EG&G
ENERGY MEASUREMENTS GROUP

EGG-1183-1741
September 1980

AN AERIAL RADIOLOGICAL SURVEY OF THE AREA SURROUNDING THE
GENERAL ATOMIC COMPANY
LA JOLLA, CALIFORNIA

DATE OF SURVEY: 20-23 JUNE 1978

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This work was performed by EG&G for the United States Nuclear Regulatory Commission through an EAO transfer of funds to Contract Number DE-AC08-76NV01183 with the United States Department of Energy.

ACKNOWLEDGMENT

For valuable discussion concerning General Atomic operations and friendly tolerance of the inconveniences generated by ours, the author wishes to thank these employees of the General Atomic Company: Frank Bold, H.N. Wellhauser, and Jerry Trimble.

ABSTRACT

An aerial radiological survey was conducted over the facilities of the General Atomic Company in La Jolla, California on 20-23 June 1978. The survey was flown at an altitude of 46 m by a helicopter containing 20 sodium iodide detectors. Enhanced gamma exposure rate levels — which could be attributed to industrial operations at the facilities — were observed at four locations.

This survey was authorized by the United States Nuclear Regulatory Commission (NRC) and conducted by the United States Department of Energy (DOE) Remote Sensing Laboratory operated for DOE by EG&G in Las Vegas, Nevada.

CONTENTS

Sections

Figures

Tables

1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains the Remote Sensing Laboratory in Las Vegas, Nevada. This facility is operated for DOE by the Energy Measurements Group of EG&G. The Aerial Measuring Systems program (AMS) is part of this group. Since its inception in 1958, the AMS program has included radiological surveys of nuclear power plants, processing and manufacturing plants employing nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites and in searches for lost radioisotopes, in addition to routine use during launch operations for Apollo, Viking, and other space vehicles which contained radioisotope thermal generators. Most of the AMS equipment and personnel were deployed in the successful search for fragments of COSMOS 954, the Russian nuclear-powered satellite which crashed in the Northwest Territories of Canada in January 1978. AMS aircraft also have mapping cameras and multispectral camera arrays for aerial photography; multispectral scanners for ultraviolet, visible, and infrared imagery; a broad array of meteorological sensors; and air sampling systems for particulate and whole gas measurements.

The AMS program is maintained and operated for DOE by EG&G. At the request of federal or state agencies AMS is deployed for various aerial survey operations.[1] The survey of General Atomic Company facilities reported here was commissioned by the U.S. Nuclear Regulatory Commission.

2.0 SITE DESCRIPTION

The survey perimeter is irregular, spanning roughly 1.9 km in the north-south direction, 3.1 km in the east-west. The land within the survey area is quite hilly, covered in many places by grass, scrub brush, and trees. The primary facilities within this area are operated by the General Atomic Company, P.O. Box 81608, San Diego, California 92138. These facilities are in northwest San Diego in a suburban area known as La Jolla. In all surveys a deliberate effort is made to survey well beyond the property lines of a subject facility: hence, privately owned land in proximity to General Atomic is covered in this survey.

The primary research and administrative facilities of General Atomic (GA) are on a hill in the east end of the survey area. Figure 1 is a plot plan of GA facilities. Also included are storage and manufacturing areas north and west of the main buildings. Figure 2 is an oblique photograph of GA with the LINAC complex (30), HTGR-TCF (31), and TRIGA Building (21) in the foreground, and Science Laboratories A, B, and C (2) in the background. Numbers in parentheses correspond to building number codes in Figure 1. Figure 3 shows the Sorrento Valley north-northwest of GA's main facilities. In the foreground are Fusion Doublet III Buildings (34, 34-1, and 34-2); in the background are the Raw Stock Facility (41), Sorrento Valley Buildings A (37) and B (39). The photograph predates the erection of Fusion Doublet III Program Buildings (34-8 and 34-9).

