WT-1314(EX)
EXTRACTED VERSION

OPERATION REDWING—PROJECT 2.52

410893

Neutron-Induced Soil Radioactivity

M. Cowan, Jr.
Sandia Corporation
Albuquerque, NM

10 December 1959

NOTICE:
This is an extract of WT-1314, Operation REDWING, Project 2.52.

Approved for public release;
distribution is unlimited.

Extracted version prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

1 September 1985

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY N/A since Unclassified 2b DECLASSIFICATION / DOWNGRADING SCHEDULE N/A since Unclassified	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S) WT-1314 (EX)
6a NAME OF PERFORMING ORGANIZATION Sandia Corporation 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Defense Atomic Support Agency
6c ADDRESS (City, State, and ZIP Code) Albuquerque, NM	7b ADDRESS (City, State, and ZIP Code) Washington, DC
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO · PROJECT NO · TASK NO · WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
OPERATION REDWING—PROJECT 2.52
Neutron-Induced Soil Radioactivity, Extracted Version

12 PERSONAL AUTHOR(S)
Cowan, M., Jr.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
	FROM 560501 TO 560731	591210	21

16 SUPPLEMENTARY NOTATION This report has had sensitive military information removed in order to provide an unclassified version for unlimited distribution. The work was performed by the Defense Nuclear Agency in support of the DoD Nuclear Test Personnel Review Program.

17 COSATI CODES

FIELD	GROUP	SUB-GROUP
18	3	
8	7	

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Redwing, Project 2.52
Soils
Yuma Burst
Cherokee Burst
Gamma Radiation

19 ABSTRACT (Continue on reverse if necessary and identify by block number)
Soil samples were exposed to neutron radiation from Shot Cherokee to help establish the importance of neutron-induced residual gamma radiation. After exposure and recovery, the samples had no detectable activity because the slant range to the nearest sample was nearly 3.5 miles, due to an error in bomb drop. After this failure, an experiment was designed in the field for Shot Yuma in order that induced-activity data could be obtained for a soil other than Nevada Test Site soil. Samples of sodium, manganese, and coral sand from Site Sally were exposed above and below the surface at a slant range of 120 yards.

The difference between the effects of pure fission and fission-fusion neutron spectra on induced activity in soil was not measured, since the soil samples on Shot Cherokee were not activated. However, a method for predicting neutron-induced gamma-radiation intensities was tested for coral soil on Shot Yuma. Predicted values were within ± 50 percent of induced dose rates inferred from field measurements.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Mark D. Flohr	22b TELEPHONE (Include Area Code) (202) 325-7559 · 22c OFFICE SYMBOL DNA/ISCM

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT-1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussion of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

Soil samples were exposed to neutron radiation from Shot Cherokee to help establish the importance of neutron-induced residual gamma radiation. After exposure and recovery, the samples had no detectable activity because the slant range to the nearest sample was nearly 3.5 miles, due to an error in bomb drop. After this failure, an experiment was designed in the field for Shot Yuma in order that induced-activity data could be obtained for a soil other than Nevada Test Site (NTS) soil. Samples of sodium, manganese, and coral sand from Site Sally were exposed above and below the surface at a slant range of 120 yards. At this same station, gamma dose rates were measured and neutron detectors were exposed by Project 2.51.

The full-field gamma radiation measured was due to a combination of fission-product and neutron-induced activities, the only important induced activity being due to $Na^{23}(n, \gamma)$ Na^{24}. At 1.1, 3.4, and 10.9 hours after zero time, neutron-induced gamma radiation accounted for 1.2, 1.1, and 0.8 r/hr of the measured 6.0, 2.2, and 1.2 r/hr. These values were found to be within 50 percent of neutron-induced dose rates predicted by the method of Reference 4.

CONTENTS

Chapter 1
INTRODUCTION

1.1 OBJECTIVE

This experiment was designed to provide data to aid the formulation of a method for predicting the gamma-radiation field caused by air bursts. Specific objectives were to measure the induced activity from a large-yield, thermonuclear air burst and to exploit the opportunity offered for an investigation of activity induced in some soil other than the soil of Nevada Test Site (NTS). When a bomb-drop error prevented any data being obtained on Shot Cherokee, an additional experiment was set up on Shot Yuma to obtain some data applicable to the second specific objective.

