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OPERATION SUN BEAM

Shot Small Boy

Project Officers Report - Project 2.1

Initial Radiation Measurements

27 February 1970

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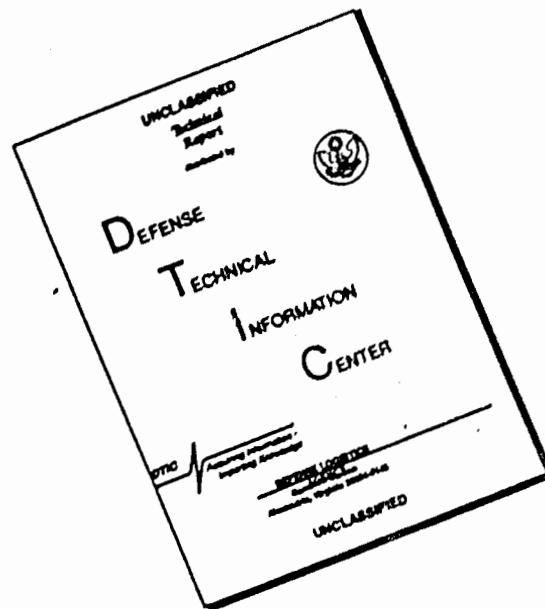
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Project 2.1, Small Boy, was designed to measure the time-resolved nuclear radiations resulting from the detonation of a Los Alamos.....device.

Reasonably complete time-resolved gamma-ray exposure rate data were obtained at 191 and 488 meters, with partial gamma-ray data obtained at 1220 meters. Reasonably complete time-resolved neutron flux data were obtained at 191 meters.

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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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ABSTRACT

(*) Project 2.1, Small Boy, was designed to measure the time-resolved nuclear radiations resulting from the detonation of a Los Alamos

device. The device was detonated on 14 August 1962 10 feet above ground, in Area 5 of the Nevada Test Site. The measured yield was

(U) Reasonably complete time-resolved gamma-ray exposure rate data were obtained at 191 and 488 meters, with partial gamma-ray data obtained at 1220 meters. Reasonably complete time-resolved neutron flux data were obtained at 191 meters.

(4) The peak gamma-ray rates measured at 191 and 488 meters were, respectively about one-half the predicted rates. The 488 meter measurement indicates that the gamma-ray rate generally agreed with the Los Scientific Laboratory (LASL) Monte Carlo Code (LMC) calculation out to about 13 microseconds but then dropped below the calculated value. At about 100 microseconds, the measured gamma-ray rate

and then dropped off with a shorter decay time than that calculated. The 191 meter data, although not as complete, was consistent with the 488 meter data.

(4) Neutron flux measurements at 488 meters showed values generally

although the time integral of these measurements agreed well with the fission-foil measurements made by personnel from the Nuclear Effects Laboratory of the Ballistic Research Laboratories.*

* Formerly the U.S. Army Nuclear Defense Laboratory and referred to as "NDL" in this report.

The integral of this peak was in reasonable agreement with the Zr value measured by NDL.

(4)

(U) The differentially shielded detector technique worked well, although there were calibration problems introduced by the time-dependent neutron spectrum present at all stations. A more detailed calculation of both the detector shields and the incident neutron spectrum would clarify some of the details of this data.

PREFACE

This measurement required a great deal of hard work by many people from the Harry Diamond Laboratories and the Nevada Test Site supporting organizations, under very trying conditions. Their contributions are gratefully acknowledged.

The painstaking and accurate work done by W.T.K. Johnson, now at American University, in reading the data film and reducing the data to a usable form was invaluable in producing the results reported here.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

(4) The objective of this project was to measure the gamma-ray exposure rate and the neutron fluence rate resulting from the detonation of the Small Boy device. These measurements were to be made at the locations of several of the stations making "free-field" electromagnetic pulses (EMP) measurements and were to be (1) made in both good (collimated) and poor (2 π) geometry; (2) capable of sufficiently high time resolution to record the gamma-ray peak; and (3) capable of recording with lower time resolution out to about 10 seconds.

1.2 BACKGROUND

(4) The gamma-ray output of nuclear devices and weapons as a function of time has been extremely well documented by the Atomic Energy Commission (AEC) for times up to or just beyond the peak (or peaks) through the usual diagnostic and alpha measurements.

(4) In the last few years, three distinct and very important considerations have arisen which make both a theoretical understanding of the production of these gamma-rays and an experimental verification of their magnitude essential:

(1) The transient radiation on electronics (TREE) work has shown that, although some important effects depend on gamma-ray rates, others depend on the number of gamma-rays, integrated over several microseconds. The prediction of these effects in tactical situations obviously requires that the expected radiation environment be known. Furthermore, a knowledge of the radiation environment at a field test is essential to understanding the test results.

(2) The nature of the EMP produced by a nuclear detonation depends on the gamma-rays in a way that certainly involves the gamma-rays produced after the peak, so that the development of a theory for the EMP requires a simultaneous measurement of the EMP and the gamma-rays. Prediction of the effects of the EMP in tactical situations again requires not only a knowledge of the nuclear radiation sources generated by the weapon but a theory relating weapon yield and type with EMP magnitude.

(3) Verification of radiation transport codes must be obtained to

supplement the results of effects tests in establishing tactics for nuclear weapons, new or old. In the case of a complete moratorium, such theoretical calculations will have to replace field testing entirely.

1.3 THEORY

(4) The intensity and spectrum of the gamma-rays present in the vicinity of a nuclear detonation depend not only on the yield of the device but on its design and environment. The situation as of 1954 has been reviewed in Malik's classic report (Reference 1). The emphasis in that report was on fission devices and times greater than 1 millisecond. Recently, Malik has made additional calculations of the gamma-radiation to be expected from various types of devices detonated in the atmosphere (Reference 2). Figure 1.1 is adapted from this report and will serve to clarify the relationship between the gamma-ray sources present for the Small Boy device in the Nevada environment. Neutron effects, other than those producing gamma-rays, have been ignored, as have been shock waves.

(4) The initial peak, responsible for the highest gamma-ray rate shown here, will, of course, occur under all circumstances of detonation altitude and device design since it is produced by interactions in the device itself. These gamma rays are quite energetic—in the

(4) The next source to appear is gamma-rays due to inelastic scattering and to capture of high energy neutrons in the air. It will be of primary importance when the detonation or detector is in

the atmosphere ,

These

gamma-rays are very energetic [

(u) The next source is due to the decay of isomeric states in fission products and will be important for any current device design and for any detonation altitude. The energy of these gamma-rays is in the 1-Mev range. Some details of this source have been studied by Walton (Reference 3).

(u) The next source, which is apparently due to fast neutron interactions in the ground, has been sketched in with somewhat arbitrary intensity. The detailed mechanism of this source is not entirely clear, but the existence of the source, apparently first observed at Small Boy, seems certain. Recent calculations by Malik and Longaire* confirm the decay time and the approximate intensity of this source. The energy of these gamma-rays is in the [The source will not be important for detonations more than a few neutron mean free paths above the ground and will be more important for

It will be discussed in more detail later in this report.

(u) The next two sources are less important for many applications because the gamma-ray intensity is quite low, although the contribution to the total gamma dose is substantial. The gamma-rays resulting from neutron capture in nitrogen will be important only when the detonation or detector is in the atmosphere but will be present for any current device design. These gamma-rays are quite energetic,

* Described in Reference 10.

having about The final gamma-ray source, fission product decay, will be present for any current device design detonated at any altitude. The energy for these gamma-rays is in the

All of these sources were present in the Small Boy situation.

(4) The neutron signal is not shown because the intensity depends strongly on device design and the distance from the detonation to the observation point. Furthermore, the arrival time for a neutron of a given energy increases linearly with distance.

(5) The primary considerations in designing this experiment were that a useful separation between neutron and gamma-ray contributions to the detector signals be obtained and that the detectors be located such that they would receive a sufficiently large signal to be recorded but would not saturate.

(6) Separation between neutrons and gamma-rays was obtained by shielding some detectors with Pb and others with polyethylene. The details of these shields will be discussed in Chapter 2. The detector currents observed from such a pair of detectors can be written as

$$I_1 = S_{1n} \dot{n} + S_{1\gamma} \dot{\gamma}$$

$$I_2 = S_{2n} \dot{n} + S_{2\gamma} \dot{\gamma}$$

Where I is the detector current (a function of time)

S is the detector sensitivity in its associated shield

$\dot{n}$ is the neutron fluence rate

$\dot{\gamma}$ is the gamma-ray exposure rate.

If all of the parameters are known at a particular time, the pair of equations can be solved for v and n at that time, providing that the determinant of the system does not vanish, i.e., that

$$S_{1v} S_{2n} \neq S_{2v} S_{1n} .$$

(4) The limiting factor determining the proximity of the detectors to the detonation in this measurement is the maximum dose rate to which the detectors can respond linearly. There is evidence that plastic fluors begin to become non-linear somewhat above $10^{21} \gamma - \text{Mev/cm}^2 \text{ sec}$. Furthermore, the scintillators have several longer fluorescence decay modes in addition to the primary, very short decay time, light output. Severe saturation could then have the effect of obscuring any decrease in gamma-ray rate in the several microseconds following the peak, since the longer decay modes would become dominant. {

} Although the dose rate resulting from these neutrons can become quite high, the peak gamma-ray rate remains the limiting factor in determining these detector locations. The peak rate may be found from the expression:

$$I = I_0 \frac{e^{-R/R_0}}{4\pi R^2 \times 10^5}$$

Where: I = exposure rate in $\text{Mev/cm}^2 \text{ sec}$ at range R

I_0 = peak rate of energy release in Mev/sec at the source

R = range in meters

R_0 = relaxation length for the gamma-rays, assumed to be 290 meters in Nevada Test Site air.

(4) The peak dose rates at the three ranges at which Project 2.1 made measurements were, for these inputs, using the predicted device output of

Range, meters	191	488	1220
---------------	-----	-----	------

These rates are below the values at which serious non-linearity should occur.

CHAPTER 2

PROCEDURE

2.1 FIELD INSTALLATION

(U) Two different types of installations were made. These used the same basic detector design, but the recording systems were considerably different. In the first type, to allow measurement of the very short initial radiation pulses, wide range recording systems were installed in bunkers. In the second type, to allow measurement of the radiation at the same location and with the same time resolution as the Project 6.2 EMP measurements, their tape recorders were used to record the output of radiation detectors installed near three of their pits.

(U) Both systems were buttoned up a few hours before the detonation, with operation initiated by EG&G timing signals obtained over hard wires. These timing signals started internal timers in the various stations shortly before zero time, after which the signal wires were disconnected and destroyed near the station.

2.1.1 Bunkers. (U) Installations were made in two bunkers jointly occupied by Projects 2.1, 6.1, and 6.3. The primary installation was in Bunker B, at 1,600 feet from GZ, with additional measurements in Bunker A, at 625 feet from GZ. The station locations are shown in Figure 2.1.

(U) These bunkers were monolithic reinforced concrete structures

buried in the desert. They were lined with 1 inch of steel plate welded at all joints. A battery powered motor-generator system in the center of each bunker supplied power for the recording and measuring instrumentation, which was mounted in spring suspended racks around the sides. The bunkers performed excellently, with more than adequate shock and EMP isolation.

(U) The predicted signal and detector coverage for the 1600-foot station, Bunker B, is shown in Figure 2.2. Detector D is not shown on this diagram since it was not a part of the basic measurement. It had only the same aluminum blast shield used on the EMP pit detectors and was installed to provide a comparison between the bunker and pit measurements.

(U) The Bunker B installation consisted of six 2π gamma-ray detectors, two collimators and detectors for good geometry gamma-ray and neutron measurements, three 2π neutron detectors, and three blank detectors to determine extracamerel effects such as EMP pickup in the detectors or cables. Recording was by means of oscilloscope photography for times near the gamma-ray and neutron peaks and a tape recorder, identical to that used by Project 6.2 for EMP measurements, for later times where the required time resolution was not so stringent. Elevation and plan views of Bunker B are shown in Figures 2.3 and 2.4

(U) The detectors were all of the same basic design, consisting of a liquid scintillator (with the exception of one plastic scintillator used in Bunker A), light pipe, an optical attenuator, a photo-

sensitive device, a blast shield and, generally, a neutron or gamma-ray discriminating shield. A very thin, optically opaque, Al foil was installed just in front of the photosensitive element in the blank detectors. This kept all of the light from the scintillator out of the photosensitive device but did not significantly alter any nuclear radiation scattered into it. The photosensitive device was a high current photodiode for measurements near the peak, or a photo-multiplier arranged to provide a wide-range, non-linear response for the measurements at later times. These detectors, except for the collimated detectors, could also see radiation coming from the ground, as will be discussed later.

(U) The detector assemblies, except for the neutron/gamma shield and scintillator, were installed below ground in 8-inch diameter steel pipes, with conduits leading to the bunker interior. These conduits were welded to the steel bunker shield at the bottom and to the 8-inch pipe at the top. The tops of the 8-inch pipes were covered by the neutron/gamma shields, which also performed as blast shields to ensure that the detector assemblies would survive the shock wave.

(U) The collimated detectors consisted of liquid scintillators and high current photodiodes, as in the 2π detectors, but in a somewhat different physical configuration. The collimators consisted of lead apertures, with the entrance aperture set into a concrete pier about 30 feet in front of the bunker and the exit aperture set into the bunker wall. Steel conduits, welded as for the 2π detectors, were provided from this detector compartment to the bunker interior.

(U) The Bunker A installation differed in that only two uncollimated detectors, one with a liquid and one with a plastic fluor, were used. Detector sensitivities were chosen to cover the range from the gamma-ray peak down to about 0.01 of the peak intensity.

(U) 2.1.2 EMP Pits. Detector installations were also made at three Project 6.2 pits and the data recorded on the same tape recorder as used for the EMP measurements. The ranges for these installations were 625 feet, 1,650 feet, and 4,000 feet. The detector and its installation were the same as for the bunker measurements, but the time resolution was limited to about 1 μ sec by the bandwidth of the tape recorder. The peak was therefore integrated by an approximately 1- μ sec time constant before being recorded. Three dynamic ranges were used, allowing the gamma-rays to be recorded out to about 1000 μ sec. Only one detector was installed at each of three pits. No Pb or CH₂ shields were used, but the 1-inch Al blast shield was installed. This installation is shown in Figure 2.5.

2.2 NUCLEAR RADIATION DETECTORS

(U) The detectors used for nuclear radiation transient measurements in this experiment fall into two categories. The first type was designed in such a manner that, as installed, they would be sensitive to radiation arriving from any direction above the horizontal. The detectors themselves were actually almost isotropic in sensitivity, as may be inferred from the design. The solid angle visible to the detector was essentially determined by the height of the scintillator above the ground. As installed, the detectors could see the

ground (through the shields) for most of the distance between the detector location and the device. These are the "2 π " detectors referred to earlier. The second type was designed to measure radiation arriving in a beam with a very limited numerical aperture and limited diameter and are referred to as collimated detectors.