3.0 SURVEY PLAN

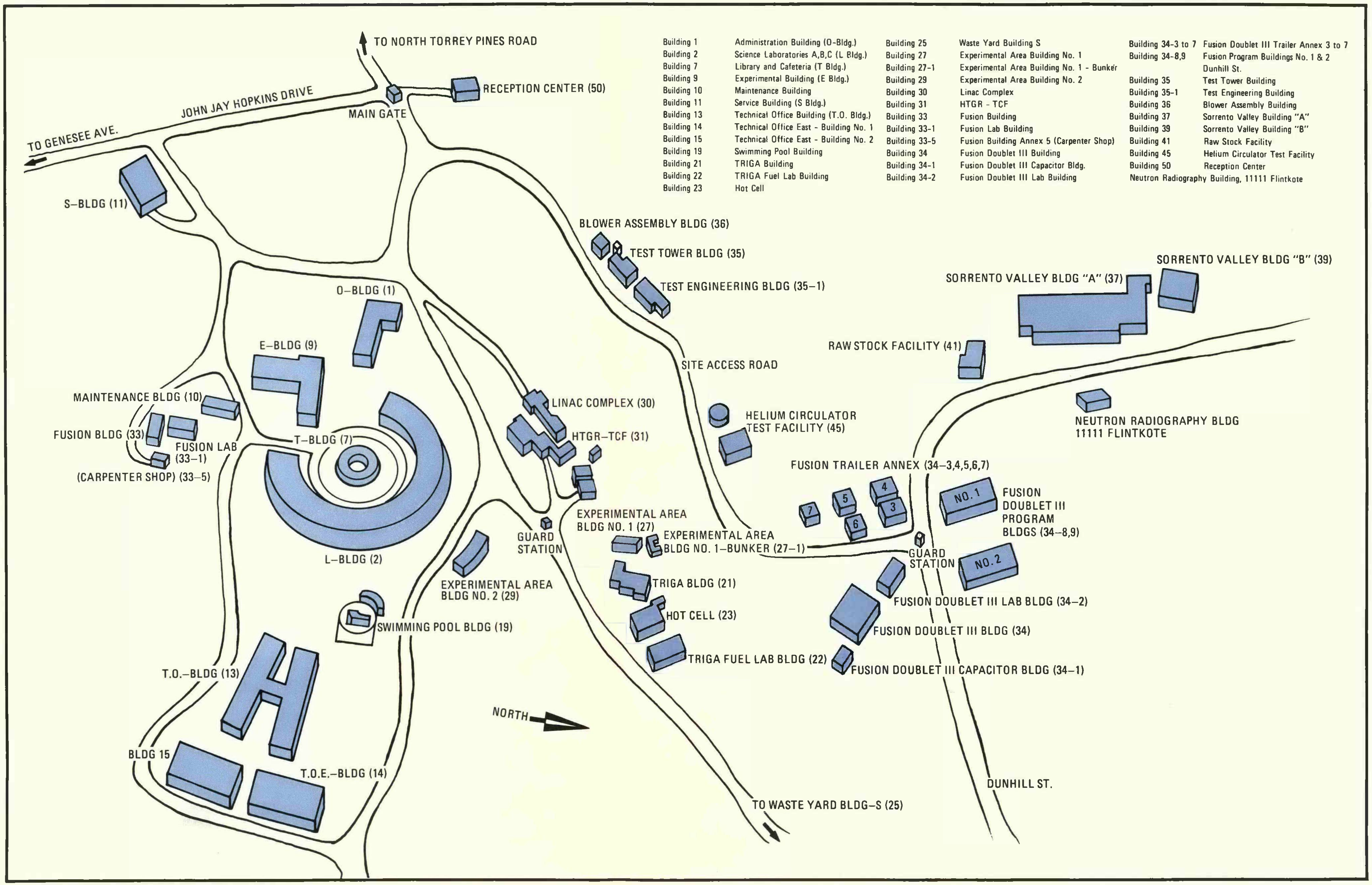
To minimize commuting time Remote Sensing Laboratory operations were based on General Atomic property. A helicopter pad was selected in the parking lot adjacent to Experimental Area Building #2 (29); the mobile computer laboratory was positioned alongside the same building.

A recent aerial photograph of the facility was used as a base map (scale 4800:1). Survey lines were laid out with 46 m (150 ft) spacing. In addition special survey lines were laid out over drainage paths leading away from GA facilities on high ground. For these lines the helicopter followed drainage paths precisely from high to low ground. All data were accumulated at the nominal survey altitude of 46 m (150 ft) above terrain.

4.0 SURVEY EQUIPMENT

A Hughes H-500 helicopter was used for the survey (Figure 4). This aircraft carried a crew of two and a lightweight version of the Radiation and Environmental Data Acquisition and Recorder system (REDAR). Two pods were mounted on the sides of the helicopter; each contained ten 12.7 cm diameter by 5.1 cm thick sodium iodide NaI(T1) detectors.

The preamplifier signal from each detector was calibrated with a ^{88}Y or ^{22}Na source. Normalized outputs of each detector were combined for each



Building 1	Administration Building (O-Bldg.)
Building 2	Science Laboratories A,B,C (L Bldg.)
Building 7	Library and Cafeteria (T Bldg.)
Building 9	Experimental Building (E Bldg.)
Building 10	Maintenance Building
Building 11	Service Building (S Bldg.)
Building 13	Technical Office Building (T.O. Bldg.)
Building 14	Technical Office East - Building No. 1
Building 15	Technical Office East - Building No. 2
Building 19	Swimming Pool Building
Building 21	TRIGA Building
Building 22	TRIGA Fuel Lab Building
Building 23	Hot Cell
Building 25	Waste Yard Building S
Building 27	Experimental Area Building No. 1
Building 27-1	Experimental Area Building No. 1 - Bunker
Building 29	Experimental Area Building No. 2
Building 30	Linac Complex
Building 31	HTGR - TCF
Building 33	Fusion Building
Building 33-1	Fusion Lab Building
Building 33-5	Fusion Building Annex 5 (Carpenter Shop)
Building 34	Fusion Doublet III Building
Building 34-1	Fusion Doublet III Capacitor Bldg.
Building 34-2	Fusion Doublet III Lab Building
Building 34-3 to 7	Fusion Doublet III Trailer Annex 3 to 7
Building 34-8,9	Fusion Program Buildings No. 1 & 2 Dunhill St.
Building 35	Test Tower Building
Building 35-1	Test Engineering Building
Building 36	Blower Assembly Building
Building 37	Sorrento Valley Building "A"
Building 39	Sorrento Valley Building "B"
Building 41	Raw Stock Facility
Building 45	Helium Circulator Test Facility
Building 50	Reception Center
Neutron Radiography Building, 11111 Flintkote	

Figure 1. *PLOT PLAN OF GENERAL ATOMIC FACILITIES*

Figure 2. *OBLIQUE PHOTOGRAPH OF MAIN GENERAL ATOMIC FACILITIES*

Figure 3. *OBLIQUE PHOTOGRAPH OF GENERAL ATOMIC FACILITIES IN SORRENTO VALLEY*

Figure 4. *HUGHES H-500 SURVEY HELICOPTER*

array in a 10-way summing amplifier. The outputs of each array were matched and combined in a 2-way summing amplifier. Finally, this signal was adjusted in the analog-to-digital converter (ADC) so that the calibration peak appeared in a preselected channel of the multichannel analyzer of the REDAR.

The REDAR system contains four memories for data storage. In the first the following are stored: gross count data, single channel data, position information, live time, radar altitude, and meteorological data from various transducers. The second and third memories are operated in a flip-flop mode to store gamma ray spectral information. Memories one and, alternately, either two or three, are transferred every 3 seconds to a 9-track magnetic tape. The fourth memory is used solely for real-time analysis on board the aircraft. Data in the fourth memory is not stored on magnetic tape.

The REDAR system can continuously acquire and record specific data at indicated rates (Table 1).

