) Means and variances (normal or log-normal as determined above) of each of the six gamma-ray parameters (eU, eTh, K, eU/eTh, eU/K, eTh/K) are calculated for each geologic map unit.

(5) Histograms of the data distribution for each parameter in each geologic map unit are generated (see subsection IV.D) and provided in paper print form. Statistical summaries of the results of the chi-squared test, the distribution medians, and the limits of standard deviations (1, 2, and 3 standard deviations above and below the mean) are compiled and provided in the individual quadrangle reports. For parameters with normally distributed data, the median is approximately equal to the mean. For log-normally distributed data, the linear median may be quite different from the linear mean. Although the mean (in the logarithmic domain) was used in calculating statistical significance of log-normally distributed data, medians of the data are included in the statistical summary tables as a measure of the central tendency. The median is considered a more efficient estimator than the mean for the purpose of gross lithologic/ geochemical comparisons.

(6) In accordance with the project work statement, the preliminary histograms were examined for significant radiometric inhomogeneities, i.e., more than one mode indicating two or more radiometrically different formations mapped together. These were separated on the basis of potassium or thorium values, whichever showed the most significant modal separation. The minimum point(s) on the histogram between the modes was (were) chosen as the separation value(s). The records were reprocessed according to this partitioning, and new histograms were plotted with the separated units identified by dash numbers (e.g., QAL-1, QAL-2, etc.). The new sample designations are recorded in the computer data listings, and the subsequent analysis was based on these.

(7) Examination of the new histograms reveals that the parameter used as a basis for the partitioning exhibits truncated distributions at the split point(s). The variation among individual samples is sufficient to generate usable histograms for the other parameters, and since the primary purpose of this survey is uranium exploration, it is concluded that the statistical evaluation of the most significant parameters (eU, eU/eTh, and eU/K) is satisfactory. If one were searching for anomalies in the parameter used for separation (K or eTh), the separation should be repeated using one of the other parameters.

(8) Each of the six gamma-ray parameters for each averaged record is analyzed with respect to the statistics for that parameter and map unit. This analysis consists of calculating the significance factor (number of standard deviations above or below the mean) and preparing significance-factor profile maps with the results (subsection IV.C).

(9) All data are then stored on magnetic tape. These data consist of a summary of the means, standard deviations, number of samples, and distribution type for each geologic map unit sampled together with a record-by-record compilation of averaged-record counting rates and statistical significances (see subsection IV.F.5).

The geologic map unit symbols are not exactly reproducible in the computer printout because the printer is generally limited to block capital letters. Mapped unit symbols are related to those used to designate the map units on the data tapes, data listings, histograms, and statistical summary tables in the listings of geologic map units in each individual quadrangle volume.

D. MAGNETOMETER DATA PROCESSING

In the data collection process, one magnetometer record is obtained coincident with each gamma-ray sample. The reduction of the magnetometer data proceeds through three sequential stages: editing and correction, line-tying, and normal International Geomagnetic Reference Field (IGRF) magnetic-field removal. The base-station magnetometer data, collected simultaneously with the airborne data and displayed on the accompanying magnetometer data profiles, are not used in this data reduction.

Following reduction of the data on the field tapes, the magnetometer data are edited and corrected for spikes, recording errors, etc., as necessary.

The data are edited at flight-line intersections, and mismatches are determined using a proprietary computer program, BISTATS, for the statistical analysis of all data at line intersections. Because the actual locations at flight-line intersections are determined directly from the flight-tracking film wherever possible, mismatches caused by improper positioning of data locations are minimized. The mismatches in total-field and residual-field values are corrected by line biasing with linear adjustments. This procedure reduces the data to a common datum and removes most of the effects caused by uncompensated diurnal changes, position uncertainties at the intersections, and small changes in magnetic-field intensity caused by differences in altitude at intersections.

The corrected and adjusted data are then normalized by removal of the nearest-month IGRF calculated on a multiple-degree grid and interpolated to individual airborne magnetic record locations.

The residual magnetic field, after all corrections, adjustments, and normalization, is then used for all stacked profiles, data listings, and data tapes, except the raw spectral-data tapes.

SECTION IV
DATA PRESENTATION

A. STACKED PROFILES

Stacked profiles of two types were prepared at a horizontal scale of 1:250,000 for each NTMS quadrangle. The radiometric stacked profiles were generated from the averaged data and consist of the following parameters (from top to bottom): eTh/K, eU/K, eU/eTh, Gross, K, eTh, eU, atmospheric U daughter contribution (UAIR), average terrain clearance, and residual total magnetic field. The magnetic-field data stacked profiles were generated from the single-record (unaveraged) data and consist of the following parameters (from top to bottom): flight-level air temperature, flight-level barometric pressure, average terrain clearance, diurnal magnetics, and residual total magnetic field. Record positions with identification numbers at regular intervals are posted along the base of the profiles. A geologic strip map, with posted record locations marked at regular intervals, appears at the top of both types of stacked profiles. These strip maps have minimum planimetry, and when they are used it is suggested that they be supplemented by copies of the published geologic and topographic maps.

Each stacked profile contains all data collected on one flight line within a specific NTMS quadrangle. The name of the quadrangle and flight-line number, together with other information, are shown in the legend for each stacked profile. The altitude trace is flagged with a small vertical tick at the location of any records collected at an average terrain clearance of 700 feet or more. Breaks in data collection because of aircraft turnarounds or where fixed-wing and rotary-wing data join are indicated as such at the base. Fixed-wing data and rotary-wing data are appropriately identified. The vertical scaling of each trace is based on an examination of flight-line histograms of the data generated before plotting profiles. Wild statistical fluctuations of the data are not accommodated by the vertical scaling, but to prevent vertical compression of the scale, certain large positive anomalies are allowed to plot above the maxima.

The stacked profiles at a reduced scale of 1:500,000 are included in the individual quadrangle volumes of this report.

B. RECORD-LOCATION MAPS

Positional maps of each NTMS quadrangle were prepared on which the location of every tenth averaged record is posted and marked at regular intervals. In addition, the location of every record recovered from the flight-tracking film is indicated with a square symbol. The scale of these maps, generated on a UTM projection, is 1:250,000. These maps are composited with the geological base maps (see subsection V.A.1.b) for final presentation. Flight-line numbers are indicated at regular intervals. The fixed-wing data and rotary-wing data are appropriately identified on the maps. The record-location maps at a reduced scale of 1:500,000 are included in the individual quadrangle volumes of this report.