2.2.1 2 π Detectors. (U) The requirements for wide angular sensitivity, large dynamic range, and length of time during which measurements were to be made led to an extremely flexible design in which the components could be easily interchanged. The detector assembly as installed in the field is shown in Figure 2.6. It consisted of a scintillator, light pipe, photo sensitive device, and auxiliary electronic assembly. Arrangement of these elements in the detector is shown in Figure 2.7. The detectors illustrated were so constructed that by a modification of the finish of the light pipe (changes in the optical density of the filter and the diaphragm diameter), the light from the fluor, as seen by photosensitive devices, could be modified by a factor of 10^4 . The sensitivity of a given detector could be adjusted downward from the maximum sensitivity by any factor up to 1×10^4 . Two types of mechanically interchangeable packages, consisting of a photosensitive device and auxiliary electronics, were available for each detector.

(u) The first package consisted of an FW-114 photodiode which was biased to a voltage of either 1,650 or 2,500 volts from a 1.7- μ f capacitor bank charged from an external high-voltage power supply through a charging resistor. This electronic package was

capable of delivering 10 to 15 amps during a radiation pulse while operating in a linear mode, i.e., without driving the photodiode into a non-linear region. With the aid of this package and the modifications discussed in the paragraph above, detectors were assembled with sensitivities ranging from approximately

(U) The second type of photosensitive device package which was used in the 20 detectors consisted of a photo-multiplier tube in an electronic feedback loop. This type of circuitry can provide a well-defined non-linear input-output relationship suitable for use in measuring transients over a wide dynamic range over long time intervals.

(U) Figure 2.8 shows the circuitry contained in the non-linear package. The operation of this circuit is as follows: If a suitable negative dc trigger is applied to the trigger input, tube V_2 becomes non-conductive. When this situation occurs, tube V_1 forms a feedback loop between the anode of the 6655-A photo-multiplier (PM) tube and the high voltage string of the 6655-A. The action of this feedback loop is to regulate the current through the high-voltage string in such a way as to cause the anode current of the photo-multiplier tube to remain constant no matter what the input illumination on the photo-cathode. Under these conditions the input illumination on the photo-cathode can be varied over a range of several orders of magnitude without causing excessive currents or saturation phenomena to occur in the PM tube. Furthermore,

under conditions of constant current through the PM tube, the input illumination is related to the high voltage string current by a well-defined function.

(U) Thus, under conditions of constant anode current the high-voltage string current can be used as a measure of the input illumination. As a practical matter, the voltage drop across part of the high-voltage string is used as a measure of the current through the string. Tube V_3 gives an output signal into a 50-ohm terminated cable which is linearly related to the high-voltage string current.

(U) The overall steady-state transfer function of a typical 2π detector circuit fitted with this package is:

$$D = \left(\frac{6.40}{V_o + 1.078} \right)^{8.80}$$

where limits of V_o are $(-0.075) \geq V_o \geq (-0.785)$

and V_o = output, volts

D = energy flux, $\text{Mev/cm}^2 \text{ sec.}$

This equation will describe the behavior of the 2π detectors, when equipped with the non-linear package, to within 0.005 volt over the entire operating range specified above. By a change in the optical system of the detector and adjustment of the two electrical controls shown in Figure 2.8 the numerical constants contained in this equation can be adjusted independently, with the exception of the exponent. By properly selecting PM tubes the value of the exponent can be varied over a small range. Thus, the transfer function of a given detector can be adjusted to suit the purpose.

(U) The function of the trigger tube V_2 is to disable the feedback loop during times when the input illumination on the photocathode of the PM tube is above or below the useful dynamic range of the electronics. This action prevents the destruction of, or damage to, the PM tube or the associated feedback loop. For this particular experiment the non-linear circuitry was triggered on and became operative at approximately 2×10^{-4} seconds after t_0 . Triggering was provided by a trigger circuit located in the instrumentation bundle.

(u) By utilizing the non-linear electronics package, 2 π detectors were assembled which gave useful signals in radiation fields ranging from approximately [

] Any one detector using one recording channel has a useful dynamic range of 2×10^4 . These detectors were designed for this experiment by EG&G, Santa Barbara. Further details may be found in their report (Reference 4).

2.2.2 Collimated Detectors. (U) The purpose of the collimated detectors used in this experiment was to allow the determination of the source strength, in the region of the nuclear device, as a function of time. Detectors used in the collimated measurements were of a type previously developed and used by EG&G for nuclear-weapons diagnostic measurements. This detector consists of a cubical aluminum structure approximately 8 inches along each edge which holds either a 6 by 6 by 6-inch plastic fluor or a 6 by 6-inch cylindrical tank containing NE-211 liquid fluor. In the present experiment liquid fluors were

used, and the axis of the cylindrical tank was oriented at right angles to the axis of the radiation beam. In all cases of interest here, the detector was oriented so that the radiation beam did not strike the photo sensitive element. Figure 2.9 shows an exploded view of the general configuration of the collimated detectors.

(U) The defining geometry of the collimator used in conjunction with these detectors is shown in Figure 2.10. Two identical collimators were used, one for each collimated detector. They consisted of three lead diaphragms, thick enough (3 inches) to be essentially opaque to gamma radiation, each with a circular conical aperture. The centers of the apertures were coaxial with the line of sight between the center of the detector and the center of the nuclear device. The entrance and exit aperture spacing and diameter were chosen to meet the following geometric criteria:

(1) No rays which originate in the neighborhood of the device at distances greater than 3 meters from the axis of the collimator can reach the detector directly, i.e., without being scattered at least once.

(2) All rays which originate within 2 meters of the center of the device and pass through the forward aperture of the collimator will reach the detector.

(3) The bundle of rays defined by the collimator will have a diameter of 0.8 inch at the rear aperture of the collimator.

(U) The criteria above assure that a negligible amount of radiation scattered by the ground will enter the detector and that no

singly scattered radiation from the ground between the collimator and device will be seen. The criteria also assure that no vignetting will occur for rays which originate within a 2-meter radius of the center of the nuclear device. The center aperture did not contribute to defining the principal beam but was used to keep radiation coming around the entrance aperture out of the exit aperture.

2.2.3 Detector Calibration. (U) The original calibration of these detectors, described in Reference 4, was predicated on the assumption that the spectrum of the fission neutrons at the detector positions would not change significantly with time and approximately resembled the SPRF* spectrum. Deviations from this were expected, but the well known rapid approach to equilibrium with distance of the time integrated spectrum was reassuring and, at that time, there were no time-dependent calculations that illuminated this question. The first attempts to analyze these Small Boy data showed that either this assumption or the detector neutron calibration was seriously in error.

(U) The symptom exhibited in the analysis was that the calculation gave negative neutron fluxes, a circumstance which was inconsistent with the presumed accuracy of the detector calibration. The measured gamma-ray exposure rates were not seriously affected by this anomaly and the values reported here will be seen to be quite similar in many respects to those previously reported on the basis of these measurements. The data was quietly tucked away with the resolve to investigate the neutron calibration of these detectors at some future time.

*Sandia Pulse Reactor Facility

This was subsequently done and the results reported in Reference 5. This later calibration was a much more detailed measurement than the original effort but did not show any deviations from the original calibration that were sufficiently drastic to account for the analysis problem.

(U) This left only the temporal dependence of the neutron spectrum at the detector positions to account for the problem. About this time the results of Straker's (ORNL) time dependent neutron calculation became available. These results are given in Reference 6. They show that the neutron spectrum is anything but time independent at these detector locations and accounts completely for the analysis problem mentioned earlier. Further, they allow a determination of the effective neutron sensitivity of these detectors as a function of time and thus make possible an analysis of the data which is quite reasonable.

(U) Essentially what has been done is to start with the original detector calibrations, which are described below, calculate the dependence of the detector sensitivity on neutron energy over the entire energy range, assume that the ORNL results describe reality, and combine these to calculate what the detector sensitivity would be as a function of time. These steps are described in the next three sections.

Basic Detector Calibration. (U) Primary calibration of these nuclear radiation detectors was accomplished from a measurement of the steady-state response of the bare detectors to a CO^{60} radiation source (Reference 4). No attempt was made to calibrate detec-

tors with radiation pulses similar in magnitude and shape to those which the detectors would see in actual use, primarily because no such sources were then available. However, tests were performed on each detector using light pulses to assure that all of the elements of the detector behind the fluor were capable of linear pulse response to levels higher than would be encountered in actual use. The accuracy in these basic detector gamma-ray sensitivities is estimated to be 10 percent.

(U) In the subsequent data analysis it has been assumed that all of the gamma-rays involved, except for those produced in the detector shields by neutrons, had an effective energy of 2.0 Mev. The sensitivity at this energy was taken to be 0.89 of the Co^{60} sensitivity, based on the results of an LRL Monte Carlo calculation of the dependence of scintillator response on photon energy given in Reference 7. The LRL calculation was done for a 6-inch cubical plastic scintillator with good collimation, but at these energies the error introduced by using these results should be negligible. The gamma-ray data presented in Chapter 3 is given in terms of roentgens/second. The conversion factor used was $2.30 \times 10^9 \frac{\gamma\text{-Mev/cm}^2}{\text{R}}$ at 2.0 Mev so that the sensitivity of a detector having:

$$S_Y = 1 \times 10^{-20} \text{ amps} / \frac{\gamma - \text{Mev}}{\text{cm}^2 \text{ sec}} \quad \text{for } \text{Co}^{60} \text{ becomes:}$$

$$S_Y = 1 \times 10^{-20} \times 0.89 \times 2.30 \times 10^9 = 2.05 \times 10^{-11} \text{ amps} / \frac{\text{R}}{\text{sec}} \text{ at 2.0 Mev.}$$

(U) The gamma-ray transmission of the detector shields was measured with a Co^{60} source in both of the calibration efforts mentioned.

The sensitivities of the shielded detectors to the 2.0 Mev. gamma-ray energy assumed here were determined by multiplying the measured transmission by the ratio of the shield transmission factors at the two energies and using the resultant value with the 2.0 Mev sensitivity of the bare detector. These values are shown in Table 2.1. The good geometry transmission factors were used, which should be adequate, except for the case of the Pb shield, since the dose build-up factor is not significantly different for these energies. The error for the Pb shield will be greater, but even here, the difference in dose build-up appears to be less than 20 percent. Since this detector was not intended to make a gamma-ray measurement and the accuracy of the neutron measurement does not depend strongly on the gamma-ray sensitivity, this value will be used. The gamma-ray detector sensitivities used in the subsequent data reduction are given in Table 2.2. Only those detectors from which data was obtained are listed.

(U) The neutron sensitivity of the basic detector, i.e., the unshielded fluor-photodiode combination, was determined for the neutron spectrum from the Sandia Pulse Reactor Facility (SPRF) and for 14 Mev neutrons from a steady-state deuterons-on-tritium source during the original calibration (Reference 4). An attempt was made to measure the attendant gamma-rays and correct the final results for their effects. An independent measurement of the neutron sensitivities of these basic detectors (using fresh NE-211) was made, for another application (Reference 8), using much the same techniques, but with considerably improved measurements of the gamma-rays. Substan-

tial differences between these measurements in both the absolute sensitivities and in the ratio of sensitivities for fission and 14 Mev neutrons were found. Two other available data bear on this. The first is an LRL Monte Carlo calculation of the neutron sensitivity of a plastic scintillator given in the report mentioned earlier (Reference 7) and an LRL experimental result quoted in that report. All of these are summarized in Table 2.3.

(U) The EG&G I results differ considerably from all of the others, probably due to the way the gamma-ray backgrounds were treated, and will not be considered further. The EG&G II value at 14 Mev will be used in this report. It differs from the LRL calculated value by about 16 percent and lies between the LRL calculated and measured values, all of which is not surprising in view of the differences in the scintillators and other parameters. The error bar on the value given by EG&G II for SPRF neutrons is considerably greater than that for the 14 Mev value and almost includes the LRL value at 1.4 Mev (the two values differ by about 22 percent). The LRL calculated values normalized to the EG&G II value at 14 Mev will therefore be used for the detector neutron sensitivity at other energies. The neutron data in Chapter 3 are given in terms of neutrons/cm²-sec so that the sensitivities used have been calculated in those units. Figure 2.11 shows the relationship between neutron sensitivity and neutron energy for a bare detector.

Effect of Shields on Neutron Sensitivity of Detectors.

(U) It appeared doubtful that a measurement of the neutron sensitivities of the shielded detectors was feasible for enough intermediate

neutron energies to make the effort worthwhile. Fortunately, the EG&G calibration described in Reference 5, which measured the neutron sensitivities of the shielded detectors at the White Sands Fast Burst Reactor Facility and at 14 Mev, also made a careful measurement of the gamma-rays incident on the shield and those transmitted through, plus those produced in, the shield. These measurements were corrected for the neutron sensitivity of the gamma-ray dosimeters.

(U) The approach adopted was to perform a hand calculation of the prompt gamma-rays produced in the shield and the neutrons transmitted through it as a function of neutron energy and normalize the resulting detector currents to the measured values. The neutron sensitivity would then be tied down to a measurement at both ends of the useful energy range and hopefully provide an acceptable representation of the sensitivity at intermediate energies.

(U) The opportunity to normalize the calculation made some liberties possible which otherwise would certainly lead to difficulty. As examples, a good geometry neutron attenuation calculation was used, apparently with impunity, and the geometry of the nxy source in the shield did not have to be precisely known. The major source of error in this calculation is that neutrons moderated in the shields are not properly treated. The decrease in scintillator sensitivity with neutron energy partially compensates for this but certainly not completely. At some future time it may be possible to perform a Monte Carlo calculation on these shields which, after normalization to the experimental values, should give a more detailed and elegant result.

(U) The neutron energy range was divided into the same 9 intervals used by ORNL, since that calculation is used in the next section to derive the effective sensitivity of the detectors as a function of time. The neutron transmission and gamma-ray production cross-sections came primarily from the ENDF/B compilation and were averaged over the ORNL energy intervals for the calculation. The scintillator neutron and gamma-ray energy dependence used were from Reference 7 and the scintillator neutron energy dependence averaged over the energy intervals. The transmission factors for the gamma-rays produced by neutrons in the shields were for the good geometry case. The details of the calculation will not be given, but the results are given in Table 2.4. The neutron and neutron-produced gamma-ray components of the detector current are listed, as well as the total sensitivity used in the subsequent data reduction.

(U) The total sensitivities, because of the way they were calculated, agree identically with the measured values reported in Reference 5, with the exception of the FBR* sensitivity for the Al + Ch₂ shield. The sensitivities for this shield given in Table 2.4, when folded with the FBR neutron spectrum, give about one-half the measured sensitivity, that is, the normalization procedure mentioned earlier was not adhered to strictly in this one case. The sensitivity that would have resulted from this normalization was completely inconsistent with the measured sensitivity at 14 Mev. The measurement at 14 Mev was thought to be more reliable than that at FBR, so that the calculated sensitivity

* White Sands, Fast Burst Reactor.

ties normalized only at 14 Mev have been used. Some of the reasons for this choice (none of which apply to the Pb shield measurement) are discussed below:

(1) What is probably the most important reason follows from the fact that most (more than 90 percent) of the neutron signal with this detector shield combination in the FBR environment comes from the nxy reactions. This component of the detector current is very small in the energy interval containing most of the FBR neutrons and increases rapidly as the number of FBR neutrons is decreasing rapidly. A small error in either the calculated detector sensitivity or the FBR spectrum used for the comparison would strongly influence the calculated FBR response (the tail of the FBR spectrum is wagging the dog). A less significant aspect of the calculated sensitivity is that any consideration of the moderated neutrons produced in the shield would raise the calculated sensitivity somewhat.