Outputs from each detector are summed before being processed by the multichannel or single channel analyzer. Windows are set on the single channel analyzers to monitor regions of the spectrum pertinent to isotopes of interest.

All of the foregoing data inputs, including the on-top marker, may be displayed by the electronic system operator for real-time monitoring. Digital data—such as count rates, meteorological information, or time of day are displayed on one of several light-emitting diode (LED) readouts. Gamma ray spectral data may be examined on the oscilloscope as the data accumulate. At any point in time a spectrum may be frozen for critical examination without affecting the continuous acquisition and recording of data. A dual-pen strip chart recorder permits visual monitoring of the time variations in any two of the following: gross count, mathematical combinations of single channel windows, radar altimeter, absolute pressure, outside air temperature, dew point, or true air speed.

Data are permanently recorded on a 9-track Cipher Data Products digital recorder capable of recording continuously for five hours. All data are

Table 1. REDAR System Data Input

Parameter	Frequency (Seconds)
1. 305 channel pulse-height analyzer plus live time	3.0
2. 5 single-channel analyzers with adjustable upper and lower discriminators	0.2
3. Gross count channel sums (all counts)	0.1
4. Position measurement	1.0
5. Microwave Ranging System (MRS) distance measurements	1.0
6. Radar altimeter	1.0
7. Absolute pressure	1.0
8. Outside air temperature	1.0
9. Wind speed	1.0
10. Wind direction	1.0
11. Dew point	1.0
12. True air speed	1.0
13. On-top marker	As required (operator push-button)
14. System configuration	1.0
15. Time of day clock (HRS-MIN-SEC)	1.0

recorded directly from sensors as raw information. The five single channels can be set to monitor natural, cosmic, or man-made gamma-active nuclides by appropriate discriminator settings. Each single channel can be weighted, added to, or subtracted from other single channels. Appropriately weighted data can be plotted in real time on the dual strip chart recorder aboard the aircraft, with filtering times between 0.2 seconds and 16 seconds. Hence, when the operator is searching for a particular radionuclide, the single channels are set up to enhance the capability of detecting this source in real time.

The helicopter position was established with two systems: a Trisponder/202A microwave ranging system and an AL-101 radio altimeter. The Trisponder master station, mounted in the helicopter, interrogated two remote transceivers; these were mounted several kilometers from the survey area. By measuring the round-trip propagation time between the master and remote stations, the master computed the distance to each. These distances were recorded on magnetic tape each second. In subsequent computer processing they were converted to position coordinates.

The radio altimeter aboard the helicopter similarly measured the time lag for the return of a pulsed signal and converted this to aircraft altitude. For these surveys, altitude was accurate to ±2 m. These data were also recorded on magnetic tape so that any variations in gamma signal strength caused by altitude fluctuation could be accurately compensated.

The detectors and electronic systems which accumulate and record the data are described only briefly here. They are described in considerable detail in previous reports.[2,3]

Precise coverage of any survey site requires that a parallel array of survey lines be programmed. The altitude must be low and the lines closely spaced so that the probability of detection is high for radiation sources of interest. Both the altitude and spacing are determined by the photon energy of the radioisotopes which may be present. Because General Atomic operations involve low energy isotopes, such as ^{235}U, low altitudes and tight spacing were desirable.

It is also obvious that programmed survey lines must be accurately flown so that small sources are not lost in accidental gaps between lines. The Remote Sensing Laboratory recently developed a Steering Indicator Computer system to aid the helicopter pilot in flying an accurate course (Appendix).

5.0 DATA PROCESSING EQUIPMENT

Magnetic tapes from these surveys are processed with the Radiation and Environmental Data Analyzer and Computer system (REDAC). This is a computer analysis laboratory built into a 5-ton step van. The interior of the van is shown in Figure 5. The REDAC system consists primarily of two Cipher Data Products tape drives, a Data General NOVA 840 computer, two Calcomp plotters, and a Tektronix CRT display screen with a hard copier. The computer has a 32k-word core memory and an additional 1.2 x 10^6-word disc memory. An extensive series of software routines is available for data processing.

Figure 5. *MOBILE COMPUTER PROCESSING LABORATORY*

Gamma spectral windows can be selected for any portion of the spectrum between, for example, 50 keV and 3 MeV. Weighted combinations of such windows can be summed or subtracted and the result plotted as a function of time or position. By the proper selection of windows and weighting factors, it is possible to extract the photopeak count rate for radioisotopes deposited on the terrain by human activity. Such isotopes disturb the natural pattern of soil radioactivity. These photopeak count rates can then be converted to isotope concentrations or exposure rates. Spectral data can be summed over any portion of a survey flight line. A block diagram of the REDAC system is shown in Figure 6.

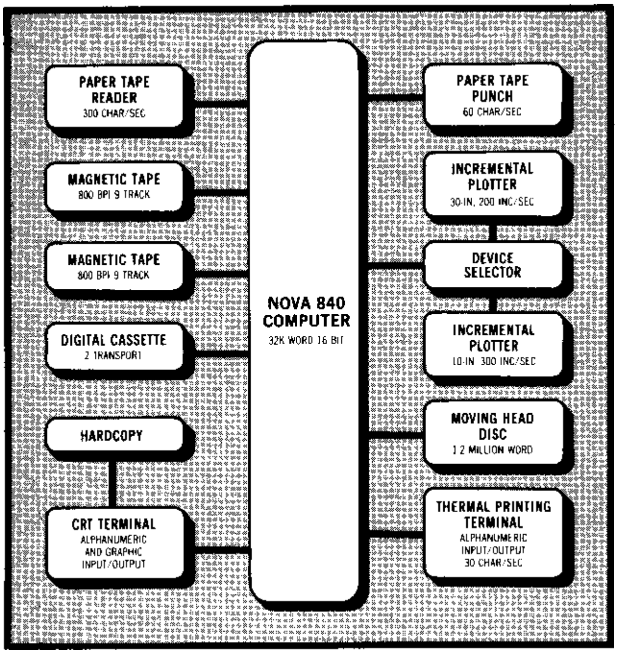


Figure 6. *BLOCK DIAGRAM OF REDAC SYSTEM*

6.0 DATA ANALYSIS

For this survey data analysis has been directed to producing two specific results: (1) a gamma gross count isopleth map, and (2) gamma radiation spectra from the aerial data which accurately characterize the sites.

