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OPERATION HARDTACK

Project 2.12c

Soil Activation By Neutrons From A Very-Low-Yield Burst

April-October 1958

Headquarters Field Command
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July 11, 1960

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The objectives of Project 2.12c were to (1) document the neutron-induced gamma field produced by a fractional-kiloton nuclear device detonated on a wooden tower 50 feet high, and (2) determine empirical factors relating the gamma dose rates measured over this large neutron-induced field with dose-rate measurements made over small samples of the same activated soil.

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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This 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 all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

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FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Hardtack. Overall information about this and the other military-effect projects can be obtained from ITR-1660, 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) discussions 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

The objectives of Project 2.12c were to (1) document the neutron-induced gamma field produced by a fractional-kiloton nuclear device detonated on a wooden tower 50 feet high, and (2) determine empirical factors relating the gamma dose rates measured over this large neutron-induced field with dose-rate measurements made over small samples of the same activated soil. The soil samples were inserted into the ground at the project stations, exposed to a measured neutron flux, then ejected from the ground and pulled from the contaminated area by cables. Dose-rate measurements were made on the soil samples after they had been reinserted into the ground in an uncontaminated area. Ground survey parties and a recording dose-rate meter measured the field dose rates. A 20-channel gamma-ray spectrometer was used to identify the major induced gamma activities in the soil samples. The spectrometer was also used to confirm the presence of fallout. The low-energy (less than 0.1 Mev) neutron flux in the ground area was determined by measuring the activity in copper strips inserted in each soil sample.

Induced activities were produced by Shot Hamilton, but could not be studied as planned because (1) the low yield of the device induced little activity in the soil and (2) an unexpectedly high level of fission-product contamination occurred in the vicinity of the project stations.

The presence of induced activity in the soil samples was determined by gamma spectrometer analysis. The major contributors to the gamma spectra in the soil samples were Al^{28}, Mn^{56}, and Na^{24} at H+16 minutes, Na^{24} and Mn^{56} at H+7 hours, and Na^{24} and Fe^{59} at H+54 hours.

The low-energy (less than 0.1 Mev) neutron flux was found to peak at 5 to 8 cm below the ground surface of normal Frenchman Flat soil and at the ground surface in more-moist Frenchman Flat soil.

Empirical factors relating field dose rates with sample dose rates could not be determined because of the low level of induced activity produced and the fission-product contamination of the project-station exposure area.

The presence of fission products was indicated by the typical fission-product dose-rate decay demonstrated by the residual field and by the presence of low-energy, fission-product-like peaks in the gamma spectra of a ground-surface soil sample recovered from the vicinity of ground zero at H+31 hours.

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SOIL ACTIVATION by NEUTRONS from a VERY-LOW-YIELD BURST

OBJECTIVES

The objectives of this project were to (1) document the neutron-induced gamma field produced by a fractional-kiloton device detonated on a wooden tower 50 feet high, and (2) determine empirical factors relating the gamma-dose rates measured over this large neutron-induced field with dose-rate measurements made over small samples of the same activated soil.

BACKGROUND

Tactical commanders should know the extent and duration of the radiological hazard due to neutron-induced activities in soils near ground zero areas after a fallout-free nuclear detonation. They should be able to estimate field dose rates of induced activity in order to best utilize nuclear weapons in support of combat ground forces.

Several empirical methods have been developed to predict such field dose rates. Cook and Cowan developed an equation for Nevada soil that is based on yield and the thickness of the high explosives surrounding the nuclear components of the device (Reference 1). Cowan later developed an empirical equation based on gold-neutron flux, soil density, and the sodium and manganese percentage concentrations in the soil (Reference 2). Canu and Dolan made a theoretical study of the problem, although they themselves questioned several assumptions (Reference 3). Kaufman and Krey developed a first-approximation theory based on neutron diffusion and age equations in soil (Reference 4).

At Operation Plumbbob, Project 2.1 exposed small soil samples to a nuclear detonation (Reference 5). Dose-rate measurements were made on these small samples and compared to concurrent field dose rates. Although the technique itself was successfully employed, the results were not valid for two reasons:

First, the small soil samples were obtained from Nevada Test Site (NTS) Area 7, whereas the shot participation was held in NTS Area 9. Insufficient notice of the change in location of ground zero did not allow time for processing new samples. The assumption was then made that the soil composition of Area 7 and Area 9 were the same; however, posttest chemical analysis showed significant differences in sodium and manganese concentrations for the two areas. Therefore, the planned comparison of the dose rates from the small samples with dose rates measured in the field could not be made.

Second, two methods had been planned for obtaining early field dose rates. Both methods failed. Automatic, pop-up gamma-dose-rate recorders had been installed at each station, but failed to operate after the shot because of shock damage. Aerial survey by helicopter was to have supplemented the gamma recorders, but a heavy dust cloud prohibited entry for about 2 hours after the shot. By this time, as well as later in the day, the air was not dense enough for the helicopter to hover and take the necessary survey readings.

It had been hoped that the results from this project would complement those from Operation Plumbbob Project 2.1 by relating induced field dose rates at early times with dose rates from small samples of neutron-exposed soil removed for dose-rate measurements to an uncontami-

nated area. Knowledge concerning this relationship is necessary to estimate field dose rates from the dose-rate measurements made at Operation Plumbbob on small samples of various types of soil. Knowing this relationship, an irradiation of any type of soil could be carried out either at a nuclear detonation or in an unshielded reactor with characteristics similar to a fission weapon and corresponding field dose rates estimated from measurements made on the soil samples.

Shot Hamilton was not an ideal neutron source for induced-activity studies because it was a tower shot rather than a balloon shot or air burst. However, no other shots of Operation Hardtack Phase II were particularly well suited for this work. Since there was a strong possibility of a nuclear-test suspension, it was decided to get whatever data possible from Shot Hamilton.

THEORY

When a nuclear device is detonated, some of the emitted neutrons are captured by certain elements in the soil around ground zero. The induced activity thus created generates a residual radiation field. If the fireball does not touch the ground, fission-product fallout is negligible and the field dose rates will be largely due to the activity induced in the soil. Since the neutron flux, and therefore, the induced activity from a nuclear detonation, falls off rapidly with distance, most induced activity is concentrated near ground zero.

The neutron capture cross sections for the principal constituents of soil show that aluminum, manganese, and sodium are the primary elements in soil that become radioactive by neutron capture. The majority of the induced gamma activity has been shown (Reference 6) to come from the capture of thermal neutrons through the following reactions:

$$Al^{27} + n^1 = Al^{28} + \gamma \quad (Al^{28} \text{ half-life} = 2.30 \text{ minutes})$$

$$Mn^{55} + n^1 = Mn^{56} + \gamma \quad (Mn^{56} \text{ half-life} = 2.56 \text{ hours})$$

$$Na^{23} + n^1 = Na^{24} + \gamma \quad (Na^{24} \text{ half-life} = 15.0 \text{ hours})$$

These same nuclides can be formed by other reactions, i.e.:

$$Si^{28} + n^1 = Al^{28} + H^1$$

$$Fe^{56} + n^1 = Mn^{56} + H^1$$

$$Al^{27} + n^1 = Na^{24} + He^4$$

However, the latter reactions will occur only with neutron energies of several million electron volts. The cross sections for these particular reactions are relatively low and the number of high-energy neutrons emitted from a normal fission device is not sufficient to make these reactions important (Reference 6).

At Operation Plumbbob, an attempt was made to estimate neutron-induced field dose rates from data obtained by exposing small samples of soil to a measured neutron flux (Reference 5). Following neutron irradiation and removal from the exposure stations, these samples were inserted into uncontaminated dose-rate-measuring areas. Dose-rate readings were taken at 3 feet above the sample at several horizontal distances. The dose-rate readings were multiplied by the horizontal distance from the sample, and this value was then plotted versus the horizontal distance. A graphical integration of the area enclosed by the resulting curve was performed. The result of this integration, when divided by the cross-sectional area of the sample and multiplied by appropriate geometrical constants, gave a value defined as the fabricated dose rate. This fabricated dose rate is the dose rate at 3 feet above an infinite plane of soil contaminated to the specific characteristics of the sample. This sample measurement method is based on the theory of reciprocity, which states that the location of the source and detector can be interchanged without a change in the measured activity.

The fabricated dose rates thus obtained from small soil samples were corrected to a common time and compared to the corresponding field dose rates for that time. The ratio of the field dose rate to the fabricated dose rate was defined as the proportionality factor, k. These proportionality factors were to be used to convert fabricated dose rates obtained by exposure of various soil samples on nuclear detonations to estimated equivalent field dose rates.

The same method,as the one above,developed for Operation Plumbbob, was intended to be used by this project to determine the proportionality factors for this experiment.

INSTRUMENTATION

The instruments utilized by this project included soil-sample holders, Jordan survey meters, Jordan survey meters with recorders, a gamma-ray spectrometer, and gamma scintillation counters.

Soil-Sample Holders. Samples of soil from each exposure station were packed to a depth of 30 inches in cylindrical polyethylene liners 30 inches long, $1\frac{3}{4}$ inches in diameter, and with

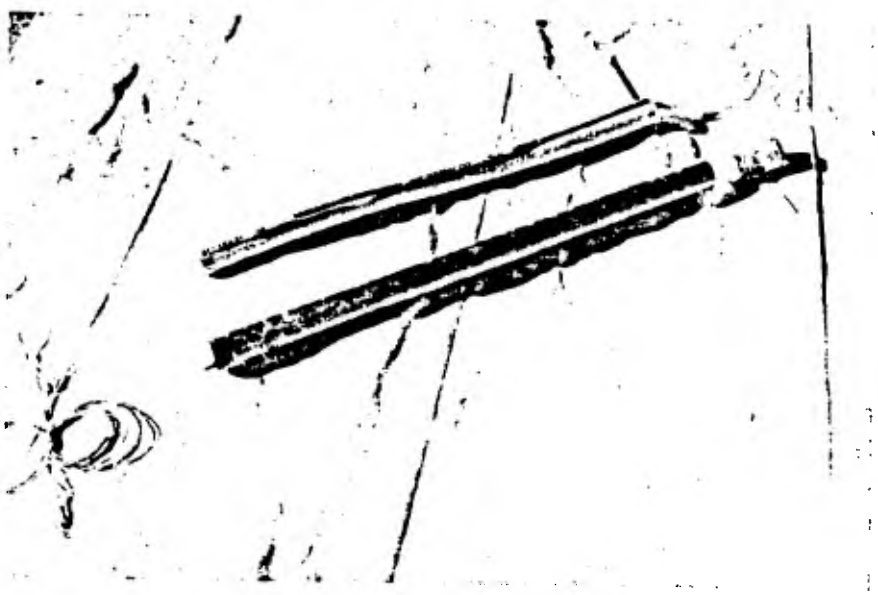

Figure 1 A core showing the steel cylinder, plastic liner, copper strips, aluminum plug, and $\frac{1}{16}$-inch connecting cable.