C. GAMMA-RAY SIGNIFICANCE-FACTOR PROFILE MAPS

For each NTMS quadrangle in the survey area, a set of six gamma-ray significance-factor profile maps was prepared. Profiles of the statistical significance factors for eU, eTh, K, eU/eTh, eU/K, and eTh/K are presented in map form, with mean values represented by the record locations on the flight lines and lines drawn north or east proportional in length to the number of standard deviations above (solid lines) or below (dashed lines) the mean for every tenth averaged value.

The scale of these maps generated on a UTM projection is 1:250,000. These maps are composited with the geological base maps for final presentation. The geologic maps have minimum planimetry, and when they are used it is suggested that they be supplemented by copies of the published geologic and topographic maps. Flight-line numbers are indicated at regular intervals.

The gamma-ray significance-factor profile maps at a reduced scale of 1:500,000 are included in the individual quadrangle volumes of this report.

D. HISTOGRAMS

Bar-graph displays are plotted for the counting rate distribution of data for each of the six gamma-ray parameters (averaged values for eU, eTh, K, eU/eTh, eU/K, and eTh/K) in each geological map unit. Histograms for all six gamma-ray parameters in a geological map unit are on a single page. Information is included on the distribution type, the median value, the absolute values at 1, 2, and 3 standard deviations above and below the mean, and the number of samples included in the data for each parameter. The histograms are included in the individual quadrangle volumes of this report.

E. COMPUTER DATA LISTINGS

Single-record and averaged-record data listings are prepared in microfiche form for each NTMS quadrangle surveyed and are contained in Appendix B of the individual quadrangle volumes. Within each quadrangle, the data are arranged by flight line and contain as heading information on each page the subcontractor's name (Texas Instruments), the name of the survey, the name and number of the NTMS quadrangle, the flight-line number, and the day of year on which the data were collected. Microfiche internal indexing is by day of year and flight-line number.

1. Single-Record Reduced Data Listings

The following is an explanation of the column headings for the single-record data listings:

Heading	Description
SEQ	Sequence number of the record in the survey
ID	Record identification number
QUAL	Quality control identification: lists in order (left to right) whether the average terrain clearance, thorium, uranium, and potassium are acceptable. Data collected at greater than 700 feet average terrain clearance are indicated as nonacceptable by an F. Counting-rate data for thorium, uranium, or potassium which are found to be statistically inadequate are indicated by F. All other data are indicated as acceptable by a T.

Heading	Description
ALT	Average terrain clearance in feet
LAT	Latitude of the ground location in ten-thousandths of a degree
LONG	Longitude of the ground location in ten-thousandths of a degree
MAG	Residual total magnetic-field value in gammas
RK. UNIT	Surface geologic map unit under the aircraft
TH, U, K	*Reduced counting rates for the three elements, equivalent thorium, equivalent uranium, and potassium, in counts per second
U/TH, U/K, TH/K	*Unitless ratios of the three elemental counting rates
GROSS	Integral counting rate in the gamma-ray energy interval of 0.4 to 3.0 MeV in counts per second
COS	Cosmic counting rate in counts per second
UAIR	Airborne uranium daughter counting rate in counts per second
PRESS	Aircraft-level barometric pressure in pounds per square inch
TEMP	Aircraft-level air temperature in degrees Celsius
SYS	Spectrometer-system number for the type of aircraft used (1 for fixed wing, 3 for rotary wing)

---

*Data found to be statistically inadequate were assigned a value of 0.

2. Averaged-Record (Statistical Analysis) Listings

The following is an explanation of the column headings for the statistical analysis data listings:

Heading	Description
ID	Record identification number
QUAL	Quality control identification: lists in order (left to right) whether the average terrain clearance, thorium, uranium, and potassium are acceptable. Data collected at greater than 700 feet average terrain clearance are indicated as nonacceptable by an F. Counting rate data for thorium, uranium, or potassium which are found to be statistically inadequate are indicated by an F. All other data are indicated as acceptable by a T.
ALT	Average terrain clearance in feet over the interval of the multiple record average
MAG	Residual total magnetic-field value in gammas. Value is not obtained by averaging.
LAT	Latitude of the ground location of the center record in the multiple-record average in ten-thousandths of a degree.
LONG	Longitude of the ground location of the center record in the multiple-record average in ten-thousandths of a degree.
RK. UNIT	Surface geologic map unit under the aircraft for the majority of the interval covered by the multiple-record average. This is blank if terrain clearance (ALT) was greater than 1000 feet.
U, TH, K	Equivalent uranium, equivalent thorium, and potassium counting rates and statistical significances. Absolute corrected counting rates for the three elements averaged over the multiple record averaging interval. Counting units are in counts per second. The symbol following each counting rate (blank, one, two, or three plus or minus signs) indicates the statistical significance of the counting rate value as being within one standard deviation, one to two standard deviations, two to three standard deviations, or

Heading	Description
	greater than three standard deviations above or below the mean for this geologic rock unit. The symbol N.A. indicates that the value was not acceptable (i.e., did not pass detection-limit test). The statistical significance of data collected over water is not determined.
U/K, U/TH, TH/K	Unitless ratios of the multiple record average values for the three elements. The symbol following each ratio value has the same meaning as that described for the three elements.
GROSS	Multiple record average of the integral counting rate in the gamma-ray energy interval of 0.4 and 3.0 MeV in counts per second.
COS	Cosmic counting rate in counts per second.
UAIR	Airborne uranium daughter counting rate in counts per second.
SYS	Spectrometer-system number for the type of aircraft used (1 for fixed wing, 3 for rotary wing).

