August, 1962

A "QUICK LOOK" AT THE TECHNICAL RESULTS OF STARFISH PRIME

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The enclosed report is a compilation of data available in the field within approximately 10 days of the Starfish Prime event, together with an introduction to the objectives of Starfish Prime and some tentative conclusions about the data obtained. As such, the reader is cautioned that all data are tentative and in most cases obtained by "quick look" techniques: in particular all numbers quoted are subject to later correction.

Abstract

The Starfish prime event (Deleted detonated at 400 km altitude SSW of Johnston Island at 2300 hours, Honolulu time on July 8, 1962) significantly increased the understanding of high altitude nuclear detonations and their effects. As an aid to penetration for incoming missiles by disrupting enemy anti-missile radars, Starfish Prime was not as effective as anticipated. Detonation degradation of communications and radar surveillance capabilities were found to be appreciably less than expected. Some data were obtained on the direct effects of bomb x rays on materials carried on pods near the burst; most pod experiments were not as successful as desired because of pod stabilization and positioning difficulties.

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Beta ray and debris pancakes were formed along magnetic field lines north of the burst at a distance of 600 km at an altitude of 120 to 150 km. The effects of these pancakes were of comparatively short durations. A pancake was also formed to the south of the burst along field lines, but a significant pancake did not form under the burst. The major visible effects of these pancakes lasted for a number of minutes; an auroral glow was still in evidence four hours after detonation in the north conjugate area; ionospheric disturbances in the south conjugate area lasted for many hours. Significant amounts of debris were deposited along the magnetic field lines intersecting the burst location at altitudes well above that of the burst. Rocket-borne

high altitude diagnostic techniques were tested; neutron, x ray, gamma ray and time interval measurements were successfully made; radiochemical sampling and alpha measurements were unsuccessful. High altitude nuclear detonation detection systems were tested with a very considerable degree of success. The small rocket weapons effects and phenomenology diagnostic program from Johnston was quite successful.

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I

Introduction

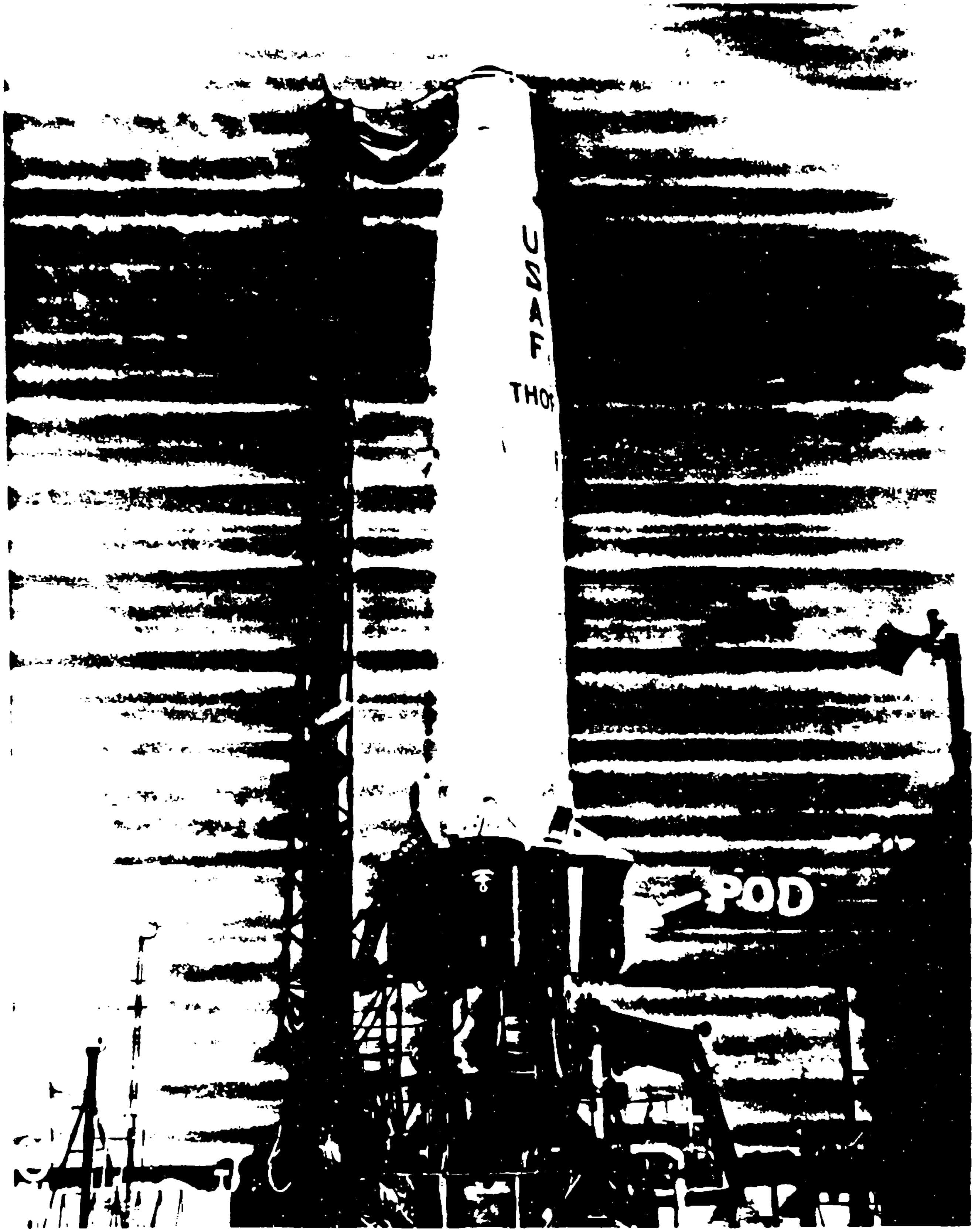
The warhead for the Starfish Prime event of Dominic was launched from Johnston Island on a Thor missile and detonated at 2300:09 hours Honolulu time, on 8 July 1962. The warhead, contained in a spin-stabilized re-entry vehicle, detonated at 400 km altitude 32 km from its launch pad with a nominal yield Deleted The Thor missile was modified for the firing by the inclusion of telemetry, safety (destruct) systems, and special external insulation to prevent excessive heating of the after structural members. (See Figure 1.)

Three 1200 pound pods, resembling re-entry vehicles, were attached to the missile at time of launch. The back plates of the pods held numerous small experiments. The pods were stabilized by heavy internal flywheels and it was hoped that after the pods were released from the missile at about main engine burnout time they would remain in a near vertical position. Release times were programmed so that the pods would be below the burst with their backplates approximately normal to the lines from the pods to the detonation. The pods contained transponders to assist in determining actual position after the detonation and recovery gear so that they could be located and recovered.

Scientific stations to obtain data from the various experiments were established throughout the Pacific area, with the most concentrated group on Johnston Island. From Johnston Island 27 rockets were fired in support

Figure 1

Thor missile with pods in Bluegill Prime configuration. Starfish Prime is essentially identical.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POD

of experiments, and a large array of optical and electromagnetic instrumentation was operated. In the area surrounding the island, a fleet of ships and aircraft operated with technical stations aboard. Stations were established in the Hawaiian area to observe the burst from elevated areas and to observe the northern conjugate area. A large number of rocket-borne instruments were launched from a firing area at Barking Sands, Kauai. The southern conjugate area was covered by establishing stations in the Fiji, Samoan and Cook groups and by stationing ships and aircraft in the general area. Other shipboard stations were utilized throughout the Pacific to study the effects of ionospheric disturbance on RF transmission and reception. An unsuccessful attempt was made to launch two rockets from Point Arguello in California in support of the TU 8.1.1 effort. Many groups participated voluntarily in the event, generally invited by the Department of Defense, in order to take advantage of the substantial interest in the event by the world's scientific community. It is hoped that the results from these groups will, in time, be reported to the scientific community.

The operation was conducted by Joint Task Force 8, commanded by Maj. Gen. A. D. Starbird, which was responsible to both the Atomic Energy Commission and the Department of Defense. The Scientific Deputy of the Task Force was Dr. William E. Ogle of the Los Alamos Scientific Laboratory. The scientific elements in the Task Force were organized into Task Units as listed:

TU 8.1.1 Los Alamos Scientific Laboratory
TU 8.1.2 Lawrence Radiation Laboratory
TU 8.1.3 Field Command, Defense Atomic Support Agency
TU 8.1.4 Sandia Corporation
TU 8.1.6 Edgerton, Germeshausen and Grier

During the period that the Starfish Prime event was being prepared, most of the Task Units were also involved with other events of Dominic on Christmas Island.

The Starfish Prime high altitude nuclear detonation had the following major scientific objectives:

1. Evaluation of missile kill mechanisms produced by a high altitude nuclear detonation.

2. Evaluation of the effects of a high altitude nuclear detonation on electromagnetic surveillance capability.

3. Evaluation of the effects of a high altitude nuclear detonation on long range communications.

4. Investigation of the basic characteristics of a high altitude nuclear detonation and the physical basis of the effects.

5. Evaluation of high altitude nuclear detonation weapon diagnostic techniques.

6. Evaluation of high altitude nuclear detonation detection systems.

Electromagnetic surveillance capabilities after a high altitude nuclear detonation were studied by a large number of experiments. Attempts were made to track objects, in, near, and at large distances from the debris and to measure the attenuation and refraction of radar signals. Measurements were made of radar scatter and clutter due to the debris and ionospheric disturbances. These experiments covered the radar frequency spectrum, specifically including those frequencies of greatest interest in anti-missile missions. The period from before detonation until after detonation effects disappeared was covered.

Long and short range communications were tested throughout the world by communications simulation experiments and by monitoring a large number of existing communication nets. Both government and private communications systems were exercised during the period of interest with the aim of determining signal propagation conditions as a function of frequency, path location, and time relative to burst.

The basic physical characteristics and effects of high altitude nuclear detonations were studied both for applicability to the other five objectives of Starfish Prime and for their inherent scientific interest. Two of the phenomena of prime importance were the debris expansion history and the geomagnetic effects. Experiments to obtain data on these phenomena included determination of the ionospheric composition, cosmic electromagnetic noise transmission through the ionosphere, magnetic field strength measurements, various satellite-borne experiments, earth current measurements, sky brightness measurements, and measurements of nuclear radiations. Ultraviolet, visible and infrared spectroscopic and photographic measurements were made near the point of burst and in the north and south magnetic conjugate areas.

Weapon test diagnostic techniques were tested by considering both the direct emission from the weapon and the effect of these emissions on their surroundings. The bomb energy emitted as x rays was determined by direct measurement of the total x ray energy and measurements of the apparent bomb temperature. X ray excited air fluorescence was studied. Neutron flux and energy distributions were determined, as were gamma ray fluxes and time histories. The behavior of the bomb debris was studied and rocket-borne debris samplers were tested. There were electromagnetic and optical measurements of the time interval between the weapon primary and secondary, as well as an attempted measurement of bomb early alpha by high resolution telemetry techniques. It was hoped that the yield could be determined by an analysis of the direct thermal radiation, the x ray yield as inferred from air fluorescence, and the kinetic energy of the bomb debris.

High altitude nuclear detonation detection systems were directly tested in the Starfish Prime event through the use of the Vela Sierra air fluorescence systems and direct optical systems. The spectral characteristics of the air fluorescence were studied to aid in distinguishing nuclear detonations from lightning flashes. Optical and electromagnetic time interval measurements were of interest in this area, as were the various measurements of the electromagnetic signal from the weapon. In addition many of the basic effects which were studied could have applications in detection systems.

II

General Summary of Results

Unfortunately difficulties in pod stabilization and positioning seriously degraded the acquisition of data on the direct effects of x rays on materials. Pod S-1, closest to burst, was essentially at its desired location of 8 km from air zero. It was pointed toward, rather than away from, the burst so that the experiments on the backplate of the pod were not exposed to the burst; therefore, no data on direct x ray effects were obtained from this pod. The pod did have a circumferential crack and a dent in the lining, but these may have been caused by impact with the water or rough handling on recovery. Pod S-3, furthest from the burst, was 23 km from air zero rather than the desired 14 km. Its backplate was slanted from normal to the burst (See Figure 2) with the axis of the pod forming an angle of 40° from a line through the burst point to the pod. As a result the experiments were degraded both by excessive distance and shadowing. No data on direct x ray effects were obtained from this pod. Pod S-2 was 12 km from air zero with the axis of the pod forming an angle of 43 degrees from a line through the burst: owing to shadowing approximately 50% of the x ray effects measurements were not obtained. Some of the material samples and indenture gauges were subject to the direct x ray flux and are being analyzed; these should yield some useful x ray effects data when completed.

Rocket-borne detectors did successfully measure the x ray yield,

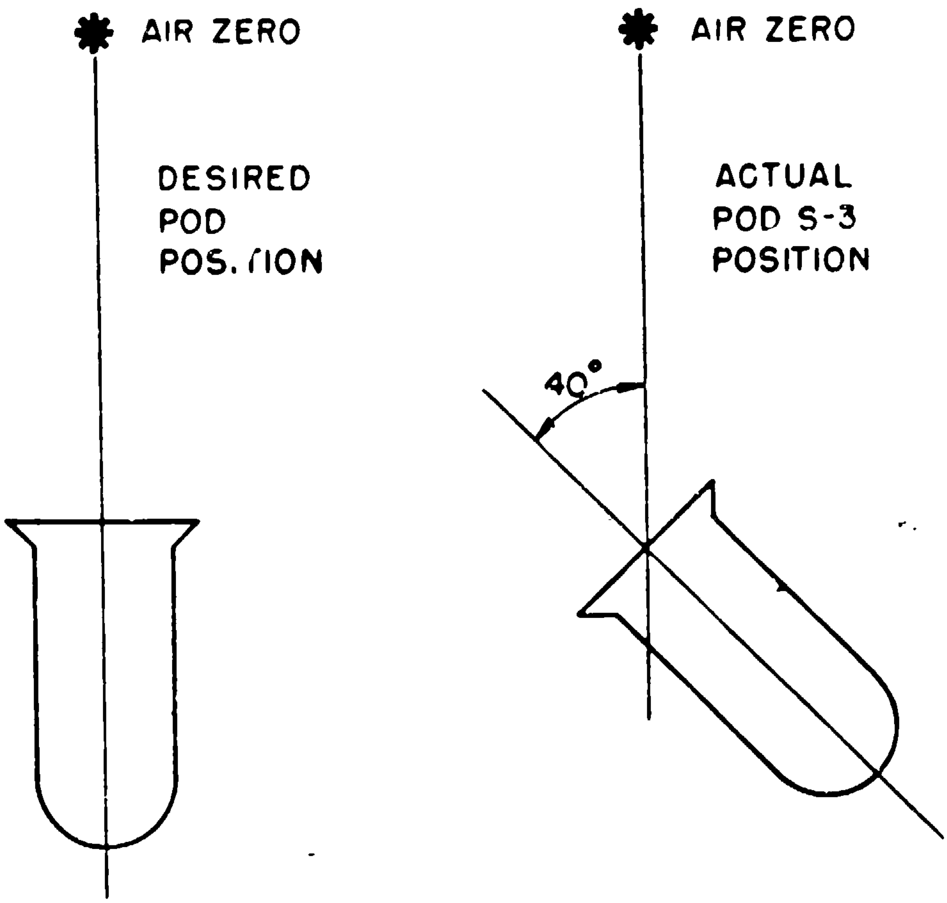

Figure 2 - Pod Position Diagram

the black body temperature of the weapon, and the neutron flux; in addition, foils carried on the pods yielded useful neutron flux data. Although there is still a fairly wide spread in the data,

