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Project Officers Report—Project 2.1

External Neutron Flux Measurements

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Edgewood Arsenal, MD

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The objective of this project was to measure the neutron flux as a function of distance from high-altitude nuclear detonations. The threshold detector system was used to measure the flux. Gold, U^{235}, Pu^{239}, Np^{237}, U^{238}, sulfur, magnesium, aluminum, and zirconium foils were employed as detecting materials. Instrument pods carried aloft by the launch vehicles were used to position the detectors near the detonation. Four sets of instruments were placed in each of three pods for Shots Blue Gill Triple Prime, King Fish and Starfish Prime.

The project was considered a success because it obtained data in all events.

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FOREWORD

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

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

ABSTRACT

The objective of this project was to measure the neutron flux as a function of distance from high-altitude nuclear detonations.

The threshold detector system was used to measure the flux. Gold, U^{235}, Pu^{239}, Np^{237}, U^{238}, sulfur, magnesium, aluminum, and zirconium foils were employed as detecting materials. Instrument pods carried aloft by the launch vehicle were used to position the detectors near the detonation. Four sets of instruments were placed in each of three pods for Shots Blue Gill Triple Prime, King Fish, and Starfish Prime.

Measurements of the neutron flux were made at three distances from Shot Blue Gill Triple Prime. Neutrons with energies greater than

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The measured total flux

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this project was to measure the neutron flux as a function of distance from high-altitude nuclear detonations.

1.2 BACKGROUND

Neutrons that are produced in excess in both the fission and fusion processes and pass into the media surrounding the reacting mass have been measured during almost all nuclear-weapon tests since Operation Sandstone. Measurements made of the neutrons that completely escape the physical boundaries of the device being detonated are referred to as external-neutron flux measurements. The determination of the number and energy of neutrons in the external environment of nuclear devices detonated at high altitudes is of prime importance in the evaluation of their effect on electronic and nuclear systems.

Both collimated and uncollimated flux measurements have been made (References 1 through 23), the latter being more common. This type of measurement has usually involved placing detecting media at various distances from the point of detonation. A myriad of physical arrangements has been used to obtain measurements on the surface and at low altitudes. High-altitude measurements have been made by carrying the detecting media into position in pods attached to the shot vehicle and in the pay loads of auxiliary rockets.

In the measurements of the uncollimated flux, the total flux at the detecting station has been measured with no consideration given to the angular distribution.

Neutron detectors of various types have been used. The usual method of detecting neutrons from nuclear detonations, however, has been by the use of small amounts of materials that are activated through nuclear transformations involving neutron capture or fission. The emissions from radioactive isotopes produced in these materials are measured and correlated directly with the neutron flux to which the materials have been exposed.

Prior to Operation Teapot, most measurements were made of slow neutrons (using gold as a detector) and fast neutrons (using sulfur as a detector). However, other materials, such as arsenic, tantalum, copper, and iodine, have also been used. During Operation Teapot, the fission-foil method of measuring fast neutrons was first successfully used on a large scale. This method gave the first indication of spectrum that was complete enough to allow the calculation of neutron dose. The measurement of neutron flux from nuclear devices detonated at high altitudes was first attempted at Operation Hardtack. Time-of-flight measurements were made by the Naval Research Laboratory (NRL) (Reference 24), and threshold detectors were flown by Sandia Corporation and Nuclear Defense Laboratory (NDL). These measurements, although limited in scope, gave a valuable insight into the external neutron environment of devices detonated at high altitudes.

1.3 THEORY

To theoretically determine the number and energy distribution of the neutrons produced by a nuclear detonation, the following must be known: (1) the source strength, (2) the attenuation and degradation caused by the case and the reentry vehicle (R/V), and (3) the manner in which the neutrons behave as they move from the point of detonation to the point of interest. The weapons laboratories usually have a prediction of the source strength for standard devices; however, the complexity of the various modifications to accommodate these devices to various reentry vehicles make the calculation of the neutron flux and spectrum at the exterior of the R/V difficult.

Many laboratories and scientists are now studying the transport of neutrons through the atmosphere. Computer codes have been written which follow a neutron on its flight path, and with these codes, the calculation of the flux and spectrum at any point is possible. However, most codes make simplifying assumptions which, in many instances, cause the results of the computations to be in error. A new, all-inclusive code is now being written by Los Alamos Scientific Laboratory (LASL) in cooperation with the Defense Atomic Support Agency (DASA). It is expected that this code will include not only cases at the ground-air interface but also cases at altitudes comparable with those that are described in this report.

CHAPTER 2

PROCEDURE

2.1 OPERATIONS

During **Fish Bowl,** Project 2.1 participated in all events for which the Thor was used as a launch vehicle. The events designated as Tiger Fish, Blue Gill, Blue Gill Prime, Star Fish, and Blue Gill Double Prime produced no nuclear environment. However, in most instances, project instrumentation was recovered and reused. The events Blue Gill Triple Prime, King Fish, and Star Fish Prime, were detonated as expected, and the results of measurements made during these events are described in this report. Table 2.1 lists parameters pertinent to these nuclear events.

All project instrumentation was contained in the rear bulkhead of three recoverable scientific instrument pods. These pods were attached to the launch vehicle and released at the proper time during the early part of the trajectory, to place them at various distances from the point of detonation. A complete description of the pods can be found in Reference 26. Figures 2.1 and 2.2 show the location and orientation of the Project 2.1 instrumentation in the pods. Table 2.2 lists information pertinent to the pods for the three nuclear events.

All pods from Blue Gill Triple Prime were recovered and returned to Johnston Island by H+8 hours. The neutron detection packages were removed and returned to the NDL mobile laboratory for analysis. The rear bulkhead of Pod B-2 was severely damaged; however, all neutron instrumentation except that located in Quadrant 4 was intact. The package in Quadrant 4 was so badly damaged that no information could be obtained.

Pods 1 and 2 from Shot King Fish were returned to Johnston Island at approximately H+6 hours. The neutron instrumentation from Pod K-1 was removed and returned to the NDL mobile laboratory. The rear bulkhead of Pod K-2, which contained the neutron instrumentation, was missing when the pod was delivered to Johnston Island. Only the nose of Pod K-3 was found.