1.2 REASONS FOR EXPERIMENT

Certain military uses of nuclear weapons demand a minimum of residual contamination. For example, it might be desirable to exploit the first shock of a nuclear burst by having friendly troops occupy or pass through the ground-zero area soon after the detonation. Although for practical purposes there is no local fallout from an air burst, a considerable area around ground zero can be rendered radioactive by neutron bombardment, and the gamma-radiation field thus produced can prove dangerous to persons entering it hours later. The intensity and decay of such a gamma-radiation field will depend on the kind of weapon, its yield and height of burst, and on the elements which make up the soil around ground zero. This experiment was expected to provide data for the evaluation of the military significance of neutron-induced activity.

1.3 BACKGROUND

Tests at the NTS have led to empirical methods for predicting neutron-induced dose rates from air bursts in the kiloton range over Nevada soil (References 1 and 2). These methods attempt to predict 1-hour dose rates over any area within the test site. However, since no attempts have been made to correlate dose rates and decay rates with the chemical composition of a variety of soils, the methods are valueless for any but Nevada-type soil. Furthermore, since in Nevada soil the amount of sodium, the most important contributor to induced activity, varies from area to area within the test site by as much as a factor of four, the accuracy of such methods is severely limited even for NTS.

A method for the prediction of induced activity which does account for chemical differences in soils has been developed by Canu and Dolan (Reference 3). Before predictions are made for a given soil, the amounts of over twenty elements in the soil must be determined. The gold-neutron flux expected is also used to help establish intensities at times of interest. However, this method has the following important shortcomings:

1. No allowance is made for the moderation of high-energy neutrons into the low-

energy region. For most weapons and soils, this is the most important source of thermal neutrons which cause most of the induced activity. Properties of soil elements pertaining to this most important effect are ignored. Elements are weighted strictly on the basis of the relative number of thermal neutrons they absorb.

2. No allowance is made for the distribution of activity with depth in soil nor for properties of the soil constituents which influence this distribution.

3. The neutron spectrum is assumed to be invariant with slant range and weapon type.

In other respects, too, this method was developed from unrealistic assumptions. From a practical standpoint, however, the shortcomings above are the most important.

1.4 PREDICTION METHOD

A prediction method (Reference 4) has been developed which requires the following:

1. Soil Data. Soil density (gm/cm^3) and percentage by weight of Na, Mn, Al.

2. Neutron Data. Gold neutrons versus slant range and total number of 14-Mev neutrons per kt produced external to the case.

1.4.1 Basic Theory. Briefly, the theory for this method is developed as follows:

N_0 = time-integrated neutron density from an isotropic source in air through a thin layer of soil at the surface

N = time-integrated neutron density through a thin layer at depth X below the surface

Then,

$$N = f(X)N_0 \tag{1.1}$$

where f(X) depends on the soil and the incident neutron spectrum.

The number of neutrons absorbed by a particular isotope in a layer of unit area dx thick at depth X is

$$dm_i = N_0 \rho_i k_i(X) f(X) dx \tag{1.2}$$

where ρ_i is the number of atoms per unit volume of an isotope (considered constant with depth), and $k_i(X)$ depends on the capture cross section for this isotope and the neutron spectrum at X.

The contribution made by the radioactive daughter of this isotope to the residual gamma-radiation field above the surface is

$$dI_i = g_i(X)\, dm_i e^{-\lambda_i t} \tag{1.3}$$

The gamma-ray attenuation function, $g_i(X)$, depends primarily on the density of the soil and the energy of gamma radiations from the radioactive daughter. When there is no gamma-emitting daughter, $g_i(X) = 0$.

Radiation of the soil by neutrons is considered to be instantaneous at $t = 0$. No daughter-daughter gamma-emitting products are considered since the neutron-induced radioisotopes of interest give rise to stable daughters.

From Equations 1.2 and 1.3

$$I_i = N_0 \rho_i e^{-\lambda_i t} \int g_i(X) f_i(X) k_i(X) dx \tag{1.4}$$

For a particular soil and incident neutron spectrum, the integral is a constant, and

$$I_i = N_0 K_i \rho_i e^{-\lambda_i t} \tag{1.5}$$

where K_i is a constant. When a number of gamma-emitting radioisotopes are formed, the dose rate above the surface is given by

$$I = N_0 \left[\rho_1 K_1 e^{-\lambda_1 t} + \rho_2 K_2 e^{-\lambda_2 t} + \ldots + \rho_n K_n e^{-\lambda_n t}\right] \tag{1.6}$$

This equation describes the dose rate at any time only for a given soil and incident neutron spectrum. Different K values may be expected for each different soil and spectrum combination.