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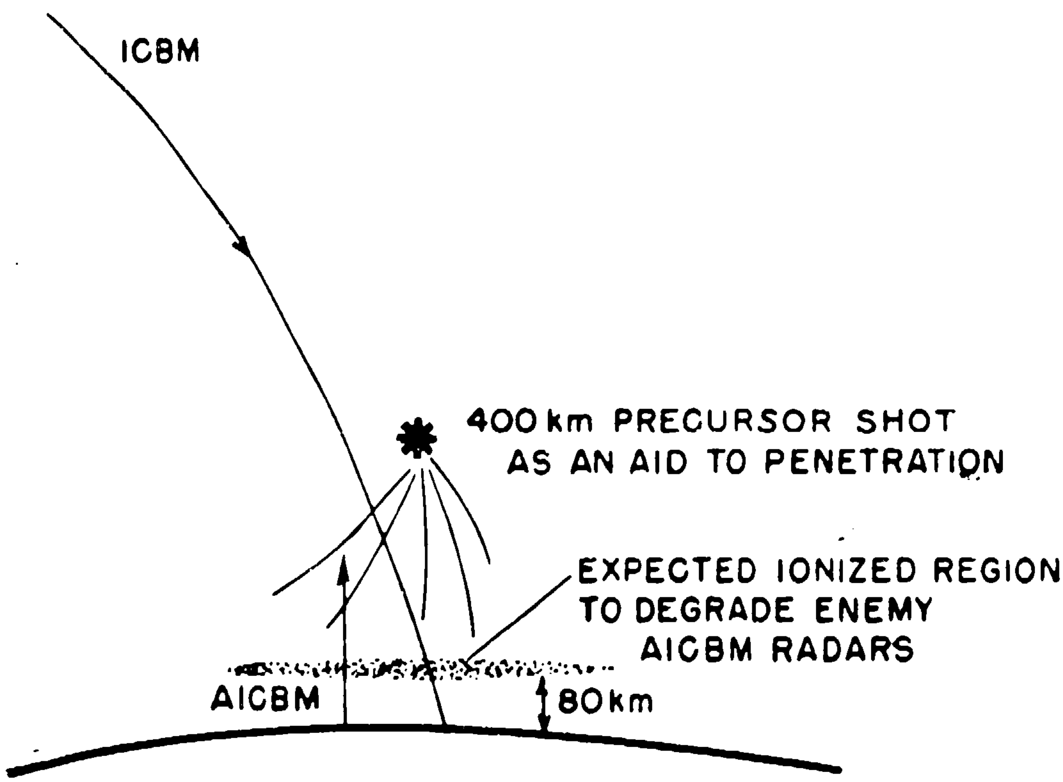

Figure 3 - Precursor Shot Tactical Condition

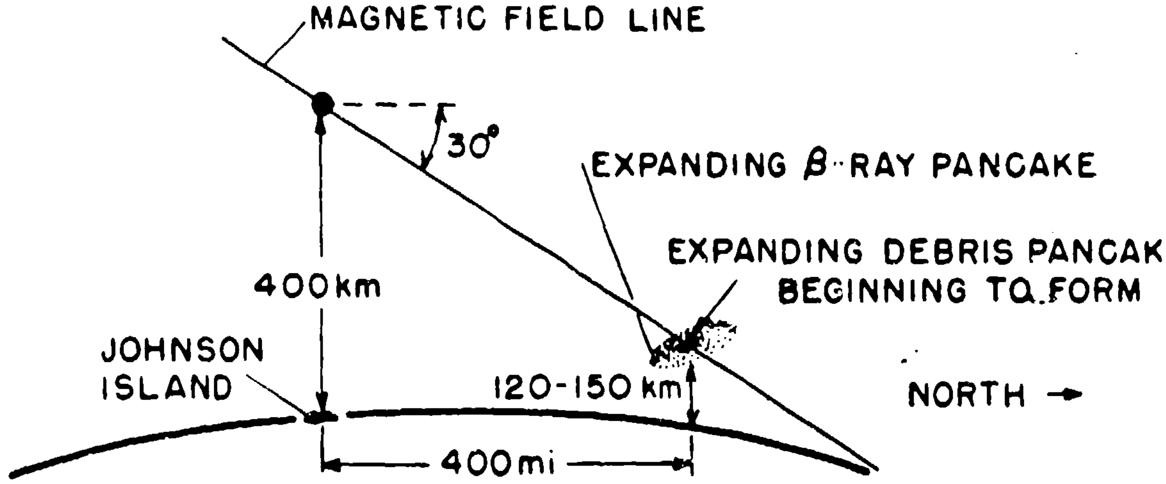

Figure 4 - Northern Pancake Location at + 70 Milliseconds

began to form in the same area; eventually the debris pancake was brighter than the beta pancake. Very large fractions of the debris were also deposited in a pancake to the south of the burst at intersections of the magnetic field lines, through burst and through points above burst, with the atmosphere. A strong pancake did not develop directly under the burst. The injection of large amounts of debris into the geomagnetic field above the burst, and the mechanism of the subsequent debris distribution are not fully understood. The effects appear to be quite complex. (See Figure 5)

The visible phenomena due to the burst were widespread and quite intense; a very large area of the Pacific was illuminated by the auroral phenomena, from far south of the south magnetic conjugate area (Tongatapu) through the burst area to far north of the north conjugate area (French Frigate Shoals). A large amount of spectroscopic data were obtained. At twilights after the burst, resonant scattering of light from lithium and other debris was observed at Johnston and French Frigate Shoals for many days confirming the long time presence of debris in the atmosphere. An interesting side effect was that the Royal New Zealand Air Force was aided in anti-submarine maneuvers by the light from the bomb. The next paragraph is an eye witness report of the detonation by Maj. C. X. McHugh, AOMC, Kwajalein; the paragraph following that is an eye witness report from Johnston.

At Kwajalein, 1400 miles to the west, a dense overcast extended the length of the eastern horizon to a height of 5 or 8 degrees. At 0900 GMT a brilliant white flash burned through the clouds rapidly changing to an expanding green ball of irradiance extending into the clear sky above the overcast. From its surface extruded great white fingers, resembling cirro-stratus clouds, which rose to 40 degrees above the horizon in sweeping arcs turning downward toward the poles and disappearing in seconds to be replaced by spectacular concentric cirrus like rings moving out from the blast at tremendous initial velocity, finally stopping when the outermost ring was 50 degrees overhead. They did not

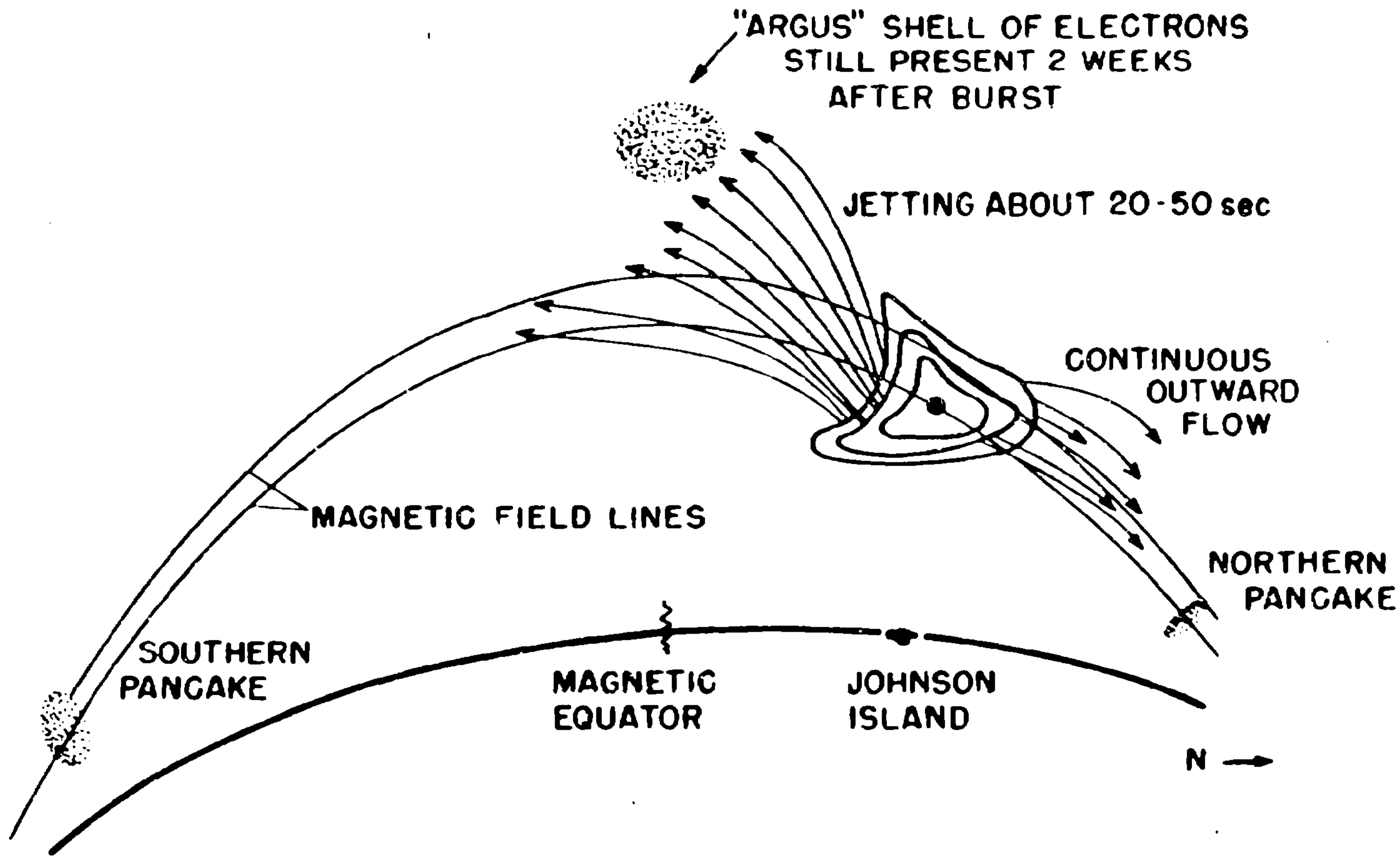

Figure 5 - Very Approximate Diagram of Debris Expansion

disappear but persisted in a state of frozen stillness. All this occurred, I would judge, within 45 seconds. As the greenish light turned to purple and began to fade at the point of burst, a bright red glow began to develop on the horizon at a direction 50 degrees north of east and simultaneously 50 degrees south of east expanding inward and upward until the whole eastern sky was a dull burning red semicircle 100 degrees north to south and halfway to the zenith obliterating some of the lesser stars. This condition, interspersed with tremendous white rainbows, persisted no less than seven minutes.

At zero time at Johnston, a white flash occurred, but as soon as one could remove his goggles, no intense light was present. A second after shot time a mottled red disc was observed directly overhead and covered the sky down to about 45 degrees from the zenith. Generally, the red mottled region was more intense on the eastern portions. Along the magnetic north-south line through the burst, a white-yellow streak extended and grew to the north from near zenith. The width of the white streaked region grew from a few degrees at a few seconds to about 5-10 degrees in 30 seconds. Growth of the auroral region to the north was by addition of new lines developing from west to east. The white-yellow auroral streamers receded upward from the horizon to the north and grew to the south and at about 2 minutes the white-yellow bands were still about 10 degrees wide and extended mainly from near zenith to the south. By about two minutes, the red disc region had completed disappearance in the west and was rapidly fading on the eastern portion of the overhead disc. At 400 seconds essentially all major visible phenomena had disappeared except for possibly some faint red glow along the north-south line and on the horizon to the north. No sounds were heard at Johnston Island that could be definitely attributed to the detonation.

Strong electromagnetic signals were observed from the burst, as were significant magnetic field disturbances and earth currents. A VLF signal

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some samples, but the rocket-borne samplers were not recovered. Balloon-borne nuclear track emulsions were not successful, possibly due to a freak temperature inversion which prevented the balloons from reaching altitudes greater than 50,000 feet, but rocket-borne emulsions have been recovered and are being analyzed. Photographic and spectroscopic coverage of the detonation was highly successful. The short range rocket-borne diagnostic program was highly successful.

Detection equipment of the Vela Sierra type was operated with good success and the range[1] and sensitivities of the method were found to be at least as good as predicted. The strong electromagnetic signals from the detonation were observed under the sea, at land stations and in airborne stations, at many hundreds of kilometers from the burst. Microbarographic signals from the detonation were observed at Johnston and Christmas Islands. Magnetic field disturbances were measured throughout the world.

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1. The detection range for a space detonation of yield Y kilotons was calculated to be approximately given by

$$\text{Range} = 10^5 \cdot \sqrt{Y}$$

where range is expressed in kilometers.

III

DATA COMPILATION

A. Seismic and Pressure Measurements

Project 1.1 (DASA). Air Blast and Pressure Measurements. Julius Meszaros, BRL.

Microbarograph at Johnston, on ships S-1, S-2. Pressure gauges and accelerometers on the pods.

Results: Preliminary data from pods S-1 and S-2 indicate no discernible pressure or acceleration. Pressure and acceleration gauges in pod S-3 not operable.

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Project 6.5a (DASA). Ionospheric Soundings and Magnetic Measurements. Dr. Philip Newman, AFCRL.

NBS microbarographs at Midway, Tutuila, Wake and Adak. Mitre Corporation, at Palmyra, had 3 Hall Stars (HS-1) 4.5 cps seismometers.

Results: Data not yet available.

Project 32.6 (Sandia). Microbarography. R. L. Eno, Sandia Corp.

Microbarographic measurements at French Frigate Shoals, Johnston Island, Kauai, and Christmas.

Results:

B. Neutron Measurements

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Results:

Pod
S-1
S-1
S-1
S-1
S-1
S-1
S-1
S-2
S-2
S-2
S-2
S-2
S-2
S-2
S-3
S-3
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S-3

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Cadmium shielded gold foils and bare gold foils gave essentially the same neutron flux.

Sandia Corporation Measurement. J. J. Miller, Sandia Corp.