0.004-inch wall thickness. A plastic disk, $\frac{1}{8}$ inch thick, was placed inside the liner behind the soil; the liner was sealed by crimping copper rings around the liner mouth. The plastic disks were used to keep the soil packed as tightly as possible near the sealed end of the bag. A 3-foot length of cord was tied behind the copper ring to aid in transferring the liner to an uncontaminated cylinder after the shot. These packed polyethylene liners were then inserted (with the crimped mouth at the bottom) into carbon-steel cylinders $32\frac{1}{2}$ inches long, $1\frac{7}{8}$ inches in outside diameter, and with 0.035-inch wall thickness. The end of the carbon-steel cylinders was sealed with spring-loaded aluminum plugs (Figure 1). The plugs exerted 15-pound forces on the soil in the cylinders so that the density of the soil would not change during recovery operations. Copper strips (0.005 inch thick, $\frac{5}{16}$ inch wide, and 31 inches long) were placed between the walls of the steel cylinders and the cylindrical plastic bags to measure the low-energy neutron flux (less than 0.1 Mev). The entire arrangement comprised the "core".

The core was placed in a buried steel sleeve 33 inches long, 2 inches in outside diameter, and with a 0.035-inch wall thickness which was attached to an L-shaped support. This L-shaped support was constructed of heavy steel and contained a control box at the top of the L. The horizontal distance from the sleeve to the vertical arm of the support was 43 cm. Since the diffusion

length of thermal neutrons in soil is about 10 cm, the L support had little effect on the neutron transport in the soil. The entire assembly was buried into the ground such that the top of the steel sleeve was flush with the surface. Soft leather gaskets were attached to the bottom of the core cylinder to provide a tight seal between the core and sleeve.

The control box contained two firing mechanisms for releasing compressed gas from small CO_2 capsules to eject the cores from their sleeves. These firing mechanisms were connected to a main recovery cable by a short $\frac{1}{16}$-inch cable. A second and longer $\frac{1}{16}$-inch cable connected the main cable to the top of the core. When the main recovery cable was pulled, the $\frac{1}{16}$-inch cables were also pulled. In this manner, the CO_2 capsules were fired and the core samples ejected from their sleeves as the short cable became taut. The cylinder was still connected to

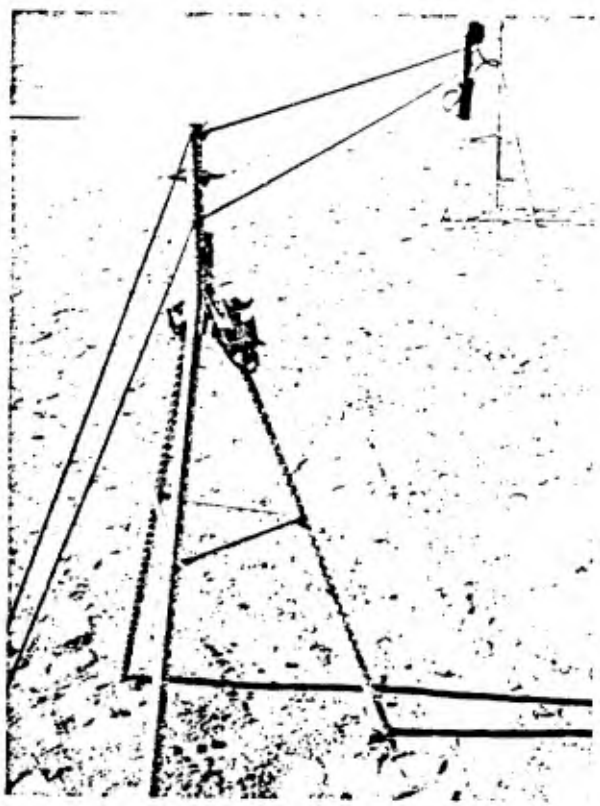

Figure 2 Trolley assembly for measuring dose rates at 3 feet above the ground versus horizontal distance from the core sample inserted into the ground.

the main cable by the longer $\frac{1}{16}$-inch cable that served to pull the sample out of the hot area as the main cable was extracted.

Jordan Survey Meters. After the core samples were recovered and inserted into the uncontaminated soils of the measuring area, dose-rate readings as described in the section on theory were made with a Jordan meter, Model AGB-10-SR. The ionization chamber of this instrument is designed to be energy independent from 80 kev to 1.3 Mev. This energy independence is reported to hold to approximately 8 to 10 percent at 2.8 Mev (Reference 7). To guarantee that the Jordan meters were maintained at the proper height while readings were being taken at various distances from the buried sources, special monitoring rigs were constructed. These rigs consisted of a trolley arrangement that supported the ionization chamber at the designated 3-foot height above the ground and rolled along a double line of very-taut $\frac{1}{4}$-inch steel cable (Figure 2). The steel cable was strung between two steel towers located on either side of the buried sample holder, such that the cable passed directly over the core samples. A locator line was connected

to the trolley with small copper crimps spaced at fixed positions along this line. Personnel standing by the more-distant tower, 16 feet away, could locate the ionization chamber at any one of the fixed positions by lining up the proper copper crimp with a pointer affixed to the tower. Since the Jordan meter has a long extension cord between the ionization chamber and the indicating meter, the positioning of the ionization chamber and the recording of the dose rate were performed by personnel standing approximately 16 feet away, thus minimizing body scattering. The rigs provided for a minimum amount of matter in the vicinity of the ionization chamber and, consequently, a minimum of gamma-ray scattering.

The Jordan meter that was to have been utilized in a planned aerial survey was similar to other Jordan meters used by this project, except that it contained three additional, higher-range scales. The ionization chamber of the Jordan meter was mounted on an aluminum tripod so that the chamber was exactly 3 feet from the ground when the tripod was standing upright (Figure 3). A cable extended from the ionization chamber into a helicopter in order to permit the reading

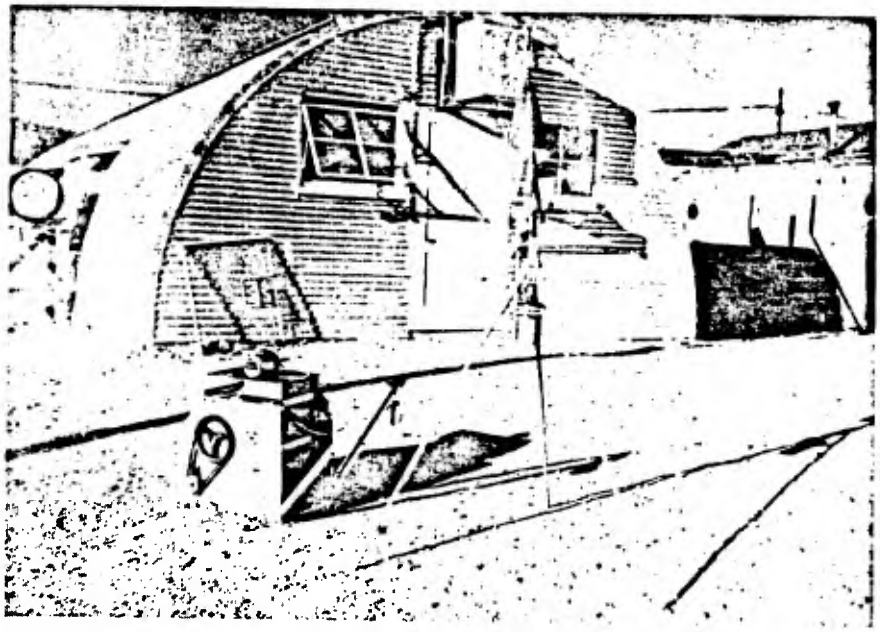

Figure 3. Aerial survey meter components.

and recording of the ground dose rates in the aircraft. A small boom and winch in the helicopter was to be used to raise and lower the tripod to any desired position while the helicopter hovered and the readings were taken. In this manner surveys could be made from altitudes up to 1,000 feet above the ground. A 28-volt, 20-ampere, direct-current power supply from the helicopter was required to operate the winch. A detailed description of the aerial survey instrument is given in Reference 8.

All the survey meters were calibrated with the 200-curie Co^{60} source located at Edgerton, Germeshausen & Grier, Inc. (EG&G) in Las Vegas or with the ½-curie Co^{60} source belonging to the Reynolds Electrical & Engineering Company, Inc. (REECO) Radiological Safety Unit at the Nevada Test Site.

Jordan Survey Meters with Recorders. Two additional Jordan survey meters were connected to recorders. One survey meter was attached to a Brown recorder and mounted on a trailer (Figure 4). This instrument was capable of recording dose rates between 10 and 10,000 r/hr. This trailer was pulled to a location 70 yards from ground zero by means of a cable immediately after shot time.

A second survey meter was attached to a Bristol recorder enclosed in a wooden box (Figure 5). The instrument recorded dose rates between 10 mr/hr and 10 r/hr. The instrument was

transported to the 10-r/hr dose-rate line at H + 8 minutes and recorded dose rates at that location for several hours.