To produce a gross count isopleth, the REDAC is programmed to select gamma counts occurring within a 1 second time interval from an extremely wide energy interval (40 keV to 4.07 MeV). A conversion factor is applied to the difference between these counts and counts of non-terrestrial origin to obtain exposure rate at the 1 m level due to sources in the soil. The sum of this exposure rate and the cosmic ray exposure rate is plotted as a function of position over the site. For most surveys the non-terrestrial counts are measured by flying the aircraft at the survey altitude over a large water body convenient to the site. Background contributions are normally measured at least once each day and during each flight, if this is practical. Over water the detectors see background counts due to cosmic rays and minute sources within the materials of which the detectors, electronic systems, aircraft instruments, and the helicopter are made. Radon gas and the other radioactive gases or particulates suspended in the air contribute to both the land flights and the water flights. The cosmic ray contribution changes diurnally and with the seasons; radon and other gas contributions may change within a few hours.

For the General Atomic survey background measurements could be very conveniently made over the Pacific Ocean during each flight. The measured background was 834 counts per second (cps), which is equivalent to an exposure rate of 0.7 microroentgen per hour (μR/h). The 834-count background is subtracted from each 1-second gross count sum so that the result characterizes terrestrial sources only. Previous calibration work with this system at the survey altitude of 46 m (150 ft) indicates that 1130 counts per second (cps), from terrestrial sources only, is equivalent to an exposure rate of 1 μR/h at an altitude of 1 m.

As the final step, the REDAC system was programmed to convert the count rate of terrestrial origin to equivalent exposure rate, 3.5 μR/h were added for the cosmic radiation contribution, and the results were plotted as a function of position. The numerical value of the cosmic exposure rate was inferred from the data of Lindeken, et al.[4] The cosmic contribution is then added to the terrestrial to make the isopleth easier to compare with other field measurements.

On a scale determined by the aerial photo used as a base map for the survey, the REDAC system plotted total exposure rate (terrestrial plus cosmic) as a function of aircraft position. Rates were then letter-coded for the General Atomic Facility (Table 2).

Only the maximum count and exposure rates are shown for each label. That is, the computer assigns the letter H to any count rate between 20,801 and 29,000 counts per second. The corresponding exposure rate for H obviously covers a range from 18.4 to 25.7 μR/h (terrestrial only).

To obtain the total exposure rate a cosmic ray component of 3.5 μR/h is added to the terrestrial, as previously indicated. Estimates of this cosmic component vary from 3.5 to 4.0 μR/h. No measurements of this contribution were made specifically for these surveys. Hence, the cosmic contribution must be inferred from the work of others. Lindeken, et al,[4] measured environmental radiation throughout the United States in 1971 with thermoluminescent dosimeters. They concluded that the cosmic exposure rate for San Diego and Santa Maria, California was 3.5 μR/h for their test period. Cosmic radiation levels change during the 11-year solar cycle; they also vary with altitude and latitude. The higher the altitude, the greater the cosmic component of the total exposure rate.

No accurate information on the variation of cosmic ray levels at these sites is available to the author. Hence, an estimated cosmic contribution of 3.5 μR/h was added to the measured terrestrial contribution in Table 2. This value could be low by a few tenths of a μR/h. The procedure is followed so that the gross count isopleth can be more easily compared with other field measurements.

Table 2. Gamma Gross Count Rate and Exposure Rate at General Atomic Facilities

Letter Label	Maximum Count Rate (cps in thousands)	Maximum Terrestrial Exposure Rate (μR/h)	Total Exposure Rate (μR/h)
A	4.2	3.7	7.2
B	6	5.3	8.8
C	8.7	7.7	11.2
D	11.0	9.7	13.2
E	13.4	11.9	15.4
F	16.2	14.3	17.8
G	20.8	18.4	21.9
H	29	25.7	29.2
I	40.2	35.6	39.1
J	55.9	49.5	53
K	77.7	68.8	72.3
L	108	95.6	99.1
M	150	133	136
N	208	184	188
O	290	257	260
P	402	356	359
Q	559	495	498
R	777	688	691
S	1080	956	960