Fluor and photomultiplier with log circuitry were rocket-borne from Kauai (Rocket No. SKI-154). Fluor and photomultiplier using HHRT (6 kMc telemetry) techniques (Rocket No. SKI-155).

Results: Rocket SKI-154 gave preliminary 14-Mev neutron source strength **Deleted** Good gamma ray information should be available from this record.

Rocket SKI-155 gave a marginal strength signal but should give more details of the neutron spectrum. These data are not yet available.

Project 6.5b-2 (DASA). Balloon Measurements of Debris Gammas.

B^{10} neutron counters at 100,000 feet carried by balloons launched from South Conjugate Area.

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OSO (Orbiting Solar Observatory) Satellite. Dr. W. Hess, Goddard Space Flight Center.

Moderated BF^3 neutron counters.

Results: No data; satellite not operating.

TRAAC Satellite. Dr. J. F. Kircher, APL

Solid state neutron detector, covered with 1 mg/cm^2 of B^{10}, and further covered with polyethylene. Range: Thermal to 2 Mev.

Results: Data not yet available.

Lawrence Radiation Laboratory Measurements. Dr. F. C. Gilbert, LRL

The following were rocket-borne: a slow neutron experiment from Kauai and a NaI crystal activation experiment from Kauai. Zr activation samples were carried in the pods on the Thor missile. Balloon-borne NaI detectors, and neutron emulsions were launched from Kauai.

Results: Fission neutrons were seen from Kauai in the slow neutron experiment and a large flux of slow neutrons was seen from 1 to 10 seconds after detonation. Kauai NaI results indicated

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however, pod angle may have degraded this experiment. Balloons did not rise above 50,000 feet due to freak temperature inversion; therefore, no data were obtained.

Los Alamos Scientific Laboratory Measurements. Dr. H. Hoerlin, LASL

Two rockets from Kauai carried calibrated U^{235} fission chambers for neutron time of flight measurements, and neutron emulsions.

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C. β and γ Ray Measurements

Project 2.2 (DASA). Gamma Radiation Measurement. John Kinch, NDL.

Film badges, glass microdosimeters, formic acid dosimeters, cobalt activated borosilicate glass dosimeters, and magnesium calcium fluoride thermoluminescent dosimeters were carried on the pods.

Results: Detectors have been removed from pods but data are not yet available.

Project 6.2 (DASA). Rocket-Borne Gamma Ray Scanner. Warren Berning, BRL

Two Javelin rockets launched from Johnston gave gamma flux as a function of scan angle and position; total gamma and total beta in analog form.

Results:

Instrument and Launch time	Altitude	Observation
Gamma scanner, +20 minutes	below 125 km	
	125-325 km	
	325 km	
	325-600 km	
Gamma scanner +40 minutes		Deleted
Total gamma detector +20 minutes	below 145 km	
	145-310 km	
	310 km	
	310-500 km	

Instrument and Launch Time	Altitude	Observation
Total Gamma Detector + 40 minutes		
Beta detector + 20 minutes	below 60 km	
	60-175 km	**Deleted**
	Rest of flight	
Bet' Detector + 40 minutes		

Project 6.3 (DASA). D Region Physical Chemistry. Warren Berning, BRL

Beta flux meter (≥ 100 kev) and 2 channel pulse height analyzer (≥ 0.5 Mev and ≥ 1.0 Mev); similar gamma ray sensor.

Results: Rocket launched at +420 seconds got data which have not yet been correlated with time, altitude, and orientation.

Project 6.4 (DASA) E and F Region Physical Chemistry. W. Pfister, AFCRL.

Beta and Gamma flux meters similar to 6.3.

Results: Most data lost due to telemetry failure. Rockets launched at +480 and +960 seconds got data up to 100 km; counting rates increased with payload altitude and appeared to level off at 50 to 70 km. Rates in +960 second rocket were perhaps lower than in the earlier rocket at a given altitude.

Project 6.5b-1E (DASA). Satellite Data Acquisition. State University of Iowa. Dr. James Van Allen.

Injun I satellite recorded beta and gamma counting rates.

Results: Data not yet available.

Project 6.5b-2 (DASA). Balloon Measurement of Debris Gammas. C. Stone, ARF

NaI scintillation counters at 100,000 feet carried by balloons launched from South Conjugate Area.

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Project 6.7 (DASA) Debris Expansion Experiment. Lt. W. Whitaker, AFSWC.

Five rockets, each with 6 beta counters and a gamma flux detector were launched from Johnston Island prior to detonation. These rockets recorded data for 27 seconds after detonation, from 100 to more than 1000 km from burst point. Beta and gamma fluxes were measured both along the magnetic field lines through the burst and perpendicular to the field lines.

Results: Data not yet available.

Project 6.10 (DASA) HF, VLF, Loran-C Propagation. Roger Whidden, AFCRL.

NaI scintillator in KC-135 at 44,000 feet with pulse height analyzer. Records in range 50-300 kev and > 500 kev.

Results: Aircraft at 177° 47' W, 15° 22' S at 43,300 feet at H hour.

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Project 6.12 (DASA) Piggyback Satellite Packages. Captain R. A. Bena, AFCRL

β and γ flux meters on Discoverers 1127 and 1128, recording DC current and 2-channel pulse height analysis ($\geq$ 0.5 Mev, $\geq$ 1.0 Mev).

Results: No data. Satellites not operating.

<u>OSO</u> (Orbiting Solar Observatory) Dr. W. Hess, Goddard Space Flight Center.

A number of gamma detectors.

Results: No data. Satellite not operating.

<u>Lawrence Radiation Laboratory Measurements</u>. Dr. F. C. Gilbert, LRL

Rocket-borne scintillator and photomultiplier (from Kauai) to measure primary alpha from the prompt gammas. Also scintillator and photodiode to measure time interval.

Results: No data obtained due to improper circuit triggering.

<u>Los Alamos Scientific Laboratory Measurements</u>. Dr. H. Hoerlin, LASL

Scintillation gamma ray detectors were rocket-borne from Kauai.

Results:

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<u>Sandia Corporation Measurements</u>. J. J. Miller, Sandia

Fluor and photodiode systems rocket-borne from Kauai to measure time interval from gamma time history. (Rockets Nos. SKI-151, 152.)

Fluor and 5" photodiode system rocket-borne from Kauai to measure alpha from gamma time history using HHRT (6 kMc Telemetry) techniques. (Rocket No. SKI-156).

Results: No time interval data due to unknown instrument malfunction. No alpha information due to failure of payload to separate from booster.

D. X Ray Measurements and Direct X Ray Effects Measurements

Project 6.3 (DASA). D Region Physical Chemistry. Warren Berning, BRL

Four rocket-borne sensors with thin Be windows; energy deposited in 3 mil CsI crystal in 1 microsecond recorded in analog form.

Results: No data due to rocket failure.

Project 6.4 (DASA) E and F Region Physical Chemistry. W. Pfister, AFCRL

Six ion chambers around Javelin rocket, with filters to select hard x rays.

Results: No data due to telemetry failure.

Project 8B (DASA) Thermal Radiation and Effects. Capt. Gillespie, AFSWC.

Indenture gauges, metallurgical samples, fracture gauges and other materials carried on pods. Also a K-edge detector.

Results: See General Summary of Results.

Lawrence Radiation Laboratory Measurements. F. C. Gilbert, LRL

The following were rocket-borne: (1) an x ray bolometer from Johnston (60-inch tantalum strip wound on a plate behind a beryllium window) measuring the increase in resistance of the strip due to x ray heating; (2) a thin fluor scintillator from Kauai; (3) x ray photo-electric diodes from Johnston.

Results:

Photo-electric diode data not yet calibrated.

Los Alamos Scientific Laboratory Measurements. Dr. H. Hoerlin, LASL

Rocket-borne scintillation x ray experiments (thin fluors over photocells) and photo-electric x ray experiments from Kauai and Arguello.

Results:

No data from Arguello instrumentation due to rocket failure.

Sandia Corporation Measurement. J. J. Miller and J. Scott, Sandia.

Fluor and photodiode system with subtraction of gamma contribution, rocket-borne from Kauai (Rocket No. SKI-153).

Silicon solid state detector, with beryllium cone scatterer with copper and titanium filters, was rocket-borne from Kauai (Rocket No. SKI-157).

Chromel constantan thermopiles to measure total x ray yield were rocket-borne from Johnston (Rockets Nos. SJI-151, 152).

Thin foil calorimeter for total x ray yield was rocket-borne from Johnston (Rocket No. SJI-153).

Results: Fluor and photodiode system failed because of a power supply malfunction at launch.

Thin foil calorimeter failed due to telemetry malfunction.

E. Light and Thermal Measurements

Note: Small scale optical measurements of limited interest (for example, rocket tracking) are omitted from this compilation.

Project 4.1 (DASA). Investigation of Chorio-Retinal Effects. Lt. Col. R. G. Allen, USAF, AMD, Brooks AFB.

Photovoltaic cells with filters and black body calorimeters were carried in a number of planes as part of the chorio-retinal burns investigation.

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Project 6.2 (DASA). Rocket-Borne Gamma Ray Scanner. Warren Berning, BRL.

A photomultiplier tube with filters measuring the intensity and duration

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Project 6.5a. Ionospheric Soundings and Magnetic Measurements. Dr. Philip Newman, AFCRL.

Photometers measuring 3914, 5577 and 6300 A at Kona, Hawaii.

Results: Record was initially saturated. Recordings were taken for 15 minutes.

Project 6.5b-1A. Photometric and Photographic Measurcments. C. Stone, ARF.

Various photometers, cameras, and a 3500-7400 A spectrometer. Generally measuring over relatively long periods of time, with one millisecond time resolution photometer. (Tonga and Tutuila).

Results: Photometer at Tutuila saturated during initial phase of phenomenon.

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Project 6.5b-3H. Tiros IV Satellite. C. Stone, ARF

Broadband radiometer covering IR and visible; IR sensors with bands at 6.0 - 6.5 microns, 7.0 - 30.0 microns, 8.0 - 12.0 microns. NASA will furnish data to ARF.

Results: Data not yet available.

Project 6.5b-3O. Radio Physics Laboratory (Australia). Dr. D. F. Martyn, CSIRO, Camden, New South Wales, Australia.

Birefringent airglow photometer, interferometers for measurement of airglow auroral temperatures by emission line widths, two auroral spectrometers, lead-sulfide detector for IR (overhead).

Results: Data not yet available.

Project 6.5b-3P. University of Canterbury, New Zealand. Dr. C. Ellyott, Department of Physics, Christ Church.

All-sky camera, sodium optical photometer, and auroral spectrograph.

Results: Data not yet available.

Project 6.5B-3Q. National Bureau of Standards, CRPL

Airglow photometer at Mt. Haleakala, Hawaii.

Results: Data not yet available.

of 700 km or greater.

Project 6.13b (DASA). Optical Measurements. John E. Hagefstration, AOMC.

Measurements in UV, visible and IR from DAMP ship. Cameras, photometers, thermograph (IR scanner, thermistor detector), radiometer (PbS).

Results: Very little data obtained at shot time because of weather. Sunrise and sunset on D + 1 yielded no measurable effects.

Project 8A.1 (DASA). Infrared Blackout and Sky Background. Hervey Gauvin, AFCRL.

Electronic scanning spectrometer in 0.35 to 0.60 micron range, 20 A resolution, pointed at detonation (10^3 scans/sec). Narrow-band spectrometers 0.2 to 3.0 micron ranges. NBS slow scan spectrometer pointed 50° from horizontal, one radiometer, UV spectrometer, and photometer packs. All the above airborne in KC-135's in Northern Conjugate Area. A few land based photometers and cameras.

Results: Generally successful operation on 98 percent of instrumentation, with some degradation at Maui due to clouds. Northern aircraft at 37,500 feet, 22° 43' N, 168° 24' W at detonation. Eastern aircraft at 41,000 feet, 15° 53' N, 166° 23' W at detonation. In general, all equipment recorded (UV, visible, IR) strong signals, more intense and persistent than expected. Below is a table of results now available.

Project 6.6 (DASA). Long Term Debris History. Dr. Edward R. Manring, GCA.

Photometers looking at early time and long term debris history by measuring resonant scattering of lithium, barium and zirconium lines. Johnston Island, Ships 2 and 4 for early times; Tongatapu, Tutuila, and French Frigate Shoals, Ships 1 and 2 for long term measurements.

Results: Unexpected signals were received at Johnston Island on all four (4454, 5535, 6130 and 6708 A) wavelengths when the instrument was uncovered at + 30 seconds. Suggested sources for the light are (1) lithium, barium and zirconium debris, excited by electron or photochemical excitation; or (2) strong emissions due to atmospheric fluorescence which leaked through the filter edge.

Location	Observation at First Twilight
Johnston	
	Deleted
French Frigate Shoals	

Project 6.10 (DASA). HF, VLF, Loran-C Propagation. Roger Whidden, AFCRL.

Scanning spectrometer with gratings for 3000 A, 3914 A and 6708 A and IR scanning spectrometers, 1 to 2 and 4 microns. All carried in KC-135 at 44,000 feet in South Conjugate Area. Scanning photometers at 4278 A, 4861 A, 5577 A, 6300 A and 6479 A.

Results: No instrument results available. Visual observation summarized as follows: center of aurora about 200 km west of theoretical Southern Conjugate calculated according to method of Vestine. (16° - 17° S, 176° W). Longest display was smoothly curved ray originating beyond northern horizon and extending over aircraft "steady in position and resembling a searchlight beam." Geomagnetic field lines in same apparent position as beam would pass Johnston Island latitude at a height

Wavelength Range, Microns	Instrument	Results
0.3-0.4	Unspecified	
0.2-1.0	Broadband dispersion units	
0.8-1.1	Filtered photometer	
1 ,-1.6	Lead sulfide radiometer	Deleted
1.56-2.55	R4K Radiometer	
3.0-3.5	NBS Spectrometer	
IR	Spatial Radiometry	

Project 8a.2 (DASA). Optical Phenomenology of High Altitude Events.

Donald F. Hansen, EGG.

This project consisted of approximately 100 cameras and spectrometers located at Johnston, KC-135 north of burst, KC-135 east of burst, Tutuila, and Tonga. For a complete list of instrumentation see DASA Projected Measurements Summary.

Deleted

The bulk of the film has not yet been developed and analyzed.

OSO (Orbiting Solar Observatory.) Dr. W. Hess, Goddard Space Flight Center, Greenbelt, Maryland.

Experiment in the UV (1100-1250 A) and 3800-4800 A ranges.

Results: No data; satellite not operating.

Injun I Satellite, Dept. of Physics and Astronomy, State University of Iowa, Iowa City, Dr. Brian O'Brien, Dr. James Van Allen.

Auroral photometer (5577 A)

Results: Data not yet available.

Deleted

Los Alamos Scientific Laboratory Measurements. Dr. H. Hoerlin, LASL.