1.4.2 Neutron Spectra. Although neutron spectra vary both with slant range and weapon type, spectra from all weapons nevertheless seem to approach the same equilibrium spectrum as slant range increases, so that for slant ranges greater than 900 yards there is invariance with slant range and weapon type.

Before this equilibrium spectrum is established, the spectrum is always softer (relatively more gold neutrons). In general, both the degree of softness and the slant range necessary to establish the equilibrium condition are greater for weapons having the largest amounts of high explosive. In this method, corrections are made for changes in spectrum when they occur.

1.4.3 Soil Differences. To establish those characteristics of soils which must be considered to give a reasonable degree of prediction accuracy, extremes in the amounts of important soil elements were considered. The influence of each element on the overall moderating or slowing-down power of soil was assessed, as was the importance of each element for absorption of thermal neutrons. Gold neutron measurements versus depth in Nevada soil served to evaluate the importance of build-up caused by moderation, so that relative dose rates could be calculated for extreme cases.

The moderating power of a soil is determined by its amount of hydrogen, the main source of hydrogen being the moisture content of soil. However, a compensating effect causes dose rates measured above the surface of soil to be fairly insensitive to the actual amount of hydrogen (over the expected range of hydrogen abundance or moisture content). When the hydrogen content is high, build-up of low-energy neutrons occurs closer to the surface, but the diffusion length (L) of thermal neutrons thus formed is correspondingly shorter, a factor which causes faster decay with depth. For a low hydrogen content, build-up near the surface is less; but the decay of thermal neutrons with depth is also less (larger L). However, activity produced near the surface must be considered more important than like amounts at greater depths, since emitted gamma rays must penetrate the soil overburden. Thus, without calculation, it is not obvious to what extent such a compensating effect operates.

Figure 1.1, reproduced from Reference 4, shows the extremes expected in relative dose rates for soils with differing amounts of hydrogen. These extremes were calculated by choosing quantities for other elements found in soil which would maximize or minimize the value of L but would not exceed the expected range of abundance of any element. The relative standing of NTS soil is also shown in the figure. For the equilibrium spectrum, the figure shows that dose rates for soils containing equal amounts of those elements which lead to gamma emitters on (n, γ) reaction could be, at most, 30 percent higher or 56 percent lower than those at NTS.

Since neutron spectra from weapons can be softer than the equilibrium spectrum, a

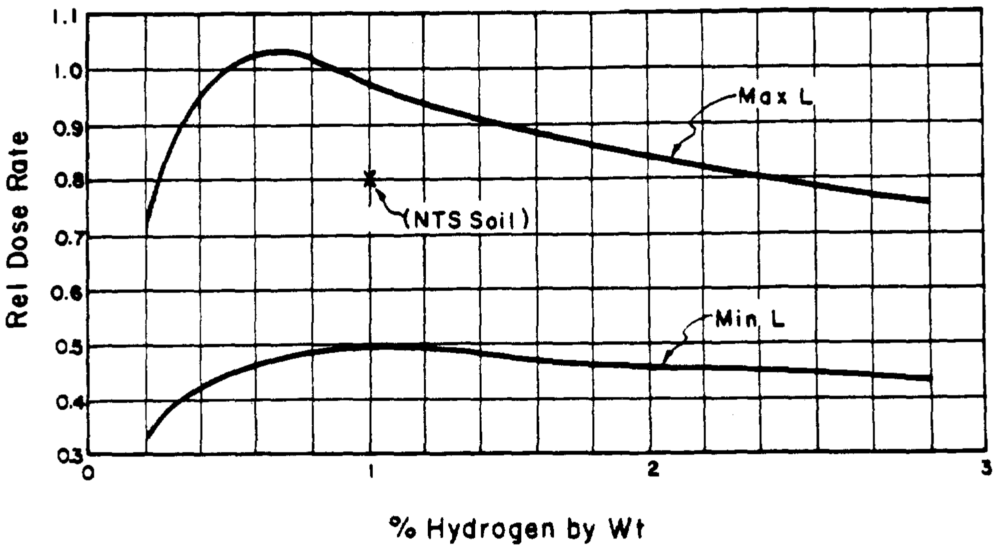

Figure 1.1 Dose rate versus hydrogen content.

similar evaluation of extremes for a 100-percent thermal neutron source was made. It was shown that dose rates for a straight thermal neutron source would be, at most, 20 percent higher or 35 percent lower than for NTS soil.

