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THE **REMOTE SENSING LABORATORY**
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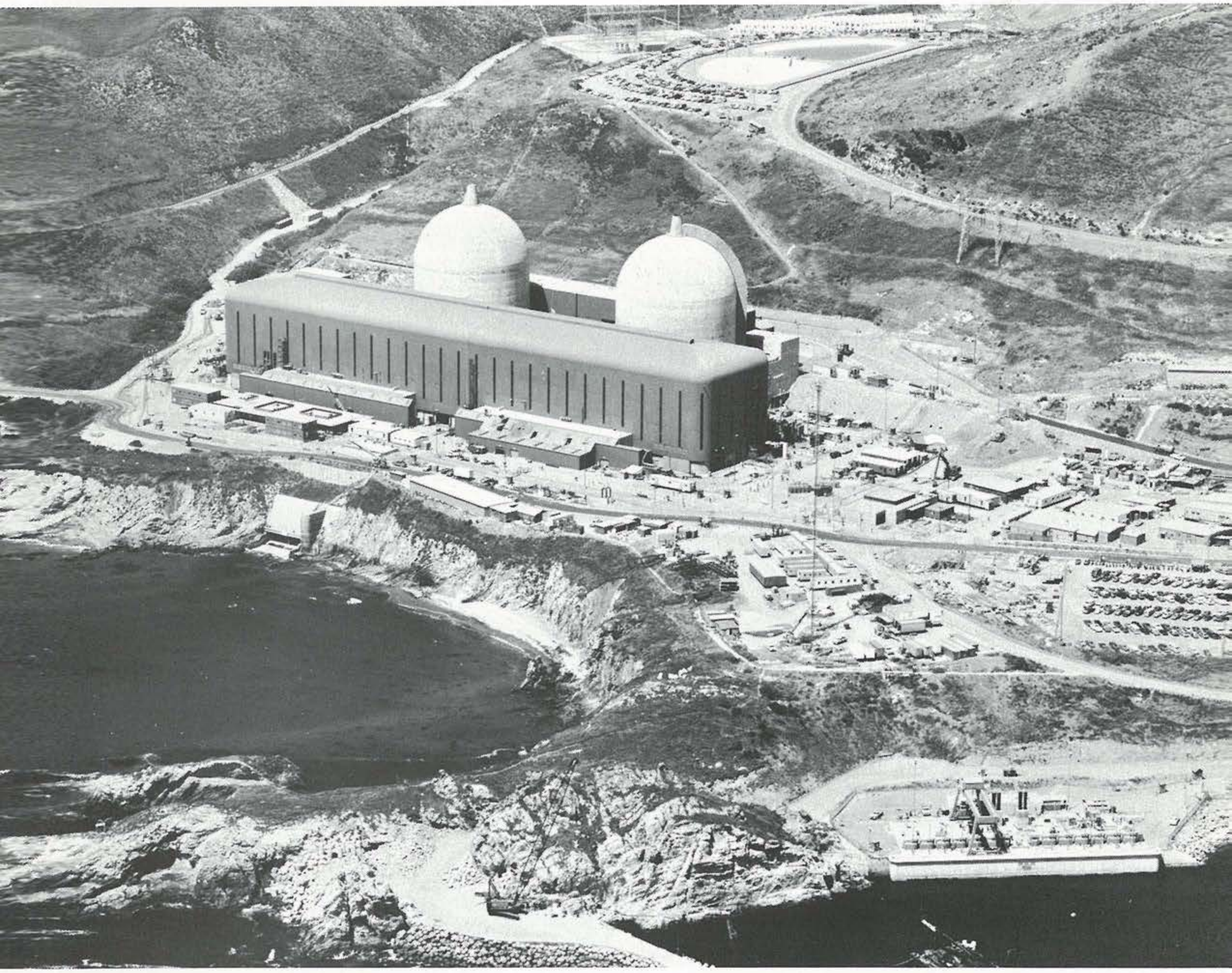

AN AERIAL RADIOLOGICAL SURVEY OF THE

DIABLO CANYON NUCLEAR POWER PLANT

AND SURROUNDING AREA

DIABLO CANYON, CALIFORNIA   DATE OF SURVEY: SEPTEMBER - OCTOBER 1984

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Classification Officer

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ABSTRACT

An aerial radiological survey was conducted over the area surrounding the Diablo Canyon Nuclear Power Plant in Diablo Canyon, California. The survey was conducted between 20 September and 3 October 1984. A series of flight lines parallel to the coastline were flown at an altitude of 91 meters (300 feet) and were spaced 152 meters (500 feet) apart. The survey covered an area of 250 square kilometers (100 square miles). The resulting background exposure rates over the survey area ranged from 5 to 21 microroentgens per hour (μR/h). The reported exposure rate values include an estimated cosmic ray contribution of 3.6 μR/h. Soil samples were also collected at several locations within the survey area and analyzed in the laboratory for isotopic composition. The results of the survey showed only the presence of naturally occurring background radiation. No man-made radioactivity was detected.