The pods from Shot Star Fish Prime were returned to Johnston Island between H+8 and H+10 hours. Pod S-1 showed signs of reentry damage, and the rear bulkhead was bent near Quadrant 1. The neutron instrumentation in that position was missing. Although Pods S-2 and S-3 showed some signs of damage, all neutron instrumentation was intact. As soon as initial examination and preliminary photography were completed, the neutron packages were removed and returned to the NDL mobile laboratory.

The location of the neutron instrumentation in the rear bulkhead of the pod presumed an orientation of the pod at detonation which would allow the instruments to look at the burst only through their covers and protective coatings (3/16-inch refrasil for Shots Blue Gill Triple Prime, and King Fish, and 3/16-inch carbon for Star Fish Prime). Any other orientation would place segments of the pod mass and other instrumentation in the angle of view and consequently introduce unknown quantities of shielding and scattering. The introduction of these unknown quantities would make interpretation of both the flux and spectral data extremely difficult.

The orientation of the pods during Shots Blue Gill Triple Prime and King Fish was apparently as planned. The good agreement of the neutron data from the four quadrants as well as the general observation of burn shadows, etc., seemed to substantiate proper orientation. During Shot Star Fish Prime, pod orientation was estimated by Project 8B (Reference 27) by the measurement of the X-ray shadows cast by various pod fittings. Two angles were determined to give pod orientation. The first, θ, was the angle between the longitudinal axis of the pod and the burst in the plane formed by this line and point. The second angle, Φ, measured the roll attitude as the angle between the burst point and the YY-axis of the pod in the plane of the rear bulkhead. Figure 2.3 is a diagrammatic representation of these angles. The angles θ and Φ for Star Fish Prime are listed in Table 2.3.

2.2 INSTRUMENTATION

Instrumentation consisted exclusively of the NDL threshold detector system (References 13, 19, and 25). This system is composed of a series of materials activated through neutron capture or fission by neutrons with energies above a threshold energy. Table 2.4 lists the materials used, the reactions, their threshold energies (E_t), and their effective cross-sections (σ_{eff}). It should be noted that U^{235} and Pu^{239} do not possess natural thresholds. However, by the use of an enriched B^{10} shield, an artificial effective cross section can be produced. The threshold energies and effective cross sections are determined by the thickness and density of the boron shield. Shields with a penetration density of 2.2 gm/cm^2 of shield surface were used during this experiment. Figure 2.4 shows this boron shield and the arrangement of the various foils within it. Although it is not necessary to place any of the foils except the U^{235} and the Pu^{239} in the boron shield, all foils except zirconium and gold are assembled within it for convenience. The boron shield, the zirconium foils in their shield, and the gold foils were assembled in an aluminum container for placement in the pods. Figure 2.5 shows the arrangement of these detectors. Figure 2.6 shows the foils ready for assembly into a completed package.

After exposure, recovery, and return of the foils to the NDL mobile laboratory, the induced radioactivity produced in the foils by neutron interactions was measured. Using previously determined calibration constants, the neutron flux required to cause the observed activation was calculated.

2.3 CALIBRATION

Periodic calibrations of the threshold detector system have been made since 1956. A major recalibration of the system was made during the period 1 April [illegible] 1959. The results of these calibrations as w[illegible]ete calibration procedures are described in Referen[illegible] 25.

Because of improved techniques for determining calibration fluxes and flux depression factors, a complete recalibration of the threshold detector system was accomplished during January 1963. Changes in the calibration constants of between 15 and 20 percent were noted for some of the detecting materials. Others did not change at all or the change was insignificant. Complete results of this calibration experiment are described in Reference 28.

Because of the special equipment required for measuring the activation induced in zirconium (see Section 2.4), the calibration of these foils was accomplished during the period the project was in the field. The results of this calibration are also reported in Reference 28.

The data presented in this report was calculated utilizing the latest calibration constants. These are summarized in Table 2.5.

2.4 COUNTING EQUIPMENT

Scintillation-counting techniques were used to measure the activities induced in the various detector materials. These techniques were selected so that the same equipment, with minor changes, could be used for all measurements. The counters were assembled from standard, commercially available equipment.

Two types of scintillators were used. Gamma activities were measured with a 1- by 1 1/2-inch NaI(Tl) crystal mounted on an RCA 6655 photomultiplier. In the case of beta activities, a scintillator-type plastic phosphor replaced the NaI crystal.

The gold samples were placed on a 1/16-inch-thick aluminum holder for measurement. This holder was machined to fit on the NaI crystal. The electronics system was biased at approximately 300 kev which permitted measurement of the 411-kev gamma rays emitted by Au^{198}. The calibration and monitoring of the electronics system was accomplished with an Sb^{125} source.

The equipment used to measure the gamma activity resulting from the mixed fission products in the fission detectors (U^{235}, Pu^{239}, Np^{237}, and U^{238}) was exactly the same as that used for measuring the activity of the gold foils. In this case the bias of the system was set at 1.1 Mev. The U^{235}, Pu^{239}, and U^{238} samples were counted on a 1/8-inch-thick brass absorber while the Np^{237} samples were counted on a 3/16-inch lead absorber. This system was calibrated and monitored with a Co^{60} source.

The Na^{24} produced in the Al and Mg detectors was measured on the same system as the fission detectors, using the 1.1-Mev bias and the 1/8-inch brass absorber.

In measuring the beta particles emitted by the P^{32} produced by the $S^{32}(n,p)P^{32}$ reaction, the plastic scintillator previously described replaced the NaI crystal in the counting system. The sulfur samples were placed directly upon the scintillator. The bias of the system was set just high enough to exclude noise. A natural uranium source was used to monitor this system.