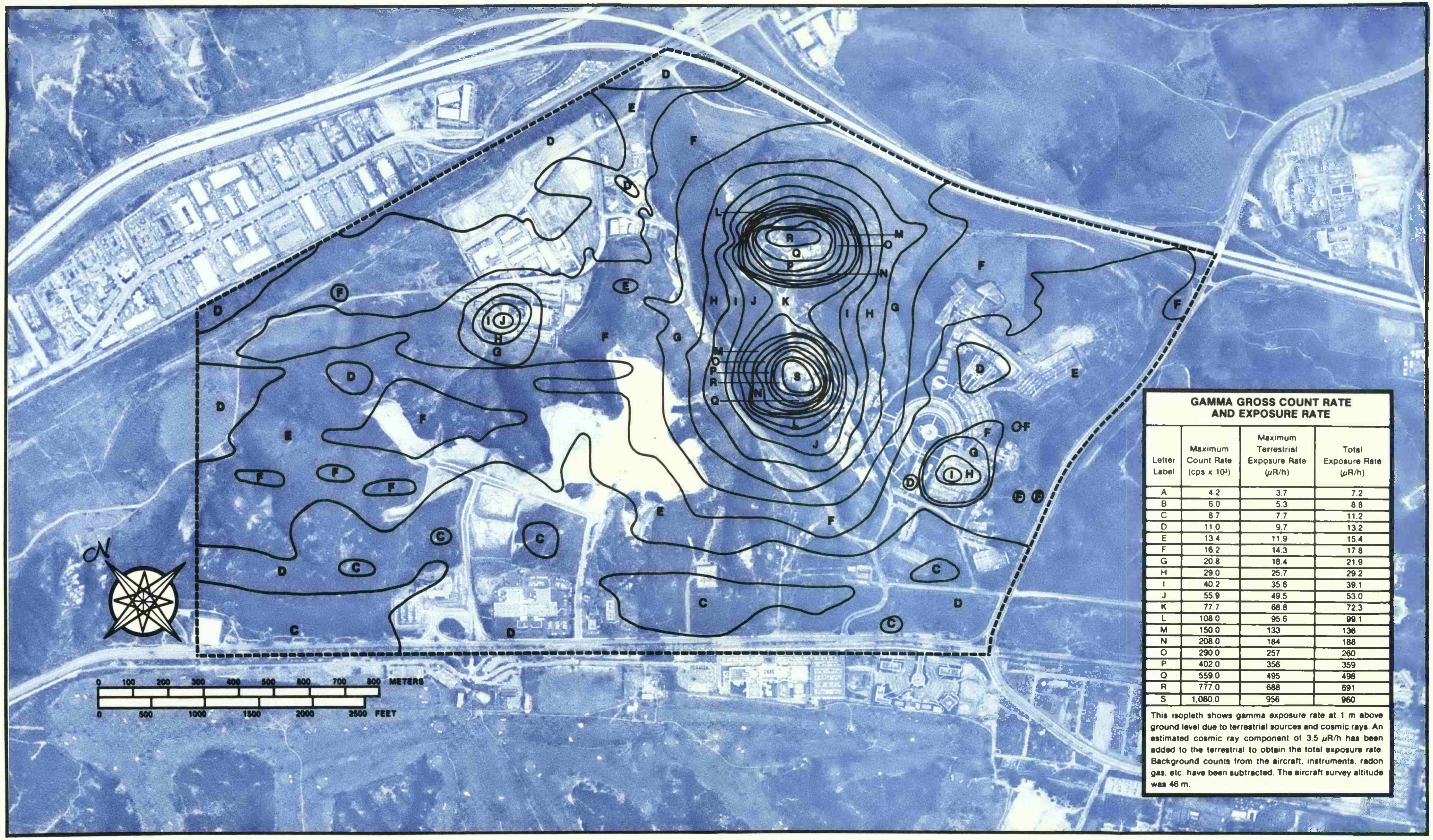
Before the gamma isopleths of the survey are considered, it should be noted that the remote sensing system in the H-500 helicopter is an uncollimated array of sodium iodide detectors. The inherent spatial resolution of such a system is one to two times the distance between the surveyed surface and the detectors. Frequently ground surveys are performed with hand-held detectors at a distance of 1 m from the surface; if the survey area contains sources with lateral dimensions which are small in comparison to aircraft survey altitudes, the ground survey results will not compare with the aerial results. A ground survey of a point source will produce a distribution pattern with a radius of, perhaps, 1 m or 2 m; an aerial survey of the same source will yield a distribution pattern with a radius of several tens of meters. Hence, the results of in situ measurements at 1 m, or from soil samples, must be averaged over a large area for comparison with aerial isopleths. Ion chamber measurements and soil samples have been collected routinely on the sites of AMS aerial surveys. When properly averaged the results are consistently within 20% of exposure rates determined from the air.[5,6]

7.0 RESULTS

Figure 7 is a gamma gross count isopleth map of the General Atomic facilities and immediate surroundings. All gamma rays between 50 keV and 4 MeV are summed and plotted as a function of position over the site. The conversion to exposure rate in microroentgens per hour (μR/h) is normalized to an altitude of 1 m to facilitate surface comparisons.

The map shows that the letters E and F generally characterize bare soil near General Atomic. That is, the terrestrial exposure rate is 12-14 μR/h. In many areas, notably along North Torrey Pines Road, the level drops to D or even C. Hence, the natural soil activity in this area has broad variability from, say, 5.4 to 14.3 μR/h. Evidently the natural concentrations of potassium-40, uranium, and thorium, and their radioactive daughters, do not blend homogeneously here.

In many cases a heavy concentration of facilities (buildings, parking lots, etc.) causes a change in natural radioactivity patterns. The construction materials may be more or less radioactive than indigenous soil. The General Administration Building (1) and Technical Office Buildings (13, 14, and 15) are apparently made of materials of lower activity than the indigenous soil.



GAMMA GROSS COUNT RATE AND EXPOSURE RATE

Letter Label	Maximum Count Rate (cps x 10^3)	Maximum Terrestrial Exposure Rate (μR/h)	Total Exposure Rate (μR/h)
A	4.2	3.7	7.2
B	6.0	5.3	8.8
C	8.7	7.7	11.2
D	11.0	9.7	13.2
E	13.4	11.9	15.4
F	16.2	14.3	17.8
G	20.8	18.4	21.9
H	29.0	25.7	29.2
I	40.2	35.6	39.1
J	55.9	49.5	53.0
K	77.7	68.8	72.3
L	108.0	95.6	99.1
M	150.0	133	136
N	208.0	184	188
O	290.0	257	260
P	402.0	356	359
Q	559.0	495	498
R	777.0	688	691
S	1,080.0	956	960

This isopleth shows gamma exposure rate at 1 m above ground level due to terrestrial sources and cosmic rays. An estimated cosmic ray component of 3.5 μR/h has been added to the terrestrial to obtain the total exposure rate. Background counts from the aircraft, instruments, radon gas, etc. have been subtracted. The aircraft survey altitude was 46 m.

Figure 7. *GROSS COUNT ISOPLETH MAP: GENERAL ATOMIC FACILITIES*

Higher than natural activity is observed at four locations. The maximum terrestrial exposure rate measured at these facilities and the probable source of radioactivity are listed in Table 3.