CONTENTS

Appendix

1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains the Remote Sensing Laboratory (RSL) in Las Vegas, Nevada and an extension facility of the RSL in Washington, D.C. The RSL is operated for the DOE by EG&G Energy Measurements, Inc. One of the major functions of the RSL is to manage an aerial surveillance program called the Aerial Measuring System (AMS).

Since its inception in 1958, the AMS has continued a nationwide effort to document baseline radiological conditions surrounding energy-related sites of interest, including nuclear power plants, manufacturing and processing plants, and research laboratories employing nuclear materials.[1] AMS aircraft have the additional capability of being equipped with mapping and multispectral scanners for ultraviolet, visible, and infrared imagery; a broad array of meteorological sensors; and air sampling systems for particulate and molecular gas measurements. At the request of federal or state agencies, and by direction of the DOE, the AMS is deployed for various aerial survey operations.

The aerial radiological survey of the Diablo Canyon Nuclear Power Plant and surrounding area was requested by the U.S. Nuclear Regulatory Commission (NRC). This survey is part of a routine environmental surveillance program conducted at all nuclear power stations.

2.0 NATURAL BACKGROUND RADIATION

Natural background radiation originates from radioactive elements present in the earth (i.e., the terrestrial component), airborne radon, and cosmic rays entering the earth's atmosphere from space. The terrestrial gamma radiation originates primarily from the uranium decay chain, the thorium decay chain, and radioactive potassium. The doses received from gamma rays emitted by these naturally occurring radionuclides depend on the nature of the minerals in the ground. Annual dose equivalents from the terrestrial component of background radiation are as low as 15 to 35 millirems (mrems) (2 to 4 μR/h) for the Atlantic and Gulf Coastal Plains and as high as 75 to 140 mrems (9 to 16 μR/h) on the Colorado Plateau.[2,3]

One member of both the uranium and thorium decay chains is an isotope of radon, a noble gas, which can both diffuse through the soil and be transported in the air to other locations. Therefore, the level of airborne radiation due to these radon isotopes and their daughter products at any specific location depends on a variety of factors, including meteorological conditions, the mineral content of the soil, and soil permeability. Typically, airborne radiation contributes between 1 and 10 percent of the natural background levels.

Cosmic rays interact with the elements of the earth's atmosphere and soil to produce an additional natural source of gamma radiation. The intensity of this radiation source depends on the altitude and, to a lesser extent, on the geomagnetic latitude. In general, the cosmic ray contribution to the natural background radiation is largest at high altitudes and high latitudes. Annual dose equivalents in the United States due to cosmic rays range from about 29 mrems (3.3 μR/h) in Florida to about twice that value in Wyoming.[3]

External radiation may also be received from radioactive elements in building materials. In structures made of stone, concrete, or brick, the radiation dose is generally higher than in nearby wooden buildings. Additionally, doses are dependent upon the nature of the materials utilized for road and highway construction. Thus, radiation doses due to "natural" background sources are highly variable from location to location and are dependent upon a number of factors.

3.0 SURVEY SITE DESCRIPTION

The Diablo Canyon Nuclear Power Plant is located on the California coastline approximately 13 kilometers (8 miles) west-northwest of Avila Beach, California.

The aerial survey was flown at an altitude of 91 meters (300 feet) with lines spaced at 152-meter (500 feet) intervals. The survey altitude was maintained as much as possible in the rapidly changing topography of the survey area. The flight lines were programmed parallel to the coastline (northwest-southeast) and were approximately 19 kilometers (12 miles) long. The survey area was 13 kilometers (8 miles) wide and covered a total area of 250 square kilometers (100 square miles). The survey area included all of the Irish Hills, south of Morro Bay, west of San Luis Obispo and north of Shell Beach.

4.0 SURVEY PROCEDURES AND EQUIPMENT

The survey and data analysis procedures and the equipment used to conduct this survey are briefly discussed in this section. A more detailed description of the procedures can be found in previously published reports.[1,4]

4.1 Aerial Data Acquisition System

A Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter was used to conduct the survey. The aircraft carried a crew of two along with the data collection and recording instrumentation.