(2) The FBR measurement of the sensitivity of this detector-shield combination can be questioned as a result of the way the gamma-ray component of the detector current was treated. The measured neutron sensitivity was calculated from the expression:

$$S_n = \frac{q - S_\gamma \phi_\gamma}{\phi_n}$$

Where: S_n is the neutron sensitivity

q is the total charge collected during a measurement

S_γ is the detector gamma-ray sensitivity (coul/R) with the shield in place

ϕ_n and ϕ_γ are the neutron and gamma-ray fluence, respectively, incident on the shield.

The charge, q , was collected until the TLD's used to measure the gamma-ray fluence could be removed, so that the measurements would be comparable. The term $S_\gamma \phi_\gamma$ was calculated from the TLD measurement after correction for neutron effects in the TLD. This procedure compensated for the residual fission product gamma-rays from the reactor between the time of the burst and the time the reactor was lowered into its pit but did not compensate for residual activity in the Al shield itself since the TLD was not located close to the shield. Furthermore, the Co^{60} transmission factor for the shield was used, although many of the gamma-rays present were more energetic than those from Co^{60} . Both of these factors, if they had been incorporated into the calibration, would have lowered the measured sensitivity but probably not enough to account for the entire discrepancy.

(3) Finally, the calculated sensitivity, before normalization, came within about 10 percent of the measured value at 14 Mev, which implies that it is probably reliable down to a few Mev, and its use does provide a self-consistent set of sensitivities. Fortunately, the value of S_n (for this detector-shield combination) below 2.35 Mev, which is where the problem, if any, really lies, could change by 50 percent without changing the value of $\dot{\gamma}$ obtained from the Small Boy data by more than about 5 percent.

Calculation of Effective Detector Sensitivity versus Time.

(4) The tables given in Reference 6 contain, among many other things, calculations of the time dependent neutron spectrum at the air-ground interface from both fission

The height of the

so that the ORNL values will not apply exactly to the operational situation. French has reported, in Reference 9, a method to correct for the source (or detector) height effects in this type of calculation, but it applies directly only to the time integrated case. The correction, for the Small Boy parameters, amounts to a decrease of about 15 percent in neutron fluence at the 1600 station. The ORNL calculation will thus give results which tend to be high, but the application of French's correction technique to the time-resolved neutron spectrum is not all straightforward; it is not attempted in this report. The time dependent spectra appropriate to the 191, 488, and 1225 meter locations are given in Table 2.5. These have been constructed by multiplying the ORNL results for fission by the respective values given by Malik in Reference 10 for the Small Boy device and adding the two resulting matrices. The values given for the Small Boy device were:

The multipliers used for the tables were:

Total Neutrons

Fission

$$4.88 \times 10^{23}$$

The ORNL calculation averaged $4\pi r^2 \phi$ over the range intervals used and tabulated the average values. The table entries here are the same except for the multipliers mentioned earlier. The first column of row-sums (i.e., the next to the last column) are simply that. The second column of row-sums are the first row-sums $\times 10^{23}$ and divided by $4\pi r_0^2$, where r_0 is the range of the station.

(U) Each table entry was divided by the row-sum for the row in which it appears, giving tables of the fraction of the total number of neutrons in a particular time interval that lie both in that time interval and a particular energy interval. The columns in these tables were then multiplied by the appropriate detector sensitivity for that energy interval and the row-sums again taken. These row-sums will represent the detector sensitivity in the particular time interval for the neutron spectrum calculated by ORNL. These values are given in Table 2.6.

(U) They were also plotted on linear paper to a large scale and a smooth curve drawn through them, conserving the area in each time interval. These curves of detector sensitivity versus time were used for data reduction at the three detector locations and are shown in logarithmic form in Figures 2.12 and 2.13. The times shown are relative to gamma-ray arrival at the station. The 191-meter station presented a problem because the ORNL range interval that contained

this station went into about 100 meters, thereby seriously distorting the time dependence with respect to that which would be expected at 191 meters. The neutron intensity would also be affected. In an attempt to compensate for these difficulties, the time scales for the two inner range intervals, i.e., 100.1-200.6 and 200.6-275.4 meters, were shifted (by adding or subtracting the appropriate time) so that neutron arrival time coincided with that at the 191-meter detector station, the detector sensitivity versus time calculated for both of them, and the average of the two values at any time used as the detector sensitivity versus time function for the 191-meter station. This average curve differed from the two input curves by less than 5 percent at early and late times and by about 20 percent around 20 μ s.

2.3 DATA RECORDING SYSTEM

(U) The signals from the detectors were brought into the recording system on RG 9/U 50-ohm coaxial cable terminated in its characteristic impedance at the end of its run. High-impedance recording devices, e.g., 541 oscilloscopes, were in some cases bridged across the 50-ohm line when any small reflections that might be produced would not be expected to be important. The oscilloscopes in Bunker A were triggered by a gamma-ray fiducial-marker generator. The output of this generator was also distributed to the other occupants of the bunker. A similar arrangement was used in Bunker B except that triggering was done by parallel trigger generators driven by two detectors, to give redundancy. The trigger generator was also used to put a zero time mark on the tape recorder timing channels in

Bunker B and to supply a zero-time trigger to the other occupants of the bunker.

(U) Gamma-ray fiducial-marker generators were also installed in Bunkers C and D to provide trigger pulses to the occupants of those bunkers, although Project 2.1 had no experiments there. This generator is described in the Project 6.2 report and will not be described further here.

2.3.1 Bunker B. (U) The detectors and associated recording devices used in Bunker B are summarized in the one-line diagrams of the instrumentation given in Figure 2.14.

(U) All oscilloscope data were recorded on 4x5 Royal X Pan sheet film using Tektronix cameras focused on the trace. The shutter was operated by a signal from the timing circuit described below. The base lines were recorded on separate film and the oscilloscope grati-cules were photographed on the shot film prior to the experiment. The oscilloscopes were operated in the single-shot mode and armed by the timing system at about T-1 second. The EG&G scopes were left armed when the bunker was buttoned up before the shot.

(U) In both bunkers and pits it was essential to isolate the recording systems from anything that could act as an antenna for the EM signal generated by the nuclear detonation, since such pick-up could easily mask the data. Both systems were activated by the usual EG&G timing signals obtained via wire lines which had to be destroyed before zero time. The lines were cut by a guillotine at the bunkers at T-5 seconds and, in addition, primacord, wrapped around the timing

signal lines and detonated at about T-2.5 seconds, was used in both cases.

(U) Both systems were provided with internal sequencers to control them after the timing lines were destroyed. The pit EM recorder system is described in the Project 6.2 report and will not be considered further here; however, the bunker system is described below.

(U) The EG&G timing signals used in the bunkers were relay closures at T-30 minutes, T-5 minutes and T-5 seconds. The lines from the relay contacts came into a central timing panel supplied by one of the agencies occupying the bunker and were redistributed to the separate project timing panels supplied by the other agencies occupying the bunker. The Project 2.1 timing panel passed the signals on to the recording equipment and generated the additional signals required. Each EG&G signal operated electrically latching relays in both the central and Project timing panels so that the signal would not be lost when the timing lines were destroyed. A block diagram of the Project 2.1 timing system is shown in Figure 2.15.

(U) The Project 2.1 Bunker B system used the T-30 minute signal to initiate the internal timer in the Bunker tape recorder. The T-5 minute signal applied power to this recorder and initiated a 4-minute time delay relay in the timing panel. The resulting T-1 minute signal started the recorder tape-puller motor. This time delay relay was necessary to replace the T-1 minute signal available at the Project 6.2 stations, the normal home of these recorders. Since all timing lines were destroyed at T-2.5 seconds, it was necessary that

the timing circuits provide all signals needed after this time. Each of the primary signals from the control point could be simulated from the timing panel by a switch, which also could isolate the panel from the signal. Panel lights indicated each of the operations and the status of the timing panel and signals.

(U) The Project 2.1 Bunker A timing system consisted of only the T-5 second section of the panel.

2.3.2 Bunker A. (U) Two radiation measurements were made in this location, using different fluors. Except for the scintillators, the detecting and recording systems used were identical. This system is summarized in the line diagram given in Figure 2.16.

(U) Each channel consisted of two Tektronix oscilloscopes: a model 519 in series with a model 517. The signal from the detector was delayed 145-nsec, to insure that the 517 sweep was in the linear portion of its range when the desired signal occurred. The signal, after the 145-nsec delay, entered the model 519 oscilloscope through a 50-ohm to 125-ohm impedance transformation. The signal taken from the output terminals of the 519 distributed-deflection system was fed on to the plates of the 517 through a 125-ohm to 50-ohm impedance transformation. An additional 2:1 attenuator was also used in this line. The 50-ohm line was terminated at the input to the 517. The oscilloscopes were operated in the single-sweep mode and armed at about T-second. The photographic recording system was the same as that described above.

(U) The oscilloscopes were externally triggered from a gamma

fiducial-marker generator pulse of 8 volts. This pulse also provided Project 6.1 with a zero-time signal, which they further distributed to Project 6.3.

2.3.3 Tape Recorder Systems. (U) Radiation measurements were recorded on tape in four locations: Bunker B, and Project 6.2 EMP pit Stations 519.02, .04, and .06. Each of the pit stations was equipped with a single gamma detector and a gamma fiducial-marker generator similar to those used in the bunkers. Associated with this detector were three tape channels covering three dynamic ranges. See Figure 2.17 for the block diagram of the tape channels in these stations.

(U) In the Bunker B tape recorder (see Figure 2.18) one of the inputs used 3 channels, as described above, 2 other inputs were covered by two dynamic ranges and the other 5 inputs included only a single range. In each recording box, channels No. 7 and No. 8 were timing channels having a very stable 100-kc crystal oscillator signal. The gamma fiducial-marker generator drove a monostable (one-shot) multivibrator to provide a fiducial-mark on these channels. Details on these timing channels are available in the Project 6.2 report.

TABLE 2.1 (U), 2.0-MEV GAMMA-RAY SENSITIVITY OF BARE AND SHIELDED DETECTORS (U)

Shield	Co ⁶⁰ Measured Transmission Factor	Ratio of Shield Transmission Factors	2.0 Mev Sensitivity amps/ $\frac{R}{\text{sec}}$
None	1	1	2.05×10^{-11}
1" Al	0.682	1.09	1.52×10^{-11}
1" Al + 3.6"CH ₂	0.554	1.28	1.46×10^{-11}
1" Al + 3.6"Pb	7.47×10^{-3}	4.73	7.20×10^{-13}

(For a bare detector sensitivity to Co⁶⁰ of 1×10^{-20} amps/ $\frac{\gamma\text{-Mev}}{\text{cm}^2 \text{ sec.}}$)

TABLE 2.3 (4) SCINTILLATOR NEUTRON SENSITIVITY (U)

Source	$\frac{S_n(14 \text{ Mev})}{S_\gamma(1.25 \text{ Mev})}$	$\frac{S_n(\text{SPRF})}{S_\gamma(1.25 \text{ Mev})}$	$\frac{S_n(1.4 \text{ Mev})}{S_\gamma(1.25 \text{ Mev})}$	$\frac{S_n(14 \text{ Mev})}{S_n(\text{SPRF}) \text{ or } S_n(1.4 \text{ Mev})}$
EG&G I (Ref. 4)	0.68	0.37	-	1.84
EG&G II (Ref. 8)	0.37	0.55	0.55	0.67
LRL Calc. *	0.32	-	0.43	0.74
LRL Mass. **	0.43 (13.6 Mev.)	-	-	-

The units are all in energy terms, i.e., amperes/ $\frac{\gamma\text{-Mev}}{\text{cm}^2\text{-sec}}$ or $\frac{n\text{-Mev}}{\text{cm}^2\text{-sec}}$

* 6 inch cubical scintillator, collimated neutrons.

** 6 inch by 6 inch cylindrical scintillator, no collimation.

TABLE 2.4 (4) NEUTRON SENSITIVITY OF SHIELDED DETECTORS VERSUS ENERGY (U)

All entries are for a detector having an unshielded Co^{60} sensitivity of 1×10^{-20} amps/ $\frac{\gamma\text{-Mev}}{\text{cm}^2\text{-sec}}$. Multiply the entries by 10^{-21} to get the component of detector current resulting from 1 neutron/ $\text{cm}^2\text{-sec}$ incident on the shield and in the energy band.

Energy Interval	Al Shield			Al + Ctl. Shield				Al + Pb Shield		
	n	nxy (Al)	Total	n	nxy (Al)	nxy (C)	Total	n	nxy (Pb)	Total
0.11 to 1.11 Mev	2.14	0.22	2.36	0.001	0.162	0	0.163	2.41	0.006	2.42
2.35	5.18	2.22	7.40	0.188	1.29	0	1.48	6.49	1.10	7.59
3.33	8.30	6.50	14.8	0.802	4.35	0	5.15	7.45	1.97	9.42
4.06	10.9	13.9	24.8	1.18	10.0	0	11.2	7.61	2.06	9.67
6.36	15.3	22.0	37.3	2.92	17.0	3.72	23.6	9.26	1.94	11.2
8.19	22.4	25.6	48.0	4.64	20.4	12.5	37.5	20.9	2.50	23.4
10.00	27.7	28.5	56.2	8.27	23.1	7.05	38.4	32.3	2.88	35.2
12.20	33.8	28.7	62.5	12.2	23.3	7.55	43.1	40.9	3.01	43.9
15.00	39.3	28.7	68.0	14.8	23.3	9.51	47.6	45.3	3.09	48.4