It should be noted that the indicated intensity levels were measured only during the survey period: 20-23 June 1978. Considerable changes may be anticipated during routine General Atomic operations. All of the spectra were taken on 22 June (Figures 8-11). A measurement made with a hand-held instrument at the center of one of the areas of enhanced activity will probably differ considerably from those shown in the figure. The airborne detectors are sensitive to sources over a circle with a diameter one to two times the survey altitude (46 m). Multiple, distributed sources (such as those in this survey) are effectively averaged by the detectors over this large circular area.

Hand-held instruments may also fail to detect enhanced radiation levels out to the distances shown in Figure 7 because adjacent buildings, foliage, and the local topography may provide shielding for an instrument only 1 meter above ground. Because of the aircraft altitude, sources are easily seen from a considerable distance. This effect, called "shine," may be so intense that low-level sources may be totally obscured in the shine from a nearby high-level source. An intense source of small physical dimensions ("point source") generates circular isopleth contours at its location. Perturbations from circular symmetry suggest the presence of multiple sources. For example, the L level perturbation northeast of the TRIGA Fuel Lab (Building 22) suggests multiple sources in that area.

The "probable source" information in Table 3 was deduced from radiation spectra accumulated over areas of enhanced activity. Several data records taken over such areas are added; total counts for a given time period versus gamma ray energy are plotted. Figure 8 shows a spectrum obtained over the TRIGA facility (Building 21) on 22 June 1978. Three records from label 225 (9, 10, and 11) are plotted after a background spectrum (records 1 through 4) was subtracted. The total live time (0.178 minutes) is roughly required for the helicopter to pass over the area of interest. The full spectrum contains 201,593 gamma counts.

In the TRIGA spectrum two isotopes, ^{60}Co and ^{134}Cs, are primarily responsible for the spectrum shape. The 0.605 MeV peak of ^{134}Cs appears to be slightly broadened, perhaps by ^{137}Cs from worldwide fallout or from research activity in the immediate area. The ^{134}Cs photopeaks not shown in this figure have considerably less intensity than the 0.605- and 0.796-MeV peaks which appear prominently.

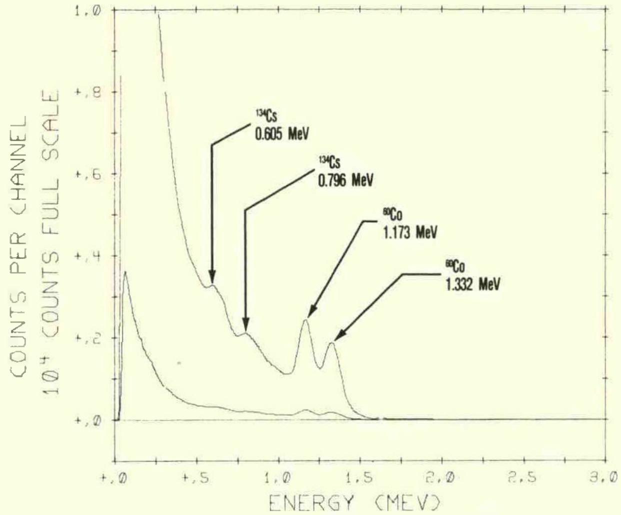
Photopeak identifications have been made with the invaluable assistance of General Atomic personnel familiar with operations at these facilities.[7] The ^{134}Cs observed here is a fission by-product. It is partially produced from the fission product ^{133}Xe, which decays into ^{133}Cs, and partly from ^{133}Cs, which is produced as a fission product.The ^{134}Cs results when ^{133}Cs captures a neutron. ^{60}Co is also produced as an activation product.

Figure 9 was also constructed by adding the data records and subtracting a local background. In this case the data were obtained near the Waste Yard Building-S (25). In addition to the ^{60}Co there is an accumulation of ^{137}Cs, which appears to be quite prominent. The presence of ^{134}Cs is inferred from the small peak at 0.796 MeV. The position shown for the 0.605 MeV peak of ^{134}Cs indicates that relatively little of this isotope is present — the

Table 3. Enhanced Radioactivity Sites at General Atomic Facilities

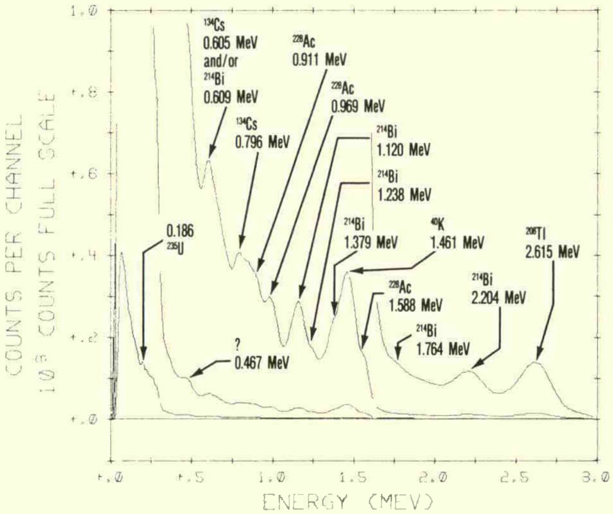
Facility	Maximum Terrestrial Exposure Rate (μR/h)	Probable Source(s)
1. TRIGA Bldg (21)*	956.0	^{60}Co, ^{134}Cs
2. Waste Yard Bldg S (25)	688.0	^{60}Co, ^{137}Cs, ^{134}Cs
3. Sorrento Valley Bldg A (37) and Sorrento Valley Bldg B (39)	49.5	^{235}U, ^{134}Cs, ^{214}Bi, ^{228}Ac, ^{40}K, ^{208}Tl
4. Experimental Bldg (9)	35.6	^{208}Tl, ^{212}Bi, ^{228}Ac, ^{214}Bi, ^{40}K

*Numbers in parentheses correspond to those indicated on the facilities location key, Figure 1.



```
SPECTRUM NO.1. 225(9.11)-(1,4)
DATE  9/22/78
LIVE TIME (MIN)         +.178
INTEGRATED CT.   +.2015932E+06
TYPE  LA JOLLA, HS-BKG(NET) `
```