The radiation detector package consisted of 8 sodium iodide (thallium-activated) NaI(Tl) log detectors. Each log detector was 10.2 cm (4 in.) square by 40.6 cm (16 in.) long. The logs were equally distributed in two pods mounted on the exterior of the helicopter (Figure 1).

A photomultiplier tube mounted to each NaI(Tl) crystal converted the scintillation pulses to voltage pulses. The voltage pulses from 8 detectors were normalized and combined in summing amplifiers to produce a single gamma ray energy spectrum with high sensitivity. Both spectra were simultaneously acquired and recorded, resulting in a wide operating range.

Figure 1. *MBB BO-105 HELICOPTER WITH DETECTOR PODS*

The outputs of the summing amplifier and the single tube were analyzed in separate analog-to-digital converters (ADCs) in the Radiation and Environmental Data Acquisition and Recorder (REDAR) system. The REDAR system is a multi-microprocessor, portable data acquisition and real-time analysis system. It has been designed to operate in the demanding environments associated with helicopters and fixed-wing aircraft.

The ADC signals were adjusted so that the photopeaks from calibration sources appeared in preselected channels of the multichannel analyzers (MCAs). Each MCA collected a 1024-channel gamma ray energy spectrum once every second. The collected spectrum was scaled to 4 keV per channel. The 1024-channel spectrum was compressed into 256 channels before storage on magnetic tape according to the partitioning scheme shown in Table 1. The energy resolution of the NaI(Tl) crystals varies with the energy of the detected photon, permitting the compression of the spectral data without compromising photopeak identification and data analysis techniques. This spectral compression technique reduced the data storage requirement by a factor of four.

All 1-second data acquired by the REDAR system were placed into a buffer. After accumulating data for 4 seconds, the buffered information was recorded on magnetic tape as a 4-second record. In addition to gamma ray spectral data, other information acquired and recorded by the REDAR system included gross count data (gamma ray

Table 1. Partitioning Scheme Utilized for Gamma Ray Energy Data Compression

E_γ (keV)	Channel Input	Energy Coefficient ΔE (keV/channel)	Compressed Channel Output
0 - 300	0 - 75	4	0 - 75
304 - 1620	76 - 405	12	76 - 185
1624 - 4068	406 - 1017	36	186 - 253
4072 - Cutoff	1018 - 1023	N/A	254
> Cutoff	Forced to Zero	N/A	256

activity integrated over the energy range 0.04 to 3.0 MeV), aircraft positional data, system live time information, and environmental conditions, i.e., absolute barometric pressure and outside air temperature.

4.2 Aircraft Positioning

Contiguous United States Geological Survey (USGS) maps were used to define the survey area. Area coverage was assured by flying a series of parallel lines over the predetermined area. A total of 85 flight lines were flown for this survey.

The helicopter position was established by two systems: an ultrahigh frequency ranging system (URS) and a radar altimeter. The URS system consisted of a master and two remote slave units. The URS master unit, mounted in the aircraft, interrogated the two remote transceivers which were mounted in an appropriate geometric configuration several kilometers outside the survey area. By measuring the round-trip propagation time between the master and remote units, the master unit computed the distance to each remote unit. These distances were calculated every second and transferred to magnetic tape every 4 seconds. In subsequent computer processing, the distances were converted to position coordinates and scaled to fit an aerial photograph of the survey area. In addition, the positional information was processed in real time flight to provide steering data to the pilot.

The radar altimeter aboard the helicopter measured the time lag for the return of a pulsed signal and converted this delay to aircraft altitude. These data were also recorded on magnetic tape so that any variation in gamma ray signal strength caused by altitude fluctuations could be accurately compensated.

4.3 Data Processing Equipment

The data recorded on magnetic tapes during the survey were processed with the Radiation and Environmental Data Analyzer and Computer (REDAC) system. This system consisted of a computer mounted in a mobile data processing laboratory (Figure 2). An extensive inventory of software routines and supporting equipment was available for detailed data analysis. Some of the data were processed during the actual survey period to assure complete data acquisition integrity and to provide preliminary results as soon as possible.

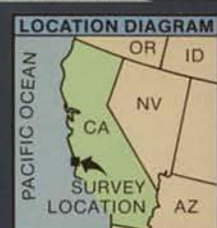
Figure 2. *MOBILE COMPUTER PROCESSING LABORATORY*

5.0 DATA ANALYSIS

Data analysis for the survey produced the following: (1) a total gamma ray exposure rate contour map (Figure 3), and (2) a typical background gamma ray spectrum from the survey area (Figure 4).