Zirconium-89, formed by the Zr^{90} (n,2n) Zr^{89} reaction, is a positron emitter. Since the foils used were natural zirconium (51.5 percent Zr^{90}), other reactions producing other beta and gamma emitters are possible. For this reason much care must be taken to measure only the positron from the Zr^{89}. Since the direct measurement of the positron would require some kind of a magnetic spectrometer, it is much simpler to measure the positron-annihilation radiation. When a positron and electron annihilate, two quanta of gamma energy are produced. The fact that they must be emitted 180 degrees apart in order to conserve momentum makes this measurement not only possible, but also easily accomplished. Two 3-inch NaI(Tl) crystals with their photomultipliers were assembled with the crystals facing each other. The irradiated zirconium foils were then placed in an aluminum holder between the crystals. The electronics used with this system required not only a coincidence between the two crystals but that the coincidence occur with an energy between 400 and 600 kev. Sodium^{22}, which is also a positron emitter, was used to monitor this system.

TABLE 2.1 PERTINENT PARAMETERS FOR SHOTS BLUE GILL TRIPLE PRIME, KING FISH, AND STAR FISH PRIME

TABLE 2.2 POD INFORMATION FOR SHOTS BLUE GILL TRIPLE PRIME, KING FISH, AND STAR FISH PRIME

Event	Pod	Distance from Point of Detonation	
		Planned	Actual
			km
Blue Gill	B-1	2500 ft	1.0
Triple Prime	B-2	4000 ft	1.4
	B-3	6000 ft	2.1
King Fish	K-1	1.9 km	2.5
	K-2	2.4 km	3.8
	K-3	3.3 km	2.9
Star Fish	S-1	7.5 km	8.7
Prime	S-2	10.0 km	12.2
	S-3	14.0 km	23.4

TABLE 2.3 POD ORIENTATION ANGLES FOR SHOT STAR FISH PRIME

POD	θ	φ
S-1	135	61
S-2	43	0
S-3	41	35

TABLE 2.4 DETECTING MATERIALS, REACTIONS, THRESHOLD ENERGIES, AND EFFECTIVE CROSS SECTIONS

Detecting Material	Reaction	Threshold Energy	Effective Cross Section
			barns
Gold	$Au^{197}(n,\gamma)Au^{198}$	a	1/v
U^{235}	Fission	1.5 kev b	1.7
Pu^{239}	Fission	10.0 kev b	1.7
Np^{237}	Fission	0.63 Mev	1.6
U^{238}	Fission	1.5 Mev	0.55
Sulfur	$S^{32}(n,p)P^{32}$	3.0 Mev	0.30
Magnesium	Mg^{24} [illegible] ^{24}	6.3 Mev	0.114
Aluminum	Al [illegible] ^{9}	8.1 Mev	0.183
Zirconium	$Zr^{90}(n,2n)Zr^{89}$	12.0 Mev	0.28

a Detector for room thermal neutrons with upper cut-off at 0.3 ev

b Threshold and effective cross section with boron shield (see text).

TABLE 2.5 CALIBRATION NUMBERS

Detector	Conditions	Calibration No. $\frac{n/cm^2}{Counts/min/gm}$
Gold	1/2-inch-diameter × 2 mil-thick foil counted on a 1/16-inch Al absorber	
U^{235}	15/16-inch-diameter foil counted on 1/8-inch-thick brass absorber	
Pu^{239}	15/16-inch-diameter foil counted on a 1/8-inch-thick brass absorber	
Np^{237}	3/4-inch-diameter foil counted on a 3/16-inch-thick lead absorber	
U^{238}	15/16-inch-diameter foil counted on a 1/8-inch-thick brass absorber	
Sulfur	1-inch-diameter 2-gram pellet placed inside the boron shield	
Magnesium	1-inch-diameter foil counted on a 1/8-inch-thick brass absorber	
Aluminum	1-inch-diameter foil counted on a 1/8-inch-thick brass absorber	
Zirconium	1-inch-diameter foil counted on positron annihilation equipment	

Note: Calibration number for the fissionable materials based on activity at H+10 hours. All other numbers based on activities at 0 time.

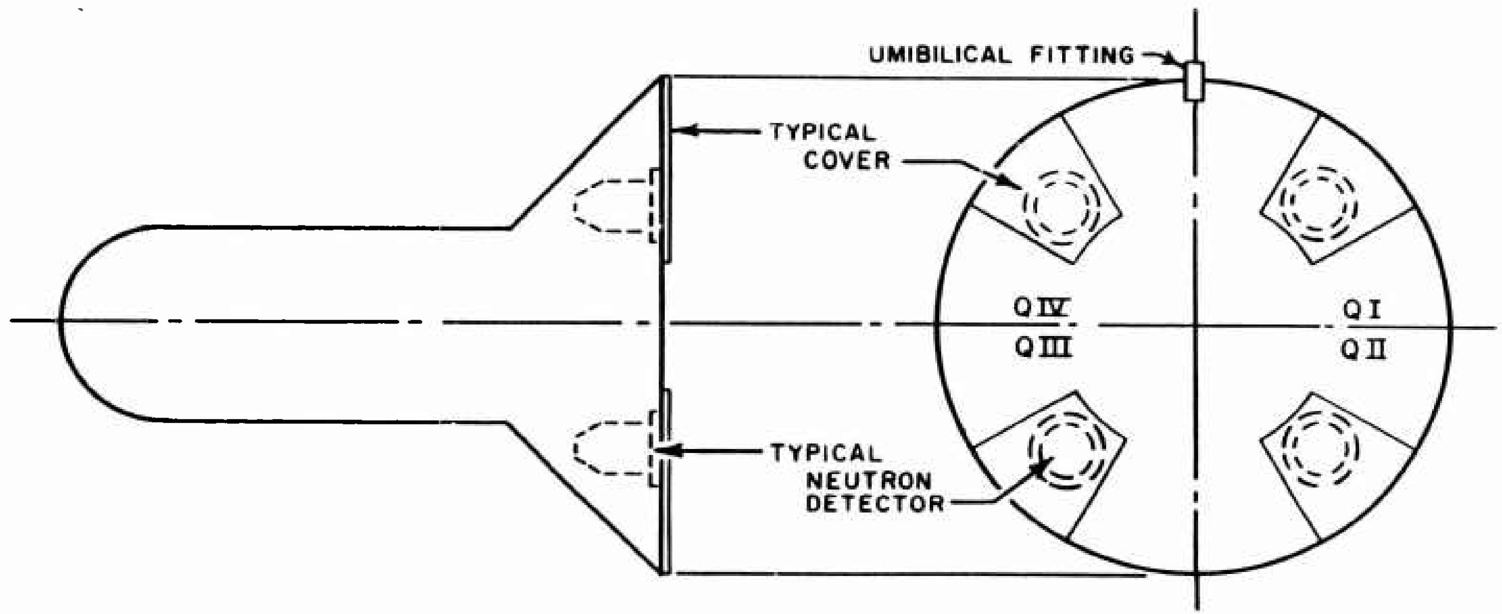

Figure 2.1 Location of neutron instrumentation in the scientific pods.