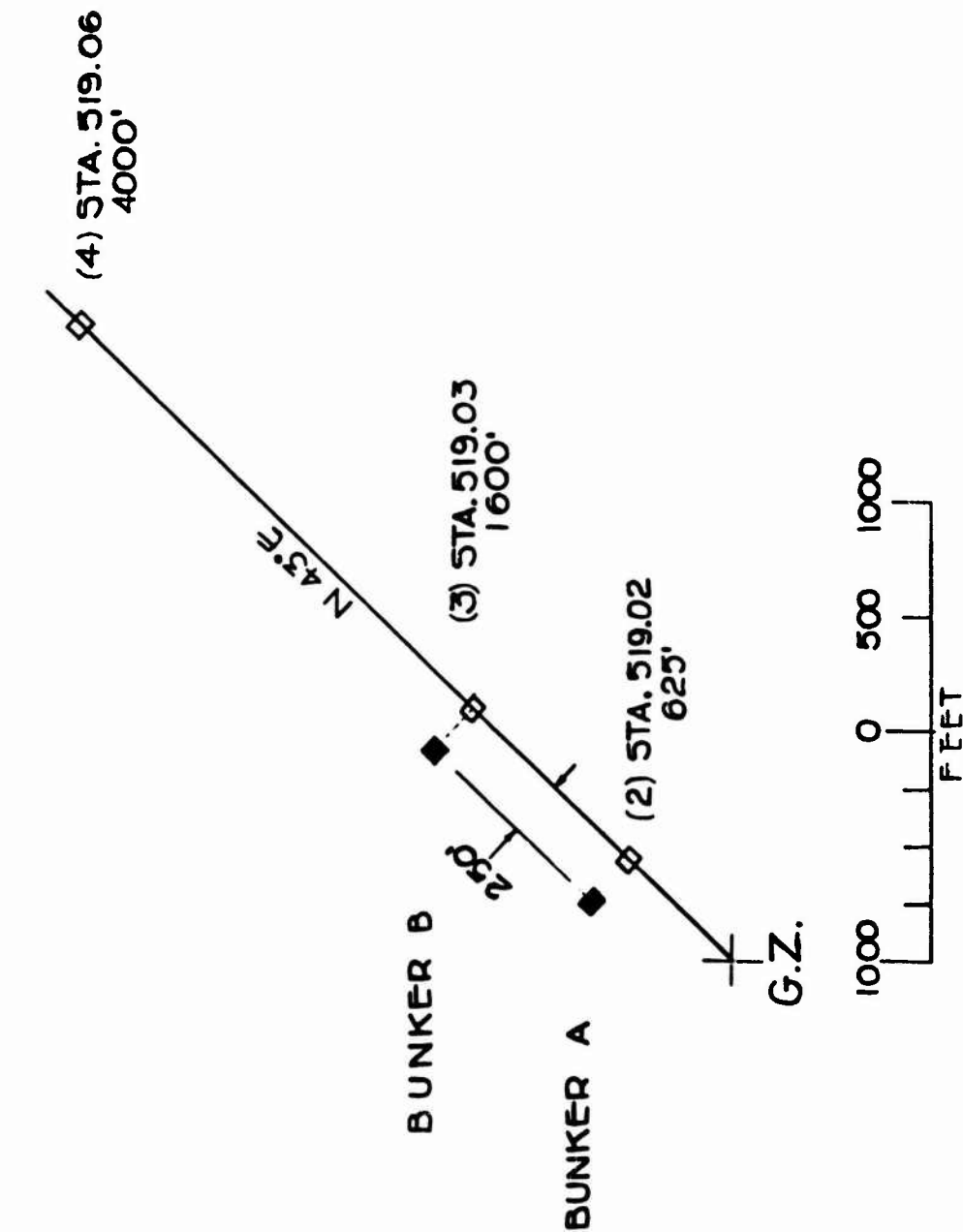
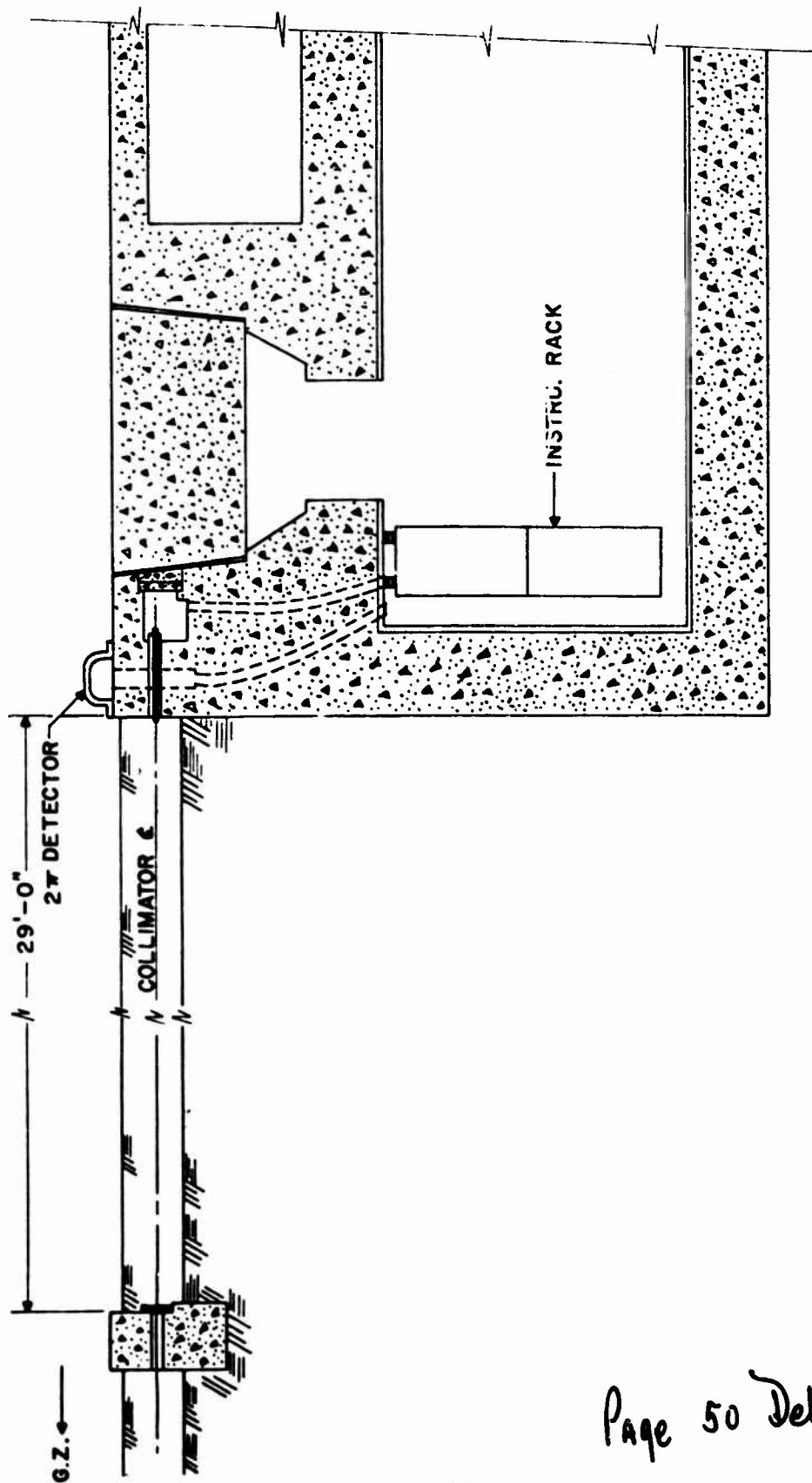


Figure 2.1 (U) Station locations. (U)

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BUNKER ELEVATION

Figure 2.3 (U) Elevation drawing of Bunker B. (U)

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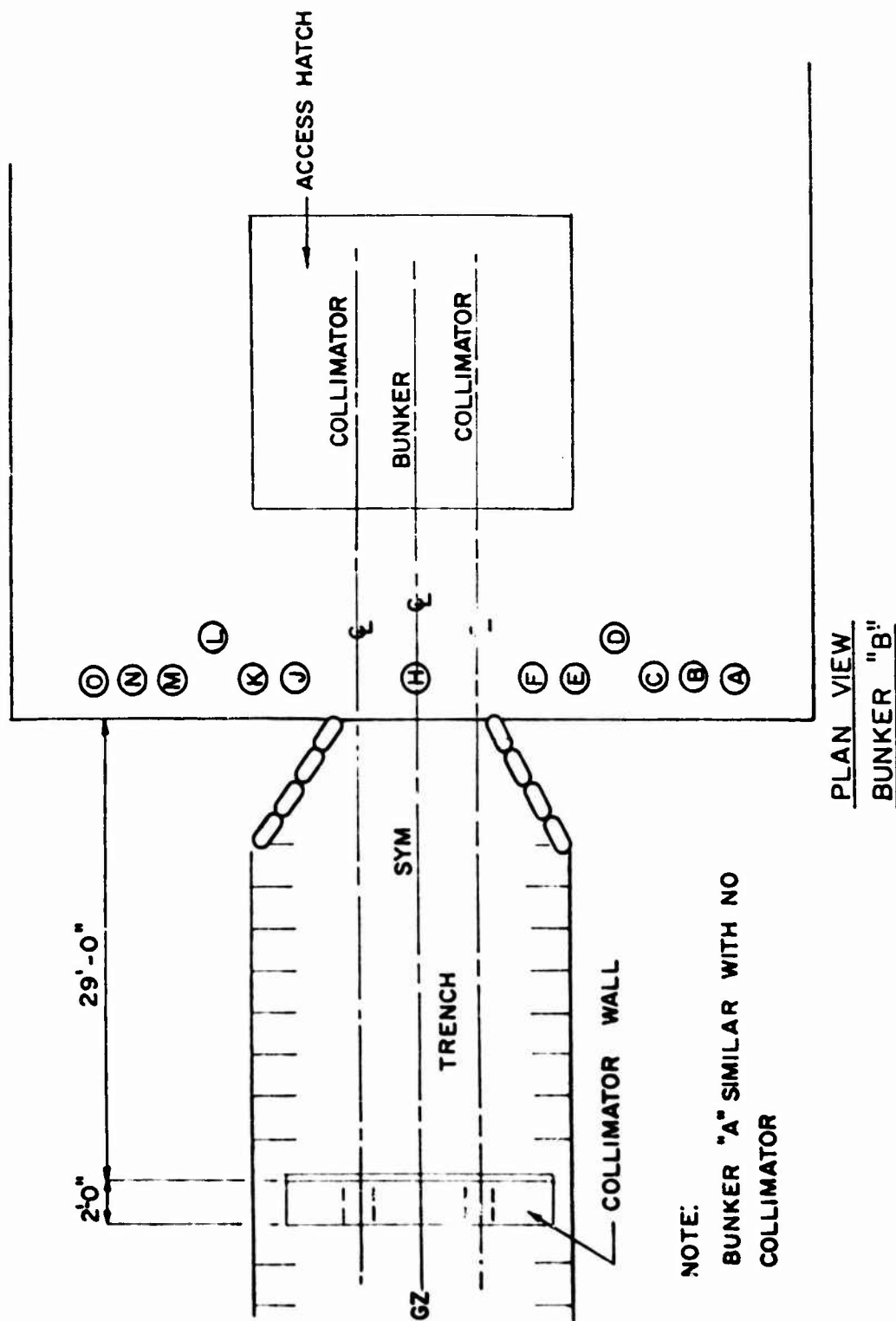


Figure 2.4 (U) Plan drawing of Bunker B. (U)

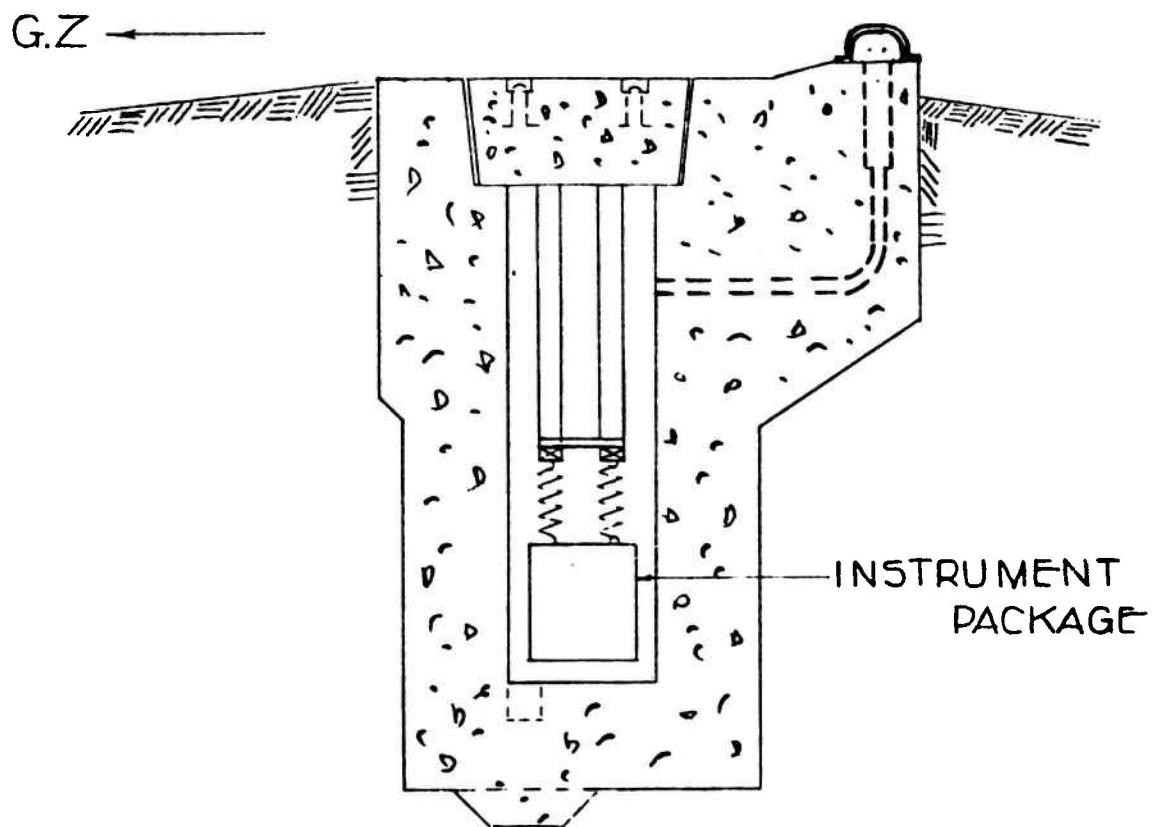


Figure 2.5 (U) Detector installation at EMP pits. (U)