F. DATA TAPES

1. General

Four types of data tapes are generated for each NTMS quadrangle surveyed: the raw spectral data tape, the single-record reduced-data tape, the magnetic-data tape, and the geologic analysis data tape. They are recorded in nine-track, 800-bpi, EBCDIC, fully IBM-compatible form on half-inch magnetic tape. Each tape consists of all data on a single file, with the data arranged internally by flight line. The data for each flight line are continuous in direction. Data replaced by subsequent reflights are deleted and the reflight data substituted. Data collected beyond the survey boundaries do not appear on any tapes. The flight-line numbers in the order as they appear on the data tapes are listed in the individual quadrangle reports.

2. Raw Spectral-Data Tapes

The raw spectral tapes contain the original spectral data before any corrections, together with a number of supplemental tag words. Each such tape contains one file of data.

A three-record header containing the name and date of the survey, the subcontractor's name (Texas Instruments), the name of the NTMS quadrangle, and the flight-line numbers is written at the beginning with a format of 20A4, 2(/40A4). Before the data for each flight line, a subheader record is written containing the following information in the format 4I6, A5, F6.2, A11, F6.2, A5: flight-line number, year and day of year, first and last record numbers, and 4-pi and 2-pi record counting times. Normal records contain both 4-pi and 2-pi information as shown in Table 4-1. At the end of each flight line, a record is written containing a negative number in word 1, and 4-pi and 2-pi summed spectral data for the preceding flight line in the format listed in Table 4-1. In all normal 4-pi records, the decimal is understood in words 2, 3, 7, 8, 259 and 508. Possible values in word 9 include: 0 for normal records collected at less than 700 feet average terrain clearance, 4 for records collected between 700 and 1000 feet, -4 for records collected at greater than 1000 feet, -3 or -5 for records with field recording errors. All data are recorded as fixed-length records of 3,055 bytes and a block length of 12,220 bytes. Because of the mass of data and low recording density, the raw spectral tapes may consist of more than a single tape reel.

3. Single-Record Reduced-Data Tapes

The single-record data tapes contain all totally reduced gamma-ray, magnetic, and geologic data. These tapes begin with a three-record header, recorded with a format of 17A4, 2(/40I3), containing the name and date of the survey, the subcontractor's name (Texas Instruments), the name of the NTMS quadrangle, and the flight-line numbers. Before the data for each flight line, a subheader record is written containing the following information in the format I4, 2I5, I6: flight-line number, first and last record numbers, and year and day of year. Each data record contains the information shown in Table 4-2. At the end of each flight line, a dummy

Table 4-1

Raw Spectral Data Tape Contents

Word	Format	Description
1	I6	Record identification number
2	I10	Latitude in ten-thousandths of a degree
3	I10	Longitude in ten-thousandths of a degree
4	I6	Time of day recorded as HHMMSS
5	I5	Total magnetic field intensity in gammas
6	I4	Average terrain clearance in feet
7	I4	Flight-level barometric pressure in tenths of a pound per square inch
8	I4	Flight-level air temperature in tenths of degrees Celsius
9	I2	Data quality number
10	I2	System number
11	I6	Channel 1 from spectrometer in counts (4-pi)
—	—	—
—	—	—
258	I6	Channel 248 from spectrometer in counts (4-pi)
259	I6	Analyzer live time in thousandths of a second (4-pi)
260	I6	Channel 1 from spectrometer in counts (2-pi)
—	—	—
—	—	—
507	I6	Channel 248 from spectrometer in counts (2-pi)
508	I6	Analyzer live time in thousandths of a second (2-pi)
509	~~I6~~ F7.0	Cosmic sum counting rate (4-pi)
510	~~I6~~ F7.0	Cosmic sum counting rate (2-pi)

Table 4-2

Single-Record Reduced Data Tape Contents

Word	Format	
1	I5	Tape sequence number
2	I4	Record identification number
3	I6	Latitude in ten-thousandths of a degree
4	I7	Longitude in ten-thousandths of a degree
5	I6	Residual magnetic field intensity in gammas
6	I4	Average terrain clearance in feet
7	A4	First half of geologic map unit
8	A4	Second half of geologic map unit
9	4L1	Quality flag code*
10	F9.2	Cosmic counting rate in counts per second
11	F9.2	eU-air counting rate in counts per second
12	F9.2	Gross counting rate in counts per second
13	F9.2	Equivalent thorium counting rate in counts per second
14	F9.2	Equivalent uranium counting rate in counts per second
15	F9.2	Potassium counting rate in counts per second
16	F9.2	eU/eTh counting rate ratio
17	F9.2	eU/K counting rate ratio
18	F9.2	eTh/K counting rate ratio
19	F6.2	Flight-level temperature in degrees Celsius
20	F6.2	Flight-level barometric pressure in tenths of a pound per square inch
21	I3	System number

---

*Lists in order (left to right) whether the average terrain clearance, thorium, uranium, and potassium are acceptable. Data collected at greater than 700 feet average terrain clearance are indicated as non-acceptable by F. Counting-rate data for thorium, uranium, or potassium that are found to be statistically inadequate are indicated by F. All acceptable data are indicated by T.

record is written containing a negative number in word 1, with a format of I5. All data are recorded as fixed-length records of 140 bytes and a block length of 8,400 bytes.

4. Magnetic-Data Tapes

The magnetic-data tapes contain all reduced and adjusted total field magnetic data. These tapes contain the same header and subheader information, with the same format as the single-record tapes. Each data record contains the information shown in Table 4-3.

The sequence and record numbers on the magnetic-data tapes also correspond to those on the single-record reduced-data tapes. All data are recorded as fixed-length records of 120 bytes and have a block length of 9,600 bytes.

Table 4-3

Magnetic Data Tape Contents

Word	Format	Description
1	I5	Tape sequence number
2	I4	Record identification number
3	I6	Latitude in ten-thousandths of a degree
4	I7	Longitude in ten-thousandths of a degree
5	I6	Time of day recorded as HHMMSS
6	I4	Average terrain clearance in feet
7	F9.2	Aircraft-level barometric pressure in pounds per square inch
8	A4	First half of geologic map unit
9	A4	Second half of geologic map unit
10	I6	Total magnetic field intensity in gammas
11	I6	Residual total magnetic field intensity in gammas
12	F8.1	Base magnetometer value in gammas
13	I3	System number

5. Geologic Analysis Data Tapes

The geologic analysis data tapes contain the general cumulative statistical data obtained from the analysis, as well as all individual averaged records in one NTMS quadrangle with their statistical significances. These single-file data tapes begin with a three-record header recorded with a format of 20A4, 2(/40A4) containing the same information as the other data tapes. The subheader record before each flight line is written in the format I4, 2I5, I6, containing the same information as the single-record data tapes.