5.1 Total Gamma Ray Exposure Rate Contour Map

A gamma ray exposure rate contour map was constructed from the gross counts obtained in the gamma ray energy spectrum between 0.04 MeV and 3.0 MeV. The exposure rate contour map was scaled and overlaid on an aerial photograph and USGS topographic maps of the survey area. Before the gross counts were converted to exposure rates, the non-terrestrial components were removed. These components consisted of: (1) aircraft background, (2) cosmic radiation, and (3) airborne radon daughter contributions. The non-terrestrial components were determined by flying over the Pacific Ocean where the terrestrial signal



* Exposure rates are inferred from gamma gross count rate measurements made at an altitude of 91 meters averaged over the detector field-of-view and extrapolated to 1 meter above ground level. A cosmic contribution of 3.6 μR/h is also included.

GROUND SAMPLE MEASUREMENTS

CONVERSION SCALE

LETTER LABEL	TOTAL EXTERNAL EXPOSURE RATE* AT 1 METER (μR/h)
A	< 5.0
B	5.0 - 8.0
C	8.0 - 11
D	11 - 15
E	15 - 21

Figure 3. *TOTAL EXTERNAL EXPOSURE RATE CONTOURS DERIVED FROM AERIAL SURVEY DATA AND LOCATIONS OF GROUND-BASED MEASUREMENTS (SEPTEMBER - OCTOBER 1984)*

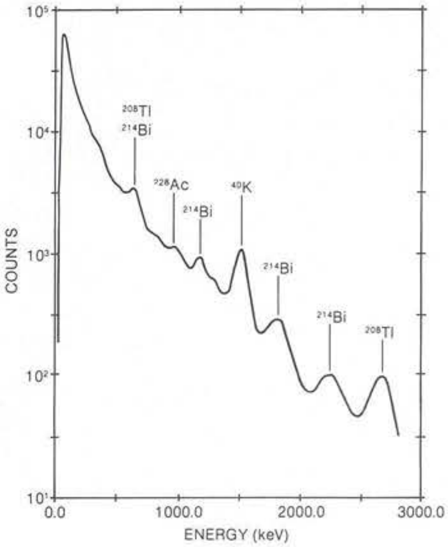


Figure 4. *TYPICAL BACKGROUND GAMMA RAY SPECTRUM OF THE DIABLO CANYON AREA*

was negligible. The resulting net gross count rate can be expressed in the form:

$$GC = [(A_e \bullet W_{GC}) \bullet LT - BKG] \bullet ALT$$

where

- GC = Net gross count rate normalized for system live time and altitude variations (counts per second).
- W_{GC} = Measured gross count rate (cps).
- A_e = Detector effective area normalization factor.
- LT = System live time counting loss normalization factor.
- BKG = Non-terrestrial radiation background count rate (cps).
- ALT = Altitude variations normalization factor.

Terrestrial exposure rate values in microroentgen per hour (μR/h) at the 1-meter level were calculated from the net gross count rate using the conversion factor of 800 counts per second equals 1 μR/h. This conversion factor was derived from experimental measurements acquired at a calibration range near Lake Mead in Arizona. The soil in the calibration area contained a typical mix of naturally occurring radionuclides consisting of potassium-40 and members of the uranium and thorium decay chains. A different isotopic mix will modify the shape of the spectrum over the energy interval covered by gross counts. Since the gross count conversion factor is dependent on spectral shape, the established conversion factor will not apply precisely to areas where the mix is atypical or where extraneous radionuclides are present. An estimated cosmic ray contribution of 3.6 μR/h was added to the terrestrial exposure rates to obtain the total exposure rate values minus any contribution from airborne radon. The exposure rate contour map is shown in Figure 3.

5.2 Minimum Detectable Activity

Table 2 indicates the minimum detectable activity for two isotopes as a function of source geometry for the aerial system used in the survey. The radioactivity was assumed to be distributed exponentially with depth in the soil according to the following equation:

$$S_v = S_v^0 \, e^{-\alpha z}$$

where

- S_v^0 = the soil activity per gram at the surface
- S_v = the soil activity per gram at a depth z, and
- α = the reciprocal of the relaxation depth.

The total activity per unit area can then be written as:

$$S_A = \rho \int_0^\infty S_v dz = \left(\frac{S_v^0}{\alpha}\right) \rho$$

where ρ is the soil density.

It was assumed in Table 2 that no additional shielding existed between the source and the detector array. It was further assumed that distributed sources were spread over an area comparable to several times the survey altitude.

6.0 RESULTS

6.1 Aerial Survey

The total (terrestrial plus cosmic) exposure rate contours (derived from gross count rates) superimposed on an aerial photograph and USGS maps are shown in Figure 3. The background exposure rate in the survey area ranged from 5 to 21 μR/h.