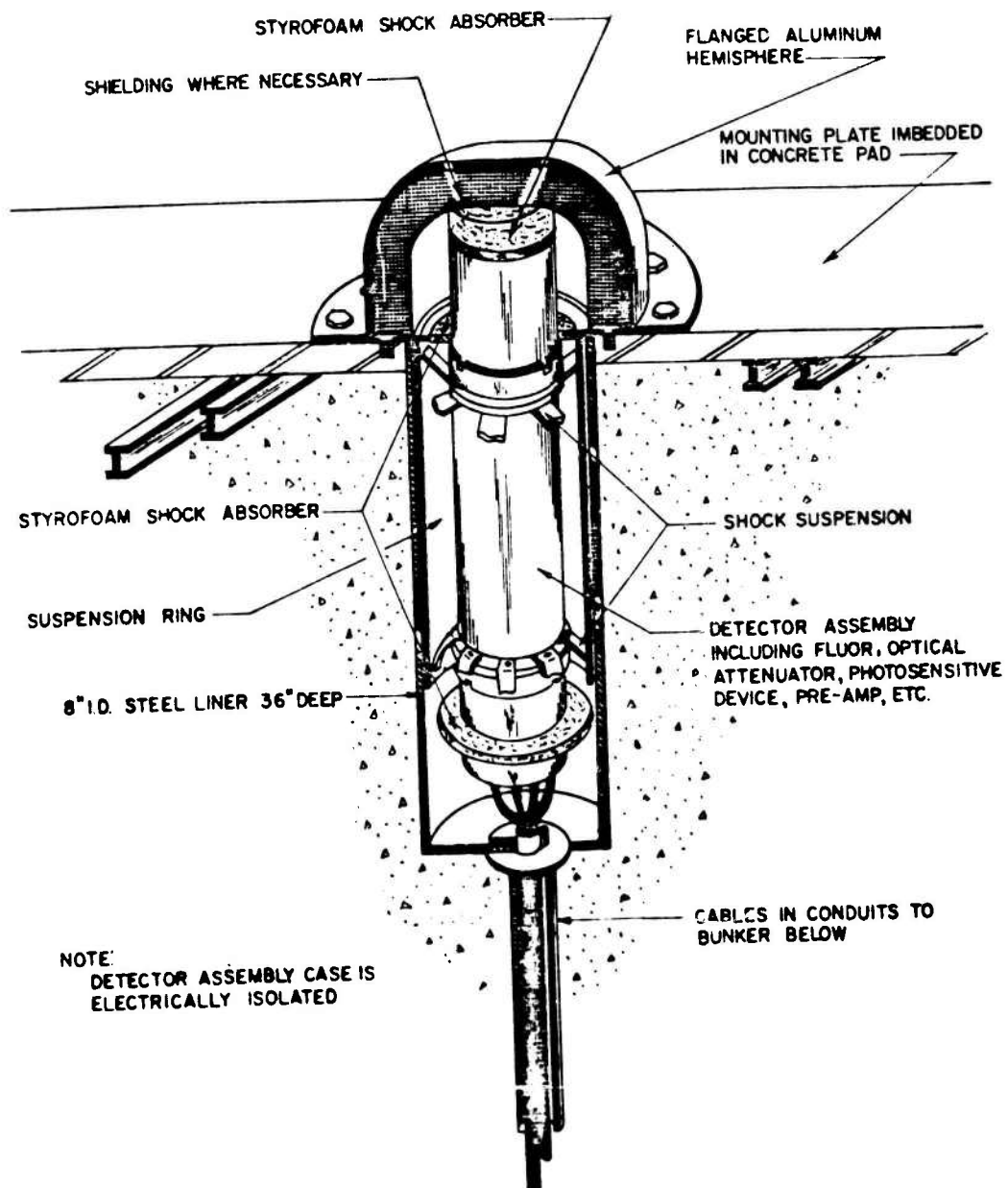


Figure 2.6 (U) 2π detector installation. (U)

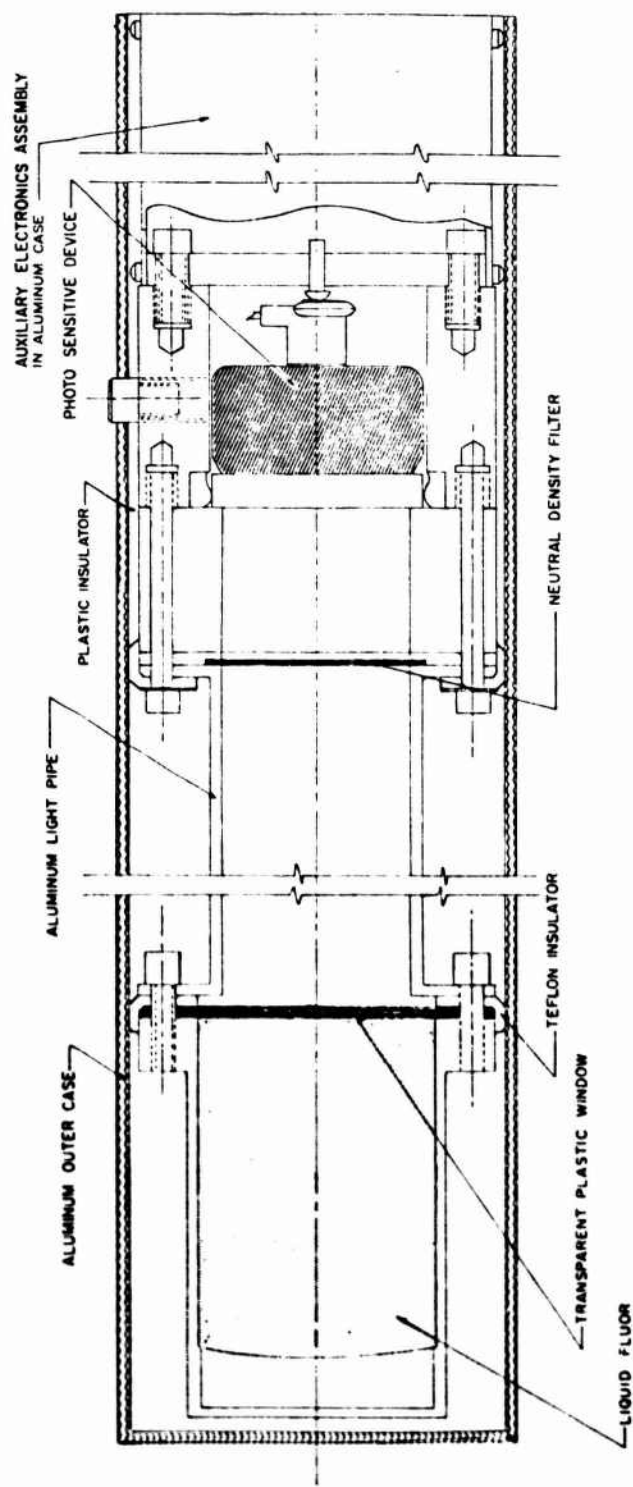


Figure 2.7 (U) 2 π detector assembly. (U)

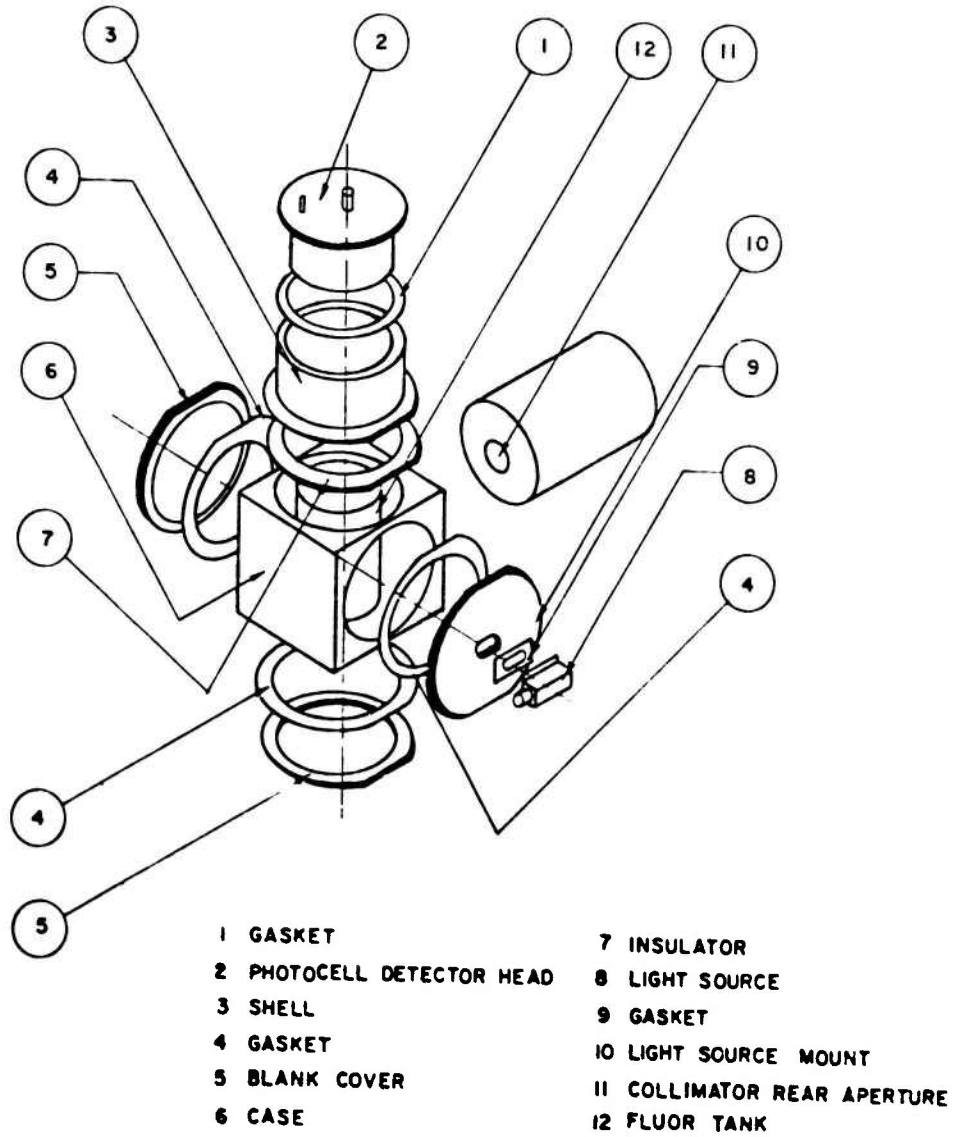


Figure 2.9 (U) Collimated detector. (U)

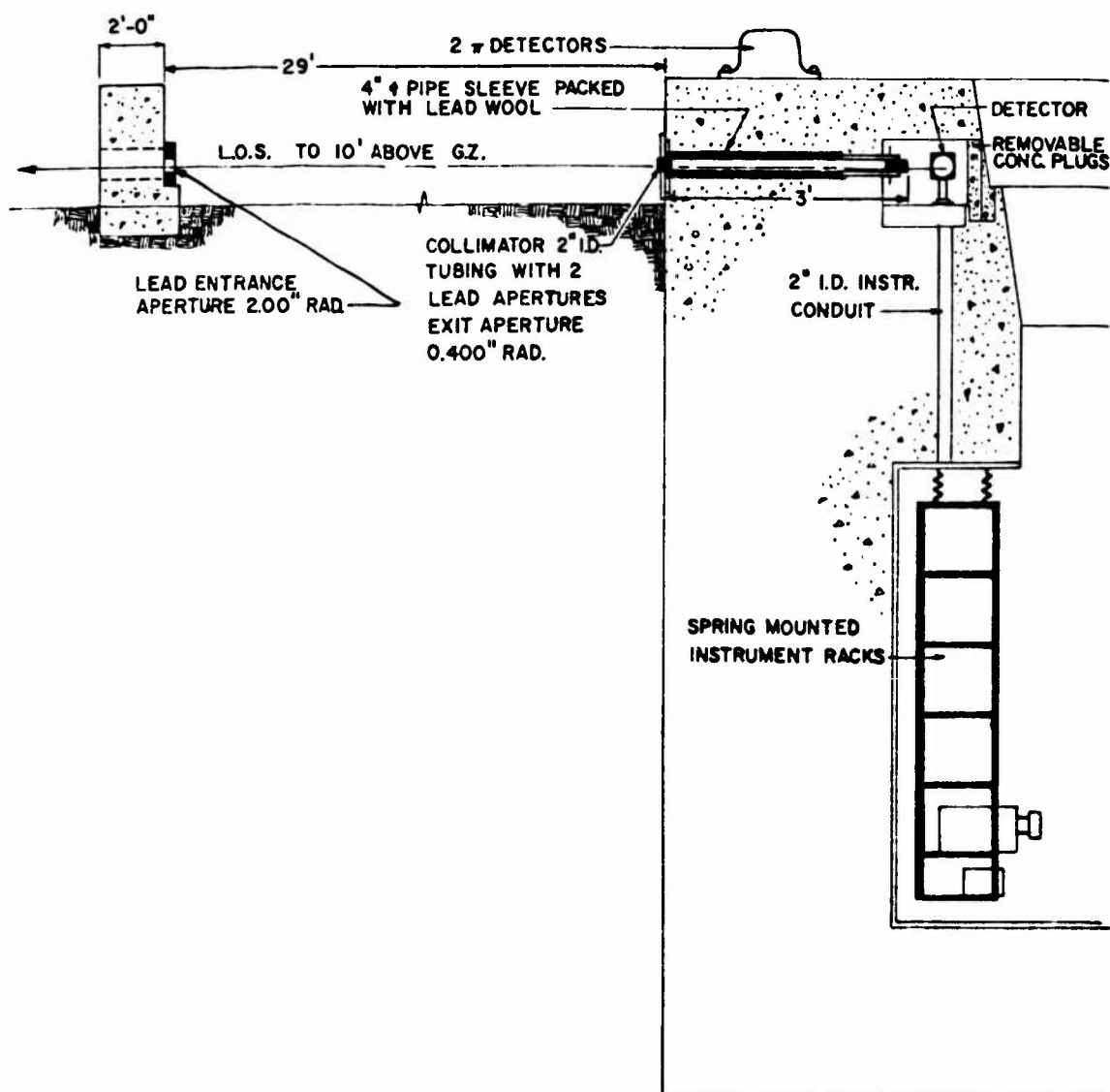


Figure 2.10 (U) Collimator geometry. (U)