For words 9 through 14 in Table 4-4, a value of 0 indicates normal distribution, 1 indicates lognormal distribution, and 9 indicates an assumed lognormal distribution (too few samples). Values recorded in words 15 through 26 will be logarithms (base e) if the appropriate indicator in words 9 through 14 indicates a lognormal distribution. To mark the end of the statistics data, the last record is a dummy containing a literal '9999' in words 1 and 2.

After the general statistical data for each geologic map unit, each subsequent record contains data for the multiple-record averages, in the order listed in Table 4-5.

If any of words 13, 14, 15, 17, 19, and 21 in Table 4-5 equal -999.99, that parameter is undefined and not mapped. The parameter is undefined because of excessive terrain clearance, bad quality of field data, open water under the aircraft, or failure to pass the detection limit test. All data are recorded as fixed-length records of 176 bytes and a block length of 10,560 bytes.

Table 4-4

Geologic Analysis Data Tape Contents - General Statistics Records

Word	Format	Description
1	A4	First half of geologic rock name
2	A4	Second half of geologic rock name
3	I5	Number of thorium samples in geologic cell
4	I5	Number of uranium samples in geologic cell
5	I5	Number of potassium samples in geologic cell
6	I5	Number of eU/K samples in geologic cell
7	I5	Number of eU/eTh samples in geologic cell
8	I5	Number of eTh/K samples in geologic cell
9	I1	Normal/lognormal indicator for equivalent thorium
10	I1	Normal/lognormal indicator for equivalent uranium
11	I1	Normal/lognormal indicator for potassium
12	I1	Normal/lognormal indicator for eU/K
13	I1	Normal/lognormal indicator for eU/eTh
14	I1	Normal/lognormal indicator for eTh/K
15	E11.4	Mean/mean-log value for equivalent thorium
16	E11.4	Mean/mean-log value for equivalent uranium
17	E11.4	Mean/mean-log value for potassium
18	E11.4	Mean/mean-log value for eU/K
19	E11.4	Mean/mean-log value for eU/eTh
20	E11.4	Mean/mean-log value for eTh/K
21	E11.4	Standard deviation/standard deviation-log value for equivalent thorium
22	E11.4	Standard deviation/standard deviation-log value for equivalent uranium
23	E11.4	Standard deviation/standard deviation-log value for potassium
24	E11.4	Standard deviation/standard deviation-log value for eU/K
25	E11.4	Standard deviation/standard deviation-log value for eU/eTh
26	E11.4	Standard deviation/standard deviation-log value for eTh/K

Table 4-5

Geologic Analysis Data Tape Contents - Averaged Gamma-Ray Records

Word	Format	Description
1	I5	Record identification number
2	I6	Latitude in ten-thousandths of a degree
3	I7	Longitude in ten-thousandths of a degree
4	I6	Residual magnetic field intensity in gammas
5	A4	First half of geologic map unit name
6	A4	Second half of geologic map unit name
7	4LI	Quality flag code*
8	F9.2	Gross counting rate in counts per second
9	F9.2	eU-air counting rate in counts per second
10	F9.2	Equivalent thorium counting rate in counts per second
11	F9.2	Equivalent uranium counting rate in counts per second
12	F9.2	Potassium counting rate in counts per second
13	F7.2	Statistical significance for equivalent thorium
14	F7.2	Statistical significance for equivalent uranium
15	F7.2	Statistical significance for potassium
16	F9.2	eU/K counting rate ratio
17	F7.2	Statistical significance for eU/K
18	F9.2	eU/eTh counting rate ratio
19	F7.2	Statistical significance for eU/eTh
20	F9.2	eTh/K counting rate ratio
21	F7.2	Statistical significance for eTh/K
22	I3	System number

---

*Lists in order (left to right) whether the average terrain clearance, thorium, uranium, and potassium are acceptable. Data collected at greater than 700 feet average terrain clearance are indicated as non-acceptable by F. Counting-rate data for thorium, uranium, or potassium that are found to be statistically inadequate are indicated by F. All acceptable data are indicated by T.

SECTION V

DATA INTERPRETATION

A. GAMMA-RAY DATA INTERPRETATION

1. Introduction

a. General

Correct interpretation of an airborne gamma-ray spectrometer survey demands an understanding of principles and theory of the survey and data processing techniques. The preceding sections have provided much of this information. However, some additional explanations, especially pertaining to statistical analysis of the data, are presented to call attention to some of the obvious and not so obvious pitfalls.

The nature of the statistical analysis used in producing the accompanying significance-factor profile maps is such that extremely high and low values will be pinpointed in each geologic map unit. Because emission and detection of gamma rays are random processes, high and low extreme values may be obtained in situations with poor counting statistics. Such is the case in areas of great topographic relief, where the survey aircraft is forced to maintain high terrain clearance. Cursory examination of topographic maps will reveal most such problematic areas, but reference to the terrain-clearance data on the stacked profiles will be necessary for detailed analyses. As discussed in Section III, in some areas data collected at extreme terrain clearance (somewhat arbitrarily set at 1000 feet) were necessarily omitted from the statistical analysis and the profile maps. Including such data and their random, meaningless extreme high and low values would have severely biased the total analysis. Reference to the data listings or the stacked profiles (in the individual quadrangle volumes) is necessary to identify such data.

In general, the significance of extreme values in any geologic map unit also becomes more questionable as the average content of uranium, thorium, or potassium decreases (with corresponding decreases in the emission rates of their gamma rays) and as the number of individual samples of the map unit decreases. This latter situation, which can be determined by reference to the tabulation of the number of samples (Table T-2 individual quadrangle volumes), prevents adequate definition of the distribution of equivalent uranium (eU), equivalent thorium (eTh), and potassium values (K).