Table 2. Minimum Detectable Activity for Several Selected Radioisotopes as a Function of Source Geometries[a]			
	Surface Sources		
Isotope	Point Source (mCi)	Distributed Source (μCi/m^2) $\alpha = 0$	Volume Source $\left(\frac{pCi}{g}\right)^b$ $\alpha = 10$ cm
^{60}Co	1.2	0.07	0.8
^{137}Cs	2.6	0.09	1.3

[a] Assuming a survey altitude of 91 meters.

[b] Conversion factor to pCi/g relates to the average value of a 5-cm deep soil sample.

Most of the survey area had exposure rates in the 5 to 11 μR/h range. Background exposure rates such as these are commonly encountered throughout the United States. A gamma ray energy spectrum typical of the background radiation present within the survey area is shown in Figure 4. The peaks in the spectrum occur at energies characteristic of the gamma rays emitted by naturally occurring radioisotopes, i.e., uranium and thorium decay chain members and potassium-40. It should be noted that for slowly varying activity distributed over large areas, such as typical of most natural background radiation, the agreement between ground-based readings and those inferred from aerial data is generally good. Due to the large area averaging property of the airborne system, very localized anomalies will appear to be spread over a larger area with a lower maximum activity than actually exists on the ground.

6.2 Ground-Based Measurements[4]

Ground-based measurements were made at four locations within the survey area. The four locations within the survey area are identified in Figure 3. Each ground-based measurement was comprised of both total exposure rate measurements, obtained with a Reuter-Stokes Model RSS-111 pressurized ion chamber, and radionuclide analyses performed on a group of soil samples.

The total external exposure rates measured by both ground-based and aerial techniques are compared in Table 3 for each measurement location. The soil analyses and aerial measurements both include a 3.6 to 3.9 μR/h cosmic ray contribution. The results of the ground-based measurements corroborate the aerial measurements. Discrepancies between the ground-based and aerial results are of the magnitude expected due to area averaging, uncertainties involved in estimating the airborne radon contribution, and soil moisture.

Results of the radionuclide assay for each sample location are presented in Table 4. Only the principal constituents are included.

Table 3. Total External Exposure Rate Comparisons			
	Gamma Exposure Rate at 1 Meter (μR/h)		
Site Number	Soil Sample Analysis[a]	Ion Chamber[b]	Aerial Data
1	8.4 ± 0.3	8.2 ± 0.5	8 - 11
2	7.3 ± 0.5	7.6 ± 0.5	5 - 8
3	9.6 ± 0.3	9.8 ± 0.5	8 - 11
4	8.3 ± 0.4	8.0 ± 0.5	8 - 11

[a] Includes a cosmic ray contribution of 3.6 to 3.9 μR/h, depending on site elevation and moisture correction of the form $1/(1 + m)$.

[b] Reuter-Stokes Model RSS-111, Serial No. Z528.

Table 4. Radionuclide Analysis of Soil Samples					
	Soil Sample Analysis (Average Values)				
Site Number	Soil Moisture (%)	U-238 (ppm)	Th-232 (ppm)	Cs-137 (pCi/g)	K-40 (pCi/g)
1	2.5 ± 2.0	1.4 ± 0.3	6.0 ± 0.6	0.16 ± 0.09	10.0 ± 0.8
2	5.2 ± 0.7	1.2 ± 0.5	5.0 ± 0.7	0.04 ± 0.01	8.4 ± 1.9
3	2.6 ± 0.4	1.6 ± 0.4	6.7 ± 0.6	0.18 ± 0.07	16.5 ± 0.3
4	8.2 ± 0.8	6.0 ± 0.6	1.7 ± 0.4	0.30 ± 0.15	2.9 ± 0.2

APPENDIX A

SURVEY PARAMETERS

Site:	Diablo Canyon Nuclear Power Plant
Location:	Diablo Canyon, California
Survey Date:	20 September to 3 October 1984
Base of Operations:	San Luis Obispo Airport, San Luis Obispo, California
Survey Coverage:	250 km^2 (19 km × 13 km)
Lines Surveyed:	85
Line Spacing:	152 m (500 ft)
Survey Altitude:	91 m (300 ft)
Project Scientist:	P.K. Boyns
Survey Aircraft:	MBB BO-105 Helicopter - N50EG
Acquisition System:	REDAR-IV
Detector Array:	Eight, 10.2-cm square by 40.6-cm long log NaI(Tl) detectors

Data Processing:

Energy Window: 0.04 - 3.0 MeV

Conversion Factor: 800 cps per μR/h

Cosmic Ray Contribution: 3.6 μR/h

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