Figure 8. *GAMMA SPECTRUM: TRIGA BUILDING (21)*



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DATE  9/22/78
LIVE TIME (MIN)         +.053
INTEGRATED CT.   +.1440655E+05
TYPE  LA JOLLA SPEC-BKG.20 TUBE
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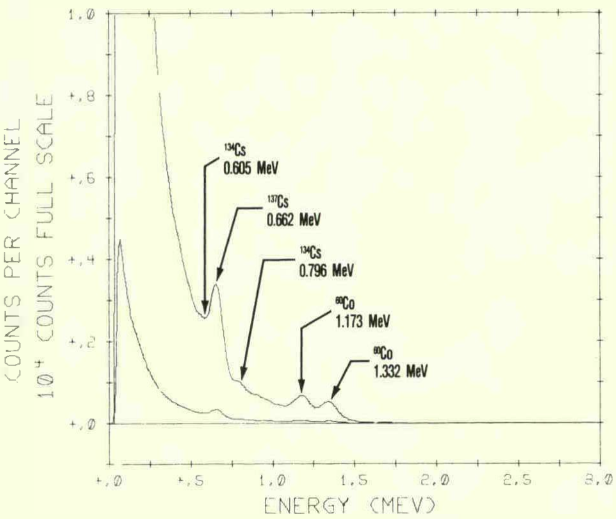
Figure 10. *GAMMA SPECTRUM: SORRENTO VALLEY BUILDINGS A AND B (37 and 39)*



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DATE  9/22/78
LIVE TIME (MIN)         +.179
INTEGRATED CT.   +.2024922E+06
TYPE  LA JOLLA. HS-BKG(NET).1 TUBE
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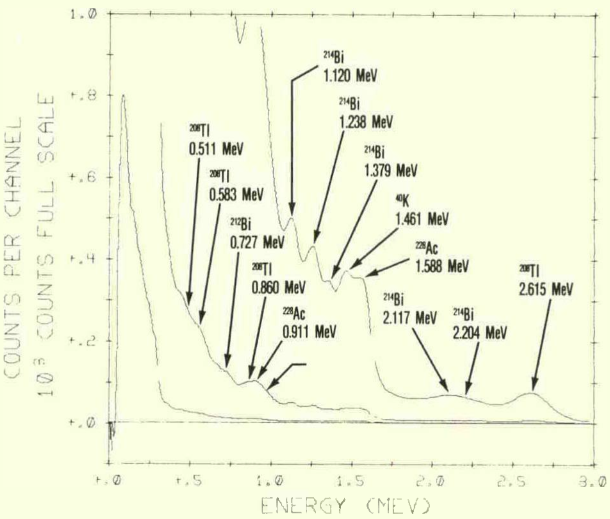
Figure 9. *GAMMA SPECTRUM: WASTE YARD BUILDING-S(25)*