High equivalent-uranium values in some cases will be caused by undetected temperature inversions that trap atmospheric radon decay products beneath the aircraft and falsely increase the reduced equivalent-uranium values. In spite of preflight monitoring of atmospheric conditions and continuous measurements of airborne radioactivity, localized atmospheric conditions can prevent the mixing of radon necessary for proper correction. High measured eU values associated with topographic lows may be the result of such conditions.

The success of the CGARD statistical analysis at delineating anomalous values depends largely on the ability to define precisely the distributions of the data in statistical terms. Ideally, only data from one geochemical unit (as opposed to lithologic or mapping unit) should be grouped together for analysis, and the proper distribution type (normal, lognormal, etc.) should be selected. If more than one geochemical unit is present in a radiometric-parameter histogram, a bimodal or multimodal distribution may result, with consequent misleading statistical parameters. In this survey, all eU, eTh, and K histograms were examined, and any distinctly bimodal or multimodal distributions were split at the minima between the modes of the K or eTh histograms. New histograms and statistical parameters were computed before CGARD processing. Examination of the new histograms showed that this "geochemical analysis" procedure generally reduced the problem of misleading anomalies caused by more than one geochemical type being included in a single map unit.

A special problem is caused by snow, water cover, and water-saturated surface materials. Where a particular formation is partly water-saturated and partly well-drained, a bimodal histogram may result, with one mean value near zero and another near the normal mean value for the formation if it were dry. If most of the formation is water-saturated, the statistical analysis will result in a falsely low mean and falsely high standard deviation and may obscure possibly meaningful broad low anomalies. Only the "tips" of the highest anomalies may be defined on the significance-factor maps. Another effect may be the definition of any particularly dry portions of the formation as anomalous even though they may contain only normal amounts of uranium, thorium, and potassium. This problem was not important in this survey.

Quaternary deposits in general and stream and glacial deposits in particular present another situation requiring special attention. Because the geochemistry of these deposits is controlled in large part by provenance, uranium, thorium, and potassium concentrations in these deposits may reflect the higher or lower content of these elements in distant source materials. On the other hand, concentrations in Quaternary deposits which are accompanied by concentrations in adjoining rocks may be considered as meaningful as any enriched zones that traverse rock-type boundaries.

Since the terms "anomaly" and "anomalous values" have no universally accepted meanings, their present usage warrants explanation. Data on the accompanying profile maps are simply indications of the statistical significance of the data at each point relative to all other sample values in the same geologic map unit. In turn, the statistical significance (or significance factor) is a measure of the degree of certainty that particular values fall above or below the mean value for that particular geologic map unit. As the significance factor increases in a positive or negative sense, the certainty that the value is different from the mean increases. In practical terms, this implies that the computed value is relatively unusual. At some level of significance, this unusualness of the value may be arbitrarily declared anomalous. The approach of Hawkes and Webb (1962), perhaps the one in widest use, is to declare values deviating at least two standard deviations from the mean (i.e., absolute values of significance factors greater than or equal to two) as anomalous. Another approach, and the one used here, is that an anomaly consists of a spatial association of statistically high or statistically low values. In addition to avoiding a conflict with the dictionary meaning of the term anomaly (i.e., deviation in excess of normal variation), the use of a spatial association is more in keeping with the regional exploration concept adopted for this survey. The terms "statistically high" and "statistically low" will be applied to individual values deviating significantly from the mean.

Some individual values may be occasionally geologically misclassified, resulting in the assignment of an incorrect statistical significance. In rare instances, this could result in a grouping of points that might be falsely interpreted as an anomaly. The relative importance of this problem is inversely dependent on the accuracy and completeness of the geologic mapping.

False equivalent-uranium anomalies caused by extreme terrain clearances, geologic misclassification, or a mixture of water-saturated and well-drained surface materials all have a general common characteristic that may be used to identify them; i.e., their potassium and equivalent-thorium values will probably be falsely anomalous also. Therefore, anomalies where there are similar positive or negative significance factors for all three elements should be viewed with suspicion. A legitimate mapped positive equivalent-uranium anomaly in most instances should be associated with an area enriched in uranium relative to thorium and potassium.

The following analysis attempts to relate the major features of the equivalent-uranium data and the eU/eTh and eU/K ratios to the geology and known uranium occurrences in the survey area. Follow-up studies could apply similar approaches to the equivalent-thorium and potassium data as well as to their ratio to yield a broader understanding of their regional distribution and relationships to the mapped equivalent-uranium anomalies.

b. Geologic Mapping

Special geologic maps at 1:250,000 scale of all quadrangles were furnished by Bendix Field Engineering Corporation for use in this program. They are described in the individual quadrangle volumes.

c. Selection of Uranium Anomalies

1) Statistical Considerations

The eU, eU/eTh, and eU/K data sets were each computer-processed to identify and outline all individual or groups of statistically high data points on the following basis. If a single statistically high point is considered in terms of multiples of the standard deviation above the mean (i.e., significance factor), the probability that its value was caused by random variation of the background is shown in Table 5-1.

Table 5-1

Probability that a Single Statistically High Point Is Caused by Random Deviations*

Point Value	Probability
Mean + 1 standard deviation	0.1587 or 1:6.3
Mean + 2 standard deviations	0.0228 or 1:44
Mean + 3 standard deviations	0.0013 or 1:768
Mean + 4 standard deviations	0.00003 or 1:33,300

---

*A probability is determined as the area under the standardized normal distribution curve above the indicated value.

The maximum probability of 1:33,300 was used to judge the reliability of single, isolated, statistically high points in the data interpretation.

Spatial groupings of statistically high values are less probable than is a scattering of the same values over the map unit. If a spatial grouping consists of adjacent statistically high points, the probability (P) that all the points were caused by random fluctuations is:

$$P = P_1 \cdot P_2 \cdot P_3 \ldots P_n$$

where

$P_1, P_2, \ldots P_n$ represent the single-point probabilities for n points.

Assuming the same certainty criterion of 1:33,300, Table 5-2 gives the minimum requirements for all adjacent points in a reliable anomaly. This allows groupings of statistically high (or low) points more than 1.45 standard deviations from the mean to be evaluated. Data including eU, eU/eTh, and eU/K are searched by the computer, and all acceptable significant anomalies are identified. These are printed out on a "preferred-anomaly" map as asterisk symbols for each data point constituting a valid anomaly. The eU anomalies are indicated by asterisks along the flight line, and eU/eTh anomalies are shown by asterisks north of E-W flight lines and east of N-S flight lines. The eU/K anomalies are indicated by asterisks south of E-W flight lines and west of N-S flight lines.