Gamma-Ray Spectrometer. This instrument was used to determine the activity concentration of Na^{24} and Mn^{56} versus depth in the core samples. A 3-by-3-inch cylindrical NaI (T1) crystal

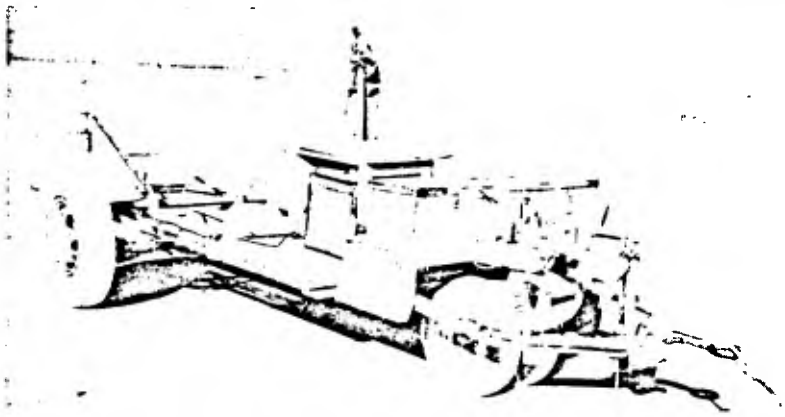

Figure 4 High-range recording dose-rate meter mounted on a trailer. The ionization chamber was suspended from a support on the rear of the trailer. The batteries and inverter were inside the steel box on the front.

was used in conjunction with a 20-channel differential pulse height analyzer manufactured by Detecto Lab. The crystal was enclosed in a 0.050-inch-wall aluminum can to protect it from damage. The photomultiplier tube and crystal were mounted in the center of a lead cubicle 36 inches on an edge and 3 inches in wall thickness. The inside walls of the cubicle were lined

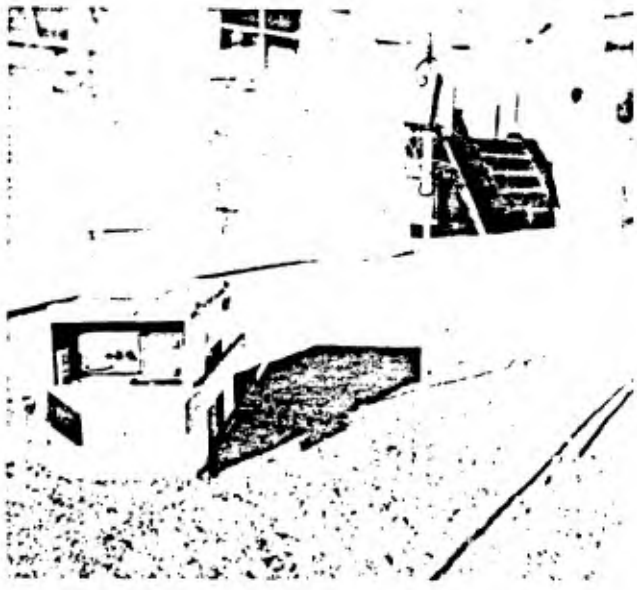

Figure 5 Low-range recording dose-rate meter. The ionization chamber is on the probe, and the batteries, inverter, and recorder are inside the wooden box.

with cadmium and copper sheeting to minimize the X-radiation generated by the interaction of the sample's photons with the lead walls. The spectrometer was housed in an air conditioned, mobile laboratory trailer.

The NaI crystal and photomultiplier tube of the gamma-ray spectrometer were calibrated with standard sources of Mn^{56} and Na^{24} after its return to the home laboratory. Plots of the

self-absorption and self-scattering corrections as a function of sample weight for each nuclide were prepared.

Gamma Scintillation Counters. These instruments were used to count the activity induced in the copper strips mentioned in the section on soil-sample holders, thereby providing a measure of the low-energy (less than 0.1 Mev) neutron flux as a function of soil depth. The sensing unit of these counters consisted of a 1-by-1½-inch NaI (Tl) crystal and a DuMont No. 6655 photomultiplier tube. The power supply was a Radiation Counter Laboratory PS-22 high voltage power supply. The pulses from the photomultiplier tube were transmitted to a preamplifier (cathode follower) and then to an A-1-D linear amplifier pulse discriminator and finally to a 1090 scaler. The preamplifier, linear amplifier, and scaler were manufactured by Atomic Instruments Company, Cambridge, Massachusetts.

After exposure in the field, the copper strips were cut into $\frac{5}{16}$-inch squares. These squares were placed in $\frac{1}{16}$-inch thick aluminum holders for counting. The aluminum holders absorbed all the beta and positron emission of the Cu^{64}. The discriminator was adjusted so that all photons below approximately 25 kev were not recorded. This technique permitted efficient detection of the 510-kev photons resulting from the annihilation of the Cu^{64} positron. During the actual counting of the copper squares, the linear amplifier system was frequently recalibrated with standard sources of Co^{60}, to maintain proper gain and voltage setting. This counting system was assembled and maintained by Project 2.12a. A complete description of the linear amplifier counting set-up is given in Reference 9.

Subsequent to the operation, copper samples were exposed to a thermal-neutron source of known flux at the Los Alamos Scientific Laboratory (LASL). A calibration factor between the count rate and the thermal flux was obtained by counting these samples on the same apparatus that was used at Shot Hamilton.

OPERATIONS

The project participated in Shot Hamilton, which had a yield of 1.17 ± 0.06 tons. Shot Hamilton was detonated from a wooden tower 50 feet high on Frenchman Flat at 0800 hours on 15 October 1958. The project station layout is illustrated in Figure 6 and a typical station illustrated in Figure 7.

Recovery of Samples. Immediately after the detonation, a recovery team left Well 5B on Frenchman Flat and proceeded to a point about 500 yards from ground zero on the neutron cable line. This team recovered the core samples attached to the neutron cable after it had been withdrawn from the hot area. Early recovery was made in an attempt to measure the contributions of short-lived induced radionuclides.

Following recovery, all except three core samples were dispatched to the cold area for fabricated dose-rate measurements. These three samples, from the 25-, 70-, and 150-yard stations, were used for gamma spectral analysis. The cores were sliced into aliquots. The thickness of the aliquot depended upon the amount of activity present. The gamma spectral analysis of these aliquots defined the photon spectrum of the induced activity in the cores, thus permitting an evaluation of the activity concentrations of Na^{24} and Mn^{56} as functions of depth underground and distance from ground zero. The gamma spectra of Al^{28} in one aliquot from the 150-yard core sample was observed. Because of the rapid decay of Al^{28}, observation of this activity in the other core samples was not possible.

Gamma Field Surveys. It was planned to make gamma dose-rate surveys at the Project 2.12c stations by helicopter and ground survey teams beginning at H+10 minutes. However, for operational reasons, helicopter surveys were not made.

Ground survey parties entered the area at H+1 minute and conducted surveys at various times for several days after the shot.

To document the dose rate of the field as a function of time a recording Jordan gamma survey meter mounted on a trailer was towed into the 70-yard station at H+11 minutes by a long cable and left there to measure and record dose rates at 3 feet above ground. Another Jordan meter and recorder were taken by truck to the 10-r/hr line (50 yards from ground zero) near the 330-degree azimuth line at H+8 minutes.

DATA REQUIREMENTS

Data to be Obtained. This project planned to obtain the following data:

1. Dose rates from each of the core samples at 3 feet above the ground as a function of horizontal distance from the core sample. During the measurements, the core samples were

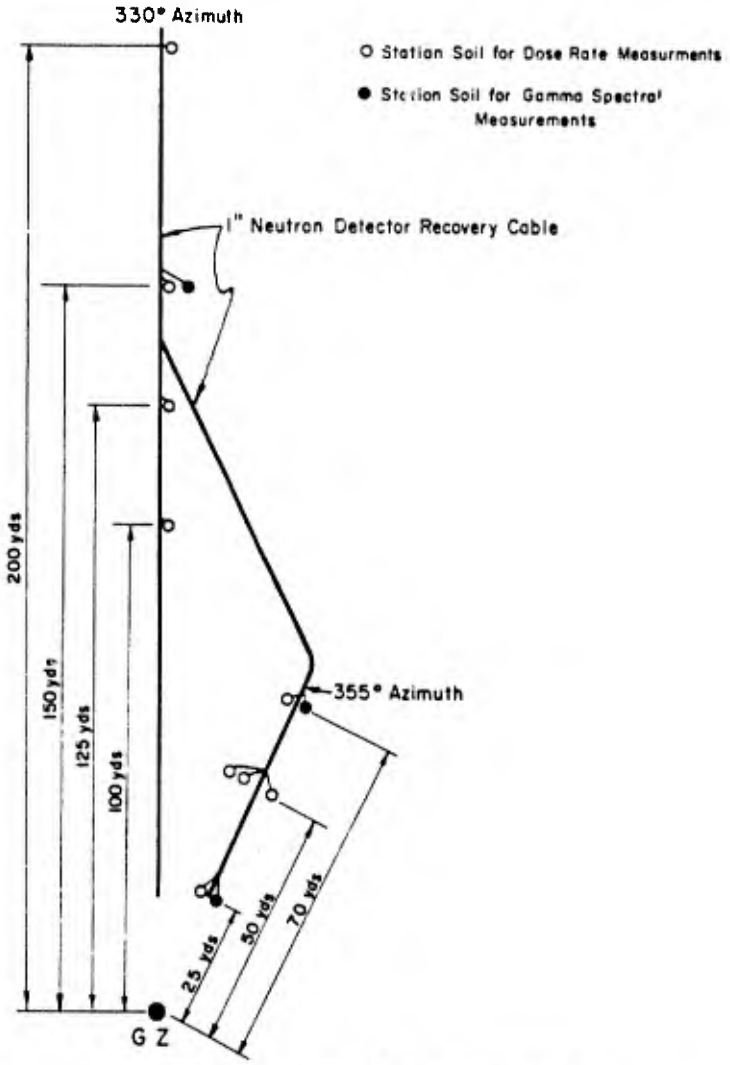

Figure 6 Project 2.12c station layout.

to have been inserted in uncontaminated ground with the top of the core flush with the ground surface.

2. Field dose rates at the project exposure stations as a function of time.
3. Gamma spectral data on three core samples as a function of depth.
4. The percentage of total activity as a function of depth in the ground.
5. Low energy neutron flux (as measured by copper strips) as a function of distance from ground zero and depth in the ground.
6. Moisture content of the soil as a function of depth at the time each station was installed.
7. Moisture content of the soil at the surface on D−1 day.

Data Reliability. The data measured by the gamma spectrometer have an estimated reliability of about ± 10 percent, due to instrument resolution, possible calibration errors, and the graphical method of reducing spectra. The neutron detectors have a reliability of ± 10 percent (Reference 9). Calibrations indicate that the dose rate data are accurate to ± 25 percent.