Refer to Appendix I for a discussion of the phenomenology of the burst. Vela Sierra system detectors, spectrographs, cameras and photometers at Maui, Johnston and on a KC-135 near French Frigate Shoals.

F. Measurement of Electromagnetic Signal due to the Weapon

Project 6.5a (DASA). Ionospheric Soundings and Magnetic Measurements. Dr. Philip Newman, AFCRL.

Mitre Corporation had detection equipment on Palmyra, including electromagnetic sensors. There were a number of other electromagnetic sensors throughout the world.

Results:

Location	Frequency Range	Data
Johnston	ELF	
Johnston	VLF	
Kona, Hawaii	VLF	
Bedford, Mass.	VLF	
Kauai, Tongatapu, Palmyra	5 kc	
Tutuila	5 kc	
Johnston	5 kc	
Christmas	20 -1000cps	

Deleted

Project 6.5b-3M (DASA). Sylvania Electronics Defense Laboratory. Dr. John T. Harding.

Deleted

Figure 7 - Christmas Island ELF Signal Facsimile

Four receivers in the 50 to 500 kc (10 kc bandwidth) range monitored electromagnetic pulse from blast.

Results: Data not yet available.

Project 7.1 (DASA). Electromagnetic Underwater Measurements. Dr. A. P. Bridges, Kaman Nuclear Corporation.

Electromagnetic signatures as a function of time were measured above and below the ocean surface as a means of indirect bomb damage assessment. Date are 35 mm film recordings of oscilloscope readout of VLF receivers. Two VLF deck-mounted whip antennas, 2 VLF underwater antennas (loop and trailing wire).

Results:

Deleted

Lawrence Radiation Laboratory Measurement. Dr. R. Partridge, LRL.

Measurement of time interval from electromagnetic signal received in Honolulu.

Results: Deleted

Los Alamos Scientific Laboratory Measurements. R.L. Wakefield, LASL

Measurement of time interval from electromagnetic signal received in C-130 aircraft, 753 nautical miles from burst, at 11° 16' N, 115° 07' W, 24, 750 feet.

Results: Deleted

Deleted

Figure 8 - EM Time Interval Signal on C-130 Aircraft
753 Nautical Miles from Burst

G. Biomedical Measurements

Project 4.1 (DASA). Investigation of Chorio-Retinal Effects. Lt. Col. R. G. Allen, USAF, AMD, Brooks AFB.

Rabbits and monkeys looking at the burst, plus photocells and a calorimeter to determine incident light. The animals' eyes were examined after detonation for retinal burns. Various filters and protective devices were tested.

Results: Five aircraft at 20,000 feet at 205, 302, 430, 663 and 723 miles, plus Johnston ground station 17 nautical miles from surface zero. Protective devices set for fast rise times apparently triggered. No chorioretinal burns were found in the tested animals. Detailed microscopic examination of the eyes will be made to determine if there were microscopic effects; however, these are not expected.

H. Measurements of Effects on Radar

Note: Small scale radar measurements of limited interest are omitted from this compilation.

Project 6.5b-3A. RADC Griffiss AFB, Rome, N. Y. Gordon Weatherup.

Backscatter radar at 12.4 Mc, 1 kw peak power at 10 pulses per second, located at Rome, N. Y. Magnetic recording of coherent signal and pen recording of phase. Total and gated backscatter energy was recorded.

Results: Data not yet available.

Project 6b.-3E. Naval Research Laboratories. J. M. Hedrick.

Madre-Backscatter radar at NRL Chesapeake Bay Annex using HF radar, 13-26 Mc, 4.6 megawatt peak, 100 kw average power. Backscatter and round the world forward scatter, amplitude versus time, continuous spectrum analysis versus range.

Results: Data not yet available.

Project 6.5b-3K. Patuxent River Naval Air Station. Donald Decker, Washington, D. C.

Measurement of oblique backscatter radar at two frequencies between 6 and 30 Mc; vertical ionospheric sounder.

Results: Data not yet available.

Project 6.5b-3L. Stanford University. Dr. O. G. Villard

HF backscatter radar looking off at one side of tests, using azimuthal slewing of array of 8 rhombic antennas (1600 ft. aperture). Range time records of the amplitude and phase of the backscatter signals were made; eventually a picture may be built up of the MHD disturbance and its motion as a function of range as well as azimuth.

Results: Data not yet available.

Project 6.5b-3N. University of Queensland, Australia. H. C. Webster, Professor of Physics, St. Lucia, Brisbane, Australia.

At Maggill, near Brisbane, latitude 27.5° S, longitude 152.9° E, there were backscatter sounders at 16, 55, and 15-30 Mc (sweep).

Results: Data not yet available.

Project 6.9. Radar Clutter and Radar Physics Measurements (DASA). Project Officer: R. L. Leadabrand, L. Dolphin (alternate), SRI.

A large number of radar measurements from Johnston, the DAMP ship, and RC-121 type aircraft. Object was to obtain data to determine the location, extent, and time history of clutter ionization due to beta electrons at the burst location and magnetic conjugate areas; determine its reflection capabilities, spectral bandwidth and general characteristics as a function of frequency; determine the relative deposition of energy at the conjugate as compared to the burst area. The 1210, 850, and 398 Mc radars used an 85 ft parabolic dish in common. The 20 through 50 Mc radars used rotating log-periodic antennas in common. The 4 to 10 Mc radars used a vertical log periodic antenna. Aircraft used AN/APS-95 radar. The 140 and 370 Mc radars used 30 ft dish antennas. The 32 and 11 Mc radars used yagi antennas.

Results:

Location	Observation
Acania, near Niua Fo'ou looking normal to field lines	
RC-121 Aircraft, 285 n miles SE air zero	
RC-121 Aircraft, 415 n miles SE air zero	Deleted
RC-121 Aircraft, South Conjugate Area	
Johnston Island HF Sounders	
Johnston Island, 398 Mc	Deleted
Johnston Island, 850 Mc	
Johnston Island, 1210 Mc	

Page 50 Deleted.

Project 7.2 Radio-Frequency Radiometry. Project Officer: James H. Pannell, Lincoln Lab., MIT.

Synchrotron radiation at 50 and 100 Mc was measured from Palmyra. K and S band radar Dicke-type radiometer systems mapped the disturbed region from Johnston.

Results: Synchrotron radiation was observed from Palmyra, randomly polarized at early times. Other data not yet available. See Appendix 2.

Project 7.9 Nuclear Effects on Operational Shipboard Radars. Project Officer: Lt. Cdr. J. S. Grischy (Op Nav OP-353).

Ships assigned to JTF-8 in and around the operation areas tracked targets of opportunity from shortly before detonation until no further effects were apparent. Record data by scope photography.

Results: Data not yet available.

Effects on Nike-Zeus Radar System from Kwajalein Atoll. Nike-Zeus Project Officer (AOMC), Kwajalein.

Target Tracking Radar (TTR), Missile Tracking Radar (MTR), Target Acquisition Radar (TAR) were all turned on at Kwajalein and looking toward the burst.

Results:

Deleted

I. Direct Ionization Measurements

Project 6.3 D Region Physical Chemistry. Project Officer, Warren Berning, BRL.

Mass spectrometric measurement of positive and negative ion species above 30 km; also ion trap. Instruments rocket-borne from Johnston Island.

Results: Data not yet fully available; some instrumentation difficulties were encountered.

Deleted

Project 6.4. E and F Region Physical Chemistry. Project Officer: W. Pfister, AFCRL.

Mass spectrometric measurement of positive ion composition as a function of time and altitude above 100 km using instruments rocket-borne from Johnston Island.

Results: No data recovered because of telemetry failure.

Project 6.7. Debris Expansion Experiment. Project Officer: Lt. W. Whitaker, AFSWC.

Rocket-borne Faraday cups measuring the presence of ionized debris plasma and betas.

Results: Data not yet available.

J. Communications and Ionospheric Disturbance Measurements.

Project 6.2 Rocket-Borne Gamma Ray Scanner. Project Officer: Warren Berning, BRL.

Project 6.4 E and F Region Physical Chemistry. Rocket Probes. Project Officer: W. Pfister, AFCRL.

Three frequency propagation experiments using rocket-borne phase coherent beacons (37, 148, and 888 Mc). Ground receivers mixed and frequency multiplied the telemetry signals to produce dispersive Doppler and Faraday rotation data. Amplitude of each frequency recorded. All rockets launched from Johnston.

Results:

Rocket Launch Time Project Number	Location of Measurement	Electron Concentration
H -600 seconds, 6.4	300 to 325 km altitude	
H +420 seconds, 6.4	Flight Path Azimuth 148° (true) below 350 km	
H +1203 seconds, 6.2	Flight Path Azimuth 28° (true) 300 km altitude, 128 km horizontal distance	Deleted
H +40 minutes, 6.2	Flight Path Azimuth 24° (true)	

Project 6.3 D Region Physical Chemistry. Project Officer: Warren Berning, BRL.

RF antenna impedance in the low megacycle region was measured as the rocket passed through the debris cloud.

Results:

Deleted

Deleted

Project 6.5b-1B. Magnetic and Electric Field Measurements and Cosmic Noise Absorption. C. Stone, ARF.

Sets of riometers at Tonga and Tutuila using various types of antennas.

Results: See Appendix 2.

Deleted

Project 6.5b-1D: HF Phase Measurements. C. Stone, ARF.

Data on additional ionization produced in D, E and F layers of ionosphere above the South Conjugate Area by broadcasting CW at 3.5, 7 and 9 Mc from Tonga to Tutuila.

Results: Data not yet available.

Project 6.5b-1E. Satellite Data Acquisition. C. Stone, ARF.

Obtain signal strength data on satellite transmission to measure ionospheric disturbances. A 4.076 kc tone generator in Injun I and 12.5 kc in TRAAC, transmitted to Tonga.

Results: Data not yet available.

Project 6.5b-3B. U. S. Army Signal Missile Support Agency, White Sands, New Mexico. Contact: NCOIC at Ionosphere Station.

Vertical Ionosonde, 1-25 Mc.

Results: Data not yet available.

Project 6.5b-3D. Naval Electronics Laboratory, San Diego, California. Project Officer: Dr. T. J. Keary, NEL, San Diego.

Measurement of phase and amplitude of VLF (11 kc) link from Arizona to San Diego.

Results: Data not yet available.

Project 6.5b-3E. Naval Research Laboratories. Contact J. M. Hedrick.

Recording of phase differences of VLF (10.2 kc) between NRL in Washington, D. C., and Bodo, Norway.

Results: Data not yet available.

Project 6.5b-3F. Commercial Communications. C. Stone, ARF.

Information was obtained on circuit outages, corrective measures taken and other significant effects. Also propagation links through the D and F layers passing in the vicinity of Hawaii, north to Alaska and south to Australia were of particular concern. A large number of links were monitored.

Results: Data not yet available.

Project 6.5b-3J. HRB-Singer Inc. Contact: Dr. Chalmers F. Sechrist, Jr., Science Park, State College, Pennsylvania.

VLF amplitude and phase measurements were made at State College for NBA (18 kc from Balboa) and NLK (18.6 kc from Jim Creek, Washington). Also atmospheric noise near 18 kc was measured.

Results: Data not yet available.

Project 6.5d. Ionospheric Soundings. Project Officer: F. H. Dickson, USASRPA.

Ionosonde at Johnston and Kwajalein, and a "Pinwheel Experiment" to determine off-great circle path effects on HF communications. Receivers at Adak, Okinawa and Palo Alto to record azimuths of strongest signal from Hawaii.

Results:

Location	Results
Okinawa	
Adak	
Johnston	Deleted
Kwajalein	
Kauai	Deleted

Project 6.5b-30: Radio Physics Laboratory. Dr. D. F. Martyn, CSIRO, Camden, New South Wales, Australia.

Vertical ionosonde, rotating backscatter measurements at 12, 18, 30 Mc.

Results: Data not yet available.

Project 6.5b-3Q. National Bureau of Standards, CRPL. C. Stone, ARF.

Vertical ionosonde, riometers at Huancayo, Peru (on magnetic equator).

Results: Data not yet available.

Project 6.5c. Vertical Sounding of the Ionosphere. Project Officer: William Utlaut, CRPL.

Vertical incidence ionosondes at Wake, Tutuila, French Frigate Shoals, Maui, Canton, Midway and Tongatapu.

Results: Chronology from Midway and Maui (Northern Area.)

Time	Observation
Within 1 second	
Remainder of night to sunrise, Maui and Midway	Deleted
Maui daytime 9 and 10 July	
Morning 11 July, Maui	

Time	Observation
+ 20 minutes, Maui + 35 minutes, Midway	
+ 30 minutes to + 5 hours, Maui and Midway	Deleted
Sunrise	

Deleted

Project 6.8. Riometers. Project Officer: S. Horowitz, AFCRL.

Riometers at Oahu, Johnston, Tutuila, Tongatapu, Midway, Wake, Fiji, Palmyra, MV Acania, S1, S2, S3, S4, S5 and DAMP ship. 300 Mc radiometer on Johnston Island.

Results: See Appendix 2 for discussion of date.

Project 6.9. Radar Clutter and Radar Physics Measurements. Project Officer: R. L. Leadabrand, L. Dolphin, SRI.

High frequency radar sounders at Johnston Island.

Deleted

Project 6.10. HF, VLF, Loran-C Propagation. Project Officer: Roger Whidden, AFCRL.

Step frequency ionosphere recorder, 1-25 Mc, in KC-135, giving a height for frequency record. Three HF receivers at 10, 15 and 20 Mc. Loran-C phase and amplitude recordings. Also ground based step frequency ionospheric recorder at Fiji. HF receivers at 5, 10 and 15 Mc at Fiji and Palmyra. Loran-C recorder on Maui and VLF receiver on Maui monitoring NPM (19.8 kc from Honolulu).

Results: At H hour KC-135 aircraft at 177°47'W, 15°22'S at 43400 ft.

Location	Measurement	Results
Under Southern Conjugate Aurora (Fiji)	Vertical ionospheric recorder	
Fiji and KC-135	Reception of Tongatapu 4 and 6 Mc HF transmission	Deleted
KC-135	Loran-C reception from Hawaii and Kure	
KC-135	NPM Oahu (19.8 kc)	
Midway to Maui	HF Data Link	
Midway to Maui	12.229 Mc	
Midway to Maui	9.043 Mc	
Midway to Maui	4.557 Mc	

Location	Measurement	Results
Maui Phase Swept Interferometer	253, 147, 52 Mc	
Maui	253 Mc	Deleted
Maui	Radio station reception	
Maui	VLF and Loran-C Phase and Amplitude of 19.8 kc	

Project 6.11. HF Communications Simulation Experiment. Project Officer: Howard Kitts, USASRDL.