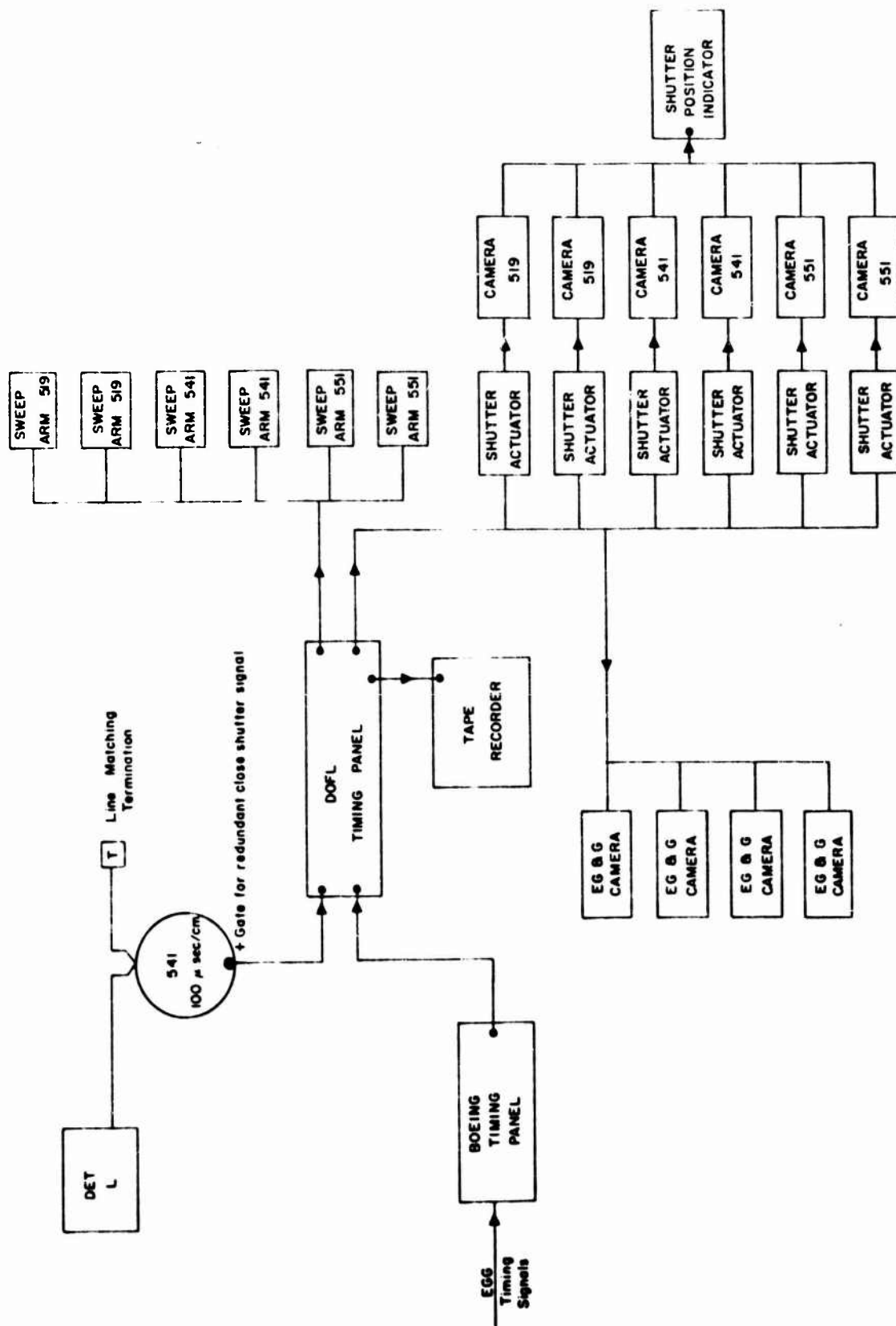
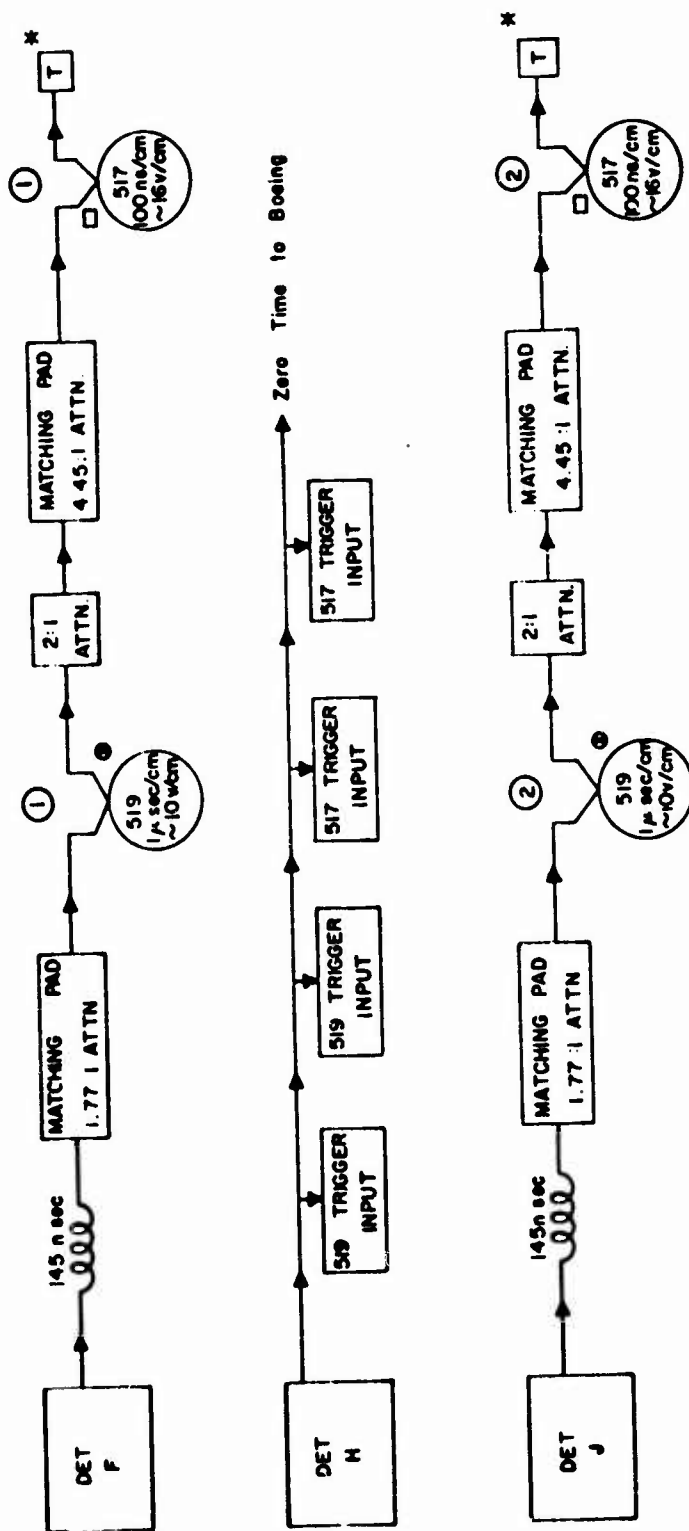


Figure 2.15 (U) Timing system, Bunker B. (U)



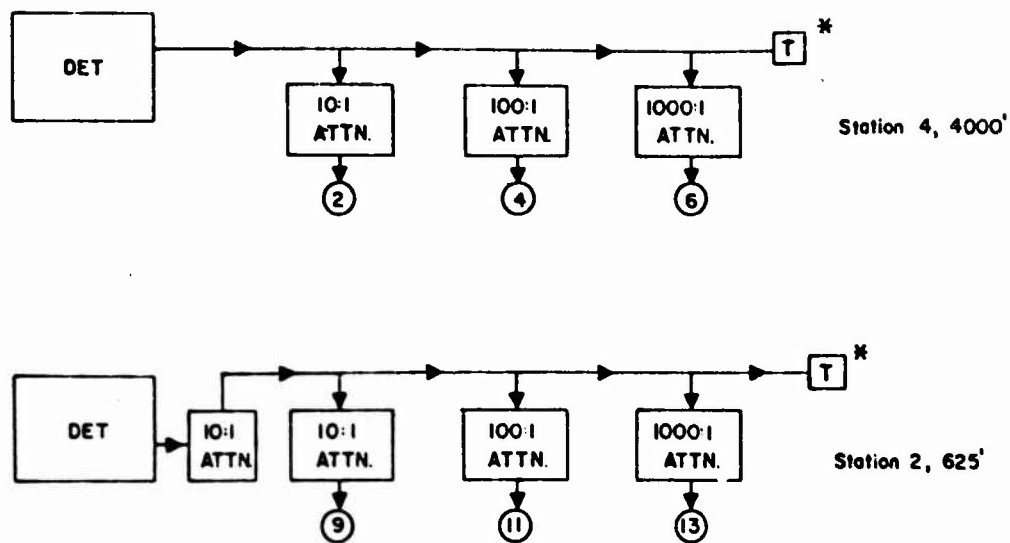
* Line Matching Termination

(2) Indicates Channel Number

● The Signal Was Taken From the 519 After Passing Through the Plates

□ The Signal Was Put Directly Onto the Plates of the 517

Figure 2.16 (U) Recording instrumentation, Bunker A. (U)



* Line Matching Termination

Ⓜ Indicates Channel Number

NOTE: Each Channel Has 10mv
Full Scale Sensitivity

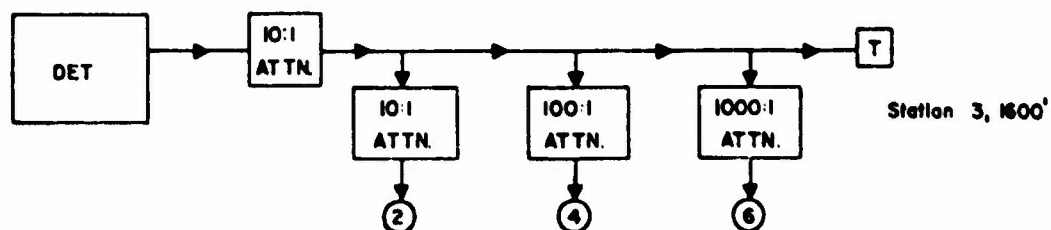


Figure 2.17 (U) EMF pit tape channels. (U)

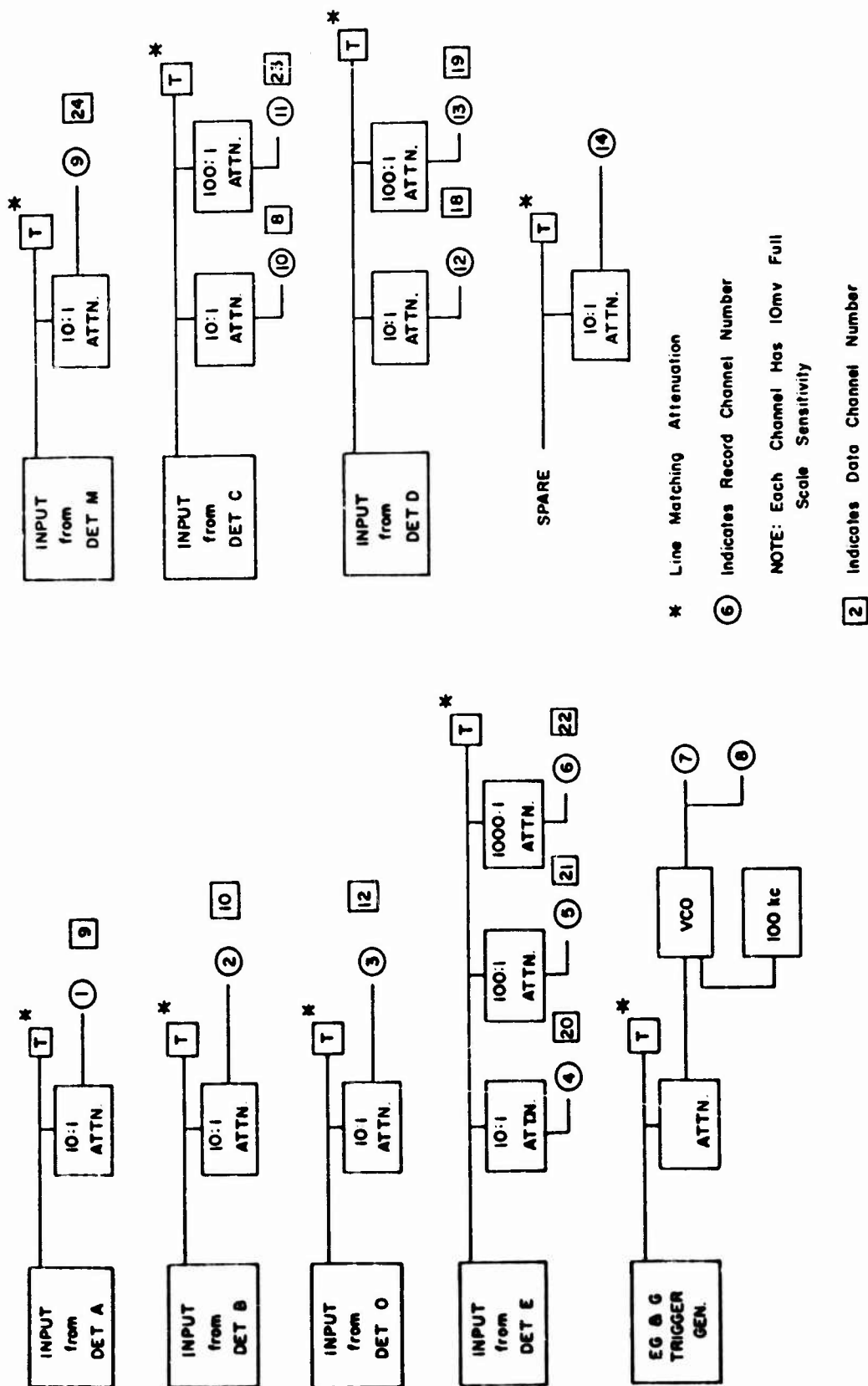


Figure 2.18 (U) Bunker B tape channels. (U)

CHAPTER 3

RESULTS

(4) Project 2.1 was relatively successful in meeting the technical objectives. In addition, a new EMP source was found, the "ground" gamma-rays, resulting from neutron interactions with the soil near a nuclear detonation. There were the usual difficulties with equipment, but some of the data that would have been available from the data channels that had problems could be recovered from other data channels. Of the three major equipment problems (all in Bunker B, at 488 meters), the most painful was the loss of the channels intended to record the gamma-ray peak at 488 meters. EG&G oscilloscopes were used for this measurement and, for reasons that no one has ever been able to determine, were left in the single-sweep mode, armed, but not connected to the arming signal from the timing system. All but one of the four oscilloscopes certainly triggered prematurely, and the data on the fourth is of questionable value. Fortunately, however, peak gamma-ray data was obtained at the 191-meter bunker. The second major problem was the failure of the oscilloscope on the Pb shielded detector, to trigger at the proper time. The gamma-ray trigger signal probably was capacitively coupled around the delay in the trigger line, triggering the oscilloscope early. This resulted in not being able to calculate the gamma-ray rate during the fast neutron arrival time (about

This loss is somewhat mitigated by the fact that the channel did record the peak gamma signal. Finally, the non-linear detector system, intended to measure the very late (after a few milliseconds) gamma-rays, did not produce any signal at all. The reason for this is not known. A summary of the results from each data channel is given in Table 3.1.

(U) Some of the oscilloscope data had to be extracted from traces which were so thin, due to writing speed deficiencies in those oscilloscopes, that normal reading of the traces was impossible. The technique used to "intensify" these traces will be briefly described because it may be useful to others with this kind of data and is quite simple. High contrast contact positives are made of the original negatives and several high contrast prints (negatives) made of each positive, i.e., this must give traces which are dark on a background that is as transparent as possible. These prints are then stacked, carefully registering them, until the signal-to-noise ratio is maximized and this stack read in the normal way. As much as another half-centimeter of readable deflection has been obtained in this way for one of these films.

(U) In the following sections the traces from each oscilloscope or tape recorder channel are reproduced. These are converted to plots of detector current versus time by applying the system recording sensitivity factors and any applicable cable attenuation factors, and finally, the radiation intensities, found via the detector calibration numbers, are given as a function of time.

3.1 OSCILLOSCOPE AND TAPE RECORDER DATA

(U) The data channel sensitivities are given in two forms for the oscilloscope data which follows: The first is the usual deflection sensitivity of the oscilloscope in volts/division at the oscilloscope input; the second is derived from the attenuation in the data channel and is the sensitivity in current at the detector output per division of oscilloscope deflection. Cable attenuation has not been included in these current sensitivities but has been included, in the one case where it was significant, in the detector current plot given in the next section. Only the current sensitivity has been given for the tape recorder data since the voltage sensitivity of the oscilloscope is related to reality only through a long chain of tape recorder channel and playback system sensitivities. A large number of playbacks were made of each of the tape recorder channels, and those reproduced here generally cover the time and amplitude range of interest. Much of the noise seen in the tape recorder data is peculiar to the wide band width FM system used, and some due to the overload properties of the VCO, but some is of external origin. The source of this latter component has not been identified.

(U) The traces from the 191 meter measurement are shown in Figures 3.1a and b. The approximately 100 Mc noise on the 517-1 trace interferes with the signal near the base line but is apparently not responsible for the step just after the peak. The source of the noise is not known. The tape recorder traces are quite noisy.

perhaps obscuring some fine structure, primarily as a result of the recording-playback system mentioned above. The initial excursions in the bottom trace are due to overdriving the VCO. These die out in about 10 microseconds but obscure the early part of the signal.