Planned Data Reduction. The data obtained were to be reduced as follows: The product of the soil sample dose rate at 3 feet above ground and the circumference of a circle of radius, r, divided by the cross-sectional area of the core sample was to have been plotted against the horizontal distance, r, from the center of the core sample at which the reading was made. The area enclosed by the resultant curve was integrated graphically and the fabricated dose rate thereby determined. The fabricated dose rates of core samples at a given time from each of

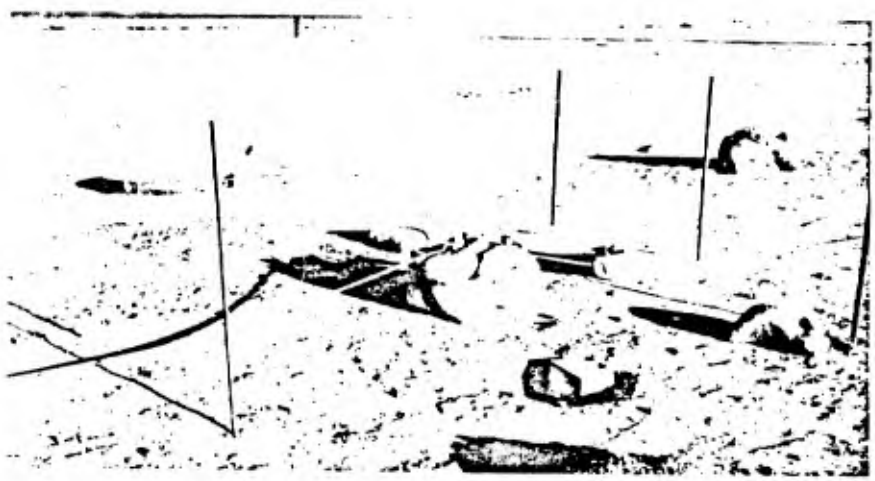

Figure 7 Project 2.12c 70-yard station, partially installed.

the seven stations were to be divided into the concurrent field dose rates measured at each of the corresponding exposure stations to obtain the proportionality factor for each station.

The gamma spectral data was to be reduced to activity concentrations in microcuries per gram of soil at time zero for Na^{24} and Mn^{56} as a function of soil depth.

Requirements from Other Projects. The neutron flux measurements at the ground surface of each of the project stations were supplied by Project 2.12a.

Early backup field gamma dose rates (up to 10 r/hr) at each station were obtained from Project 2.12b. Approximate residual gamma activity and dose-rate decay at the 100- and 200-yard stations from the time of detonation until H + 20 minutes were also to have been obtained from the Emmett recorders of Project 2.12b. Unfortunately, an accident during development of the Emmett film badges caused this data to be destroyed.

RESULTS

Of the twelve stations installed by this project, all but one of the cores (at the 150-yard station) ejected successfully when the main recovery cable was pulled at H + 5 minutes. Six of the eleven ejected cores were pulled out of the contaminated area by the neutron project's recovery cable; these cables were transported back to the uncontaminated dose-rate measurement area prior to H + 20 minutes. The remaining cores were recovered on later trips into the contaminated area, at which time it was found that the $\frac{1}{16}$-inch cable between the neutron cable and the cores had parted following ejection. No explanation for the cable failure was apparent.

Field Radiation Levels. The yield of Shot Hamilton was considerably lower than had been anticipated; as a result, the field dose rates were correspondingly low. The aerial survey was

therefore cancelled because (1) the dose rates at the project stations were under 10 r/hr even at early times, (2) recovery groups from other projects were operating in the contaminated area, and (3) the presence of the aerial survey helicopter in the station area created an air traffic hazard to the cloud-sampling aircraft operating in the area.

Ground survey parties from Project 2.12b entered the area immediately after the shot to obtain dose-rate measurements. The 10 r/hr line was located by this project along twelve axes originating at ground zero and spaced at 30-degree intervals. Readings were taken at H+10, H+15, H+30, and H+60 minutes. The 10 r/hr contours obtained by these surveys are presented in Figure 8. More extensive survey data may be obtained from the report prepared by Project 2.12b for this operation.

These isodose-rate contours indicate that the gamma field produced by the combination of local fallout and induced activity from a 50-foot-high detonation of this type of device is limited

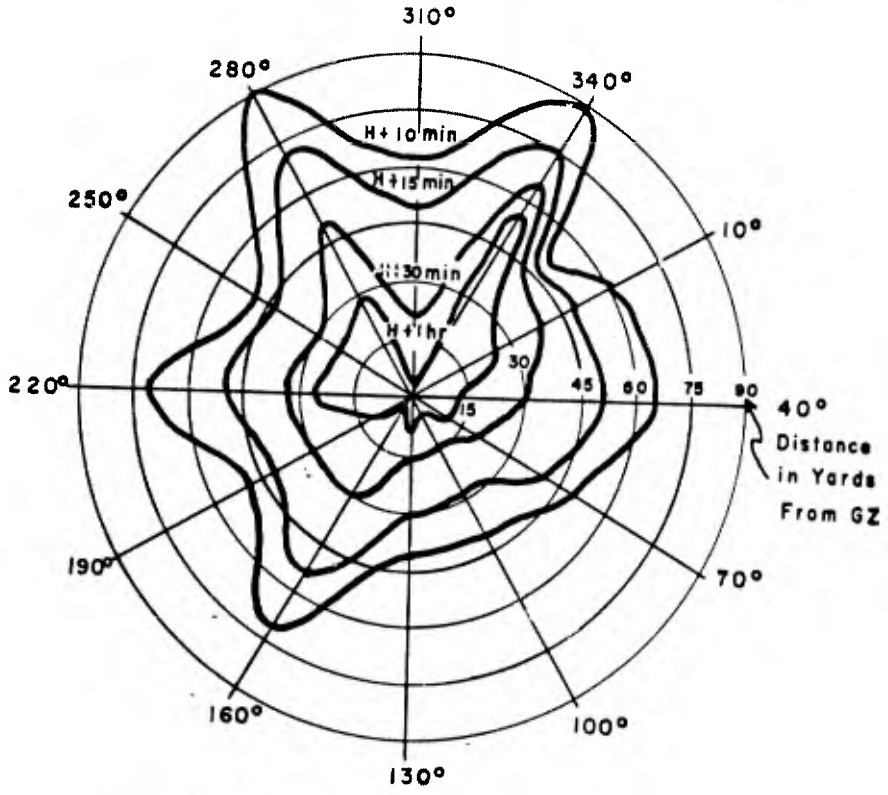

Figure 8 Estimate of 10 r dose rate contour at H+10 minutes, H+15 minutes, H+20 minutes, and H+1 hour.

to a very small area. Project 2.12c stations were surveyed by Project 2.12b personnel with T1B Radiac Meters from H+69 to H+73 minutes and by Project 2.12c personnel from H+2 to H+50 hours with Jordan survey meters. (The T1B and Jordan meters were not cross-calibrated.) These readings are presented in Figures 9 and 10.

The low-range recording Jordan meter was deposited at the 10 r/hr line at H+8 minutes. The probe was 50 yards from ground zero and about 15 feet to the east of the 355-degree azimuth. The recorder gave data only intermittently because of a faulty recorder driving mechanism; however, records were obtained from H+8 minutes to H+74 minutes, H+143 minutes to H+280 minutes, H+420 minutes to H+660 minutes, and for a short interval at H+29.5 hours. The dose-rate decay is plotted in Figure 11, with dashed lines indicating intervals when the recorder was inoperative.

The high-range recording dose-rate meter on the trailer produced no information because no dose rates above 10 r/hr were encountered. The trailer was pulled into position near the 70-

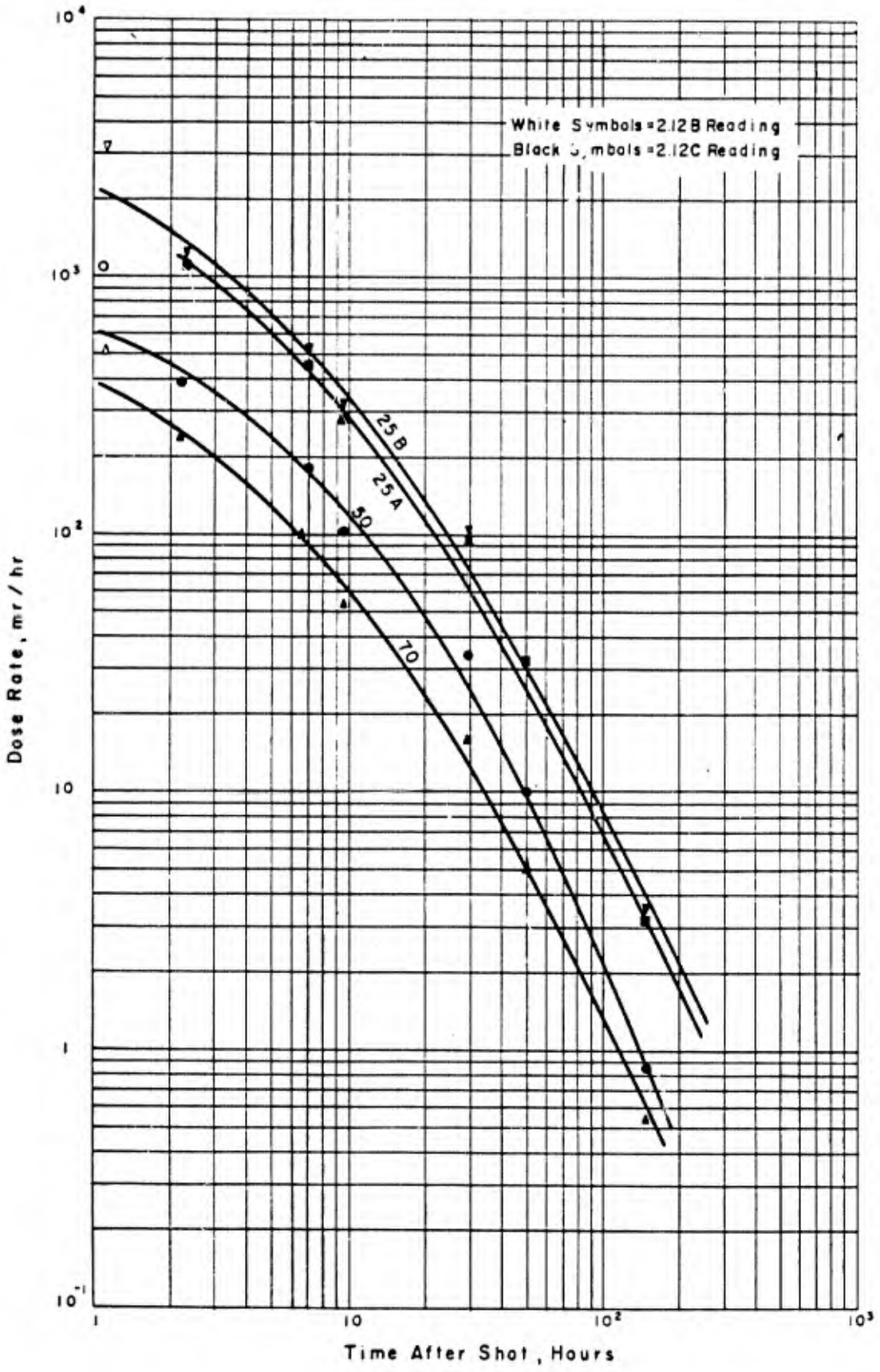

Figure 9 Dose rate as measured by the ground survey teams at the 25-, 50-, and 70-yard stations on the 355-degree azimuth line.