A complex set of 4 Granger sounders (Okinawa, Roi-Namur, Canton, and Kauai) and 8 receivers (Tutuila, Fairbanks, Palo Alto, Midway, Tongatapu, Rarotonga, Wake, Viti Levu and Hawaii) throughout the Pacific area, operating at 4 to 63.6 Mc. Monitoring of NBA and other communication links.

Results: Deleted

Observation	Location
Deleted	Okinawa to Palo Alto, Hawaii, Tutuila; Roi-Namur to Fairbanks, Palo Alto; Canton to Wake, Fairbanks, Hawaii; Kauai to Wake, Midway; Kauai and Canton backscatter.
	Kauai-Tutuila, Roi-Namur-Wake, Okinawa-Fairbanks, Roi-Namur-Tutuila, Canton-Midway, Canton-Palo Alto, Canton-Rarotonga, Canton-Tutuila and Roi-Namur-Kauai.
	Other paths.

Observation		Location

Deleted

Project 6.12. Piggyback Satellite Packages. Project Officer: Capt. R. A. Bena, AFCRL

Retarding potential probe and ion trap, and synchrotron noise measurement from Discoverers 1127 and 1128.

Results: No data. Satellite not operating.

Project 7.2. Radio-Frequency Radiometry. Project Officer: James H. Pannell, Lincoln Lab., M.I.T.

Measurement of synchrotron noise with VHF rotating dipole assemblies at Palmyra, and Dicke-type radiometers systems at Johnston, to measure

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Receiver Location	Observation at Receiver
Oahu	
Midway	
	Deleted
Viti Levu	
Palo Alto	
Wake, Canton, Samoa, Hawaii, Roi-Namur	Data not yet available.

Signals in the HF band from various places were received on a KC-135 located 200 miles NE of Johnston.

Transmitter Location	Observation at Receiver
March AFB, California	
	Deleted

Communications from Kwajalein: Nike Zeus Project (AOMC) Kwajalein.

All communications circuits monitored.

Frequency and Receiver Location	Description
13 Mc to Honolulu	
20 kc to Honolulu	
9, 12, 15 Mc to California	Deleted
14 Mc to Alaska, Far East and Australia	
14 Mc to U. S. A.	

Sandia Corporation Measurements. J. J. Miller, Sandia Corp.

Signal strengths were measured from the rocket-borne telemetry systems used in other Sandia experiments.

Results: The following data were reported from the Kauai receiving station:

Frequency	Rocket Altitude	
200 Mc	160 km	
200 Mc	50 km	Deleted
6 kMc	160 km	

Project 7.5: VLF Monitoring Through Nuclear Environment. Project Officer: Capt. L. R. Raish, CNO.

A worldwide VLF net check on 14.7, 22.3, 18.6, 19.8, 17.44 and 18 kc.

Results: Data not yet available.

Project 7.6. LF Monitoring Through Nuclear Environment. Project Officer: Capt. L. R. Raish, CNO.

A check of LF communications throughout the Pacific area, transmitted at 185 kc (Honolulu) and 155 kc (Guam). Receivers at Guam, Adak, Honolulu, Japan and shipboard.

Results: Data not yet available.

Project 7.7. MF Ground Wave Monitoring Through Nuclear Environment. Capt. L. R. Raish, CNO.

A check on ship-to-ship MF communications in the 2 to 3 Mc range.

Results: Data not yet available.

Project 7.8. HF Radio Teletype Broadcast Monitoring Through a Nuclear Environment. Project Officer: Capt. L. R. Raish, CNO.

HF radio teletype transmissions were monitored in the Pacific Area.

Results: Data not yet available.

Project 7.11. Nuclear Effects on Certain Operational Electronic Navigation and Identification Equipment. Project Officer: Lt. Cdr. J. S. Grischy.

To determine the effects on TACAN, IFF/SIF equipment with ships and aircraft operating in the Pacific area.

Results: Data not yet available.

K. Magnetic Field Measurements and Earth Current Measurements

Project 6.5a. Ionospheric Soundings and Magnetic Measurements. Project Officer: Dr. Philip Newman, AFCRL.

Variometers at Hawaii, Midway, Palmyra, Tutuila, Canton, Okinawa, Wake, Palo Alto, Huancayo, Genoa. Earth current probes at Hawaii, Palmyra, Tutuila, Ghana, Alaska, New Zealand.

Results: Variometer Readings

Location	Readings
Kauai	
Canton	
Tutuila	Deleted
Trinidad	
University City, Pa.	
Kona , Hawaii	
Wake	

Project 6.5b-1B. Magnetic and Electric Field Measurements and Cosmic Noise Absorption. C. Stone, ARF.

Magnetometers and buried electrodes at Tongatapu and Tutuila.

Results: Measurement	Results
Earth Current	Deleted
Magnetometer N component change	

Magnetometer declination change

Magnetometer Z component change **Deleted**

Project 6.5b-1E. Satellite Data Acquisition. C. Stone, ARF.

Magnetic field strengths from Injun I and TRAAC satellites.

Results: Data not yet available.

Project 6.5b-3C. SRDL, Ft. Monmouth, N. J., Robert Noyes, Camp Evans Signal Lab.

Earth current and magnetometer measurements in the U. S. A.

Results: Data not yet available.

Project 6.5b-3N. University of Queensland, Australia. Contact: H. C. Webster, Professor of Physics, St. Lucia, Brisbane, Australia.

Flux gate-type geomagnetic variometer near Brisbane, Australia. Earth current and geomagnetic micropulsation measurements near Brisbane.

Results: Data not yet available.

Project 6.5b-30. Radio Physics Laboratory (Australia). Contact: Dr. D. F. Martyn, CSIRO, Camden, New South Wales, Australia.

Z-magnetometer in Australia.

Results: Data not yet available.

Project 6.5b-3P. Department of Scientific and Industrial Research, New Zealand. Contacts: J. W. Beagley, A. L. Cullington.

Flux gate magnetometer in New Zealand.

Results: Data not yet available.

Project 6.5b-3Q. National Bureau of Standards, CRPL

Askania magnetometer at Huancayo, Peru.

Results: Data not yet available.

Project 6.5e. Magnetic Measurements. Project Officer: Dr. H. A. Bomke, USASRDL.

Magnetometers at Waimea (Hawaii), Tutuila, Dallas, Texas, and other locations. Earth current measurements in Florida.

Results:	Instrument	Chronology
Waimea, Island of Hawai'	Large loop magneto-meter confirmed [illegible] metastable heli[illegible] magnetometer	Deleted
Tutuila	Metastable helium magnetometer	
Columbus, S.C.	Large loop magnetometer	
Lebanon State Park, N. J.	Large loop magnetometer	
Lebanon State Park, N. J.	Rubidium Electron Spin Magnetometer	
Dallas, Texas	Metastable helium magnetometer	
Baxter State Park, Maine	Large loop magnetometer	Deleted

Project 6.7. Debris Expansion Experiment. Project Officer: Lt. W. Whitaker, AFSWC.

Rocket-borne magnetometers launched from Johnston.

Results: Equipment apparently operated properly but data not yet available.

I. Miscellaneous Measurements

Project 9.1a. Falling-Sphere Project. Project Officer: Dr. K. S. W. Champion, AFCRL.

Measurement of ambient air density at 30 to 100 km, using a sensitive accelerometer to measure drag on a sphere ejected from a rocket.

Results: Data obtained but not yet available.

Project 9.1b. Measurement of Upper Atmospheric Winds. Dr. K. S. W. Champion, AFCRL.

Nike Cajun rockets containing sodium vapor experiment to measure wind and wind shear at 230,000 feet to 480,000 feet. Rockets launched at pre-shot and post-shot twilights.

Results: Each payload operated normally. Both rockets were successfully skin tracked by the Range Tracker. From the dusk rocket data were obtained from 200,000 feet (61 km) to 432,000 ft (132 km). Shears were noted at 80 and 115 km. Winds appeared typical. From the dawn rocket data were obtained from 150,000 feet (46 km) to 429,000 feet (131 km). Two marked shears were observed, and there may have been some slight disturbance of the atmosphere at this time.

Lawrence Radiation Laboratory Measurements. Radio Chemical Samplers. F. C. Gilbert, LRL.

1. Rocket-borne aluminized mylar balloons were inflated prior to entry into the debris area; after passing through the area, the balloons, with the debris adhering to them, were punctured and drawn into a small container. The containers were sealed and were to be recovered.

2. Small sample collection cups were carried on the pods.

Results: The rocket-borne samplers were not recovered. The pod-borne samplers were recovered;

Deleted

Sandia Corporation Measurements. J. Scott, Sandia

Rockets SJS-151, 152 contained rad-chem samplers which used 6 foot mylar sails which were to be retracted after exposure, sealed and recovered.

Results: Containers were not recovered.

APPENDIX 1

STARFISH PRIME
JTF-8

PRELIMINARY FIELD REPORT
STATUS AS OF H + 5 DAYS

"With Additions as of July 31, 1962"

By: Herman Hoerlin, LASL

STARFISH

JTF-8

TU 8.1.1, LASL

Preliminary Field Report

Status as of H + 5 Days

"With Additions as of July 31, 1962"

Herman Hoerlin

This report is based on cursory inspection of photographs, records and data supplied by the following project officers and staff members and also by EG+G: E. Bennett, R. Bussard, R. Cowan, T. Godfrey, M. Hane, D. Holm, R. Kiehn, K. Mitchell, M. Peek, W. Regan, D. Steinhaus, S. Stone, D. R. Westervelt; also H. Argo, J. Conner, J. Coon, S. Singer and R. Taschek. The contributors of all Task Unit members participating in the high altitude phase of Dominic are acknowledged. Special thanks are due to D. R. Westervelt, E. Bennett, D. Steinhaus, R. Kiehn, H. M. Peek, and B. Hayes for taking on many difficult operational responsibilities.

The Sandia Corporation was responsible for small rocket firing and telemetry; the assistance of D. Shuster, J. Scott and J. J. Miller was invaluable.

ABSTRACT

The LASL H + 5 days field report on Starfish reviews in a cursory fashion the phenomenological features of this event as they are understood at this date. The early hydrodynamic debris expansion in vacuum was observed and found to have a velocity of 2000 km/sec; the later expansion is mainly governed by the geomagnetic field at higher altitudes and by air and field at lower altitudes. Very large fractions of the debris were deposited north and south of the burst at the intersections of the magnetic field lines through burst and through points above the burst with the atmosphere at altitudes of about 120 to 150 km, producing north and south large localized areas of strongly ionized air. Recombination appears to be slow. The brightness-time history and the spatial characteristics of these phenomena were recorded with photographic, photoelectric and spectroscopic instrumentation; data obtained are believed adequate to arrive at an understanding of the physical phenomena occurring during and after such an energy release at the Starfish altitude of 400 km.

Diagnostic methods for measuring X-ray yield, time interval and other characteristic source characteristics were developed; rocket born instrumentation demonstrated a high degree of space testing capability. Ground based optical methods were found useful.

Detection equipment of the Vela Sierra type was operated with good success and range and sensitivities of the method were found to be at least as good as predicted.

The scientific fringe benefits that can be derived from a large array of data appear to be very rewarding indeed.

I. Operational Information

A. Burst Location and Burst Time

Starfish was fired July 8, 2300 Hawaii time. Burst location was well within the error box; nominal altitude was 400 km; ground zero about 36 km south of Johnston Island on the geomagnetic meridian. According to latest information provided by Sandia Corporation the deviation from air zero was

$$\Delta X = -1890 \text{ feet N}$$
$$\Delta Y = -2190 \text{ feet E}$$
$$\Delta Z = +617 \text{ feet H}$$

B. Station Operation

1.) Johnston Island. The station operated according to plan with 95% of the instrumentation getting data. At shot time the direct line of sight was almost clear, only a thin cirrus layer intervening. The preliminary estimate for transmission is 50%.

2.) Maui. The station operated according to plan with about 80% of the instrumentation getting data. The direct line of sight was clear, surrounded by a comfortable hole in the clouds. However, a large part of the sky above burst position was obscured preventing data acquisition from late phenomena.

3.) KC-135 Aircraft. The LASL instrumented KC-135 took off from Hickam Air Force Base, Honolulu, at 2035 hours Hawaii time, and flew to geographic position 24°, 14' N, 166°, 12' W, arriving there at 2158 hours. According to aircraft navigational instruments at detonation the geographic position of the aircraft was 24°, 08' 45" N, 165°, 53' W, its altitude was 39,250 feet, and the geographic heading was 114° 45'. This position is approximately 3 nautical miles east of the planned position at detonation time and 4250 feet higher than the planned altitude.

These differences in altitude and position would be expected to produce a change in the burst location of about 0.3° azimuth and about 0.07° elevation; both errors are well within the field of view of any instrument used on the aircraft.* At detonation time, the aircraft was above all detectable clouds. The pre-shot computed line of sight distance from the aircraft to the burst is 1040 km.

Instrumentation worked according to plan with more than 90% of the units getting data.

4.) Kauai. All eight LASL instrumented rockets flew and good telemetry signals were received. All instruments operated according to plan and yielded data.

5.) Arguello. Arguello locked on the JTF-8 count at minus 780 seconds and both vehicles were fired at the proper time. However, no data was obtained due to the failure of both vehicles. Details are:

1. Telemetry contact with the Astrobee was lost about 15 seconds after launch. The vehicle apparently disintegrated early during the powered phase of flight. Cause is suspected but not yet definitely known, and telemetry records and photos are being evaluated in an attempt to determine reason for failure.

2. Telemetry contact with the Argo was lost about 385 seconds after launch, and radar track indicates splash at about 410 seconds after launch. Preliminary investigation indicates that the second stage igniter fired, but did not ignite the propellent and because of vehicle design this would also prevent the third stage from firing. The fourth stage fired as planned.

* 7/31/62 - Subsequent analysis of one of the aircraft cameras records that the aircraft was probably mispointed to a greater degree.

3. Obviously, no diagnostic data was obtained because payloads impacted prior to event time.

4. Preliminary evaluation of the telemetry records indicate that the entire payload on each vehicle was functioning properly until vehicle breakup or splash. Pre-launch calibrate signals were normal, and DC level of detectors during flight appeared correct.

II. Phenomenology

A. Early Debris Expansion

This expansion phase is shown in a good framing camera record, taken from Johnston Island, parts of which are reproduced in Figure 1. It appears that the bomb materials are separated into two parts, a, the central core which expands rather slowly and b, an outer spherically expanding shell. It is not certain to what extent core and shell are related. Hydrodynamic expansion of debris was expected to proceed in spherical fashion without leaving a substantial core behind. One may therefore consider the possibility that the core represents the upper part of the warhead which contains the primary and much of the fusing and firing equipment,

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In any case the separation of the debris into two distinct fractions has a bearing on the later explosion history.

The diameter of the expanding shell is approximately 2 km at 500 microseconds, corresponding to a mean expansion velocity of 2 cm per shake.