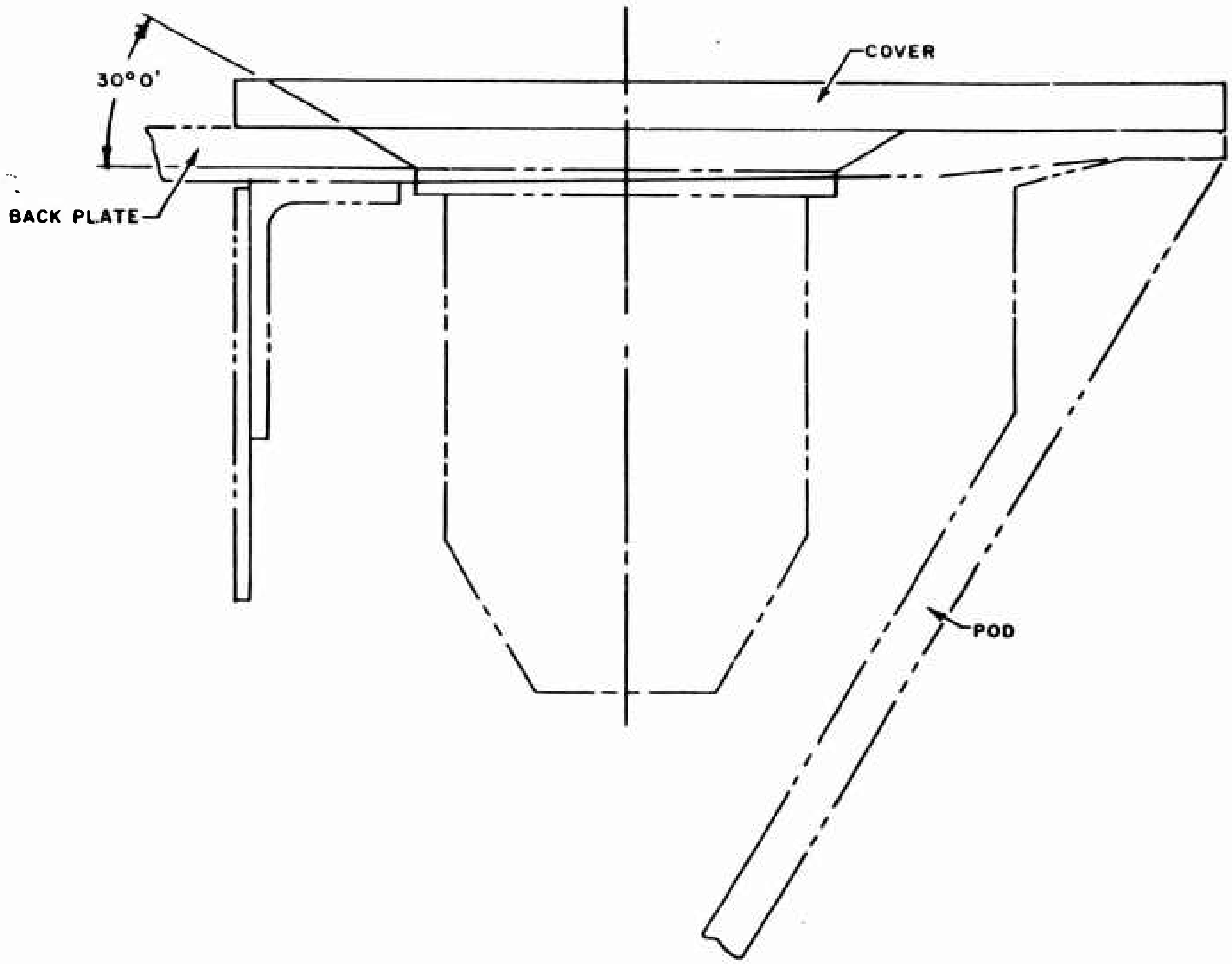

Figure 2.2 Detailed orientation of neutron instrumentation in the scientific pods.