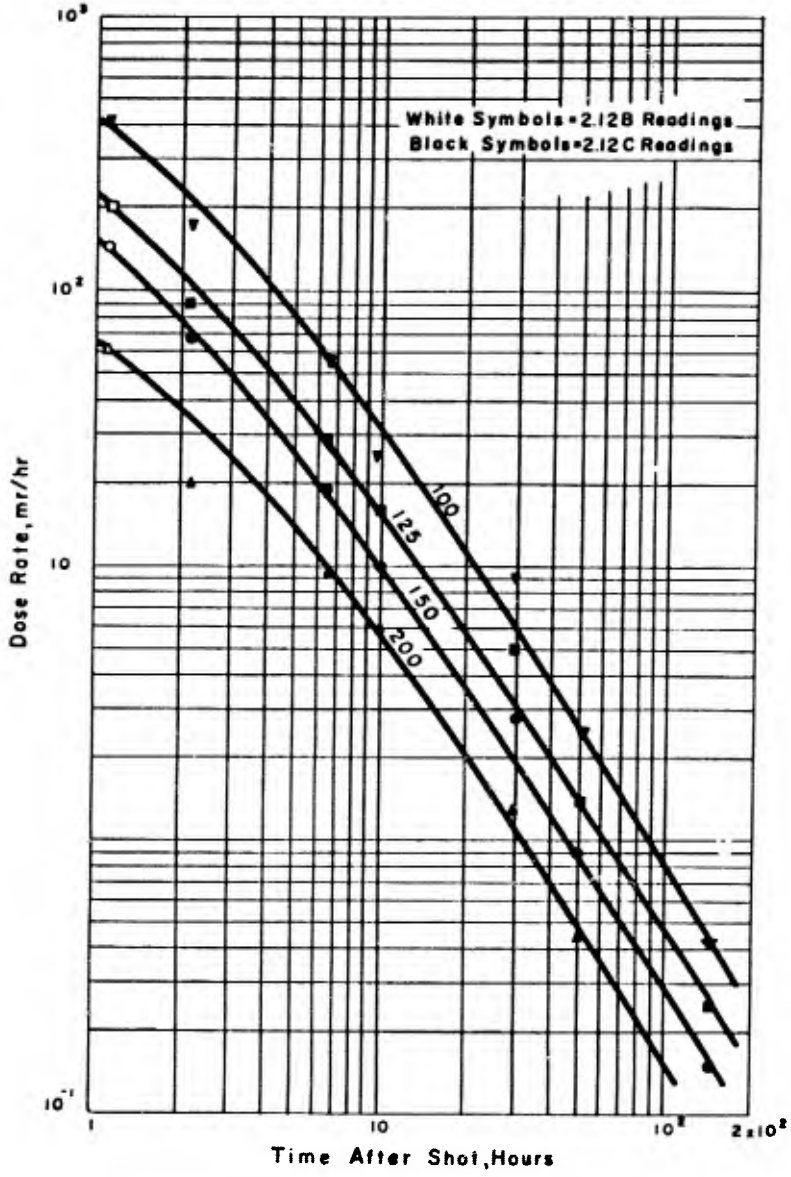

Figure 10 Dose rate as measured by the ground survey teams at the 100-, 125-, 150-, and 200-yard stations on the 330-degree azimuth line.

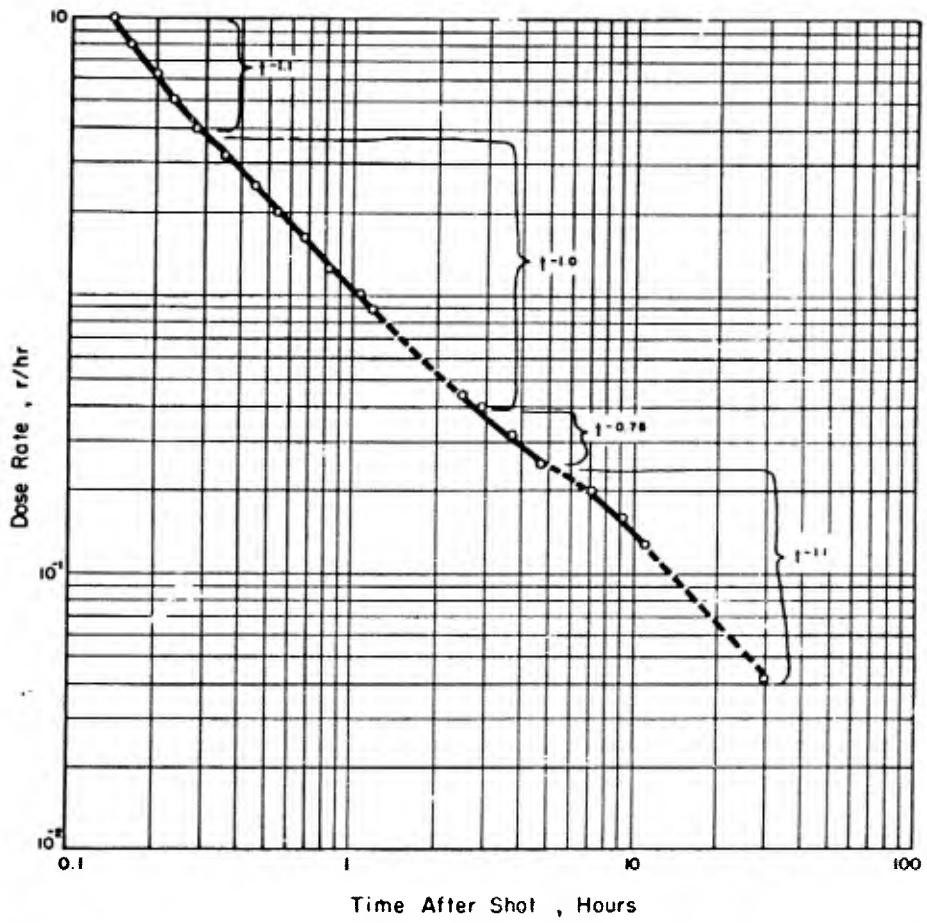

Figure 11 Dose rate decay measured by Jordan meter placed at 10 r/hr line at H+8 minutes. Interpolated decay is shown by dashed line.

yard station at about H+11 minutes, but by then the dose rates were considerably below 10 r/hr and therefore did not activate the recorder.

Soil-Sample Analysis. Only a small amount of induced activity was found in the core samples. As a result, the dose rates produced by the core samples when inserted into the uncontaminated ground holders were all too low (less than 1 mr/hr) for meaningful measurements. Even so, attempts to measure these dose rates were made, but the background radiation level rose to a level as high as 70 mr/hr, making dose-rate measurements impossible. This rise in background was due to the radioactive cloud passing over the area in which measurements were being attempted. By the time the background returned to normal, the core samples had decayed to a point where measurements were no longer possible. The empirical (proportionality) factors were therefore not determined.

In order to assess the constancy of the soil composition of Frenchman Lake, samples of soil for analysis were taken from the project stations prior to Shot Hamilton. Analyses were made of samples from the 50-, 70-, and 150-yard stations for manganese, sodium, and aluminum; as these elements are the most important contributors to the gamma dose rate. Analyses for additional elements (see Table 1) were made on three samples from the 70-yard station. The analyses were done by the Analytical Chemistry Group of the Chemical Warfare Laboratories (CWL), Army Chemical Center, Maryland. Two other samples of Frenchman Lake soil were taken by CWL as a part of a NTS soil analysis program during the spring of 1958. They were analyzed at the Department of Agriculture Soil Survey Station at Beltsville, Maryland. The results from all samples are presented in Table 1.

TABLE 1 FRENCHMAN LAKE SOIL ANALYSES, DRY BASIS

Azimuth from Ground Zero	Distance from Ground Zero	Depth	Percent by Weight											
			Al	C	Ca	Fe	H	K	Mg	Mn	Na	P	S	Si
deg	yds	in												
355	25	0 to 6	5.2*	—	—	—	—	—	—	0.07*	0.79*	—	—	—
		6 to 12	4.9	—	—	—	—	—	—	0.07	0.85	—	—	—
		12 to 18	4.8	—	—	—	—	—	—	0.07	0.85	—	—	—
		18 to 24	5.1	—	—	—	—	—	—	0.05	0.80	—	—	—
		24 to 30	4.3	—	—	—	—	—	—	0.06	0.84	—	—	—
355	70	0 to 6	6.2‡	2.4	10.4*	4.1*	0.9	2.0*	2.1*	0.07‡	0.74‡	0.16*	0.03*	23.4*
		6 to 12	5.2	—	—	—	—	—	—	0.07	0.75	—	—	—
		12 to 18	5.2†	—	12.6*	3.7*	—	1.9*	2.3*	0.07†	1.17†	0.17*	0.07*	21.4*
		18 to 24	4.7	—	—	—	—	—	—	0.08	0.75	—	—	—
		24 to 30	5.2†	—	14.4*	3.4*	—	2.0*	2.1*	0.06†	0.80†	0.16*	0.07*	21.3*
330	150	0 to 6	5.6*	—	—	—	—	—	—	0.07*	0.75*	—	—	—
		6 to 12	4.6	—	—	—	—	—	—	0.08	1.1	—	—	—
		12 to 18	5.0	—	—	—	—	—	—	0.09	0.74	—	—	—
		18 to 24	5.3	—	—	—	—	—	—	0.06	1.1	—	—	—
		24 to 30	6.1	—	—	—	—	—	—	0.08	0.57	—	—	—
227	260	0 to 12	4.5*,§	—	—	—	—	—	—	0.04*,§	0.52*,§	—	—	—
143	1,450	0 to 12	6.1*,§	—	—	—	—	—	—	0.05*,§	0.55*,§	—	—	—

All analyses are on single aliquots of soil sampled in September 1958, except (*) average of two aliquots, (†) average of three aliquots, (‡) average of four aliquots. Those marked (§) are analyses results by the Department of Agriculture from soil sampled in March 1958.