The subsequent expansion was recorded with a total of at least four, probably five 35 mm Photosonic cameras operating at Johnston Island, Maui, and in the aircraft. The majority of these pictures show good, well resolved data. Inspection so far has been very superficial and little can be said at this time with the exception of the following.*

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Figure 1

This is a partial reproduction of a Model 6 - 40" - Framing Camera record taken from Johnston Island. Full coverage of 160 frames at approximately 5 microseconds between frames was recorded with good densities.

The lower 3 frames of the enlarged reproduction to the right were taken during the first 15 microseconds. This part is overexposed and shows also a series of lower density images of the very bright core, resulting from off-axis window reflections.

The second row shows frames 58, 59 and 60; the third row frames 85, 86 and 87 and the upper row frames 121, 122 and 123. The dense spot appearing in the periphery of the latter pictures is probably the missile booster.

The main film is amenable to brightness evaluation, with the exception of the first frames. These in turn can be evaluated from the color-film-bipack, which shows well developed images during this phase.

Not reproduced here are the data obtained with the Model 104-32" streak camera. This camera was running successfully and yielded two well exposed bipack films, which should also give good data.

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Figure 1a

This is a reproduction of the first frames of an EG+G Photosonic film, 35 mm, taken from Johnston Island at 2600 frames per second.

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booster and with the three pods is clearly recorded; it is also visible in 70 mm Photosonic records, one of which is reproduced, in part, in Figures 2 and 3. The booster appears very bright for a relatively long time and - as will be described later - yields also an interesting spectrum (Figure 12).

The early photographs have not been evaluated yet in terms of brightness versus time, but should yield good results.

Useful early debris brightness time data were recorded photoelectrically, on all three stations; the more or less collimated photodetectors recorded incident flux versus time. The problem in all cases was to eliminate the contribution of the X-ray excited air fluorescence which, while not as bright as the source in terms of surface brightness, covers a very large area and is therefore substantial. Successful attempts were made to differentiate or eliminate the fluorescence light. One "Direct Optical" signal trace is shown in Figure 4. Preliminary analysis shows a shape not strikingly different from the predictions by Longmire et al in LASL document T-1316; the peak amplitude is however, three times higher than calculated - though well within the safety factor used in eyeburn calculations. Analysis of other detector data is in progress.

B. Late Debris Expansion

The description of the later phases is rather inaccurate and may require serious revision later because it is based on one rather cursory inspection of motion picture and still photographs only. No geometric or densitometric readings have been taken.

Slow EG+G Mitchell camera films taken on Maui create the impression that the outer shell of expanding bomb materials assumes, after a few frames, i.e., at H + 1/25 to 1/10 sec, an elongated ellipsoidal shape with the long axis oriented along the magnetic field lines. This is a fairly well delineated pattern, that continues to develop for a long time thereafter, indicating that at least a substantial fraction of the bomb debris remains ionized. One gains the impression that at this

Figure 2

Frames 0 to 7 of Photosonic record taken from aircraft in southwesterly direction. Framing rate 300 per second; focal length 135 mm; distance to burst 1040 km. The debris expansion is shown in the upper left; close inspection reveals presence of booster and of all three pods and interaction of debris with them. The lower right shows the growth of the "near geomagnetic beta ray pancake." This is a contact print from the 70 mm original.

Photo by EG+G.

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Figure 3

Continuation of the 70 mm Photosonic record shown in Figure 2, frames 18 through 26. This picture series shows the growth of beta ray pancake and the beginning of the debris pancake. The debris pancake is shown as a slowly growing bright spot in the lower right section of the frames. Eventually it extends (not shown) to the same size as the beta cake but exhibits much greater brightness. Photometric analysis ought to yield valuable data.

Photo by EG+G.

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Direct Optical Detection System
Johnston Island

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stage a large fraction of the debris is following the field lines in an upper, southerly direction; the fraction moving down, north appears to be somewhat smaller. The development of the northern branch is documented rather well in the 70 mm Photosonic film, parts of which are reproduced in Figures 2 and 3. A good 35 mm Mitchell camera color film, also taken from the aircraft, supplements this picture. In these films one observes very clearly the arrival of a large stream of beta particles followed by a much more intense and rapidly expanding debris beam. This latter phase is very pronounced in the later frames of the original film, which are not reproduced here. Photometric analysis of the cake photographs may permit an estimate of the fraction of bomb debris deposited here.* We also hope to gain related information from spectral data. One aircraft spectrograph was pointed at a point below the burst. Because of the lateral expansion of the "magnetic debris pancake" into the line of sight a well exposed record was obtained. This time integrated spectrum "Lower Hilger Medium Quartz Spectrogram" is reproduced in Figure 5; its dominant features are air-emission; whether bomb debris are recorded among the many so far unidentified weaker lines remains to be seen.

The strong pancake expected by some to develop directly underneath the source was apparently very weak indeed. There is diffuse light emitted from the space below the zero point for some time; however, this emission could possibly be produced by the "afterglow" phenomenology of the X-ray excited air and by fission gamma rays.

The upwards motion of the debris is very fast and is well documented; not all its features are clearly understood. However, three phases are evident; some are demonstrated in Figure 6:

* 7/31/62 - Rough Photometric analysis of the debris pancake brightness integrated over time and space yields a total kinetic energy for the incoming debris

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a) Broad diffuse and narrow sharp streamers move from a large core to the "upper right," that is north from the rising debris; they are believed to arc over the aircraft and French Frigate Shoal until they hit the atmosphere at points 200 - 300 km north of French Frigate Shoal. The auroral display there was described as being spectacular and unexpectedly brilliant.

b) The Mitchell camera operating in the aircraft shows distinct streamers moving apparently straight up; thus, some debris may have escaped into space.

c) Injection into the southern magnetic pipelines was very strong and is well demonstrated in Figures 6a, b, and c. Interesting enough and hard to understand is the seeming reversal of this southerly trend. Whether this is due to field distortion or due to a misleading perspective can not be firmed up yet.

d) 7/31/62 - Figure 6, frame d, shows streamers that originate along the right edge of the frame and move down to the left with apparent strong magnetic focusing action along the earth's field lines to the south.

At this stage it is too early to state whether or not we will be able to account for the debris disposition quantitatively and with adequate accuracy. The amount of data collected is however large and the chances for success are good.

Many records and observations cannot be incorporated in this report; two picked at random are added.

One observation deals with a detailed phase of the early debris expansion.

In frames 19 and 20 of Figure 5 one observes at the "near geomagnetic beta ray pancake" in the lower right the beginning of what appears to be the debris pancake.

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Figure 6

Reproductions of four 2-1/4 x 2-1/4 color shots taken by W. Regan from KC-135.

a.) H + 25 sec, f = 38 mm, field of view at burst ~ 580 x 580 km.

b.) H + 35 sec, same optics.

c.) H + 50 sec, same optics.

d.) H + 180 sec, f = 80 mm, field of view at burst ~ 300 x 300 km.

Exposure time 15 sec.

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However, it has been calculated by Longmire* in 1959 that hydrodynamic acceleration of the surface layers of a bomb in vacuum may lead to heavy particle velocities of this order of magnitude. These fast particles should be hard to see at the source, but indeed at least one Photosonic record 's a halo-like extension of the expanding sphere, which could conceivably consist of such a particle precursor. It is hard to visualize other mechanisms that would explain the early appearance of the interaction of debris with the denser atmosphere.**

The second observation is a series of good auroral spectra taken by S. Stone from the USS Iwo Jima which, over a period of 39 minutes, covers various phases of the northern and southern branches of the debris aurora. Several of these spectra are reproduced in Figure 7. No analysis has been attempted yet, although the presence of well known auroral lines and bands is clearly evident.

* Argo, Hoerlin, Longmire, Petschek and Skumanich, Scientific Applications of Nuclear Explosions, Plowshare Meeting, San Francisco, California, May, 1959.

** W. Ogle suggests the alternate possibility that delayed fission products might be the source.

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III. Diagnostics

A. Rocketborne Instrumentation

The following is taken from J. Coon's monthly laboratory report for August.

Rocketborne diagnostics were attempted on the July 8 Starfish Prime shot from Johnston Island, with rocket launches from Kauai, Hawaii and from Point Arguello, California. Although readiness status at Arguello appeared to be good and instrumentation checkout was satisfactory, no data were obtained because of failures of both of the two rockets launched, an Astrobee 1500 and an Argo D-8. At Kauai, of the eight Nike Apache rockets launched (by Sandia Corp.) carrying LASL diagnostic instrumentation, all eight rockets and their radiotelemetry performed satisfactorily, and successful diagnostic data were obtained from all instruments. It is felt that the objective of proving the feasibility of getting good bomb diagnostics from instrumented rockets in a space testing program is in some measure already achieved, although further participation Deleted with the hope of getting data from Point Arguello as well as Kauai would add much to the development of techniques.

Presented below are the data obtained from the Kauai launches on Starfish Prime. The rocket altitudes at burst time were high enough to be in line-of-sight with negligible attenuation by the residual atmosphere. Distance from burst point Deleted to rocket instruments was about 1300 km. Quoted values of diagnostic data presented below are based on absolute sensitivity calibrations carried out in the Laboratory.

B. Neutron Yield and Spectrum

Neutron arrival time history records appear to be good for times from the first arrival of neutrons of energy about 16 Mev to arrival times of several seconds. However, atmospheric scattering becomes increasingly important for times longer than those corresponding to 10 Mev line-of-sight neutrons, and has not yet been evaluated. The experimental value for the integral of the number of neutrons escaping from the bomb, on the

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F. Optical, Groundbased Instrumentation

1. Time interval

The gamma ray excited air fluorescence was measured with moderately collimated photoelectric detectors using various optical band-pass or no filters. The data obtained are as follows, on basis of preliminary analysis:

Johnston Island:

KC-135 : Deleted

The time interval detectors used on Maui went off scale probably due to an unexpectedly large electromagnetic signal and inadequate shielding. Figure 8 shows a reproduction of two time interval traces taken on Johnston Island.

2. X-ray flux measurements

The X-ray excited air fluorescence was measured from all three optical stations with photoelectric detectors collimated to 3° and looking off-burst by 1.5° to 20°. A total of 15 records were obtained with good time resolution. The frequencies selected are mainly from the

Page A1-28 Deleted

N_2 second and first positive and the N_2 + first negative systems; i.e. 4060 Å, 8911 Å, 3914 Å, 4709 Å, 5228 Å and others. None of the data are completely reduced in view of need for further analysis of air transmission corrections. The late transmissometer measurements on Johnston Island were disturbed by rocket light. Furthermore the observed relative intensities in the 0,0; 0,2 and 0,3 sequences of the first negative system were again abnormal, Deleted - short wavelengths being of lower intensity. The aggregate of data is, however, so extensive (including the photographic spectroscopic records) that one can be confident to obtain eventually useful quantitative numbers.

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IV. Vela Sierra

A. All Sky System

The 1960 model of the all sky detection system was operated at Johnston Island with all three channels, 3914, 5228 and the background channel at 4140 Å operating properly. Neutral density filters had to be employed to reduce the incident fluxes by eight powers of ten. Data were obtained in all channels; they have not been read yet but are of the expected order of magnitude. One typical signal trace is reproduced in Figure 11.

Two channels of the new Z-system were operated on Maui; channel 1 had a 4140 Å filter while channel 2 had a 3914 Å filter. Because of a peculiarity in the triggering system only the 3914 Å channel yielded a good record, which, however, was of excellent quality.

In addition to the operational field systems three separate groups of four each all sky detectors were operated in the three stations. The CCP-type detectors (constant current photodetectors) are more amenable to yielding quantitative data than the field-operational systems. All channels worked. Data are being analyzed; generally the signals were substantially higher than computed by the High Altitude Fluorescence code using fluorescence efficiency data derived from pertinent electron gun laboratory experiments. Analysis of these data and their bearing on the detection range of such systems will be most interesting.*

B. Direct Optical System

Records of early bomb light were obtained on Johnston Island and Maui. The results of the J. I. measurement were discussed in Chapter II, Phenomology, and a record is reproduced in Figure 4. The analysis of the Maui data is incomplete at this writing.

* 7/31/62 - a detection range of approximately $R = 2.5 \times 10^5 \sqrt{y}$ km (y in kilotons) is indicated.

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V. Spectroscopy

The discussion of spectroscopic data should properly fall into the related chapters of the phenomenological aspects of the burst. However, analysis of spectrograms is tedious and only very qualitative information is available so far. There ore, I am restricting myself to a description of the type of coverage achieved and to the presentation of a few, though relatively poor reproductions.

Spectrograms were obtained as follows:

1. Good streak record of burst seen from Johnston Island. Time resolution ~ 5 μ sec; cine-quartz-fluoride spectrograph. The bomb debris spectrum shows many lines during the first few hundred microseconds and a strong continuum extending well into the ultra violet.

2. A very interesting time resolved streak record of the debris spectrum over the first several milliseconds was obtained from Maui. Both continuum and lines are noticeable. Lines of lithium and aluminum, also H alpha and H beta have been identified so far. The same record shows also at H + 1.4 milliseconds a very rich line spectrum extending in time to H + 20 milliseconds. This spectrum originates from the heated booster and is also seen in two other spectrograms (it would be nice to get numbers for the related temperature and the amount of blow-off from this vehicle.) The spectrum is reproduced in Figure 12.

3. Two medium resolution spectrographs (ARL, 1.5 m and a Bausch and Lomb grating instrument) gave well exposed time integrated spectra of the burst, showing mainly a continuum with growth of lines at the edges. These instruments used small images of the source as entrance slits and growth of source is reflected in line spectra above and below the continuum. Figure 13 is a demonstration of a typical spectrum of this sort.

4. The 3.4 meter Ebert on Maui saw the first 10 microseconds of the burst; it shows a continuum whose only unusual feature is a faint hint of the 3914 Å N_2^+ (0,0) band in absorption.

5. The Hilger medium quartz spectrograph in the aircraft obtained a weak exposure of the burst in the time interval 315 to 700 microseconds.

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6. A much stronger bomb debris spectrum was obtained with the Meinel from Johnston integrating from 500 μ sec to 1 msec. A continuum and many broadened lines are present. Figure 14.

7. Another debris spectrum covering the period 500 to 800 μ sec was obtained with the Hilger Intermediate Quartz from the aircraft.

8. An additional field of the Meinel was exposed to the bomb debris with an integrated exposure from 1 msec to 200 msec. A continuum and numerous lines appear on the record. Figure 14.

9. The fourth field of the Meinel was exposed from 0.2 sec to 40 sec looking at the burst. The main features are strong atomic oxygen lines. Debris have moved out of the field of view.

10. Spectrograms of air fluorescence were obtained with several instruments.

a) from J.I. with the Meinel looking 20° off burst. This is a strong very well developed spectrogram.

b) from the aircraft with the Hilger medium quartz pointing 12° below the burst, exposure interval from 50 μ sec to 170 μ sec.

c) from J.I. the Infrared spectrograph integrated from 10 sec to 110 sec covering wavelengths from 4500 to 9000 Å. Oxygen emission is dominant.

d) The below burst "pancake" spectrum obtained with the Hilger Medium Quartz (Figure 5) and the auroral spectrograms obtained from the Iwo Jima (Figure 7) were described in Chapter II.