From the evaluation of these extreme situations, it was concluded that neutron-induced dose rates can be predicted with reasonable accuracy with only a knowledge of those elements which produce gamma-emitting radioisotopes. That is, for a given spectrum, one set of K's may be used in Equation 1.6 for all soils.

1.5 SUMMARY OF PREDICTION METHOD

Only three terms will be needed in Equation 1.6, one each for sodium, manganese, and aluminum. Assuming that capture cross sections for these three elements have similar behavior with neutron energy, for the equilibrium spectrum Equation 1.6 may be written:

$$I = \rho n_0 K \left[(\%\ Na) e^{-\lambda_1 t} + 24.7\ (\%\ Mn) e^{-\lambda_2 t} + 60.3\ (\%\ Al) e^{-\lambda_3 t} \right] \quad (1.7)$$

Where: ρ = density of soil (gm/cm^3)

n_0 = gold neutron measurement or estimate ($n_0 \sim N_0$ for a given spectrum)

K = $3.93 \pm 0.15 \times 10^{-13}$ (evaluated from NTS results)

$(\%)$ = percentage by weight of element

λ_1 = 0.046/hr

λ_2 = 0.266/hr

λ_3 = 18/hr

The numbers 24.7 and 60.3 in the equation give added weight to the manganese and alu-

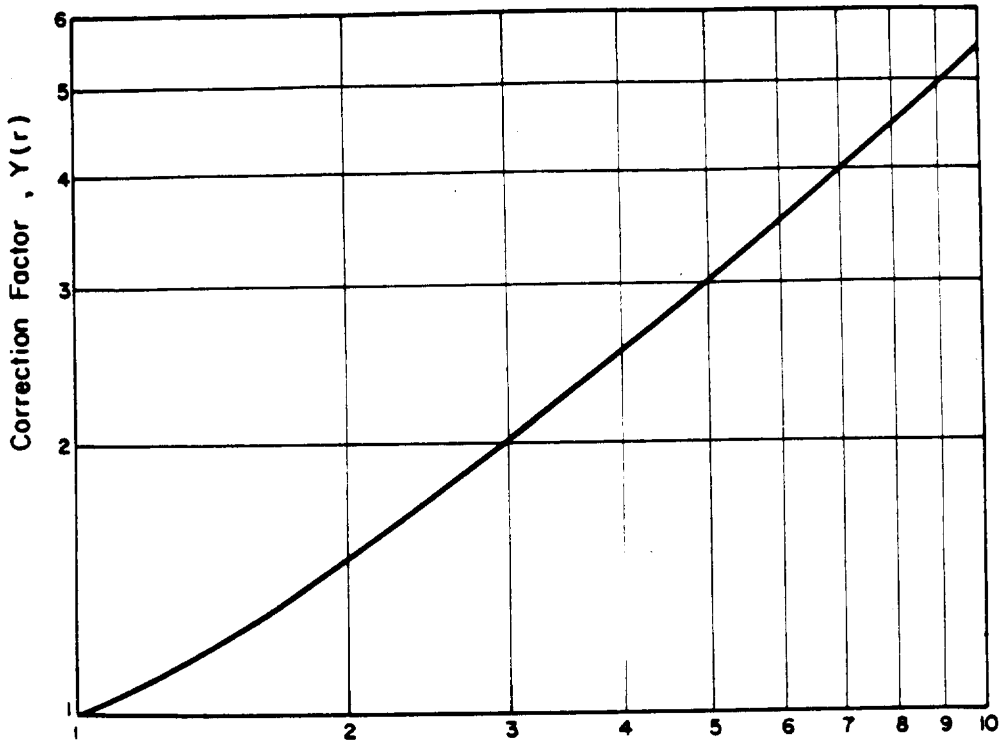

Figure 1.2 Corrections for variations in neutron spectrum.

minum relative to sodium on the basis of capture cross section, half-lives, atomic weights, and gamma energies per disintegration.