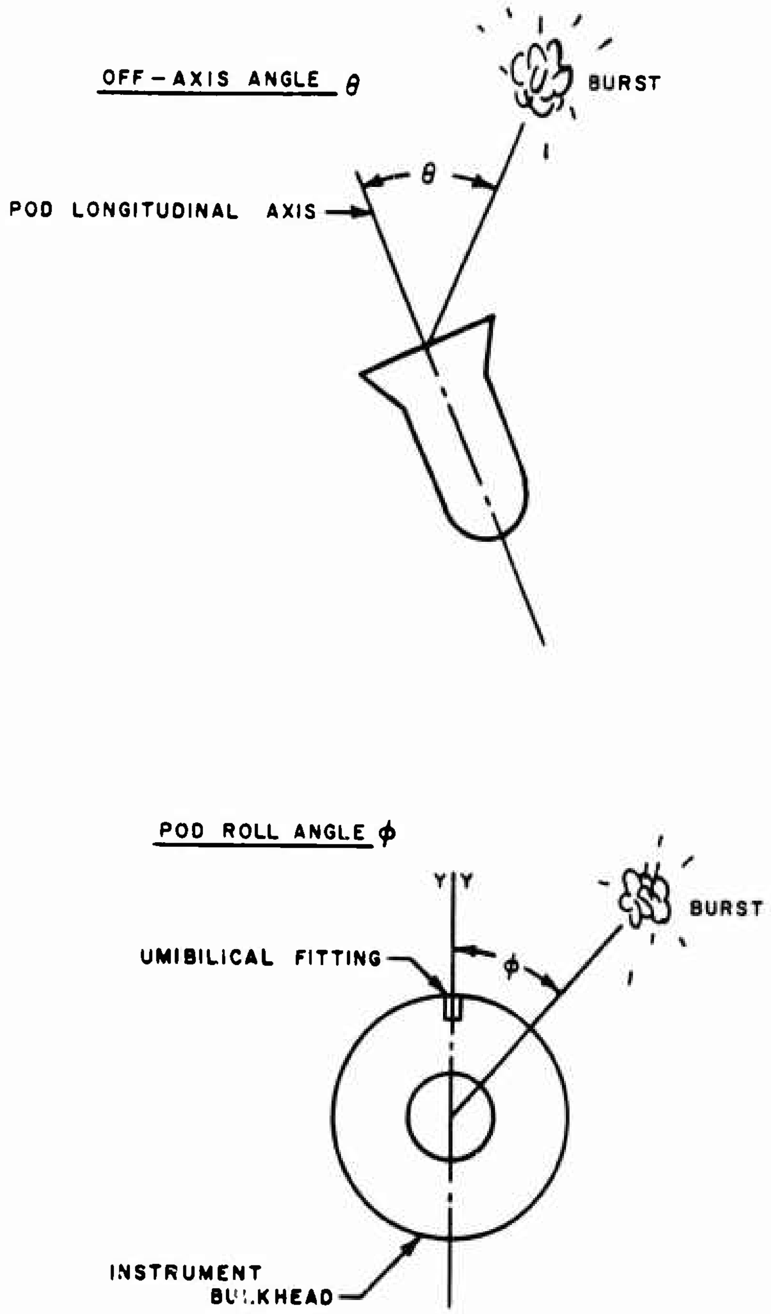

Figure 2.3 Diagrammatic representation of pod orientation angles for Shot Star Fish Prime.

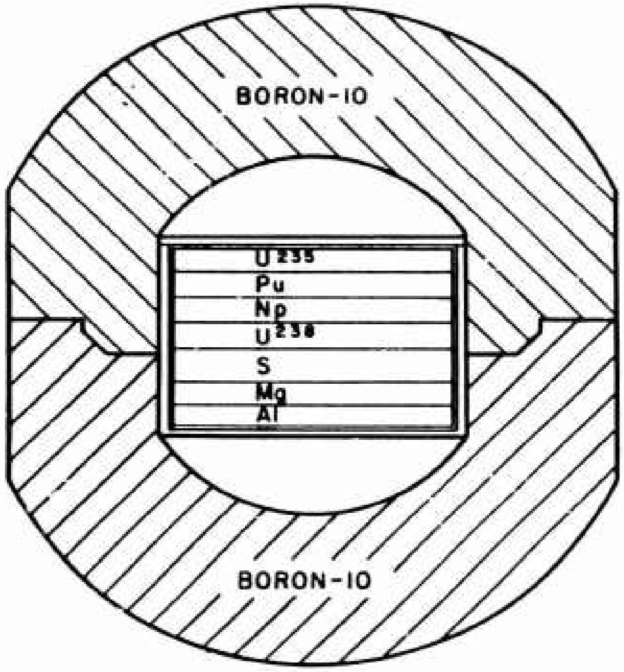

Figure 2.4 Boron shield showing arrangement of the various detecting materials.

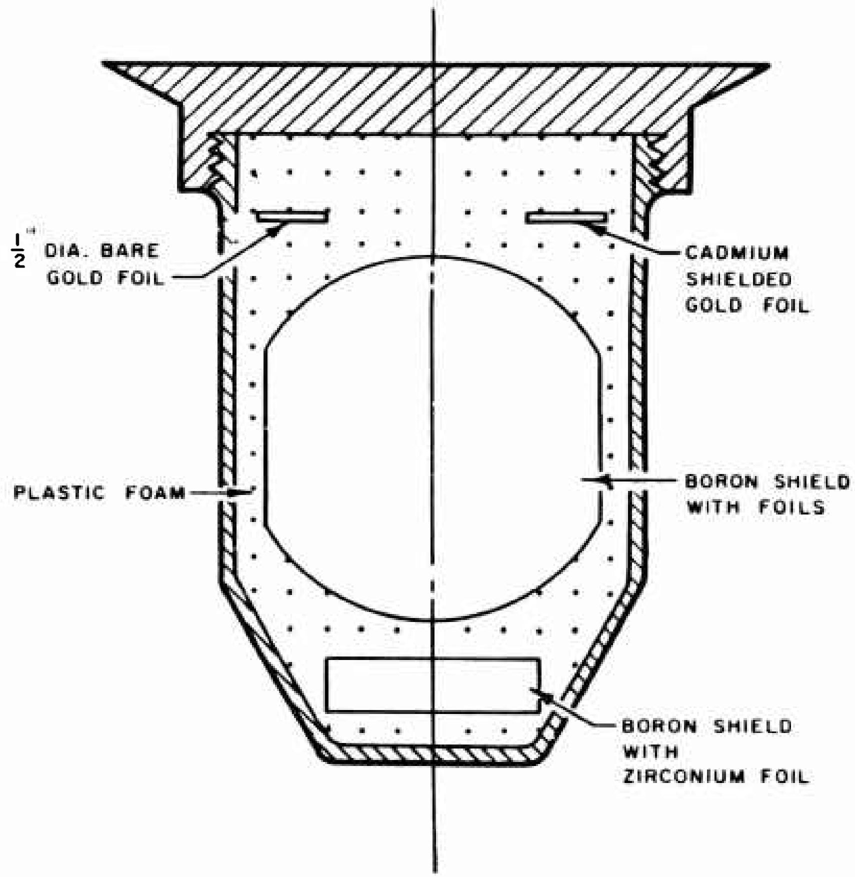

Figure 2.5 Arrangement of completed neutron detection package for placement into the pods.