Table 5-2

Minimum Deviation from the Mean for all Points for Limiting Probability of 1:33,300 (Elkins, 1940)

Number of Points Supporting Anomaly	Minimum Deviation
1	4.00 standard deviations
2	2.54 standard deviations
3	1.87 standard deviations
4	1.45 standard deviations

The next step is to identify eU anomalies that show a geochemical enrichment of eU over the eTh and/or K present. First-priority anomalies are those that show simultaneous valid eU, eU/eTh, and eU/K anomalies. The preferred-anomaly maps are marked to show all such first-priority anomalies, and they are presented with accompanying anomaly evaluation tables in Table 2-3 of the individual quadrangle volumes.

The data user can outline these anomalies on the appropriate profile maps to evaluate more quantitatively the relative magnitudes of the anomalies. The profile maps also are useful in delineating areas relatively depleted of uranium. These may have been sources from which the uranium was removed by geochemical activity and concentrated in nearby deposits. Recent study has shown that the Gas Hills and Shirley Basin uranium districts are accompanied by uranium-barren altered areas detectable by aerial gamma-ray spectrometry (Texas Instruments, 1977b).

Second-priority anomalies that under special circumstances may indicate potential uranium prospects are those showing only a combination of two statistically valid anomalies out of the three parameters: eU, eU/eTh, and eU/K. These are easily identifiable on the preferred-anomaly maps in the individual quadrangle volumes (Figure 2-1). Examples of special situations where second-priority anomalies can be important indicators of uranium prospects are presented in Table 5-3.

Table 5-3

Examples of Potentially Important Second-Priority Anomalies (Texas Instruments, 1977)

Valid Anomalies	No Anomaly	Locality Description
eU + eU/K	eU/eTh	Shirley Basin, Wyoming; high thorium due to surface layer of monazite yields normal eU/eTh even in areas where eU is anomalously high.
eU + eU/eTh	eU/K	Regions with surface evaporite deposits rich in potash yield normal eU/K even when eU is anomalously high.
eU/eTh + eU/K	eU	Areas of water-saturated surface material or heavy vegetation can shield eU, eTh, and K radiations simultaneously, but the ratios will still reflect the hidden relative eU enrichment.

d. Evaluation of Anomalies

The translucent preferred-anomaly maps were examined, along with the supporting data tables, published topographic maps, and the geologic maps, to evaluate each first-priority anomaly by judging its validity as a potential indication of actual uranium enrichment that deserves further investigation. Each valid or preferred first-priority anomaly should fulfill the following requirements:

- It should not be suspect of being caused by an atmospheric inversion or other uncompensated atmospheric Bi-214; i.e., it should not be confined to a topographic low and be accompanied by other anomalies also in topographic lows on the same flight line. (Another criterion of suspect inversion effects is the presence of early morning calm-wind conditions as indicated on the flight log.) Under normal conditions, this buildup has dissipated before 10:00 a.m., when flying normally began during this survey.

- It should be associated with geologic formations that would be reasonable hosts for vein or stratiform uranium deposits that might be worked economically. This would include most sedimentary, metamorphic, or igneous map units. The presence of black shales and other lithologies in a given map unit would suggest that the shales caused the anomaly and that under present economic conditions the deposit would not be workable. The presence of alluvium and high eU, normal eU/eTh, (high eTh), and high eU/K could indicate a placer deposit of monazite and/or radioactive "blacks" that also probably would not be economic at present. The presence of continental sandstones or alkaline intrusives, however, would indicate favorable prospects for possible economic uranium recovery.
- It should not be suspect of resulting from any cultural cause unrelated to natural radioactivity such as nuclear testing, reactor operations, structures such as highways, railroads, dams, levees, or buildings.

The final anomaly evaluations are presented in the individual quadrangle volumes of this report.

B. MAGNETOMETER DATA INTERPRETATION

1. Applications of Magnetic Data

The utility of aeromagnetic data in enhancing results of reconnaissance gamma-ray surveys lies not in any direct relationship but rather in providing a better understanding of the geology of the region. The magnetic data may be interpreted to map:

- Regional tectonic patterns
- Lithologic variations in the crystalline basement
- Depth to and structural configurations of the crystalline basement surface
- Location, depth, and areal extent of plutons, dikes, sills, and volcanic horizons
- Major faults in the crystalline basement and fracture zones.

These geologic features are identified by the qualitative recognition of characteristic variations in magnetic patterns supplemented by the quantitative analysis of individual magnetic anomalies (Domalshi, 1966; Paterson, 1962; Reford and Sumner, 1964).

The study of magnetic anomalies and the rocks that cause them shows that the anomalies are chiefly caused by the presence of the mineral magnetite, which occurs as an accessory mineral in igneous and metamorphic rocks. In general, the greater the amplitude of a magnetic anomaly, the higher the magnetite content of the rock causing the anomaly. It is also likely to have a relatively basic composition. Sedimentary rocks are essentially nonmagnetic, except for iron formations. Major rock units can be differentiated on the basis of variations in the frequency, areal extent, shape, orientation, local amplitude, and general intensity level of their corresponding magnetic anomalies. Faults are displayed magnetically by disruptions in magnetic pattern or by persistent gradients or pattern changes over long distances; plugs, dikes, and related igneous intrusions can be detected by the shape and intensity of their magnetic expression. Techniques have been developed for the quantitative analysis of magnetic anomalies with regard to the depth, dimension, shape, and susceptibility contrast of their sources; but these techniques are far more complex than the qualitative assessment of variations in the magnetic pattern. The quantitative analysis of even relatively simple geometric forms representing geologic bodies such as dikes involves complex computations.