Then, for some other slant range, r,

$$I_r = Y(r) I_{r_1} \frac{r_1}{r} e^{(r_1 - r)/200} \tag{1.8}$$

where $Y(r) \geq 1$. The factor Y(r) accounts for the effect of a spectrum which is softer than the equilibrium spectrum. Y(r) is a function of X(r) where

$$X(r) = \frac{(r\,n_0)\,r}{(r_1\,n_0)\,r_1}\, e^{(r - r_1)/200} \tag{1.9}$$

The factor X(r) is the ratio of the surface thermal-neutron density actually measured or predicted for slant range, r, to that which would exist at r if the equilibrium spectrum obtained between r and r_1. Because of the importance of build-up of thermal neutrons below the surface,

$$X(r) \geq Y(r)$$

Figure 1.2 is a plot of Y(r) versus X(r) calculated by assuming that the relative importance of build-up is inversely proportional to X(r). That is,

$$X(r)\, q(x)_r = q(x)_{r_1}$$

where $q(x)_{r_1}$ is the build-up for equilibrium spectrum. The correction factor shown is for a low H content and is therefore conservative. That is, errors will occur from overestimating, not underestimating, dose rates. For modern weapons with small amounts of high explosive, X(r) will probably never exceed three.

Chapter 2
PROCEDURE

Shot Cherokee, a [redacted] air burst to be detonated 5,000 feet over Site Charlie, was chosen to investigate induced activity from large-yield, thermonuclear weapons. The ten types of soil used on Shot 5 of Operation Teapot (Reference 4) were exposed to the neutron flux from Shot Cherokee near each of three neutron-detector stations of Project 2.51, located at 80, 1,250, and 2,500 feet from the intended ground zero. Also exposed at each station were a sample of coral sand taken from the island and one sample each of sodium and manganese in the form of salt (NaCl) and manganese dioxide (MnO_2). The latter were included so that a long delay in sample recovery would not result in a loss of all data.

All samples were exposed in watertight steel containers attached by $^5/_{16}$-inch aircraft cable to large eyebolts set in concrete. The soil sample container was covered with coral soil so that the neutron spectrum incident on the soil samples would be typical of that 1 to 4 inches below the surface. This was thought to be the depth range for maximum thermal neutron density.

Recovery was made at H + 6 hours by helicopter, and all samples were taken to Site Elmer where the soil samples were measured with a gamma-ray spectrometer. Dose-rate measurements were made at each of the three stations by the recovery crew.

When the results expected from Shot Cherokee were not obtained, Shot Yuma, a [redacted] burst on a 200-foot tower at Site Sally, was chosen to investigate the effect of neutron-induced gamma-radiation fields on a soil different from Nevada soil. Samples of NaCl, MnO_2, and coral soil from the island were exposed at 100 yards ground range near Station 253.08 of Project 2.51. Six samples were exposed, each of the three materials in a steel container about 3 inches above the ground and each in a thin aluminum container about 1 inch below the soil surface. The activity of the recovered samples was measured in a gamma spectrometer, and the resulting spectra were determined as functions of time for all samples. The dose rate near Station 253.08 was measured by a Rad-Safe helicopter hovering at 25 feet at H + 1.1 hours and by ground crews at H + 3.4 and H + 10.9 hours.

The gamma spectrometer used was the 20-channel differential pulse-height analyzer manufactured by the Atomic Instrument Company, equipped with their Model 810 scintillator head, which contained a 2-inch diameter NaI well crystal. The primary calibration was made with chemically pure NaCl and MnO_2 activated in the Los Alamos Laboratory's water-boiler reactor. Properties of the sample holder were minimized by substitution; the same kind were used to obtain the final data and for the calibration runs. Calibrations were made with the pure materials and with a mixture of pure materials and coral soil. Calibrations involved about 2,000 counts per channel; final data runs, about 1,000. It should be noted that the spectrometer required too much maintenance to be entirely satisfactory.

Chapter 3
RESULTS

Because of a bombing error, the estimated slant range from Shot Cherokee burst point to the nearest station on Site Charlie was 3.5 miles. There was no detectable activity in any of the samples when measured at H + 7 hours. Gamma dose rates at Site Charlie were background only.

Chemical analysis of two Site Charlie soil samples indicated their sodium content to be 0.11 and 0.16 percent by weight, while one sample from Site Sally indicated 0.15-percent sodium by weight. In Table 3.1, these values are compared to several values determined for NTS soils.

The two samples of coral soil exposed to Shot Yuma showed only Na^{24} activity when first measured at H + 5 hours. In Table 3.2, a summary of data on activity induced in the six samples is given. Activities are given in dis/min-gm of sample, extrapolated to zero time. The kinds of activity present were identified by the energies and half lives of gamma radiation emitted. The probable error in these activation data is ± 5 percent. Figures 3.1 through 3.3 show sample records for coral soil, NaCl and MnO_2.