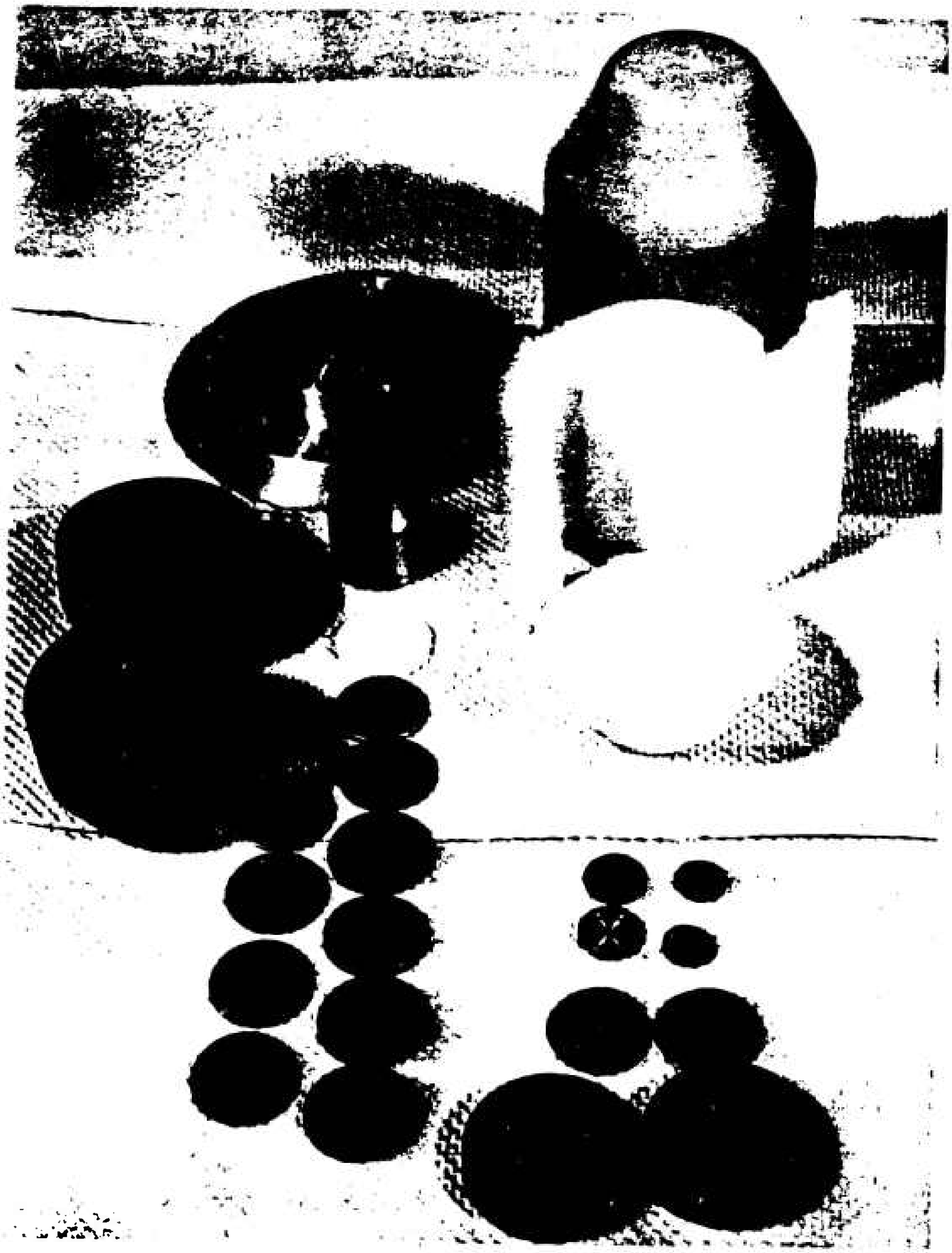

Figure 2.6 Photograph of all foils ready for assembly into a completed package. (NDL photo)

CHAPTER 3

RESULTS

3.1 NEUTRON FLUX

The results of the neutron flux measurements made during Shots Blue Gill Triple Prime, King Fish, and Star Fish Prime are presented in units of neutrons per square centimeter for each detecting material and slant distance. For all materials this is the total number of neutrons above the effective threshold of that material.

Tables 3.1 and 3.2 list the data from Shots Blue Gill Triple Prime and King Fish, respectively. Data is missing from positions and pods for which detector packages were lost, as explained in Chapter 2. Table 3.3 lists the data from Shot Star Fish Prime. The apparently anomalous measurements in quadrant 3 of Pod S-1 are attributed to pod orientation and are not included in the average. The wide spread in the data from the other pods is also attributed to shielding and scattering caused by the misorientation of these pods. The data for Shots Blue Gill Triple Prime and Star Fish are plotted in Figures 3.1 and 3.2, respectively.

Several researchers have expressed a special interest in the gold foil information from these events. This information is therefore presented separately. The counting rates in relative counts per minute are presented as well as the difference [calculated as (N_B - 1.025 N_C) where N_B is the counting rate of the bare foil and N_C is the counting rate of the cadmium-shielded foil]. The flux below 0.3 ev is generally calculated by multiplying this difference by the calibration number shown in Table 2.5. However, because of the doubtfulness of the validity of these small differences, no flux values have been calculated. These data are presented in Tables 3.4, 3.5, and 3.6 for Shots Blue Gill Triple Prime, King Fish, and Star Fish Prime, respectively.

3.2 NEUTRON DOSE

Neutron dose is presented in Table 3.7 as first collision rads for each pod. These results were calculated by applying the dose per neutron per square centimeter at the average energy between the thresholds of the various detecting materials. The following formula gives the dose-flux relation:

$$\text{Dose (rads)} = [1.0\,(N_{Pu}-N_{Np}) + 2.5(N_{Np}-N_U) + 3.2(N_U-N_S) + 4.5(N_S-N_{Mg}) + 5.3(N_{Mg}-N_{Al}) + 5.9(N_{Al}-N_{Zr}]\;1.07\times10^{-9} \quad (3.1)$$

Where the dose is in rads and N_{Pu}, N_{Np}, N_U, N_S, N_{Mg}, N_{Al}, and N_{Zr} are the number of neutrons per square centimeter above the thresholds of plutonium, neptunium, uranium, sulfur, magnesium, aluminum, and zirconium, respectively. No spectral effects were considered.