11. Late light was observed in the burst region from Maui with the Steinheil and auroral spectrographs until three minutes after burst. Mainly air components and H alpha appeared.

12. A line width experiment operated satisfactorily at Maui. Quality of data not yet established.

13. Photoelectric records of the brightness of the 6300 Å and 5577Å oxygen lines were taken at angles of 2°, 10° and 20° from burst over a period of 16 minutes.

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Postscripts 7-31-62

II. Phenomenology

A. Early Debris Expansion

An EG+G Photosonic Camera record from Maui 360 cm focal length, 3200 frames per sec, shows the expansion of the bomb debris from approximately 1/3 msec to almost 10 msec. The partition of the bomb debris into two parts described on page 7 is shown; in particular the development of the "core" into an upwards mushroomlike expansion configuration is seen clearly. The fast moving fraction takes the shape of a thick disc. Also the interaction of the bomb debris with the booster at an apparent distance (projected) of approximately 1.5 km is shown. Figure 15 is a reproduction of frames 2 through 7.

B. Late Debris Expansion

Two Mitchell camera pictures taken from Maui show the debris expansion in the near horizontal, in the upwards (hump) and in the northern downwards direction i.e. along the magnetic field lines until they make contact with the yellowish-[illegible] looking upper edge of the beta ray "pancake" just above the horizon. The early expansion of the disc seems to be governed by the attitude of the R/V at burst time.

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Figure 16

Mitchell camera record at +0.05 sec, enlarged.

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Figure 17

Mitchell camera record at +0.12 sec, enlarged.

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Table of Contents

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A. Immediate Attenuation

Following the burst immediate attenuation of cosmic noise was noted at riometer locations within line-of-sight of the detonation point. The rapid onset and decay, frequency dependence, and decrease with radial distance from the detonation point of the attenuation appear to agree with predictions of absorption caused by prompt radiation (X-rays, prompt gamma rays, neutrons). Because of the slow chart speed the immediate attenuation appears as a sharp pulse on the EA records. A detailed examination of the onset and decay can be obtained from Rustrack records limited by the riometer time constant of about 1 second. Table A lists riometer locations where immediate attenuation due to prompt radiation was recorded.

TABLE A

Riometer Locations Recording Immediate Attenuation

Oahu

French Frigate Shoals

AMERICAN MARINER (DAMP)

S 1, S 2, S 3, S 4, S 5

Wake

Midway

Johnston Island

Palmyra

Canton Island

Christmas Island

In addition to the riometer locations listed in Table A, immediate attenuation (within a few seconds) was noted at Fiji, Rarotonga, Tongatapu, Tutuila, Viti Levu, and the ACANIA. Reports of prompt absorption were also received from Adak and Boston (but not from Menlo Park). Since these stations are beyond line-of-sight from the burst, the attenuation is not due to X-rays or prompt gamma rays. In the conjugate region beta rays following the earth's magnetic field lines from the burst locale or beta and gamma rays emitted from debris which has been directed along the magnetic field lines to the conjugate region may account for attenuation within a few seconds after burst. A possible source of attenuation at Adak is upward directed neutrons which, after spontaneous disintegration, produce beta rays which can be guided by the earth's magnetic field to locations beyond line-of-sight from the burst.

B. Delayed Attenuation

D-region absorption caused by beta and delayed gamma rays emitted from the fission debris is a source of persistent attenuation of cosmic noise. Because beta rays are confined by the earth's magnetic field, the D-region absorption is a function of the spatial distribution of the debris and the inclination of the magnetic field. Delayed gamma rays radiate in all directions from the debris causing D-region absorption over a region similar to that experiencing immediate attenuation. While the presence of synchrotron noise makes estimates of attenuation due to gamma ray absorption difficult, the riometer locations listed in Table B appear to have experienced gamma ray absorption without concurrent beta ray absorption (at early times after burst).

TABLE B

Riometer Locations Recording Delayed Gamma Ray Absorption

Oahu	Midway
S 1	Johnston Island
S 3	Palmyra
S 4	Canton

As previously mentioned beta rays are confined by the earth's magnetic field producing D-region absorption down the field lines from the burst point and at the southern magnetic conjugate area in a region determined by the spatial distribution of the debris. In the northern hemisphere, strong absorption was recorded at riometer locations (especially at S 5) where the magnetic field lines passing through the detonation point intersect the D-region.

Table C lists the riometer locations which best describe beta ray absorption immediately following the burst.

TABLE C

French Frigate Shoals	ACANIA
AMERICAN MARINER (DAMP)	Viti Levu
S 2	Fiji
S 5	Tongatapu

Table D shows the 30-MC attenuation observed at the riometer stations for several intervals of time. The data in Table D are only preliminary based on assumptions which attempt to compensate for synchrotron radiation.

TABLE D

30 MC Attenuation (db)

Time After Shot - In Minutes

Station	5 Min.	15 Min.	30 Min.	60 Min.	120 Min.
Oahu					
Fr. Frigate Shl.					
American Mariner (DAMP)					
S 1					
S 2					
S 3					
S 4					
S 5					
Wake					
Midway					
Johnston Island					
Palmyra					
Canton					
Christmas Is.					
Acania					
Viti Levu (Fiji)					
Rarotonga					
Tutuila (Samoa)					
Tongatapu					

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Note: S - off scale reading due to synchrotron radiation.

Following the first recovery of absorption in the region north of the detonation, there is a second phase of absorption which can be associated with debris motion. Table E lists the approximate onset time of this second phase of absorption and the time when it reached maximum.

TABLE E

Onset and Maximum Times of Second Phase of Beta Ray Absorption

Station	Time of Onset Minutes	Time of Maximum Minutes
S 4		
Johnston		
S 2		
AMERICAN MARINER	Deleted	
S 5		
S 3		

Note that the second absorption phase appears to be spreading from the detonation region. A possible explanation is that part of the debris originally trapped at about the burst point (causing the hot spot around S 5) falls to lower altitudes where it then spreads horizontally.

There are several interesting characteristics of the riometer data which will require more detailed examination and correlation with other projects before deciding upon the best explanation. One of those is the apparent anamoly in the attenuation recorded by the AMERICAN MARINER and the ACANIA.

These two ships were located at opposite ends of the same magnetic field line (conjugate to each other) so the beta ray absorption would be expected to be the same at each location. It does not appear that the difference in absorption (particularly the time variation) can be explained by the effect of delayed gamma radiation.

Other variations in the cosmic noise records of interest are: (1) the brief recovery of attenuation noted at Tongatapu and Viti Levu about 10 seconds after burst; (2) the apparent build up of delayed attenuation at Midway following the immediate attenuation; (3) the rather complicated nature of the Viti Levu records which show three distinct phases of attenuation in the first few minutes after burst; and (4) the immediate attenuation noted at Rarotonga. Small sunrise effects can be noted at several locations; however, the effect of synchrotron noise makes estimates of long term debris motion difficult.

C. Synchrotron Radiation

When high speed electrons on the order of 1 Mev energy or higher are influenced by the earth's magnetic field, their rotary motion causes wide-band radio noise to be emitted in the VHF spectrum. Successful launch of these electrons into the earth's magnetic field requires high burst altitude in order to avoid containment by neutral air of beta producing fission debris. Mirroring must occur at altitudes in excess of about 400 km at the longitude of Johnston Island in order that electrons will have some possibility of surviving a single trip around the world (30 minutes for 1 Mev approximately). Continual feeding by high altitude fission debris is likely to offset the loss of trapped betas and could, in theory, result in an increase of synchrotron radiation with time. The end-points of the field dip deepest into the earth's neutral atmosphere and so the synchrotron radiation would be expected to persist longest at the magnetic equator (Christmas and Huancayo, Peru). Estimates of the frequency spectrum have been attempted (see Schwartz, R. N.) on the basis of estimates of fission beta spectrum, likely trapping altitudes, radiation per electron of given energy, and directional characteristics of the radiation with respect to the earth's magnetic field. It is concluded that synchrotron radiation at 30 Mc would be expected to be a factor of 10 greater than cosmic noise maximum.

As a result of Starfish Prime, two phases of synchrotron radiation were observed. The first was most intense and lasted only a few minutes after burst. The second phase starting after plus 10 minutes can be isolated from the first because, at Wake, the betas which circumnavigated the globe appeared at plus 10 minutes where no synchrotron radiation had been observed earlier. This second phase was not changing perceptably with time (for equatorial stations) in the course of several days of observation.

1. Early Phase

Following the initial strong absorption due to the burst, synchrotron radiation (discerned by the record exceeding the normal cosmic-noise level) was observed at Oahu, Johnston, S 1, S 3, Palmyra, Christmas, Canton and Tutuila. Other ships and French Frigate Shoals might have observed early-phase synchrotron radiation if the attenuation had not been so extreme. The effect was greatest at the stations long and to the east of the magnetic meridian of the shot and was apparently greatest for the stations closest to the equator.

In general, the synchrotron radiation reached a maximum at about plus 30 seconds, and died in the course of several minutes. Presumably the synchrotron radiations were maximum immediately after burst time but was attenuated in the D-region before reaching the riometer.

At Canton Island, special equipment was provided to measure the nature of the polarization of the synchrotron radiation. On 53 Mc, four total power receivers were operated in conjunction with four zenithal antennae, each having a different polarization, so as to uniquely determine the polarization ellipse as well as the random polarization component.

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On 120 Mc, a riometer was connected to a zenithal, linearly-polarized Yagi antenna turning about a vertical axis, at a rate of about 3.3 rotations per minute. This equipment should have been able to determine the ratio of axis of the polarization ellipse, but the polarization also appeared to be random. On 60 Mc, a 10-wavelength interferometer with slowly sweeping lobes was arranged on an east-west line to measure the width of the radiating "tube" of trapped betas overhead. The antenna spacing was chosen too large so that all that was shown was that the radiating source was larger than about 5 degrees in width.

At Johnston Island, two auxiliary 120 Mc riometers were operated with high-speed Rustrak recorders, one riometer attached to a Yagi in the meridian plane and the other Yagi scanning the horizon. The meridian plane equipment showed early synchrotron radiation arriving from approximately overhead (within about 40 degrees). The rotating equipment showed early synchrotron radiation arriving from the south-east.

As the electrons spiral about the magnetic field lines and oscillate along the field lines from one hemisphere to the other, there are several forces which cause negatively-charged particles to migrate eastward and positively-charged particles to migrate westward. Only the electrons are expected to give synchrotron radiation of importance in the VHF spectrum. Hence, stations located along the magnetic meridian of the shot and to the eastward should observe the strongest radiation during the first few minutes. (There is a high population of 1 and 2 Mev betas which require roughly 30 minutes and 15 minutes, respectively, to travel around the world.)

The riometer network did not observe synchrotron radiation at any of the stations west of the magnetic meridian (Wake, Midway and Fiji). Midway and Oahu are located roughly magnetic east-west of each other at about the same magnetic latitude. Oahu observed off-scale synchrotron radiation but Midway observed none.

Stations far to the north and far to the south did not observe synchrotron radiation (Tongatapu) because the radiation is emitted primarily at right angles to the magnetic field.

French Frigate Shoals and the northern ships did not observe synchrotron radiation because of heavy absorption at the time (due to fission-debris, or beta bombardment overhead of those sites).

2. Round-the-world Phase

Once betas are trapped in the earth's field, they will migrate eastward and reappear at the riometer network from the west. This was especially clear at the Wake station, well to the west of significant delayed absorption and well to the west of early synchrotron radiation. The Wake 30 Mc riometer began to show noise above the normal cosmic noise level at about plus 10 minutes, which maximized at about 25 minutes, holding approximately this level thereafter.

The round-the-world phase appeared at the rest of the riometer stations even before the other effects of the shot had disappeared, making interpretation difficult. The South African magnetic anamoly is expected to cause a considerable loss of the trapped electrons, especially at latitudes well removed from the equator. Consequently, each transversal around the globe emphasizes the equatorial stations such as Christmas, Canton and Palmyra.

3. Long-Term Decay

It is abundantly clear that there is long-term synchrotron radiation at these and other stations. Canton, for example, showed no significant decrease of the synchrotron radiation in the course of five post-shot days of observation (53 Mc). At Christmas on the magnetic equator the synchrotron radiation (at 30 Mc) appeared to have decreased 20 percent in going from plus 10 hours to plus 100 hours.

D. Summary

From the preliminary analysis attempted here, it would appear that at least part of the fission debris was contained within a few hundred kilometers of the detonation point. In the northern hemisphere, the prompt radiation absorption agreed in magnitude and extent with expectations. The presence of debris spreading to altitudes on the order of 1000 km or higher is difficult to determine because there were no riometer sites north of French Frigate Shoals and south of Tongatapu where beta rays would be directed by the earth's magnetic field. However, the appreciable absorption at French Frigate Shoals, Viti Levu and Tongatapu (particularly the absorption seen with oblique riometers looking south from Tongatapu) and the moderate absorption observed by the northern hemisphere ships, suggest that a sizeable fraction of the debris was spread over a considerable altitude distribution. This is confirmed by the significant efficiency of the synchrotron radiation during the first five minutes.

Before the shot there was a suspicion that the snow-plowing of the debris at several hundred kilometers height could give rise to an "ion-curtain" of very heavy attenuation. However, the fact that the Johnston Island riometer had recovered in agreement with the X-ray deposition indicates that the ion-curtain effect did not significantly occur.

For Starfish, detailed predictions of synchrotron radiation were not made. The long lifetimes clearly imply that injection of betas occurred well above detonation altitude.

A search was made for absorption associated with the appearance of sunlight. Weak effects were found at many stations implying that the debris was spread over great distances very thinly. There was evidence for the debris region slowly falling and spreading in radius during the night (migrating slowly from Johnston to S 5); the magnitudes imply that at least some of the debris went into this system. The fraction is difficult to determine.

Appendix 3

Miscellaneous Reference Data

1. **R/V and Pod Positions, and Time of Burst**

Detonation occurred at 090900:9.029Z, 820.7 seconds after lift off, corresponding to 9.029 seconds after 2300 hours, 8 July 1962, Honolulu time.

The following are the preliminary positions of the pods and the re-entry vehicle relative to the Thor launch pad on Johnston Island. Note that both Cubic Corporation and Sandia Corporation tracked Pod S-3, and that there is a slant range discrepancy between the two measurements on Pod S-3 of 1.5 km.