(U) The 488 meter traces are reproduced in Figures 3.2a thru e. One must look carefully to see the data on 541-1 (Detector C). It is off-scale in the upper right hand corner, but the oscilloscope deflection is still linear with applied voltage. The tape channels on this detector shows one form of the externally generated noise mentioned earlier. Another form of noise, probably due to the severe overdriving this VCO experienced, appears on Tape Channel 12, Detector D. However, there is some evidence that the VCO in this channel was misbehaving, and this noise may be a result.

(u) The one trace recovered from the EG&G scopes is shown at the bottom of Figure 3.2b. The gamma peak was off-scale and there is appreciable noise—origin unknown, but possibly breakdown in the detector high voltage system—so that it is difficult to establish the timing for this trace.

This is interesting but doesn't help with the timing problem.

(u) The 551-1 record for Detector E shows ringing, caused by capacitance in the tape recorder. (The period of the ringing is right for the length of coax between the detector and recorder.) The recorder was not intended to handle pulses with rise times as short as this prompt gamma-ray

pulse and had considerable distributed capacitance as well as a filter designed to increase the pulse rise time to avoid VCO problems. The net result was that although the coax line was terminated in 50 ohms at the recorder, it was shunted by a few hundred picofarads. This problem did not arise on any of the other channels, perhaps fortuitously: Oscilloscope 541-1 on Detector C might have shown it, had it been on scale during the right time period, and Detector M had a Pb shield, considerably attenuating the prompt gamma pulse.

(4)

The trigger signal apparently coupled capacitively around the delay and triggered the oscilloscope in time to record the gamma-ray peak but too early to record the neutron peak.

The lower trace on 551-2 is the blank Pb-shielded detector. The signal is so small that extraneous effects are negligible for the Pb-shielded detectors and probably for the others as well.

(U) The tape recorder data from the 1220 meter EMP pit measurement is shown in Figure 3.3.

(U) Base lines and the sweep and pulse calibrations for the oscilloscopes were recorded on separate films but are not repro-

duced here. The oscilloscope traces were read on a microscope capable of about 5-micron resolution; however, some of the traces are several hundred microns wide. This is what really determines the reading accuracy, which is estimated here to be about 0.2 trace widths. The overall reading accuracy is then between 30 and 100 microns, depending on the trace width, so that the reading process is a minor part of the overall accuracy, except within about one trace width of the base line. The base line traces were read on the same microscope and treated as data in determining the deflection of the data trace. This was essential in reading some of the 519 data since their horizontal traces tend to have considerable curvature unless very carefully adjusted. The overall accuracy of the oscilloscope measurement of detector current as a function of time is probably better than 5 percent, except where the deflection is very small or the signal appears at the start of the sweep (e.g., 519-1 in Bunker B).

(U) The tape data is another matter. Although the recording and playback systems were well calibrated and the traces could be read to about the same accuracy as the oscilloscope data, the noise is a serious problem on some traces. In an effort to alleviate this, the noisier traces were read several times, attempting each time to estimate the location of the signal in the noise and the results of these readings averaged. It is doubtful that the accuracy of the signal amplitude is better than 20 percent for some of these traces, particularly near the base line. However, the timing accuracy

should be comparable to that for the oscilloscope data, since the tape had an accurate timing signal recorded at the same time as the data, and the playback system was tape-speed compensated. Dashed lines have been used in the detector current graphs to indicate severe noise or signals so near the base line that their reliability is decreased.

(4) A word about the timing on the detector current and radiation plots will be helpful:

(1) 191 meters - the gamma-ray peak has been arbitrarily set at and the time scale, as shown, is correct.

(2) 488 meters - It was originally thought that there was no gamma-ray peak data at this station,

This was convenient and slightly expanded the time scale around neutron arrival time. When some gamma-ray data was extracted, it was plotted on the same time scale with the peak arbitrarily set at

so the missing

should not present a serious problem.

(3) 1220 meters - gamma-ray arrival at station used as zero-time, as at 488 meters.

3.2 DETECTOR CURRENTS

(4) 191 Meters. The detector current from Detector F, the NE-211 liquid scintillator, during the prompt gamma pulse is shown in Figure 3.4a. The peak has been arbitrarily set at and

corrected in amplitude by 10 percent for cable attenuation. The short (approximately 35 feet) cable runs had negligible attenuation for any other portion of this signal so that the correction was applied only over the boost period. The noise on the portion of this curve contributed by the 517 oscilloscope is troublesome. The solution adopted was to draw in the dashed line and use it in all that follows. The entire record from this detector is given in Figure 3.4a. The short pulse at about 0.7 microsecond is probably noise, and the dashed line has been used in the subsequent data reduction.

(4) Figures 3.5a and b show the detector current from Detector J, the NE-102 plastic scintillator, in the same format as Detector F. It had been hoped to compare the behavior of liquid and plastic scintillators through these measurements, but the loss of the 517 on this detector made this impossible. The signals from the two detectors are in general agreement,

which may imply that saturation effects are worse in the plastic than in the liquid scintillators. The trace from the 519 on the plastic scintillator is not very good, so that this conclusion is very tentative. Since the data from Detector J is not complete and is not as good as that from Detector F, it will not be analyzed further.

(U) The detector current from the detector at the EMP pit is shown in Figure 3.6. The dashed line indicates that the signal is

near the base line and not as reliable as the rest of the curve.

488 Meters. (U) The Detector C current is shown in Figure 3.7. Over the short period of the oscilloscope data, it is about 25 percent higher than the tape data. The tape data was quite noisy in this region, so the difference is not surprising. The dashed portion of the curve again indicates that the signal was near the base line and of lower reliability. The Detector D current is shown in Figure 3.8. This detector had only the A1 blast shield and was included to allow a comparison with the detector in the EMP pit at 488 meters. The drive belt on the pit recorder broke, so that this comparison was impossible, which is probably somewhat academic, because the Detector D data does not look very good. The one usable data channel was very noisy in the 200 microsecond region and neither the shape of the curve nor the amplitude agree with the data from Detectors C and E. No further analysis of the data from this detector was done.

(u) Quite complete coverage was obtained with Detector E, shown in Figure 3.9. The portion of the curve over which the channel was ringing was obtained by averaging the peak values to obtain the lower frequency component. The decrement of the oscillation was about 15 percent per cycle so that a large error was not introduced by this procedure. The error will be greatest during the rise of the neutron pulse where the signal is changing rapidly and the data is less reliable in that region. The capacitance which produced the ringing would also have reduced the peak of the signal and broadened it, but the integral should be essentially unchanged.

correction for this has not been made because it is impossible to establish the magnitude of the capacitance. The oscilloscope and tape data agree very well in the 30-microsecond interval where they overlap and have not been separately plotted. The dashed curve from 100 to 600 microseconds has been drawn to average what are probably noise pulses and will be used in the subsequent analysis.

(4) The Detector F current is shown in Figure 3.10, where the peak has been arbitrarily set at It was impossible to establish accurately the timing for this trace, but the film shows the trace apparently coming down from the peak at about the right time, so that has been used to locate the origin on this plot. The dashed line drawn through the noise on this data will be used in converting to gamma-ray intensity.

(U) The current from the collimated detector, I, is shown in Figure 3.11. The dashed line at the bottom comes from some uncertainty in the base line and that at the top from a very faint trace.

(U) The detector current from the Pb-shielded Detector K is shown in Figure 3.12. As mentioned earlier, the gamma-ray peak should not have appeared on this detector and is not too reliable because of the heavy Pb shielding. The detector currents from the other two Pb-shielded detectors, L and M, are shown in Figures 3.13 and 3.14, respectively. They agree very well in the region of overlap. Again, the dashed line at the top of the Detector L curve comes from a very faint trace and that at the bottom from a very small deflection.

1220 Meters. (U) The detector current from the detector at

the EMP pit station is shown in Figure 3.15. This detector recorded some of the gamma-rays before neutron arrival, went off scale during neutron arrival and recovered.

3.3 NEUTRON AND GAMMA-RAY INTENSITIES

(U) The detector currents discussed in the preceding section have generally been converted to radiation intensities by straightforward use of the detector calibrations discussed in Section 2.2.3. Those portions of the detector current curves previously identified—usually by dashed lines -- as somewhat questionable have been treated as valid in this section. The detectors at 191 and 1220 meters all had a single type of shield, the aluminum blast shield, so that it was not possible to separate the neutron and gamma-ray components at those stations as it was at 488 meters. However, estimates of these components which seem reasonable can be made at these ranges for at least portions of the measurement time.

191 Meters. (u) The measured prompt gamma-ray exposure rate and that calculated by Malik (Reference 10) are shown in Figure 3.16. The measured peak value is about one-half of the calculated value and in the intensity range where fluor non-linearity may be a factor. There is apparently no information on the saturation characteristics of liquid fluors, but Lauzon and Panaro (Reference 11) have measured the response of plastic fluors at very high radiation rates and given an expression relating apparent sensitivity and radiation rate:

$$\frac{S}{S_0} = (1 + 10^{-4} S_0)^{-1}$$

Where:

S is the effective fluor sensitivity

S_0 is the fluor sensitivity at low radiation rates

ϕ is the incident radiation rate

σ cross section for photon emission by luminescent centers

τ mean lifetime of luminescent centers

The value of $\sigma\tau$ given in Reference 11 for their fluor was 10^{-21} for ϕ in units of $\text{Mev}/\text{cm}^2\text{sec}$. It has been used to calculate the effect of fluor non-linearity for this measurement in the absence of specific data on liquid fluors. This correction has been made to obtain the values given in Figure 3.16, but this is the only detector for which the correction was required. The expression can be rewritten in the form:

$$\phi = \frac{I}{S_0 - I\sigma\tau}$$

where $I(=S\phi)$ is the measured current, allowing the incident exposure rate to be calculated directly from the measured detector current. The correction is 30 percent at the peak current measured here (2.3 amperes), less than 10 percent at currents less than 1 ampere, and less than 2 percent at currents less than 0.5 ampere. The product $\sigma\tau\phi$ in the original expression is 0.3 at the peak current measured, so that if the value of $\sigma\tau$ appropriate to the liquid fluor does not differ from the value used by more than 50 percent, the corrected peak intensity will not be changed by more than about 15 percent.

The pulse height (proportional to σ) for NE-211 is somewhat greater, but the decay time (proportional to τ) is somewhat less than the values for the LRL fluor, tending to cancel each other, so the estimate used here seems reasonable.

(4) The early part of the pulse does not rise as rapidly as the calculated pulse. The 519 oscilloscope sweep speed was almost certainly not that much faster than planned, and the system response was certainly not sufficiently slow to account for it

so there is no apparent explanation for the discrepancy.

(4)

Scintillators have been observed to become opaque, at very high radiation rates, to their own light in several measurements, and the first plateau may be the result of the scintillator recovering from this phenomenon. There is no quantitative information at present on this phenomenon. The second and third bumps may be due to a noise pulse between them — the oscilloscope deflection is rather small at this time — but are thought to be real. There is another explanation which would account for all of them, namely, inelastic encounters between the neutrons and massive objects near the device and with the ground in the immediate vicinity of the device. The first plateau occurs at a time when the neutrons have traveled about one-half meter, the second, about 2 meters, and the third begins just as the neutrons reach the ground.

(4) The measured curve has been re-plotted in the bottom

portion of Figure 3.17, which shows the entire gamma-ray signal measured (and conjectured) at 191 meters. The dashed line shows the ground gamma-rays predicted by the LMC calculation described in Reference 10. The initial portion of the curve results from neutron scattering ($nn'\gamma$) in the ground near the device (and in the air) and is the dominant gamma-ray source out to about 10 microseconds. The final portion results from neutron capture in the ground and is the dominant gamma-ray source out to about 2 milliseconds. The agreement between the measurement and the calculation

is quite good,
as will also be seen at 486 meters.

(u) The rise is due to $nn'\gamma$ reactions in the immediate vicinity of the detector. It was assumed that the gamma-ray rate just at the arrival time of the fastest neutrons was maintained throughout the fast neutron pulse, fell off in about the same way it rose, and followed the calculated value where the data ends.

the reasons
for this depend on the neutron intensities, which are discussed below.

(U) Two of the many possible neutron intensities are shown in the upper portion of Figure 3.17. The solid horizontal bars are from the ORNL calculation, using the Small Boy neutron spectrum discussed

earlier, for the range interval 200.6 to 275.4 meters. The time bins have been modified slightly: the first and part of the second of the ORNL time bins have been combined and shifted slightly to fit the fast neutron arrival time at the station. The total number of neutrons has been conserved and the rates adjusted to compensate for the time bin changes.

(4) In the time interval

the LMC values of gamma-ray flux would give detector currents less than 30 percent of those measured, so that it appears likely that no more than about 30 percent error in the neutron flux would be introduced over this time interval by neglecting the gamma-ray component of the detector current. However, since the gamma-ray measurement agrees so well with the calculation before the neutrons arrive, the neutron flux in Figure 3.17 was calculated from the difference between the measured detector current and that which would have been produced by the estimated gamma-rays shown on that figure.

(4) The situation is somewhat more difficult at later times, particularly where the theoretical neutron and gamma-ray components of the detector current become comparable and add up to approximately the measured current. One approach where the data begins, is to assume that the LMC gamma-ray intensities are correct and calculate a neutron flux from the difference between the measured detector current and the component of current that the assumed gamma-rays would have produced. The neutron flux

resulting from this assumption is labeled "A".

(4) In this same time period, the detector currents that the ORNL calculated neutron intensities would produce are considerably greater than those measured, while the detector currents that the LMC gamma-ray intensities would produce are from only 25 to 30 percent of those measured. Further, the 488 meter data shows that the initial intensity of the neutron capture portion of the ground gamma-rays is probably lower than that calculated by LMC. This leads to the other approach, which is to assume that the gamma-ray component of the detector current is negligible in the interval.

the case is not quite as clear since the theoretical neutron detector currents are only 10 percent greater than those measured, and the theoretical gamma-ray currents are 40 percent of those measured. However, the same assumption has been made in this interval, i.e., that the gamma-ray component of the detector current is negligible, since this will lead to an upper limit for the neutron flux in the entire interval.

the theoretical neutron and gamma-ray detector currents are nearly equal and add up to nearly 90 percent of that measured. The theoretical neutron current has been assumed in this interval. The final time bin, contains very few neutrons. On the basis of neutron curve "A" in Figure 3.17, essentially all of these neutrons are assumed to reach the detector and the corresponding flux used as the neutron

Figure 17. The results of all of this are labeled "L" in the neutron curves in Figure 17 and the gamma-rays estimated on the basis of these assumptions similarly labeled "B".

(3) The measured detector current results only from gamma-rays are those after t_1 and is shown by the solid curve in Figure 17. If the neutron current becomes negligible before t_1 , the gamma-ray intensity can be found directly from the detector current.