Pages 28, 29, 30, 31, 32, 33 deleted.

CHAPTER 4

DISCUSSION

4.1 NEUTRON FLUX AND DOSE

The neutron flux data presented in Chapter 3 for Shots Blue Gill Triple Prime and King Fish are consistent, and no anomalies appear. The small variation in the data among the detectors placed in the various quadrants of the same pod indicates that the measurements were not affected by pod orientation. It would also tend to indicate that shielding or scattering by adjacent instrumentation was minimal; however, it is obvious that such was not the case for Shot Star Fish Prime. From the measurements of pod orientation shown in Chapter 3, it can be concluded that the detector package located in Quadrant 3 of Pod S-1 was looking at the burst point through a large part of the pod mass. The detector packages located in Quadrants 2 and 4, on the other hand, looked at the device through the outer flange of the pod. However, it is expected that scattering and degradation in the pod mass influenced the measurements to some extent. This is substantiated by an examination of the flux ratios which show a quite different spectrum in the vicinity of Pod S-1 than in the vicinity of Pods S-2 and S-3. The rather wide spread in the measurements made in Pod S-3 can also be attributed to pod misorientation.

Special mention should be made of the gold foil information presented in Chapter 3. No values are presented for the neutron flux below 0.3 ev even in instances when a difference between the unshielded and the cadmium shielded foils exists. It was expected that some moderation would occur in the pod mass (1,200 pounds), but the extent of this moderation was not estimated. Considering the number of parameters which can affect the amount of activation in gold foils, the significance of a small difference between the counting rates of the unshielded foil and the cadmium-shielded foil in the second decimal place is questionable; and it is certain that a difference in the third decimal place is not significant. Estimates of the thermal flux by other means (Reference 29), however, agree in order of magnitude with the values presented here.

As mentioned in Chapter 3, the neutron doses presented are single-collision rads. Should multiple-collision doses be desired, they may be calculated from the following formula:

$$D = [0.344\ N_{Au} + 1.08(N_{Pu}-N_{Np}) + 3.98(N_{Np}-N_{U}) + 4.52\ (N_U-N_S) + 5.65(N_S-N_{Mg}) + 7.35(N_{Mg}-N_{Al}) + 7.55\ (N_{Al}-N_{Zr}) + 6.90\ N_{Zr}]\ 1.07\times10^{-9} \quad (4.1)$$

Where:

N_{Au}, N_{Pu}, N_{Np}, N_U, N_S, N_{Al}, N_{Mg}, N_{Zr}, are the number of neutron above the threshold of gold, plutonium, neptunium, uranium, sulfur, aluminum, magnesium and zirconium, respectively.

4.2 DATA RELIABILITY

The threshold detector system is assumed to have an internal accuracy of ±5 percent and an absolute accuracy of ±20 percent. The foils exposed during all events exhibited activities high enough to permit good statistical accuracy in counting. The decay of all foils were checked against standard values, and all were correct. Except in cases where pod orientation interfered with the measurements, there is no reason to believe that the measurements made during this operation are not as reliable as any ever made with the threshold detector system.

4.3 COMPARISON WITH PREDICTIONS

When comparing the data presented in this report with other data or predictions, three things must be kept in mind: (1) The inherent accuracy of the threshold detector system, (2) the inaccuracies caused by pod misorientation during Star Fish Prime, and (3) the difference in R/V configurations and orientation between Blue Gill Triple Prime and King Fish. The first two items have already been discussed. The relative importance of the third has not been quantitatively estimated; however, that it will affect the measurements is unquestionable. The R/V for Blue Gill Triple Prime was oriented with the

These orientations and configurations are shown in Figures 4.1 and 4.2 for Blue Gill Triple Prime and King Fish, respectively.

Calculations of the expected fluxes above the thresholds of the various detectors were made by personnel at Kaman Nuclear, Colorado Springs, Colorado. Table 4.1 lists predicted and measured values of the flux above 10 kev (Pu^{239}), 3 Mev (sulfur), and 12 Mev (zirconium). An examination of this table will show that the total measured flux (above 10 kev) was

A good indication as to change in spectrum between pod positions or shots may be had by comparing the ratio of the flux as measured by the various detectors to that as measured by plutonium (total flux). These ratios are presented in Table 4.2. It can be seen from this table that there is a slight change in spectrum as distance increases for Blue Gill Triple Prime and that this spectrum is different from that for King Fish

The values for Star Fish Prime are rather non-conclusive because the effect of the misorientation of the pods during this event is questionable.

Pages 38, 39 & 40 deleted.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Measurements of the neutron flux were made at three distances from Shot Blue Gill Triple Prime.

Only the neutron detectors from the 2.5-km pod were recovered after King Fish. These detectors showed

Measurements made during Shot Star Fish Prime showed that neutrons with energies greater than 1.5 kev varied from

The measured total flux (above 10 kev)

The project obtained data in all events in which it participated and can be considered a success.

5.2 RECOMMENDATIONS

None.

REFERENCES

1. C. W. Luke and others; "Neutron-Flux Measurements"; Project 2.51, Operation Redwing, WT-1313, 1959; Chemical Warfare Laboratories, Army Chemical Center, Maryland; SECRET-RESTRICTED DATA.

2. Scientific Director's Report, Operation Sandstone, Volume 18, Annex R, Part K and Addendum, 1948; SECRET-RESTRICTED DATA.

3. W. Ogle and others; Operation Ranger, Los Alamos Scientific Laboratory Report LAB-J-2095; "Neutron Measurements"; SECRET-RESTRICTED DATA.

4. J. Allred and others; "Neutron Measurements"; Preliminary Report of Group LAJ-3, Greenhouse, 1951; SECRET-RESTRICTED DATA.