Dose rates measured after Shot Yuma near Station 253.08 are shown in Table 3.3. Gold neutron measurements made on Shot Yuma are summarized in Figure 3.4 (Reference 5).

TABLE 3.1 SODIUM AND MANGANESE CONTENTS OF VARIOUS TEST SITE SOILS

Location	Sodium	Manganese
	pct by weight	pct by weight
Center, Site Charlie	0.16	—
Shore, Site Charlie	0.11	—
Station 253.09, Site Sally	0.15	—
Area 1, NTS	1.25	0.158
Area 2, NTS	0.43	0.027
Area 3, NTS	1.60	0.024
Area 4, NTS	0.95	0.032
Area 7, NTS	1.84	0.045
Area 7, NTS	1.81	0.047
Area 7, NTS	1.33	0.030
Area F, NTS	0.62	0.023

TABLE 3.2 SAMPLE ACTIVATION DATA, SHOT YUMA

Sample	Kind of Activity	Above Surface	Below Surface	Ratio Below/Above
		dis/min-gm	dis/min-gm	
Coral	Na^{24}	5.09×10^5	9.81×10^5	1.93
NaCl	Na^{24}	5.73×10^7	1.34×10^8	2.34
MnO_2	Mn^{56}	5.32×10^9	1.18×10^{10}	2.22

TABLE 3.3 DOSE RATES NEAR STATION 253.08, SHOT YUMA

Time	Dose Rate 3 ft Above Surface	Method
	r/hr	
H + 1.1 hr	6	Inferred from 25-ft helicopter measurement
H + 3.4 hr	2.2	Ground monitor reading
H + 10.9 hr	1.2	Ground monitor reading using AN/PDR-T1B

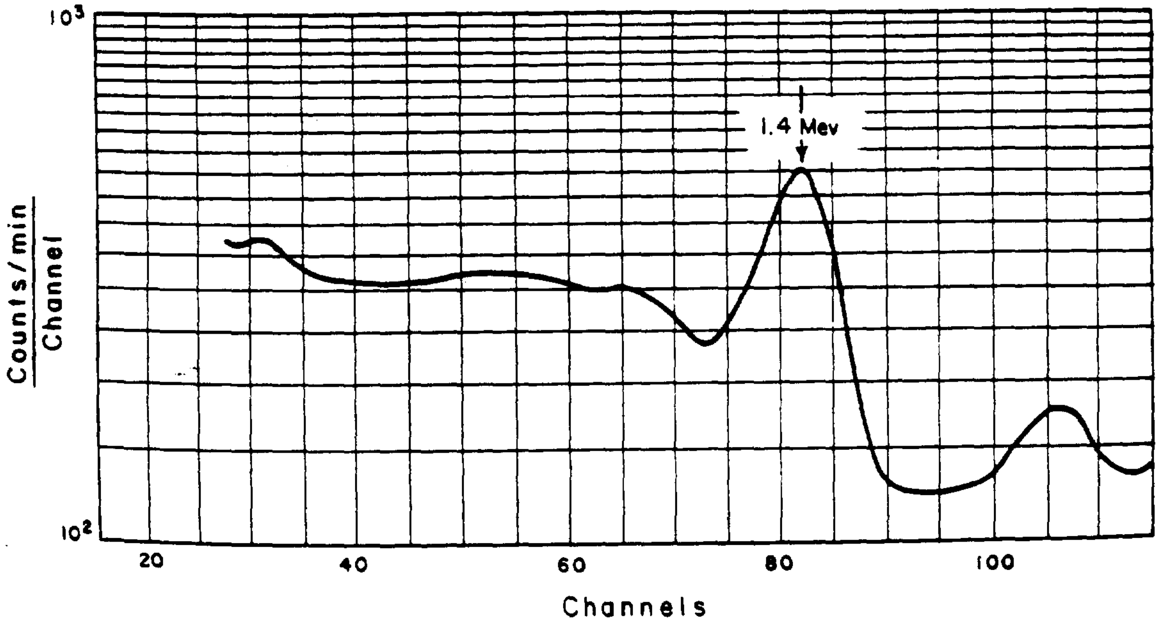

Figure 3.1 Sample of coral soil data.