Soil samples for moisture content determinations were taken when the project stations were installed on D−30 and D−29 days. These samples were taken from each 6-inch strata of soil to a depth of 30 inches, and placed in tightly capped polyethylene bottles for later analysis.

In making the moisture content determinations, approximately 1-gram aliquots of each sample were used. These were dried for 1 hour in an oven kept at a constant temperature of 110 C. Upon removal, the samples were cooled for at least 20 minutes in a dessicator before re-weighing.

Because of the watering of areas adjacent to the closer stations, it was believed that the moisture content of the soil may have changed. For this reason, surface samples of soil from each station were taken on the evening before the shot. These samples were treated in the same manner outlined above. The results of the analyses are listed in Tables 2 and 3.

Neutron Flux. The copper, gold, and sulfur neutron flux at the ground surface for each of this project's stations is presented in Table 4. Agreement in the flux values between the two

TABLE 2 SOIL MOISTURE ANALYSIS

Station	Percent of Moisture at Depth of				
	0 to 6 inches	6 to 12 inches	12 to 18 inches	18 to 24 inches	24 to 30 inches
25A	7.9	11.0	9.9	10.0	8.0
25B	9.9	12.0	13.0	12.0	12.0
50	12.0	13.0	14.0	15.0	16.0
70A	4.3	7.9	10.0	8.9	9.4
70B	3.4	6.0	7.2	7.3	7.8
100	9.0	11.0	10.0	10.0	10.0
125	8.5	11.0	10.0	9.8	11.0
150A	7.8	12.0	11.0	10.0	11.0
150B	7.8	13.0	11.0	11.0	13.0
200	8.2	10.0	12.0	9.9	11.0

TABLE 3 SURFACE SOIL MOISTURE ANALYSIS ON D-1 DAY

Station	Percent Moisture
25A	4.6
25B	8.6
50	5.2
70	2.9
100	2.8
125	2.7
150	2.6
200	3.2

70-yard stations and the two 150-yard stations is excellent. The neutron flux at various depths as obtained by copper measurements is presented in Figure 12.

Gamma Spectral Analysis. Figures 13 through 16 show representative gamma-ray spectra of the induced activities in Frenchman Lake soil at four times after Shot Hamilton. Figure 13 shows the Al^{28} portion of the gamma-ray spectrum at H+16 minutes; the Mn^{56} contribution to the Al^{28} photo peak at the same time is indicated by dashed lines.

Table 5 presents the activity of Mn^{56} and Na^{24} as a function of depth for three distances from ground zero. The deepest sections of the cores had insignificant activity levels and are not included in the table. Table 6 gives the average Mn^{56}/Na^{24} activity ratios for each distance. The activity levels in the deepest section of the cores were so low they were considered unreliable, and are not included in these averages. Estimated values for Al^{28} near the surface at the 150-yard station are included in both tables. Table 7 lists the cumulative percentage of total activity with depth for these three samples.

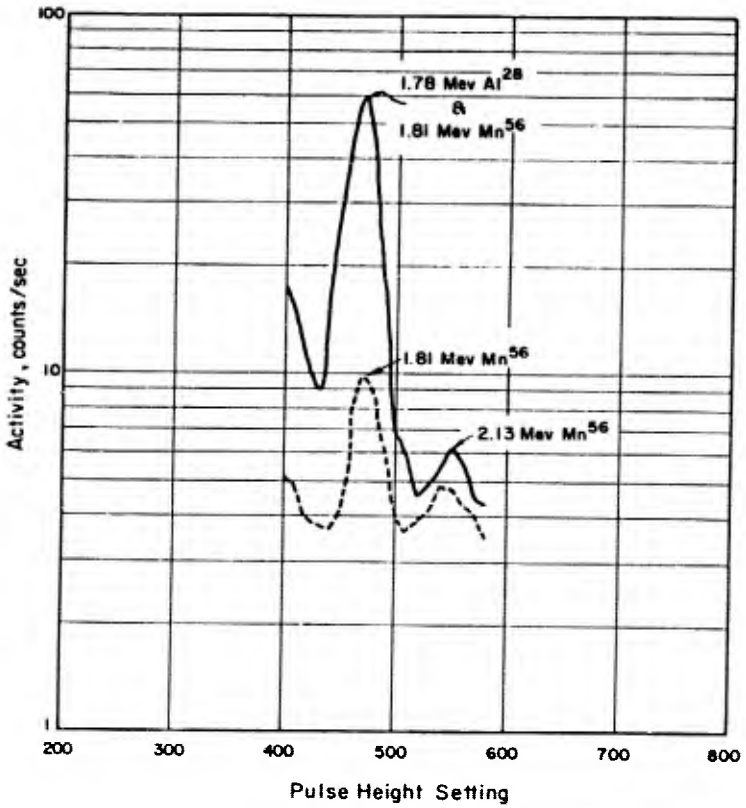

Figure 13 Al^{28} portion of the gamma-ray spectrum from the 150-yard station on the 330-degree azimuth line at H + 16 minutes showing the Mn^{56} contribution to the Al^{28} photo peak.

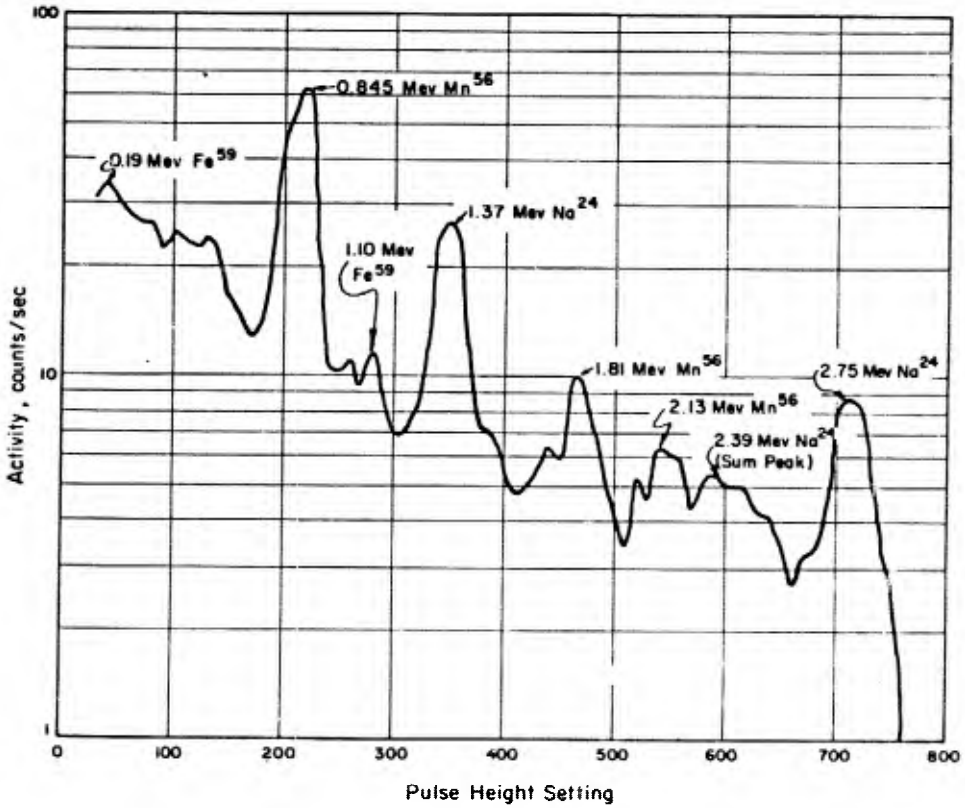

Figure 14 Representative gamma-ray spectrum of the induced activities in Frenchman Lake soil from the 25-yard core sample on the 330-degree azimuth line at H + 7 hours.

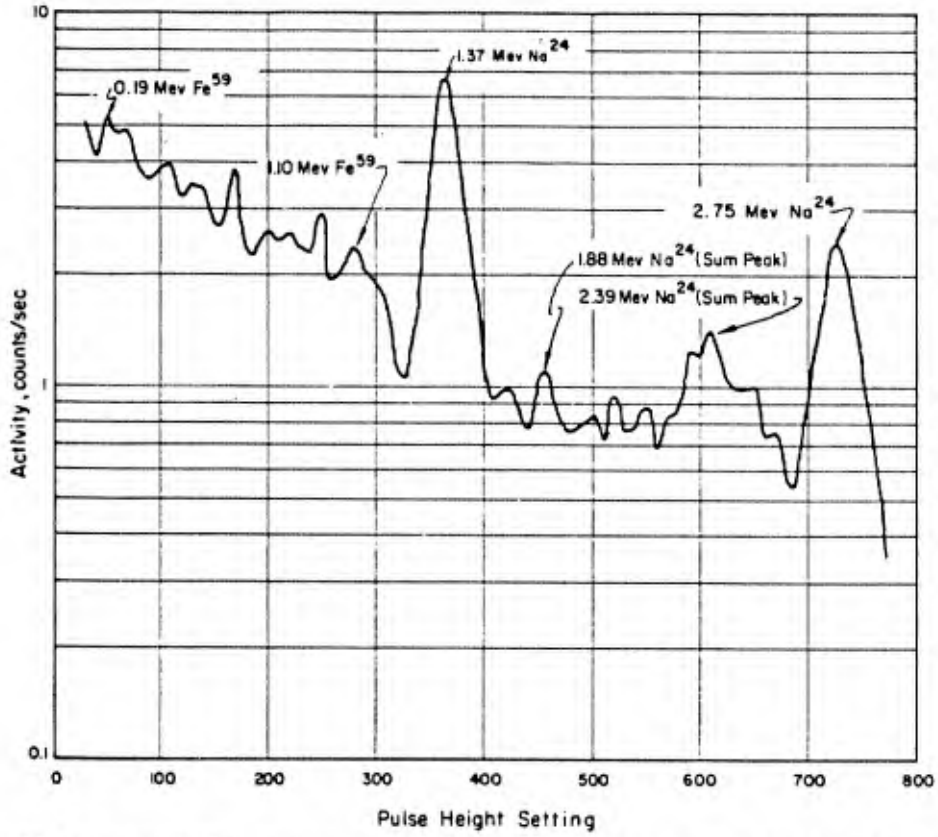

Figure 15 Representative gamma-ray spectrum of the induced activities in Frenchman Lake soil from the 25-yard core sample on the 330-degree azimuth line at H+36.5 hours.