5. T. D. Hanscome and others; "Neutron Flux Measurements"; Project 2.3, Operation Tumbler-Snapper, WT-524, 1953; Office of Naval Research, Washington, D. C.; SECRET-RESTRICTED DATA.

6. D. K. Willet, T. D. Hanscome, and L. W. Flagg; "Neutron Flux Measurements"; Project 2.3, Operation Upshot-Knothole, WT-720, 1953; Office of the Naval Research, Washington, D. C.; SECRET-RESTRICTED DATA.

7. T. D. Hanscome, D. K. Willet, and A. Brodsky; "Neutron Flux Measurements"; Project 2.3, Operation Castle, WT-914, October 1955; Naval Research Laboratory, Washington, D. C.; SECRET-RESTRICTED DATA.

8. P. S. Harris and others; "Physical Measurement of Neutron

and Gamma Radiation Dose from High Neutron Yield Weapons and Correlation of Dose with Biological Effect"; Project 39.7, Operation Teapot, WT-1167, 1956; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; SECRET-RESTRICTED DATA.

9. W. A. Biggers and others; "External Neutron and Gamma Flux Measurements by Sample Activation"; Annex 1.5, Part II, Section I, Operation Greenhouse, WT-114, 1957; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; SECRET-RESTRICTED DATA.

10. W. A. Biggers and others; "External Neutron Measurements with Threshold Detectors"; Project 17.1, Operation Upshot-Knothole, WT-826, March 1955; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; SECRET-RESTRICTED DATA.

11. W. A. Biggers and others; "External Neutron Measurements"; Project 14.1, Operation Castle, WT-952, October 1955; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; SECRET-RESTRICTED DATA.

12. D. L. Rigotti and others; "Neutron Flux From Selected Nuclear Devices"; Project 2.3, Operation Plumbbob, WT-1412, April 1960; Chemical Warfare Laboratories, U. S. Army Chemical Center, Maryland; SECRET-RESTRICTED DATA.

13. J. W. Kinch and others; "Neutron Flux From Large-Yield Bursts"; Project 2.4, Operation Hardtack, WT-1622, May 1960; Chemical Warfare Laboratories, Army Chemical Center, Maryland; SECRET-RESTRICTED DATA.

14. D. L. Rigotti and others; "Neutron Flux From Very-Low-Yield Burst"; Projects 2.4A/2.11/2.12a, Operation Hardtack, WT-1679, 1960; Chemical Warfare Laboratories, U. S. Army Chemical Center, Maryland; SECRET-RESTRICTED DATA.

15. G. S. Hurst and others; "Techniques of Measuring

Neutron Spectrum with Threshold Detectors-Tissue Dose Determination"; The Review of Scientific Instrument, Volume 27, No. 3, March 1956: UNCLASSIFIED.

16. G. S. Hurst, R. H. Richie, and H. M. Wilson; Scientific Instrument 22, 981, 1951; UNCLASSIFIED.

17. K. M. Case, F. Dehoffman, and C. Placzek; "Introduction to the Theory of Neutron Diffusion"; Volume 1, June 1953; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; UNCLASSIFIED.

18. Samuel S. Holland and Paul I. Richards; "Penetration of Neutrons in Air"; AFSWC-TR-55-27, September 1956; Air Force Special Weapons Center, Kirtland AFB, New Mexico; SECRET-RESTRICTED DATA.

19. J. H. McNeilly and J. W. Kinch; "Recent Developments in the Threshold Detector System as Used by the U. S. Army Nuclear Defense Laboratory"; NDL-TR-15, October 1961; U. S. Army Nuclear Defense Laboratory, Army Chemical Center, Maryland; UNCLASSIFIED.

20. Health Physics Annual Report for Period Ending July 31, 1959, ORNL-2806, P. 173-174; Oak Ridge National Laboratory, Oak Ridge, Tennessee; October 1959; UNCLASSIFIED.

21. D. J. Hughes and J. A. Harvey; "Neutron Cross Sections"; BNL Report 325; 2nd Ed., January 1960; Brookhaven National Laboratory, Upton, New York; UNCLASSIFIED.

22. C. J. Cosenza; "Vulnerability of Missile Structures to Nuclear Detonations"; Project 8.6, Operation Hardtack, WT-1652, 1962; Wright Air Development Division, Wright Patterson Air Force Base, Ohio; SECRET-RESTRICTED DATA.

23. T. D. Hanscome and others; "Neutron Flux From Very-High Altitude Bursts"; Project 2.6, Operation Hardtack, WT-1623; May 1961; U. S. Naval Research Laboratory, Washington, D. C.; SECRET-RESTRICTED DATA.

24. P. A. Caldwell and others; "Nuclear Radiation From a Detonation at Very-High Altitude (C)"; Project 2.7, Operation Hardtack, ITR-1624, July 1958; U. S. Naval Research Laboratory, Washington, D. C.; SECRET-RESTRICTED DATA.

25. J. W. Kinch and John H. McNeilly; "An Activation Type Neutron Detection System and its Calibration"; CWLR-2282; 1959; Chemical Warfare Laboratories, Army Chemical Center, Maryland.

26. Arthur J. Starnes et al; "Pod and Recovery Unit Fabrication"; Fish Bowl Project 9.4b, Operation Dominic, POR–2041; Air Force Special Weapons Center, Kirtland AFB, New Mexico; SECRET-RESTRICTED DATA.

27. C. M. Gillespie et al; "Nuclear Weapon X-ray Effects as Measured by Passive Instruments"; Fish Bowl Project 8B, Operation Dominic, POR–2038; Air Force Special Weapons Center, Kirtland AFB, New Mexico; SECRET-RESTRICTED DATA.

28. McNeilly, John H.; "Calibration of Threshold Detectors During January 1963"; U. S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Maryland (to be published).

29. Kinch, J. W., Jenkins, R. W.; "Gamma Radiation Measurements"; Project 2.2, Fish Bowl Series, Operation Dominic, POR–2013; U.S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Maryland.