3.4.4.4. Example. (4) Both Pb and CH₂ shielded detectors were used at the same time, so that it is possible to determine the neutron and gamma-ray components of the radiation directly over most of the measurement interval. These are found by solving the pair of simultaneous equations discussed in Chapter 1 for each value of time at which the radiation intensities are desired, using the values of the detector currents and sensitivities at that time. The time interval over which this could be done began where the Pb-shielded detector data starts, and ends where both the Pb-shielded detector data and the majority of the neutrons expire. The system was apparently well-behaved, except in calculating the gamma-ray intensity. The condition that the calculated value of the gamma-ray intensity be positive is that $(S_{1n} I_2 - S_{2n} I_1)$ have the same sign as $(S_{1\gamma} S_{2n} - S_{2\gamma} S_{1n})$, which was always positive for these detectors, so that a solution always exists. The basic problem lies in the fact that there are uncertainties in both the detector sensitivities and the current measurements. If

both of these were sufficiently accurately known, the solution of this pair of equations would always be positive. In practice, however, it may be necessary to find the flux from the difference of two rather large numbers, so that a 10 percent error can easily change the sign. The quantitative effect of errors in a detector system of this type is discussed in Reference 12.

(4) All of the gamma-ray data from the 488 meter measurement appears in the lower portion of Figure 3.18, which also includes Malik's calculated value for the peak and the LMC values for the ground gamma-rays (the dashed curve). The data from Detectors F and K are included because they are the only measurements in the region of the peak. As previously discussed, both of them are troubled by timing and base line uncertainties, and Detector F is very noisy over much of its range. The uncertainties will be most severe for timing at the beginning of the trace and for amplitude below about 20 percent of the maximum amplitude for Detector K and 5 percent for Detector F.

(4) It was again necessary to estimate the gamma-ray intensity during the early part of the neutron signal. Essentially the same approach was used as at the 191 meter station. The gamma-ray intensity before neutron arrival appears to be about 80 percent of the LMC value but appears to coincide fairly well for a short period

The $nn'\gamma$ component was again assumed to increase, as the data shows, then to be constant during the very fast neutron arrival period, i.e., from

which time the data probably represents the fall-off of the $nn'\gamma$ component. The estimated $nn'\gamma$ rate is shown as a dotted line in Figure 3.18.

there is no significant neutron component in the detector currents, so that the gamma-ray intensities may be calculated directly from the detector sensitivities. Detectors E and C agreed so well over this region that Detector C data has been shown only where it extended the measurement range.

(4) The gamma-ray signal from the collimated detector is also shown on Figure 3.18. This signal comes down to about the gamma-ray level that would be expected for the Small Boy device from the decay of isomeric states in fission products measured in the laboratory by Walton and Sund (Reference 3).

(4) Detectors L and M agree within a few percent over most of their common range except in the interval from about microseconds, where the difference slowly increases to about 20 percent and then again becomes negligible. These detector currents were averaged over this interval and the result used in calculating the neutron and gamma-ray intensities. The neutron intensity is shown in the upper portion of Figure 3.18, where the fast neutron peak shown has been calculated from the Detector E current on the basis of the estimated gamma-ray intensity shown on Figure 3.18 for that time period. The neutron intensities calculated for the Small Boy neutron spectrum from the ORNL results are shown on this figure for comparison (the first two time bins in that calculation have been combined, again conserving neutrons and adjusting the rate, to fit

the fast neutron arrival time at this station).

(4) Figure 3.19 gives the neutron flux derived from the collimated Detector I measurement. The 2π neutron flux is also shown for comparison.

1220 Meters. (4) There was only a single detector at this range. It was at the EMP pit and, like the detectors at 191 meters, had only the Al blast shield. Much the same circumstances obtain here as at 191 meters in that the measured detector currents are less than would be expected from the calculated neutron flux over most of the measurement interval, and the same approach to analysis has been used. The gamma-ray intensities are shown in the lower portion of Figure 3.20, where the neutron capture component of the ground gamma-rays, shown as a dashed curve, has been calculated from the LMC expression given in Reference 10. The neutron intensity resulting from assuming this gamma-ray intensity is shown in the upper portion of Figure 3.20 as the curve labeled "A".

(u) From the detector current that would result from the calculated neutron intensity is less than that observed, so it was subtracted from the measured detector current and the remaining detector current assumed to be due to gamma-rays. The gamma-ray intensity is, as before, assumed to be zero

(where the recorder recovered from being over-driven) to about giving an upper limit to the neutron intensity. The values resulting from these assumptions are labeled "B" in Figure 3.20. The gamma-rays in the

before neutron arrival at the station, and those
are not affected by either of these assumptions.

3.4 DISCUSSION

(4) The gamma-ray and neutron intensities interact in much of this measurement and it is probably worthwhile to examine the neutron measurements in a little more detail so that their implications with respect to the gamma-ray measurements will be clear. The neutron intensities resulting from this measurement are generally lower than those calculated by ORNL, and it is difficult to choose among the many possible explanations. The neutron sensitivities of the detectors are very low at the later times — because the neutrons are of low energy — and the apparent neutron intensity can change greatly without seriously affecting the apparent gamma-ray intensity. This appears explicitly in the figures for the 191 and 1220 meter stations and is also true at the 488 meter station, so that the gamma-ray intensities reported here for all three stations i.e., just before and during the decay of the capture component of the ground gamma-rays, are on reasonably solid ground.

(4) During the period between the end of the neutron scattering component of the ground gamma-rays the only reasonably solid data is that at 488 meters. The neutron sensitivity of all the detectors is higher here than at later times, and the deviation from the ORNL values is substantial. Fission-foil measurements of neutron fluence were made by the Nuclear Defense Laboratories at these three stations. Some of those results, from Reference 13,

together with the fluence obtained by integrating the ORNL results and the HDL 488 meter results are given in Table 3.2 under the heading "Total". Integral values have also been given for each of the neutron rates assumed at 191 and 1220 meters and are listed under the heading "Partial". Where the HDL measurement terminates in one of the ORNL time bins, the bin has been truncated as if the neutron distribution were uniform with time in the bin, so that the integrals are over the same time intervals (the fission-foil measurements are independent of time). The values in parentheses are the ratios of the measurements to the ORNL values.

(4) The first point to note is that the ORNL values at the first two ranges are slightly higher than the NDL plutonium measurements, even though the ORNL low energy cut-off was 110 Kev, considerably higher than the 10 Kev threshold of Pu. The second point is that the integral of the time resolved measurement lies between the Pu and Np values—about what would be expected from the energy sensitivity of these detectors. Thus, it is not surprising that the ORNL results are generally higher than the results of this time resolved measurement. This argument applies primarily to later times, since that is where most of the neutrons arrive. At intermediate times there is little basis for choice between assigning the problem to the neutron cross-sections used in the calculation or to the neutron energy calibration of these detectors.

(4) At 191 meters, assumption B leads to a ratio (to the ORNL results) very close to that observed at 488 meters, giving some support

to the conjecture that the ground gamma-rays at 191 meters are also lower than predicted by the LMC calculation during the early part of the neutron capture component. At both 191 and 488 meters, they apparently build up to about the level predicted by the LMC calculation and fall off about as predicted.

(4) The ratios for both assumptions at 1220 meters are close to that at 488 meters, so the use of even that rather shaky crutch is denied.

(4) There is one further bit of information relevant to the gamma-ray intensities that can be extracted from the Small Boy measurements and a measurement made at Shot Hood during Operation Plumbbob. The measurements at Small Boy made by HDL and those made by EG&G at 860 meters (with a 2π detector) together with those made by NRL (Reference 14) at Shot Hood and the LMC calculation of the neutron capture component of the ground gamma-rays for Small Boy are shown in Figure 3.21. The ordinate is relative intensity for each curve only, since the individual curves have been moved vertically to allow easy comparison of their slopes. Also, the curves for the HDL 488 meter measurement and the LMC calculation represent gamma-ray intensity, while the others are detector current, which will include contributions from any neutrons present. These curves represent the data over their entire range

(u) The interesting point about these curves is that, except for the HDL 1220 meter measurement and the LMC calculation, they all have essentially the same slope,

The HDL 488 meter data should not have any neutron component and the ORNL calculation indicates that after

All of this suggests that the primary component of the detector current is due to gamma-rays, except possibly at 1220 meters, and that the gamma-ray decay time in this time period is shorter than that predicted by the LMC calculation. The average decay time, excluding the 1220 meter data,

If the neutrons are actually negligible over this time period, the gamma-ray intensity can be found directly from the detector current at 191 meters (it has not been shown on Figure 3.17). There does not seem to be a ready explanation for the 1220 meter behavior. Also, the difference in geometry between the Small Boy and Hood shots makes comparison difficult, so that the agreement between the Hood measurement and the rest of the Small Boy data may be fortuitous.

(u) At later times, the decay times of both the 191 and 488 meter data approach that of the LMC calculation and generally agree with it

(u) Neutron fluence values are given in Table 3.3 for 191 and 488 meters.

Columns 3 through 5 show the integrals of the HDL 2π detector measurements and the ORNL results (for all energy groups) over the time intervals indicated. The time intervals, extend from neutron arrival at the HDL detector to the first break in the curve at the bottom of the peak. Where it was necessary to partition one of the ORNL time bins, it was again assumed that the neutrons were uniformly distributed in the bin.

The agreement between the ORNL and HDL values for both the shorter time interval at 191 meters and the 488 meter results is quite good in view of the approximations involved. The integrals in the longer interval at 191 meters differ substantially and again, as at 488 meters, the ORNL value is higher. The last column gives the predicted fluence calculated from the device neutron output

for comparison with the integral of the collimated neutron

flux at 488 meters.

(4) The assumptions made concerning the gamma-ray intensities during these time periods do not substantially affect the measured neutron flux values since the neutron-induced component of the detector current was a large fraction of the total current. This is not the case at intermediate times at 191 and 1220 meters, as was discussed earlier, and there seems to be no apparent way to attack this problem, beyond the approach used, until more complete neutron calculations and detector calibrations are available.

TABLE 3.1 (U) SUMMARY OF DATA OBTAINED (U)

TABLE 3-1 (C) SUMMARY OF DATA OBTAINED (C)							
	Detector	Shield	Oscilloscope	Tape Channel	Function	Data	Remarks
<u>191 Meters</u>							
Bunker A	F	A1	517-1		Y peak	Yes	
			519-1		Y, n	Yes	
	J	A1	517-2		Y peak	No	Only partial sweep.
			519-2		Y, n	Yes	
EMP Pic.		A1		9,11,13	Y, n	Yes	
<u>488 Meters</u>							
Bunker B	A	A1+CH ₂		1	Non-linear	No	None of the non-linear detectors had any apparent output.
	B	"		2	Y Det.	No	
	C	"	541-1		n & late Y	Yes	
				10,11	"	Yes	
	D	A1		12,13	n & late Y	Yes	
	E	A1+CH ₂	551-1		Y, n	Yes	
				4,5,6	Y, n	Yes	
	F		3343-1		Y near peak	Yes	Trigger time is uncertain.
			3445-1		Y peak	No	Triggered early, no trace.
	G	Collimated	3343-2		Y near peak	No	Triggered early, no trace.
			3445-2		Y peak	No	Triggered early, no trace.
	I	Collimated	551-1		Y, n	Yes	
	J	A1+CH ₂	519-2		Blank Det.	No	No sweep.
	K	A1+Pb	519-1		n(14 Mev)	No	Triggered on Y and gave some Y data.
	L	"	541-2		n (Fiss)	Yes	
	M	"	551-2		"	Yes	
				9	"	Yes	
	N	"	551-2		n Blank Det.	Yes	
	O	A1+CH ₂			3	Non-linear Blank Det.	No
EMP Pic.		A1		2,4,6	Y, n	No	Tape recorder drive belt broke.
<u>1420 Meters</u>							
EMP Pic.		A1		2,4,6	Y, n	Yes	

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

(U) The primary objectives of this measurement were met, resulting in nearly complete gamma-ray data at 191 and 488 meters, with partial data obtained at 1220 meters, and nearly complete neutron data at 488 meters, with partial data at 191 meters.

4.1 GAMMA RAYS

(u) The peak gamma-ray rate obtained at 191 meters was r/sec, about 50 percent of the predicted value, and the measured peak is narrower. There is more structure apparent in the measured peak, which may be due to neutron interactions in the immediate vicinity of the device or to non-linearity in the scintillator used. This point cannot be resolved on the basis of present information. At 488 meters, the measured peak gamma-ray rate was about 40 percent of the predicted value, although this measurement is not regarded as very reliable. However, both of these measurements indicate that the peak rate could have been somewhat lower than that predicted. The 191 meter data also indicates that the rise time was somewhat longer than predicted.

(u) In the period both the 191 and 488 meter measurements show gamma-ray intensities up to a factor of five higher than that given by the LMC Monte Carlo calculation for Small Boy, probably due to nn'γ in the ground near the device.

During the time from

at the 191 and 488

meter stations, the measured gamma-ray intensities agree to within about 20 percent with the LMC results. The 488 meter measurement also agrees well with the LMC results

and the 191 meter data is not inconsistent with the LMC results in this time period. On the basis of this data it appears that the LMC results for the fast component of the gamma-rays (air and ground neutron inelastic reactions) are valid, but the interval between the needs more attention.

(4) The collimated measurement at 488 meters shows that the gamma-ray rate from the device itself falls

the level expected from decay of isomeric states in the fission products.

(4) The 488 meter data indicates that the gamma-ray intensity drops to a considerably lower level than that given by the LMC calculation in the time period immediately after decay of the fast gamma-ray component. This conclusion is not inconsistent with the 191 or 1220 meter data. The 488 meter data shows that the ground capture component increases from this very low value to about 30 percent greater than the LMC result and then decays somewhat more rapidly than the LMC result. The 191 meter data and other measurements at Shots Small Boy and Hood show this same rapid decay. The average decay time from the measurements (neglecting the 1220 meter Small Boy measurement,

which had an anomalously fast decay rate) is about 50 percent of that given by the LMC results.

At later times the measured decay time approaches the LMC value. The difference in decay times could result from either the assumptions of the LMC calculation or, possibly, to the neutron calibration of the detectors used in these measurements. This question cannot be resolved on the basis of present information but should be investigated.

4.2. NEUTRONS

(a) The only reasonably firm neutron data obtained at 191 meters was the neutron peak. The peak rate observed was

(b) The 2nd detector measurements at 455 meters gave peak rates

(This second value is from detector E, which had an integrator with a time constant not known with any accuracy.) The integral of the second measurement is

(c) The collimated detector at 488 meters gave a

The integral of this peak is which agrees well with the

value of calculated from the predicted device output.

(4) The only firm neutron data other than that on neutrons was obtained at the 488 meter station. It is generally lower than the values calculated by ORNL and is in reasonably good agreement with the NDL measurement. The neutron data obtained at 191 and 1220 meters is not inconsistent with this conclusion. The ORNL values are generally higher than either the HDL or the NDL values, a circumstance difficult to reconcile with the conditions of the determinations. There is, therefore, a three-way inconsistency that cannot be resolved on the basis of present information (fortunately, it does not seriously affect the gamma-ray intensities reported here). A recalculation of the neutron transport for the Small Boy geometry and a more detailed calculation of the neutron detector calibrations might provide the answer.

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