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SPECTRUM NO.  4, L43(26)-L24(5.9)
DATE  9/22/78
LIVE TIME (MIN)         +.317
INTEGRATED CT.   +.3882411E+05
TYPE  LA JOLLA SPEC-BKG.20 TUBE
```

Figure 11. *GAMMA SPECTRUM: EXPERIMENTAL BUILDING (9)*

lower photopeak does not appear at all. However, any isotope present in small quantities becomes increasingly difficult to identify as the photopeak energy decreases and merges with the Compton continuum. Some of the waste in this area has been evaporated; some has been placed in barrels and wooden containers.

The third spectrum (Figure 10) was obtained over Sorrento Valley Buildings A and B (37 and 39); the helicopter skirted the north edge of Building A and flew directly over Building B. These are fuel manufacturing and research areas which contain ^{235}U , ^{238}U, and ^{232}Th. As one might expect, the decay products of ^{238}U and ^{232}Th dominate the spectrum; because of the many overlapping photopeaks the spectrum is correspondingly difficult to interpret. Naturally occurring ^{40}K appears at 1.461 MeV. The presence of ^{238}U or one of its longer lived daughters is indicated by strong photopeaks from the daughter product ^{214}Bi at 0.609-, 1.120-, and 2.204-MeV; the 1.238-, 1.379- , and 1.764-MeV peaks appear as barely discernible shoulders on more prominent photopeaks.

The ^{232}Th appears through its daughters ^{228}Ac and ^{208}Tl. The 0.969 MeV peak of ^{228}Ac is relatively strong; bare hints of the 0.911- and 1.588-MeV peaks also appear. ^{208}Tl, also a daughter of ^{232}Th, is strongly indicated by the peak at 2.615 MeV; weaker thallium peaks at 0.511- , 0.583- , and 0.860-MeV are apparently hidden by their proximity to other large photopeaks.

An unexplained photopeak appears at 0.467 MeV. Many low energy photopeaks in both decay chains could combine to produce an apparent photopeak at 0.467 MeV. Perhaps additional spectra with better statistics are required to unravel this complex spectrum with greater certitude.

Finally, there appears a small peak at approximately 190 keV. This is thought to be the 0.186 MeV peak of ^{235}U. This is the most prominent of the many low energy gamma rays of ^{235}U.

Complicated spectra, such as Figures 10 and 11, are difficult to unravel without prior knowledge of the survey site. The present interpretations are consistent with the site characteristics known to General Atomic personnel.[7] In some cases arrows have been drawn to show the expected positions of isotopes which GA personnel know are present.

Figure 11 is also difficult to interpret. It was flown over the Experimental Building (9) which contains thorium in fairly large quantities, with smaller quantities of uranium in natural or depleted form. There is spectral evidence for thorium daughters ^{208}Tl (0.511- , 0.583- , 0.860- , and 2.615-MeV), ^{212}Bi (0.727 MeV), and ^{228}Ac(0.911- , 0.969- , and 1.588-MeV). Similarly there is evidence of ^{238}U or one of its long-lived daughters because of ^{214}Bi photopeaks at 1.120-, 1.238- , 1.379- , 2.117- , and 2.204-MeV. In some cases these photopeaks are weak, perhaps just shoulders on large photopeaks. Additional spectral data would have to be accumulated directly over the Experimental Building for more accurate photopeak identifications.

It appears that all evidence of man-made contributions to the site radioactivity are well known to General Atomic personnel. No evidence of contamination was observed over drainage paths from GA property to lower ground; many helicopter passes were made along these paths.

8.0 CONCLUSION

An aerial radiological survey of General Atomic facilities was conducted on 20-23 June 1978. The survey was conducted from a United States Department of Energy helicopter equipped with 20 sodium iodide detectors, a multichannel analyzer, and a magnetic tape recording system. The survey altitude was 46 m.

Four areas within the survey site show evidence of GA activity: 1) ^{134}Cs and ^{60}Co were observed at the TRIGA Building; 2) ^{134}Cs, ^{137}Cs, and ^{60}Co were measured at the Waste Yard Building-S; 3) ^{235}U and ^{232}Th daughter products were seen over the fuel manufacturing and research Buildings A and B in Sorrento Valley; and 4) thorium and uranium daughters were also observed over the Experimental Building. No evidence of these isotopes was measured outside the boundaries of the General Atomic site or in natural drainage paths from GA facilities to lower ground.

APPENDIX*

Microwave Ranging System and Steering Indicator/Calculator

A line-of-sight, X-band microwave system, comprised of a master (aircraft) and two remote (ground) stations, is used to determine the distance of the aircraft from the ground stations. Each of the three transceiver units provides an output of up to one kilowatt peak power. The system is capable of measuring ranges up to 100 nautical miles under line-of-sight conditions. Resolution of the system is one foot, and accuracy is better than ± 10 feet. Transmissions are coded to differentiate between the two ground-based transponders. Signals from the transponders are at a frequency different from the master's in order to guard against ranging from the master to microwave-reflecting objects.

A control unit in the aircraft initiates a complete interrogation cycle every 250 milliseconds. This cycle consists of a group of pulses to establish which of the two transponders is being interrogated, followed by ranging pulses (up to forty) until ten valid returns have been received. The control unit then outputs the average measured range to external equipment. If ten valid returns are not received, the control unit will output a "zero-range" to the external equipment. The procedure is repeated for the second transponder. To acquire, the two ranges may take from 45 milliseconds to 140 milliseconds. The microwave system idles for the remainder of the 250 millisecond cycle.

External Equipment Use of MRS Ranges

External equipment receiving range data from the control unit are the Radiation Data Acquisition and Recorder system (REDAR) and the Steering Indicator Calculator (SIC). A range pair is recorded on the REDAR tape along with the concurrent radiation data for each 1 second of data acquisition. The processing of REDAR tape recorded ranges is described elsewhere. The steering indicator/calculator reads in a range pair every quarter-second. These data are processed in real time to give the aircraft pilot an on-line or quantitative left- or right-of-line indication.

Calculator Program

Arithmetic calculations, using the actively measured ranges, are performed by the calculator to do the following:

- Measure the distance between the two ground stations (the "baseline" length).
- Translate and rotate the desired survey grid from the orthogonal system of the baseline to an orthogonal system centered on two observable terrain features.
- Provide the pilot with left/right steering information.
- Provide the SIC operator with information on line number, direction of flight, steering error, in or out of survey area, distance to end (or beginning) of line, and ground speed.

Steering Indicator Calculator System

The heart of this system is a programmable desk-top calculator which weighs only 25 pounds (Hewlett-Packard 9825A). It is programmable in a high level language (similar to FORTRAN) and has about 6800 bytes of user memory for program and data storage. The unit also contains a drive mechanism for magnetic tape cartridges, a small thermal printer, and a 32-character display. The use of a high level language facilitates modification of the calculator program to fit unique field situations.

A special interface circuit effects compatibility between the MRS's 24 data output lines and 2 strobes with the calculator's 16 byte input data buss, control, and status lines. Also provided in this circuit is a digital-to-analog converter to drive the pilot's steering meter. The interface is under the direct control of the calculator program.

Operational Sequence

The relative location of the survey area with respect to the baseline (i.e., "above" or "below") must first be keyed into the calculator in order to remove the positional (bipartite) ambiguity caused by the MRS giving only two ranges and no angular information.

Prior to the start of the actual survey certain flight maneuvers are required to measure parameters.

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* Written by A.E. Villaire. May 1979. Las Vegas, NV: EG&G

- Baseline measurement: the distance between the ground-based transponders is measured by flying across the baseline (preferably mid-way) at as low an altitude as is practical. The value calculated for the baseline length is the minimum of the sum of the two ranges.
- Survey orientation and location: the aircraft crew must find two terrain features, natural or man-made, that can also be found on the map or aerial photo depicting the survey lines. Instantaneous ranges measured while passing directly over these features are entered in the calculator memory using a "hack" button. The two range pairs obtained are used by the program to calculate the angle between the baseline and the survey lines and the offset of the survey area from the baseline. If the two hack points do not lie on a line parallel to the desired survey lines, an angular correction may be manually entered in the calculator. The operator must then key in the intended survey line spacing; he may also enter values representing the longitudinal extent of the lines. The latter option is sometimes not used for extremely long lines where loss of reliable signal determines the ends of the lines. All these data are printed out and are recorded on tape so they may be recalled for use at another time.

The survey then proceeds with the operator keying in the initial line number and direction of flight (handled simply as "+" or "-"). At the end of a line, the operator increments or decrements the line number and reverses the sign of the flight direction. The pilot, after negotiating a turn, may use the steering meter to "home in" on the new line. The operator may relay to the pilot the distance to the start of the line (if the longitudinal extent values were keyed in) so that no harsh maneuvers are required in order to start the next line. (Even moderate aircraft banking causes loss of microwave signal as the fuselage or wings occlude the line of sight).

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