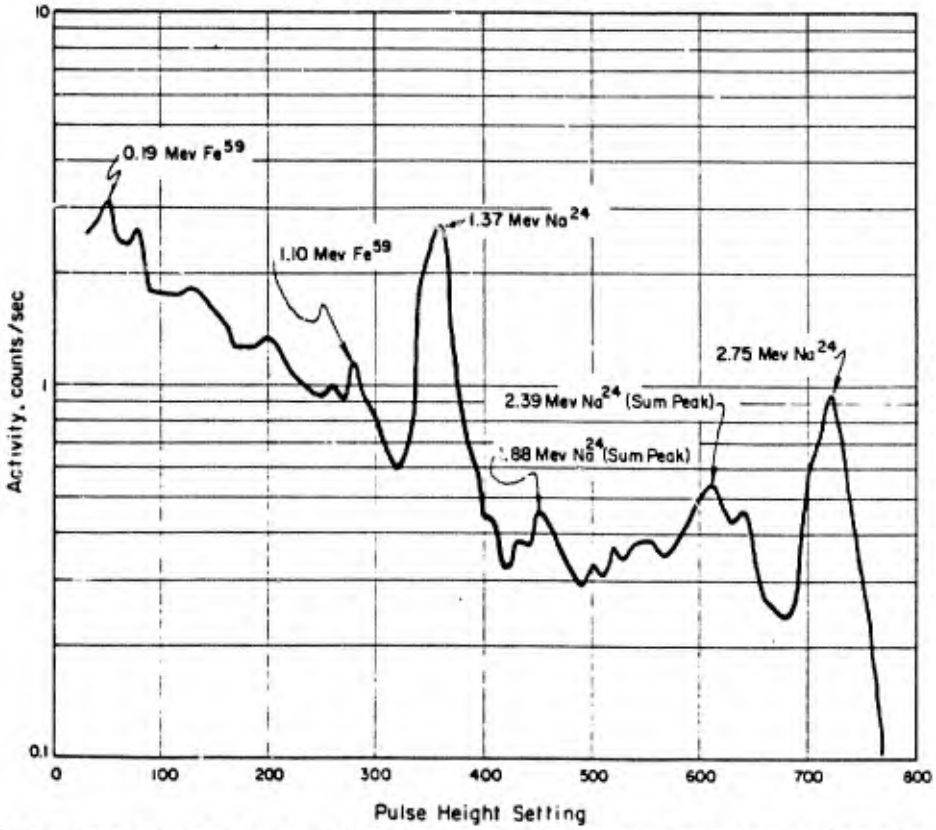

Figure 16 Representative gamma-ray spectrum of the induced activities in Frenchman Lake soil from the 25-yard core sample on the 330-degree azimuth neutron line at H+54 hours.

Figure 14 shows a representative gamma-ray spectrum of the induced activities in Frenchman Flat soil at H+7 hours. The soil was taken from the core sample which was recovered from the 25-yard station. Analysis of the spectrum shows that the major contributors to the total activity are Mn^{56} and Na^{24}. The presence of 54-day Fe^{59} is also seen as a minor contributor.

Figures 15 and 16 show the gamma spectrum of the same sample, but at H+36.5 and H+54 hours, respectively. At H+36.5 hours Na^{24} was the major contributor, and the Fe^{59} contribution became more significant. Other apparent peaks visible at this time are due to Compton effects. At H+54 hours the Fe^{59} contribution to the total activity became even more significant.

Gamma Spectrum of Surface Sample. Figure 17 shows the gamma spectrum of a surface sample taken from a point 50 yards distant from ground zero near the 330-degree azimuth at H+31 hours. This was the point where the low-range recording meter was deposited shortly after the detonation. A standard spectrum for Na^{24} was subtracted from the spectrum in Figure 17 to obtain the spectrum appearing in Figure 18. Several peaks are evident that could be a result of either fission products, or induced activities in the tower materials, or both. In view of the typical fission-product-field-decay curve observed (Figures 9 to 11), it is likely that these peaks are principally due to fission products.

DISCUSSION

Chemical Composition of Soil Samples. Table 1 shows that, at least in the top 6-inch layer, the soil composition of aluminum, manganese, and sodium appears to be fairly uniform in the

immediate vicinity of the project stations. This layer is the most important one from the induced activity standpoint, because the majority of the neutron-activated soil is in this layer (as can be surmised from Table 7) and also because the preponderance of gamma radiation above ground comes from the activated soil in this layer. The deeper layers show more variation in soil composition. Such variations might be caused by geological factors or by possible inaccuracies in the chemical analyses of the soil samples. The chemical analysis for sodium, for example, may be less accurate than are the chemical analyses for the other important elements in soils. The estimated accuracy of the sodium results is ± 30 percent.

These factors may account for the variation in the soil compositions in the deeper layers and in the difference between the CWL and the Department of Agriculture results. The important conclusion to be derived from the data in Table 1 is that the surface soil composition appears to be reasonably uniform in the vicinity of the project stations. The surface soil composition at Frenchman Lake is apparently more uniform than at some other areas of the Nevada Test Site (Reference 5). Further indication that the average Frenchman Lake soil composition is fairly uniform with depth is shown by the good agreement of the average activity ratios of Mn^{56} to Na^{24} together with percent standard deviations of about 20 percent (Table 7).

Nature of Activity. Before the shot, it was expected that the induced activity from Shot Hamilton would be largely due to Al^{28}, Mn^{56}, and Na^{24}. It was also expected that the gross dose-rate decay would be largely due to Al^{28} (2.3-minute half life) before about H+15 minutes, then to Mn^{56} (2.56-hour half life) until about H+8 to 15 hours, after which the gross decay would be essentially 15-hour Na^{24}. The gross field dose rate at the 70-yard station decayed by $t^{-1.1}$ from H+8 to 20 minutes as shown in Figure 11. During this period, the Al^{28} contribution to the field dose rates should have been noticeable if much induced activity were present. Since Al^{28} decay is not apparent, the observed decay rate must be due to fission-product fallout from the device. The field decay at later times also resembles fallout fission-product decay, which was unexpected since the tower height exceeded the expected fireball radius. Another indication that fission prod-

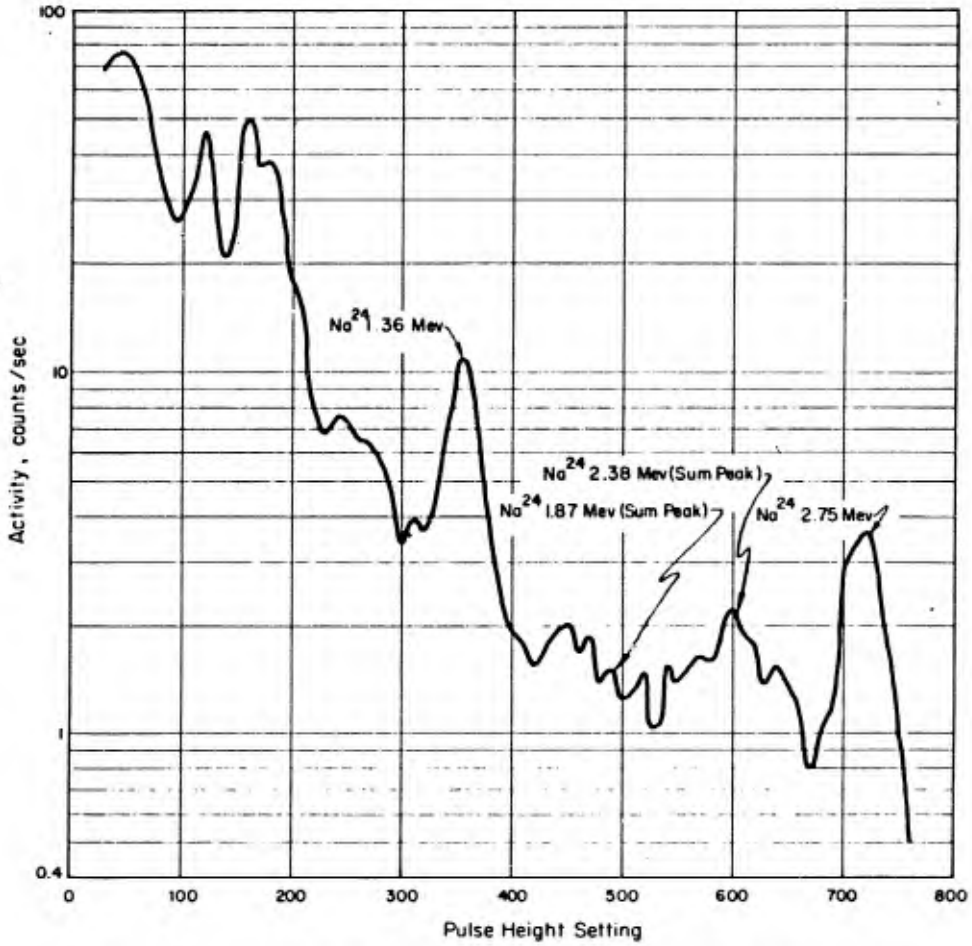

Figure 17 Representative gamma-ray spectrum of a surface soil sample at 50 yards on the 355-degree azimuth line at H + 31 hours.