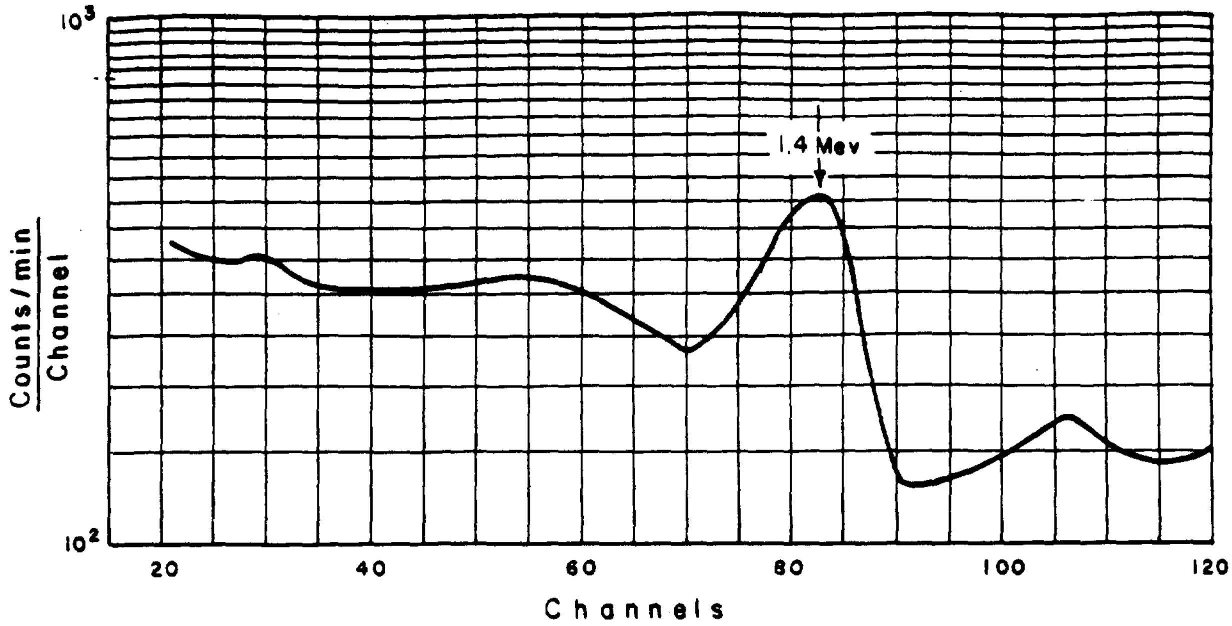

Figure 3.2 Sample of NaCl data.

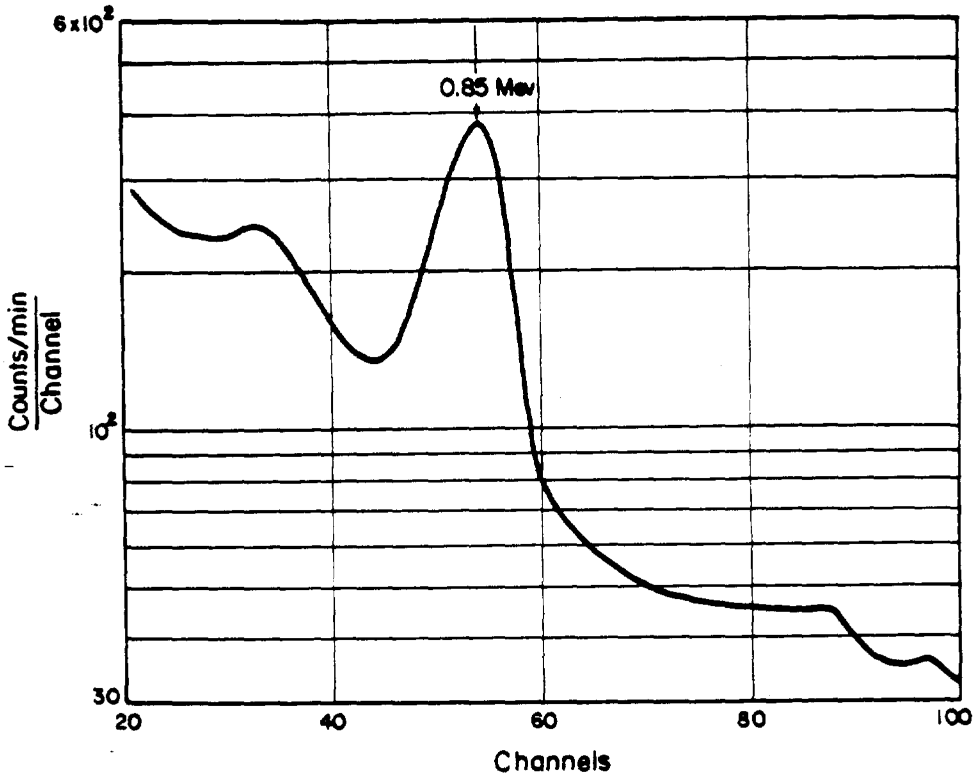

Figure 3.3 Sample of MnO_2 data.