Preliminary Measured Positions

Pod S-1	30,950 ft W	102,000 ft S	1,285,300 ft high	(Cubic)
Pod S-2	30,200 ft W	101,500 ft S	1,274,000 ft high	(Cubic)
Pod S-3	29,600 ft W	100,350 ft S	1,236,200 ft high	(Cubic)
Pod S-3	31,900 ft W	96,900 ft S	1,235,400 ft high	(Sandia)
R/V	34,950 ft W	100,800 ft S	1,312,450 ft high	(Sandia)

2. SMALL ROCKET DATA*

a. Rockets Launched from Johnston Island (Total number, 27)

Time of Launch	Pad No.	Project ID	Rocket Type	Azimuth true (degrees)	Elevation (degrees)	Apogee (nautical miles)	Last Stage Impact Point	Type of Measurement
H-2 3/4 hrs.	21	9.1	Nike Cajun	155	85	74	33 n miles	Winds with Na Vapor
H-30 min.	20	9.1	Nike Cajun	155	85	74	33 n miles	Winds with Na Vapor
H-600 sec	19	6.4	Javelin	90	83	270	16.48°N, 162.48°W	X β γ-rays, Ionization
H-510 sec	25	6.7	XM 33	198	78	555	.3°S, 172.6°W	Mag. field and Debris Expansion
H-500 sec	1	6.7	XM33	10	85	715	24.4°N, 169.6°W	Mag. field and Debris Expansion
H-280 sec	2	6.7	XM33	10	85	715	24.4°N, 169.6°W	Mag. field and Debris Expansion
H-206 sec	14	SJI 152	Nike Apache	195	88	93	18 n miles	X-ray
H-201 sec	10	SJI 152	Nike Apache	195	88	86	17 N miles	X-ray, β-ray
H-200 sec	7	SJI 111	Nike Apache	195	88	86	17 n miles	X-ray, Rad. Chem. Sampler
H-199 sec	9	SJI 151	Nike Apache	195	88	86	17 n miles	X-ray, Rad. Chem. Sampler
H-190 sec	8	SJI 112	Nike Apache	195	88	86	17 n miles	X-ray, Rad. Chem. Sampler
H-160 sec	24	6.7	XM33	198	83		5.8°N, 172.2°W	Mag. field and Debris Expansion
H-140 sec	23	6.7	XM33	198	78	555	.3°S, 172.6°W	Mag. field and Debris Expansion
H-132.5 sec	13	SJS 151	Nike Apache	195	86.5	95	33 n miles	Rad Chem Sampler
H-90 sec	6	6.3	Honest John Nike	120	85	48	25 n miles	X, β, γ-rays, Ionization
H-60 sec	16	6.3	Nike Cajun	90	85	64	29 n miles	Mass Spectrometry
H+220 sec	3	6.13	Speedball	10	84	124	75 n miles	Radar Jitter
H+420 sec	18	6.3	Honest John Nike	90	85	48	25 n miles	X, β, γ-rays, Ionization
H+420 sec	22	6.4	Javelin	120	80	237	11.47°N, 161.36°W	X, β, γ-rays, Ionization
H+480 sec	15	6.3	Nike Cajun	90	85	64	29 n miles	Mass Spectrometry
H+710 sec	26	6.13	Speedball	190	82	124	98 n miles	Radar Jitter
H+960 sec	17	6.4	Javelin	90	83	270	16.48°N, 162.3°W	X, β, γ-rays, Ionization
H+1200 sec	5	6.2	Javelin	15	80	345	27.09°N, 167.9°W	γ, β, Photometry
H+1860 sec	27	6.13	Speedball	180	82	121	98 n miles	Radar Jitter
H+2400 sec	4	6.2	Javelin	15	80	345	27.09°N, 167.9°W	γ, β, Photometry
H+3540 sec	11	SJS 152	Nike Apache	195	86.5	95.4	33 n miles	Rad. Chem. Sampler
0549, D+1	21	9.1	Nike Cajun	155	85	74	33 n miles	Winds with Na Vapor

* All data are based on pre-shot planning and therefore approximate.

b. Rockets launched from Barking Sands, Kauai (Total Number 21)

Note: All rockets are Nike-Apaches.

Time of Launch (seconds)	Identification	Sponsoring Organization	Azimuth (degrees)	Elevation (degrees)	Apogee (Nautical miles)	Second Stage Impact distance (nautical miles)	Type of Measurement
H-205	SKI-153	Sandia	345	80	90	91	X-Ray
H-205	SKI-111	LRL	345	80	85	80	Neutron
H-205	SKI-112	LRL	345	80	85	80	Neutron
H-205	SKI-115	LRL	345	82	84.5	64	Alpha
H-205	SKI-131	LASL	345	82	85	65	Neutron
H-205	SKI-137	LASL	347	82	84	63	X-Ray
H-205	SKI-151	Sandia	345	80	85	85	Time Interval
H-205	SKI-154	Sandia	345	82	86	69	Neutron, γ-ray
H-195	SKI-113	LRL	352	84	86	49	X, γ-ray
H-195	SKI-114	LRL	352	84	86	49	X, γ-ray
H-195	SKI-133	LASL	347	82	84	63	X-ray
H-195	SKI-138	LASL	347	82	84	63	X-ray
H-189	SKI-116	LRL	345	82	85	64	Alpha
H-189	SKI-134	LASL	347	82	84	63	X-ray
H-189	SKI-152	Sandia	345	80	85	85	Time Interval
H-164	SKI-155	Sandia	345	84	78	46	Neutron, γ-ray
H-184	SKI-157	Sandia	356	84	77	46	X-ray
H-175	SKI-156	Sandia	345	80	75	74	γ-ray
H-49	SKI-132	LASL	345	82	85	64	Neutron
H-49	SKI-135	LASL	345	82	86	64	γ-ray
H-49	SKI-136	LASL	345	82	86	64	γ-ray

c. Rockets launched from Point Arguello, California (total Number, 2)

Both the H-480 second Argo D-18 and the H-470 second Astrobee 1500 failed. Each payload included neutron and X- and γ-ray experiments; no data was obtained as both payloads impacted before detonation.

3. Ship, aircraft and island locations

a. Ship Locations

Name	Latitude	Longitude
S-1 Oak Hill	10° 27' N	171° 28.5' W
S-2 Ft. Marion	18° 57.5' N	169° 6.5' W
S-3 Polk County	17° 57' N	164° 24' W
S-4 Pt. Barrow	16° 53' N	172° 12' W
S-5 Taylor	21° 33.0' N	168° 50' W
(DAMP) American Mariner	19° 52.5' N	168° 58.5' W
Acania	Within 2 miles of Niua Fo'ou Approximately 175° W, 15° S	

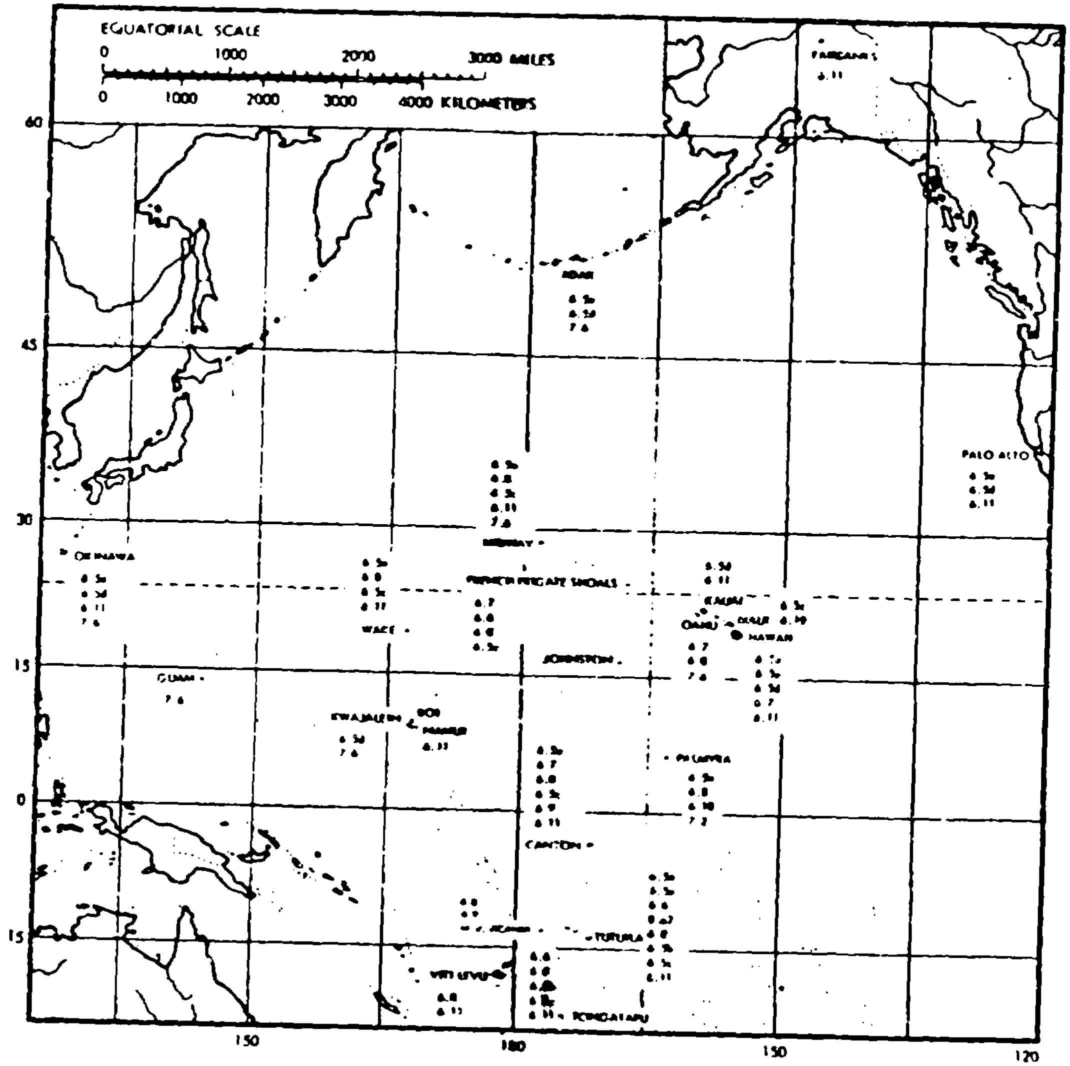
b. Aircraft Locations

Project	A/C Call	Type	Latitude	Longitude
8A.1, A.2	Kettle 1	KC 135	22° 43' N	168° 24.5' W
8A.1, A.2	Kettle 2	KC 135	15° 53' N	166° 23' W
6.10	Kettle 3	KC 135	15° 22' S	177° 47' W
4.1	Caboodle 11	C 118	19° 11' N	167° 27' W
4.1	Caboodle 12	C 118	20° 03' N	165° 56' W
4.1	Caboodle 13	C 118	20° 08' N	163° 04' W

Project	A/C Call	Type	Latitude	Longitude
4.1	Caboodle 14	C 118	21° 00' N	159° 00' W
4.1	Caboodle 15	C 118	21° 21' N	157° 55' W
7.4	Baxter	B-47	19° 55' N	161° 05' W
7.4	Cognac	KC 135	17° 57' N	166° 13' W
7.4	Cordova	KC 135	15° 07' N	172° 20' W
6.9	Lambkin 1	RC 121	14° 00' N	165° 28' W
6.9	Lambkin 2	RC 121	10° 57' N	165° 47' W
6.9	Lambkin 3	RC 121	12° 43' S	170° 10.5' W
6.9	Lambkin 4	RC 121	08°55'S	169° 01' W
LASL	Hewstone	C-130	11° 16' N	115° 07' W
LASL	Kibosh 2	KC-135	24° 08' N	165° 53' W

c. Island Locations

See Map (Page x of Reference e.) next page.



STARFISH PRIME ISLAND LOCATIONS WITH SOME PROJECT LOCATIONS

4. REFERENCES

The major references used in this compilation are listed below; however, very much of the data was obtained from conversations, notes and specialized TWX's which are not listed here.

a. TWX OIC TE 8.1.3.2 Hickam AFB, Hawaii, to Chief DASA, July 10, 1962, TU3H621062-D, (H Plus 24 Hour Report).

b. TWX OIC TE 8.1.3.2 Hickam AFB, Hawaii, to Chief DASA, July 12, 1962, TU3H621093-D, (H Plus 72 Hour Report).

c. TWX CTU 8.1.3, Johnston Island to Chief DASA, July 12, 1962, TU3H621094-D, (H Plus 72 Hour Report).

d. TWX CTU 8.1.3, Johnston Island to Chief DASA, July 10, 1962, TU3J621824-D, (D Plus 1 Day Report).

e. DASA Special Report 1 (Revised), Operation Fish Bowl, Projected Measurements Summary, May 23, 1962, J2-65,

5. ORGANIZATIONAL ABBREVIATIONS

AFCRL	Air Force Cambridge Research Laboratories
AFSWC	Air Force Special Weapons Center
AMD	Aerospace Medical Division
AOMC	U. S. Army Ordnance Missile Command
APL	Johns Hopkins University, Applied Physics Laboratory
ARF	Armour Research Foundation
ARPA	Advanced Research Projects Agency
ASD	Air Force, Aeronautical Systems Division
BRL	U. S. Army Ballistics Research Laboratory
CNO	Chief Naval Operations
CRPL	Central Radio Propagation Laboratory, National Bureau of Standards
DASA	Defense Atomic Support Agency
EGG	Edgerton, Germeshausen and Grier, Inc.
GCA	Geophysics Corporation of America
LASL	Los Alamos Scientific Laboratory
LRL	Lawrence Radiation Laboratory
MIT	Massachusetts Insitute of Technology
NDL	Army Chemical Center, Nuclear Defense Laboratory
NEL	Navy Electronics Laboratory
RADC	Rome Air Development Center, Griffiss AFB
SRDL	U.S. Army Signal Research and Development Laboratory
SRI	Stanford Research Institute
USASRDL	U. S. Army Signal Research and Development Laboratory
USASRPA	U. S. Army Signal Radio Propagation Agency

6. Weather Summary for Starfish Prime

Johnston Area: 0900 Z (Shot Time). 2/8 alto-cumulus over Johnston, 1/8 thin cirrus. Poorer conditions over ships to the north, with some light showers to the north.

Maui Area: 0900 Z. 2/8 cumulus, bases 3,000 ft., 6/8 strato-cumulus, bases 4,800 ft., 2/8 cirrus, visibility 15 miles plus. From the station on Mt. Haleakala the direct line of sight was clear through a hole in the clouds.

South Conjugate Area:

1. Samoa 0600 Z. 4/8 cumulus, bases 2,000 ft., visibility 10 miles plus.

1200 Z. 1/8 cumulus, no other change.

2. Nandi 0600 Z. 1/8 cumulus, bases 3,000 ft., overcast with alto-cumulus and cirrus, visibility 10 miles plus.

1200 Z. 1/8 cumulus and strato-cumulus, bases 3,000 ft., scattered alto-cumulus, visibility 10 miles plus.