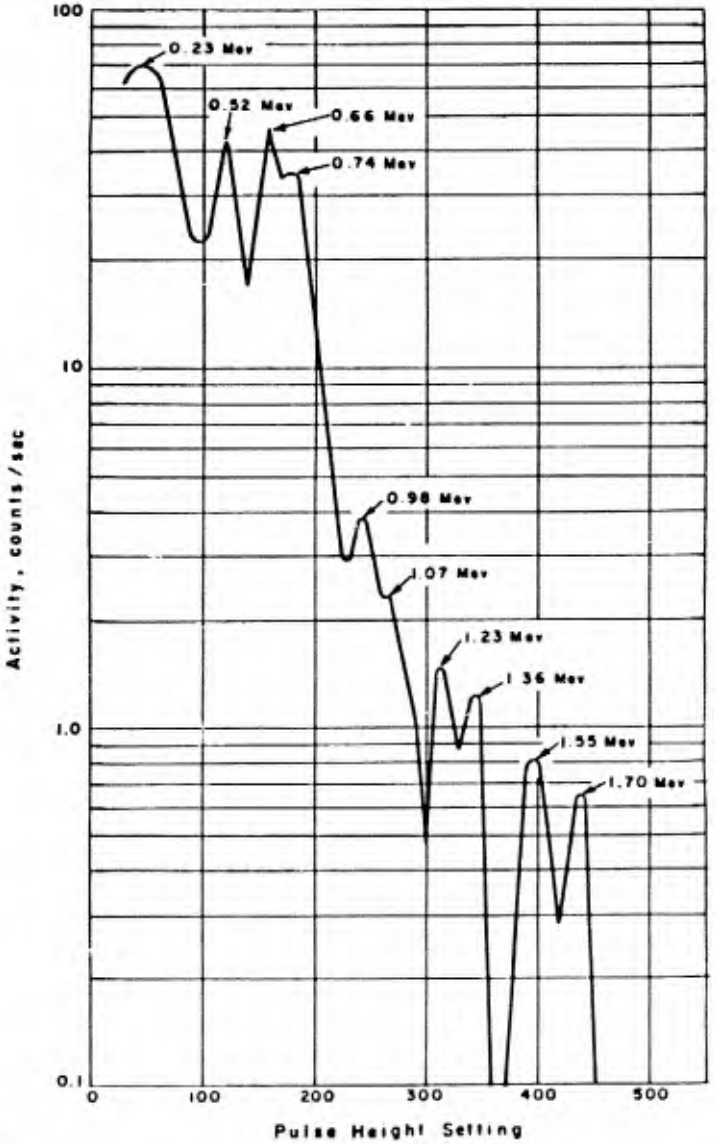

Figure 18 The gamma-ray spectrum remaining after a spectrum for Na^{24} was subtracted from the spectrum in Figure 17.

ucts were present was found in the spectral analysis of a surface soil sample taken from under the probe of the low-range recording dose-rate meter at the 70-yard station on D+1 day. This gamma spectrometer analysis showed several low-energy peaks in addition to the Na^{24} peak. These low-energy peaks resembled those from a fallout spectrum, though there was also an in-

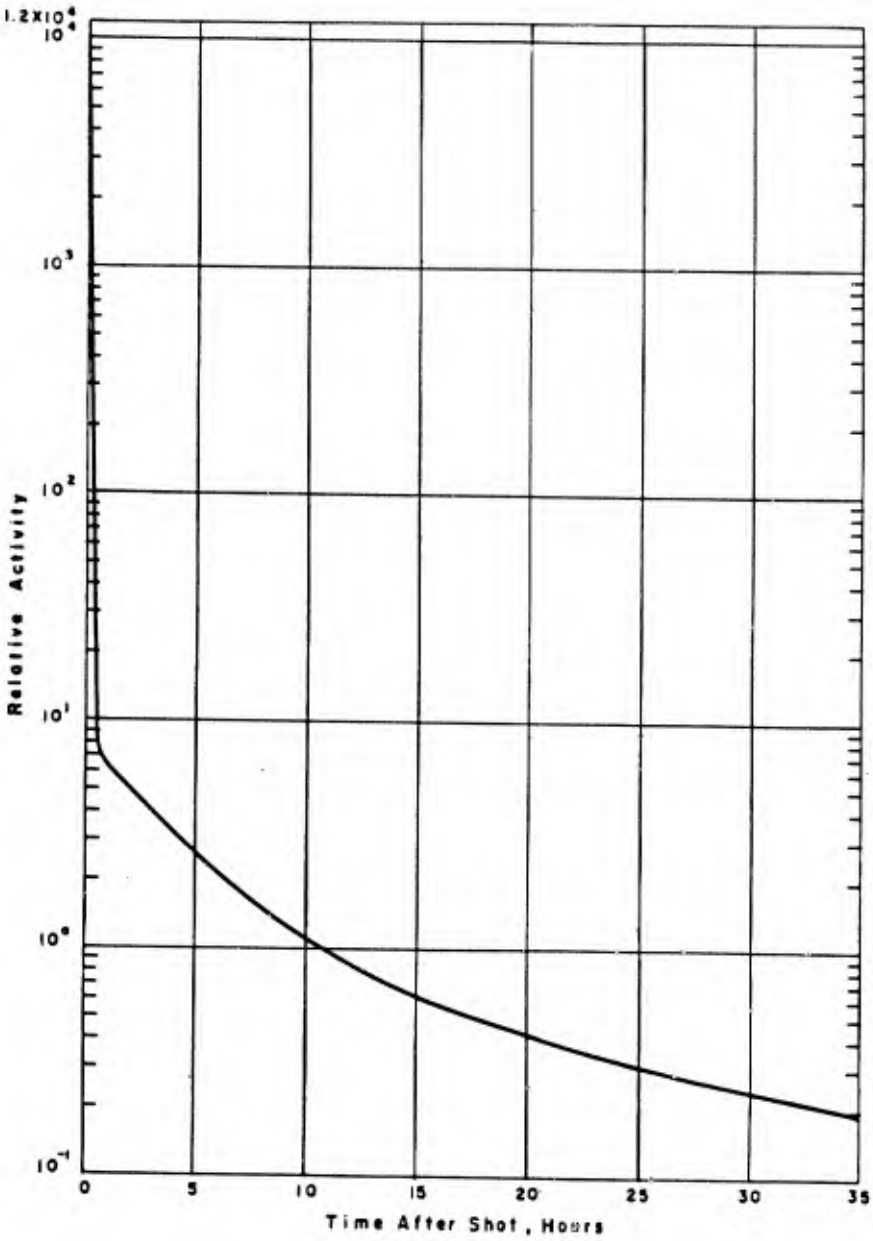

Figure 19 Decay of Al^{28}, Mn^{56} and Na^{24} in soil at the 150-yard station calculated from the zero-time Al^{28}/Na^{24} and Mn^{56}/Na^{24} microcurie ratios.

dication of unresolved induced activities in this spectrum. The local fallout could have resulted through deposition of fission products by unburned wood splinters from the tower. The local area after shot was heavily littered with unburned wooden debris from the tower.

A calculated gamma field decay due to Al^{28}, Mn^{56} and Na^{24} at the 150-yard station is shown in Figure 19. The curve is based on the zero-time activity ratios of Al^{28}/Na^{24} and Mn^{56}/Na^{24}, which were decayed graphically according to their individual half lives. The overall decay curve was obtained by summing the decay curves of the three induced radionuclides. The contributions of other induced nuclides should be negligible during this period and were not considered. The

field decay at the 150-yard station should have been substantially the same as this curve if no fission-product contamination had been present. Figure 19 should also approximate the induced activity decay characteristics at the other project stations since the Frenchman Lake soil composition is fairly uniform.

The percentage of the gamma dose rate generated by neutron-induced activity in the soil at H+1 hour was estimated by the Kaufman-Krey method (Reference 4) using the ground-surface copper neutron flux. These percentages ranged from about 30 percent of the total gamma dose rate at the 25-, 50- and 70-yard stations to about 20 percent at some of the more-distant stations.

Behavior of Copper Flux with Depth. Figure 12 shows that the maximum copper flux was at the surface of the ground at the 25- and 50-yard stations and from 5 to 8 cm below the surface at the rest of the stations. The flux falls off faster with depth at the 25- and 50-yard stations than at the 70-yard station. The activities in the copper strips from the lower parts of the remaining cores were too low to be measured.

The peaks at about 5 to 8 cm below the ground surface at the more-distant stations are believed to result from the degradation of numbers of fast neutrons in the soil into the energy-sensitive range (less than 0.1 Mev) of the copper detector. However, it is believed that the absence of similar peaks at the 25- and 50-yard stations, where the maximum copper flux is at the ground surface, is due to the effect of increased ground moisture which thermalizes many fast neutrons near the ground surface. The 25- and 50-yard stations were in an area near the ground-zero tower which was frequently sprinkled with water in order to keep down dust. The extra moisture at these stations is indicated in Table 3. The samples taken for moisture analysis on the evening before the shot were simply skimmed off the ground surface; so these results are not directly comparable with the results in Table 2 where the top-layer sample for moisture analysis was taken from the surface to a 6-inch depth. Similar effects of soil moisture content upon the copper flux were noted by Project 2.1 during Operation Plumbbob.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions. Induced activities were produced by Shot Hamilton, but the induced contamination could not be studied as planned because (1) the low yield of the device induced little activity in the soil and (2) an unexpectedly high level of fission-product contamination occurred in the vicinity of the project stations.

The presence of induced activity in the soil samples was indicated by gamma-spectrometer analysis. The major contributors to the gamma spectra in the soil samples were Al^{28}, Mn^{56}, and Na^{24} at H+16 minutes, Na^{24} and Mn^{56} at H+7 hours, and Na^{24} and Fe^{59} at H+54 hours.

The low-energy (less than 0.1 Mev) neutron flux was found to peak at 5 to 8 cm below the ground surface of the normal Frenchman Flat soil and at the ground surface in more-moist Frenchman Flat soil.

Empirical factors relating field dose rates with sample dose rates could not be determined because of the low level of induced activity produced and the fission-product contamination of the project-station exposure area.

The presence of fission products was indicated by the typical fission-product-dose-rate decay demonstrated by the residual field and by the presence of low energy, fission-product-like peaks in the gamma spectra of a ground surface soil sample recovered from the vicinity of ground zero at H+31 hours.

Recommendations. This experiment should be repeated at a future nuclear weapons-effects test when test conditions will result in probable experimental success. The required test conditions are an air burst or balloon shot at Frenchman Flat yielding a total thermal neutron flux from 10^{13} to 10^{14} n/cm^2 at the project stations.

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