Especially pertinent to NURE surveys are the experiences of Zietz, et al. (1966, 1969, 1971) in reconnaissance aeromagnetic surveys using flight-line spacings of approximately 5 miles. They were highly successful in delineating differences in the crustal fabric associated with each tectonic unit and in mapping gross basement lithologic units and structural trends. Providing this sort of information is compatible with the concept of regional uranium exploration by airborne gamma-ray spectrometric techniques. Individual profiles flown at relatively constant barometric altitude during portions of the survey can be interpreted in detail to provide:

- Depth-to-basement computations
- Qualitative basement lithology
- Location of major faults, dikes, etc.

2. Interpretation of the Survey Data

Because the main purpose of the contracted survey was to collect and analyze airborne gamma-ray spectral data, the interpretation of the magnetic data was excluded and reserved for future efforts.

C. CONCLUSIONS

Conclusions and suggestions for further work are included in each of the individual quadrangle volumes.

SECTION VI
REFERENCES

Brinck, J.W., 1974, "The Geochemical Distribution of Uranium as a Primary Criterion for the Formation of Uranium Deposits," in Formation of Uranium Ore Deposits, Proc. Series, Int. Atomic Energy Agency. Vienna, pp. 21-32.

Currie, L.A., 1968, "Limits for Qualitative Detection and Quantitative Determination," Anal. Chem., Vol. 40, pp. 586-595.

Darnley, A.G., 1972, "Airborne Gamma-Ray Survey Techniques," Uranium Prospecting Handbook (S.H.U. Bowie, et al., eds.), Institution of Mining and Metallurgy, London, pp. 174-211.

Darnley, A.G., 1973, "Airborne Gamma-Ray Techniques-Present and Future," Uranium Exploration Methods; Proc. of a Panel, Vienna, 10-14 April 1972. International Atomic Energy Agency, Vienna, pp. 67-108.

Dodd, P.H., 1976, "Airborne Radiometric Reconnaissance: The Why's and Wherefore's," Summaries and Visual Presentations, Uranium Geophysical Technical Symposium, U.S. Energy Research and Development Adm. and Bendix Field Engineering Corporation, Grand Junction, Colorado, September 14-16, pp. 13-20.

Domalshi, W., 1966, "Importance of Aeromagnetics in Evaluation of Structural Control of Mineralization," Geophys. Prospecting, Vol. 14, No. 3, pp. 273-291.

Elkins, T.A., 1940, "The Reliability of Geophysical Anomalies on the Basis of Probability Considerations," Geophysics, Vol. 5, No. 4, pp. 321-336.

ERDA, 1976, "National Uranium Resource Evaluation," Preliminary Rpt. ERDA Ser. No. GJO-111 (76), U.S. Energy Research and Development Adm., Grand Junction, Colorado, 132 pp.

Everhart, D.L., 1958, "Summary of Unsolved Problems and New Trends in Uranium Geology," Proc. 2nd U.N. Int. Conf. on Peaceful Uses of Atomic Energy, Vol. 2, pp. 310-314.

Hawkes, H.E. and J.S. Webb, 1962, Geochemistry in Mineral Exploration, Harper and Row.

Klepper, M.R., and D.G. Wyant, 1957, "Notes on the Geology of Uranium," USGS Bull. 1046-F, pp. 87-148.

Levinson, A.A., 1974, Introduction to Exploration Geochemistry, Applied Publishing Ltd., Calgary, Canada, 612 pp.

Malan, R.C., 1972, "Distribution of Uranium and Thorium in the Precambrian of the Western United States," Rpt. AEC-RD-12, U.S. Atomic Energy Comm., Grand Junction, Colorado, 59 pp.

Paterson, N., 1962, "Geological Mapping by Magnetometer Surveys," Proc. of the Benedum Earth Magnetism Symposium.

Reford, M., and J.S. Sumner, 1964, "Aeromagnetics," Geophysics, Vol. 29, No. 41, pp. 482-516.

Saunders, D.F., 1978, "Characterization of Uraniferous Geochemical Provinces by Aerial Gamma-Ray Spectrometry," presented at Annual Meeting, SME-AIME, Denver, Colorado, February 26-March 2, 1978 (available as reprint number 78-L-18).

Saunders, D.F., and M.J. Potts, 1978, Manual for the Application of NURE 1974-1977 Aerial Gamma-Ray Spectrometer Data, Doc. GJBX-13(78), Bendix Field Engineering Corporation Subcontract No. 76-031-L, Texas Instruments Incorporated, 183 pp.

Scott, R.C., and F.B. Barker, 1958, "Radium and Uranium in Groundwater in the United States," Proc. 2nd U.N. Int. Conf. on Peaceful uses of Atomic Energy, Vol. 2, pp. 153-177.

Texas Instruments Incorporated, 1975, "Airborne Geophysical Survey - Southeast Arizona," Doc. GJO-1643, U.S. Energy Research and Development Administration Contract No. AT(05-1)-1643, Grand Junction, Colorado.

Texas Instruments Incorporated, 1977, "Study of Airborne Gamma-Ray Spectrometer Data Procedures - Casper Quadrangle, Wyoming," Vol. I, Final Rpt., Doc GJBX-88(77), Bendix Field Engineering Corporation, Subcontract No. 76-031-L, prepared for U.S. Department of Energy, Grand Junction, Colorado.

Turneaure, F.S., 1955, "Metallogenetic Provinces and Epochs," Econ. Geol., Fiftieth Anniversary Volume 1905-1955, Economic Geology Publishing Co., Lancaster Press, Inc., Lancaster, Pennsylvania, pp. 38-98.

Zietz, I., et al., 1966, "Crustal Study of a Continental Strip from the Atlantic Ocean to the Rocky Mountains," Geol. Soc. Am. Bull., Vol. 77, pp. 1427-1448.

Zietz, I., et al., 1969, "Aeromagnetic Investigation of Crustal Structure for a Strip Across the Western United States," Geol. Soc. Am. Bull., Vol. 80, pp. 1703-1714.

Zietz, I., et al., 1971, "Interpretation of an Aeromagnetic Strip Across the Northwestern United States," Geol. Soc. Am. Bull., Vol. 82, pp. 3347-3372.