page 19 deleted

Chapter 4
DISCUSSION and CONCLUSIONS

4.1 DISCUSSION

By comparing Na^{24} activities in the coral and NaCl samples (Table 3.2), the percent by weight of Na in coral was determined to be 0.31 ± 0.03. This is twice the amount determined by chemical analysis (Table 3.1). The Na^{24} activity must be assumed to be due to $Na^{23}(n, \gamma)Na^{24}$, since neither coral nor NaCl contains enough Al or Mg to produce competitive amounts of Na^{24} by (n, α) or (n, p).

For such small amounts of sodium, it is believed that the comparative activation method is the more accurate. This could imply a consistent chemical error, because two other samples of coral from Site Charlie (Namu Island, Bikini) show 0.16 percent and 0.11 percent by chemical analysis. It is also possible that the sodium content in coral may vary by as much as a factor of two within a small area.

From Equations 1.7, 1.8, and 1.9 and the neutron measurements of Project 2.51, dose rates were calculated at 1.1, 3.4, and 10.9 hours after zero time. Results are shown in Table 4.1.

The greatest slant range at which a gold neutron measurement was made for Shot Yuma was 604 yards. In order to make a dose rate calculation by the method of Reference 4, it must be assumed that the equilibrium spectrum was established at 604 yards slant range.

When the amount of sodium used for coral is that determined by the comparative activation method, calculated values range from 1.33 to 1.25 times the values inferred from field measurements. When the chemically determined value for sodium is used, inferred dose rates are 1.50 to 1.6 times the calculated dose rates. This suggests that the correct average sodium content for coral lies somewhere between 0.15 and 0.31 percent. However, errors implicit in the prediction method and in field measurements of dose rates do not allow confidence in this deduction.

Measured dose rates are probably subject to ±25-percent error, and the estimated probable error in prediction method is ±30 percent. Assuming that these are the major sources of error, agreement between calculated and measured dose rates is subject to probable error of ±40 percent.

Page 21 deleted

The build-up of thermal neutrons with depth in soil is indicated by the relatively high activity of buried samples; however, activity differences between buried and unburied samples are greater than expected. The samples which were exposed above the surface may have been shielded somewhat by the sandbags which were used by Project 2.51 to hold their detectors off the ground. Although the samples were between the sandbags and the device, shielding could still be significant because low-energy neutron flux is nearly isotropic.

4.2 CONCLUSIONS

The difference between the effects of pure fission and fission-fusion neutron spectra on induced activity in soil was not measured, since the soil samples on Shot Cherokee were not activated. However, a method for predicting neutron-induced gamma-radiation intensities (Reference 4) was tested for coral soil on Shot Yuma. Predicted values were within ± 50 percent of induced dose rates inferred from field measurements.

REFERENCES

1. "Capabilities of Atomic Weapons" (U); TM 23-200, Revised Edition, November 1957; Armed Forces Special Weapons Project, Washington, D.C.; Confidential.

2. T.B. Cook and M. Cowan; "Residual Contamination from Nuclear Bursts"; SC-3466 (TR), February 1955; Sandia Corporation, Albuquerque, New Mexico; Secret.

3. J.F. Canu and P.J. Dolan; "Prediction of Neutron-Induced Activity in Soils"; AFSWP 518, June 1957; Armed Forces Special Weapons Project, Washington, D.C.; Secret Restricted Data.

4. M. Cowan; "Neutron-Induced Gamma Radiation from Nuclear Air Bursts"; SC-3800 (TR), November 1957; Sandia Corporation, Albuquerque, New Mexico; Secret Restricted Data.

5. C.W. Luke, Capt, USA, and others; "Neutron-Flux Measurements"; Project 2.51, Operation Redwing, ITR-1313, December 1956; Chemical Warfare Laboratories, Army Chemical Center, Maryland; Secret Restricted Data.

pages 25-27 deleted