APPENDIX A

PRODUCTION SUMMARY AND REDUCED TEST-LINE DATA

APPENDIX A

PRODUCTION SUMMARY AND REDUCED TEST-LINE DATA

1. Production Summary - 12 Quadrangles

Flight-Line Miles by Quadrangle

Shelby	2,015
Great Falls	2,691
Lewistown	2,098
Twin Falls	2,643
Pocatello	2,643
Butte	2,738
Choteau	1,398
Havre	2,669
Cut Bank	1,381
Ritzville	2,701
Hot Springs	2,927
St. Johns	3,311
Total Flight-Line Miles	29,215

	RW	FW	Total
Total Field Days	81	63	144
Production Time	44%	43%	44%
Down Time	36%	43%	39%
Mobilization and Demobilization Time	20%	14%	17%
Total	100%	100%	100%

	Flight-Line Miles Per Production Day		
Average Production Rate =	388	565	464

Note: Ground-speed and altitude summaries are on microfiche in Appendix B, and additional production summary data are in Appendix A of the individual quadrangle volumes.

2. Reduced Test-Line Data

a) Fixed-Wing Survey

Date (1978)		Preproduction Test (Counts per Test Line)	Postproduction Test (Counts per Test Line)	Average of Previous Tests (Counts per Test Line)	Last Test Minus Previous Average	Percent Difference
Month	Day					
9	14	56,107		(new line)		
			51,303	56,107	-4804	8.6
9	16	55,470		53,705	1765	3.3
			51,767	54,293	-2526	-4.7
9	21	55,081		53,662	1419	2.6
			55,374	53,946	1428	2.6
9	22	57,392		54,184	3208	5.9
			56,746	54,642	2104	3.9
9	24	56,222		54,905	1317	2.4
			53,627	55,051	-1424	-2.6
9	25	56,305		54,909	1396	2.5
			57,947	55,036	2911	5.3
9	26	54,027		(new line)		
			57,231	54,027	3204	5.9
9	27	56,007		55,629	378	0.7
			59,615	55,755	3860	6.9
9	28	55,188		56,720	-1532	-2.7
			51,672	56,414	-4742	-8.4
9	29	50,712		55,623	-4911	-8.8
			50,793	54,922	-4129	-7.5
9	30	52,775		54,405	-1631	-3.0
			52,386	54,224	-1838	-3.4
10	1	50,109		54,041	-3932	-7.3
			50,251	53,683	-3432	-6.4
10	7	54,286		53,397	889	1.7
			55,551	53,466	2085	3.9
10	8	48,679		53,615	-4936	-9.2
			52,038	53,285	-1247	-2.3
10	10	59,253		(new line)		
			62,674	59,253	3421	5.8
10	11	62,015		60,964	1052	1.7
			58,580	61,314	-2734	-4.5
10	13	64,345		(new line)		
			59,072	64,345	-5273	-8.2
10	14	68,682		61,709	6974	11.3
			65,742	64,033	1709	2.7
10	22	54,013		(new line)		
			52,587	54,013	-1426	-2.6
10	23	58,883		53,300	5583	10.5
			52,151	55,161	-3010	-5.5
10	24	48,931		54,409	-5478	-10.1
			53,846	53,313	533	1.0
10	28	59,385		53,402	5982	11.2
			61,591	54,257	7334	13.5
12	5	55,621		(new line)		
			49,548	55,621	-6073	-10.9
12	10	48,339		52,585	-4246	-8.1
			(equipment)			
12	12	52,550		51,169	1381	2.7
			59,718	51,515	8204	15.9
12	13	45,777		53,155	-7378	-13.9
			53,527	51,926	1602	3.1
12	14	48,119		52,154	-4035	-7.7
			56,019	51,650	4369	8.5

b) Rotary-Wing Survey

Month	Day	Preproduction Test (Counts per Test Line)	Postproduction Test (Counts per Test Line)	Average of Previous Tests (Counts per Test Line)	Last Test Minus Previous Average	Percent Difference
7	13	2711		(new line)		
			2648	2711	-63	-2.3
7	14	2790		2680	111	4.1
			2631	2716	-85	-3.1
7	15	2672		2695	-23	-0.8
			2510	2690	-180	-6.7
7	22	2873		(new line)		
			2852	2873	-21	-0.7
7	23	2829		2863	-34	-1.2
			2943	2851	92	3.2
7	24	2930		2874	56	1.9
			2922	2885	37	1.3
7	25	2792		2892	-100	-3.4
			2917	2877	40	1.4
7	26	2899		2882	17	0.6
			2840	2884	-44	-1.5
7	30	2899		(new line)		
			3281	2899	382	13.2
7	31	3281		3090	191	6.2
			3202	3154	48	1.5
8	3	2886		(new line)		
			2746	2886	-140	-4.9
8	4	3052		2816	236	8.3
			2660	2894	-235	-8.1
8	5	3146		2836	310	10.9
			(weather)			
8	6	2560		2898	-338	-11.7
			(weather)			
8	7	2551		2842	-291	-10.2
			2546	2800	-254	-9.1
8	9	2760		(new line)		
			2566	2760	-194	-7.0
8	10	2658		2663	-5	-0.2
			2571	2661	-90	-3.4
8	12	2542		2639	-97	-3.7
			2522	2619	-97	-3.7
8	19	2347		(new line)		
			2443	2347	96	4.1
8	22	2483		2395	88	3.7
			2576	2424	152	6.3
8	24	2501		2462	39	1.6
			2127	2470	-343	-13.9
8	26	2816		(new line)		
			2511	2816	-305	-10.8
8	27	2390		2664	-274	-10.3
			2537	2572	-35	-1.4
8	28	2729		2564	166	6.5
			2573	2597	-24	-0.9
8	30	3062		(new line)		
			3257	3062	195	6.4
8	31	3082		3160	-78	-2.5
			2950	3134	-184	-5.9
9	1	2904		3088	-184	-6.0
			2899	3051	-152	-5.0
9	9	2929		3026	-97	-3.2
			2913	3012	-99	-3.3
9	13	2356		(new line)		
			2252	2356	-104	-4.4
9	19	2737		(new line)		
			3022	2737	285	10.4
9	20	3047		2880	168	5.8
			3084	2935	149	5.1
9	21	3069		2973	97	3.2
			3177	2992	185	6.2
9	27	2451		(new line)		
			2519	2451	68	2.8
9	28	2465		2485	-20	0.8
			2534	2478	56	2.2