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DATA ANALYSIS OF HIGH RESOLUTION PHOTOGRAPHIC RECORDS FROM DNA OPERATION HULA HOOP-1973 (U)

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Technology International Corporation
75 Wiggins Avenue
Bedford, Massachusetts 01730

May 1975

Final Report for Period 15 February 1974—30 April 1975

CONTRACT No. DNA 001-73-C-0214

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

(S) Photographic data from five nuclear events (Fr 47, Fr 48, Fr 49, Fr 50 and Fr 51) and one high explosive safety experiment were obtained during DNA Operation Hula Hoop with optical instrumentation provided for the primary radar clutter experiments. The rise times and expansion rates of the early time luminous phase and late time debris cloud were determined from the photographic records. The radiance histories of the events were determined from photographic exposures. Typical spectral data are also presented.

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18. SUPPLEMENTARY NOTES (Continued)

(S) Sensitive methods were used to collect data discussed in this report. The sensitive aspects of the collection program are described in HULA HOOP Classification Guide, 1 June 1973. Readers are urged to be familiar with this guidance before further disseminating the existence or substance of the data contained in this report. Current guidance may be obtained from DNA/ISCM.

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1.0 (S) INTRODUCTION (U)

1.1 (S) Background (U)

(S) During the summer of 1973, a series of French atmospheric nuclear tests was conducted in the vicinity of Mururoa Atoll in the Taumotu Archipelago of the south Pacific. These tests were monitored by the Defense Nuclear Agency, in conjunction with the U.S. Atomic Energy Commission and the U.S. Air Force as part of an ongoing experimental measurements program. Technology International Corporation was responsible for providing a wide array of optical coverage of the French tests under the direction of DNA as part of Operation Hula Hoop.

(S) The primary objectives of the DNA projects were to acquire data relevant to radar clutter and transmission properties of nuclear environments and, also, optical infrared properties of the atmospheric environment in proximity to such detonations. Other priority objectives included the recording of early time fireball phenomenology, atmospheric excitation effects, and overall cloud development history. In concert with these objectives, optical measurements performed by TIC were designed to:

a) Provide optical image data of the spatial structure of the debris cloud as a function of time for correlation with the primary radar clutter experiments (0 to 20 minutes).

b) Provide data documenting air entrainment, debris-air contact, torus formation, turbulence and other special morphological features in nuclear debris clouds for correlation with current theoretical models (0 to 20 minutes).

c) Provide optical records of the events from which luminosity, apparent surface temperature, and spectral information may be obtained (0 to 20 seconds).

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(S) The French nuclear test series included the detonation of four balloon borne devices and one aircraft dropped device. In addition to the nuclear experiments, a non-nuclear tower shot occurred on 13 September 1973. In the balloon borne events, each device was suspended from a gas-filled, fin-stabilized balloon guyed by a three cable tethering system to barges floating in the Mururoa lagoon. These four near-surface events encompassed yields ranging from approximately 0.05 to 13.5 kilotons, while the yield of the airdrop was estimated at approximately 6.6 kilotons. Table I summarizes the date, time, yield and optical coverage for each of the five nuclear events, utilizing a U.S. adopted numbering system for the French events.

1.2 (U) Operational Platforms

DNA employed three platforms for the monitoring and experimental programs. TIC operated the majority of its optical measurements instrumentation aboard the USNS Wheeling, a Pacific Missile Range vessel, in support of the primary radar experiments conducted from that platform. In addition, several TIC photographic systems were operated from a LASL/AEC KC-135 aircraft (no. 600369) deployed from Hickam AFB, Hawaii, and on board the USS Corpus Christi Bay (which included project helicopters). The Wheeling's course was planned as a constant radius arc around the test site area. The positions at zero time for the ship and the ground track of the aircraft are given for each individual event in Figures 1 through 5. Table II contains the exact location and range of each event from each of the three platforms.

TABLE I (S)

DNA OPTICAL COVERAGE - 1973 ATMOSPHERIC TEST SERIES (S)

EVENT	TIME (Z)	YIELD RANGE	OPTICAL COVERAGE
Fr 47	211800 Jul 1973	13.5 + 2 kt	0 - 2 sec (ship) 26 - 80 sec (ship) 97 sec - 19 min (ship) 47 sec - 6 min 17 sec (A/C)
Fr 48	282300 Jul 1973	0.05 - 0.1 kt	0 - 19 min (ship)
Fr 49	181815 Aug 1973	4.3 ± 0.6 kt	0 - 2.4 sec (ship) 1 min 12 sec - 2 min 45 sec (A/C) 6 min 48 sec - 11 min 21 sec (A/C)
Fr 50	241800 Aug 1973	0.125 - 0.2 kt	0 - 13 min 22 sec (ship) 0 - 10 min 18 sec (A/C)
Fr 51	281830 Aug 1973	6.6 ± 1 kt	2 min 40 sec - 7 min 40 sec (A/C)

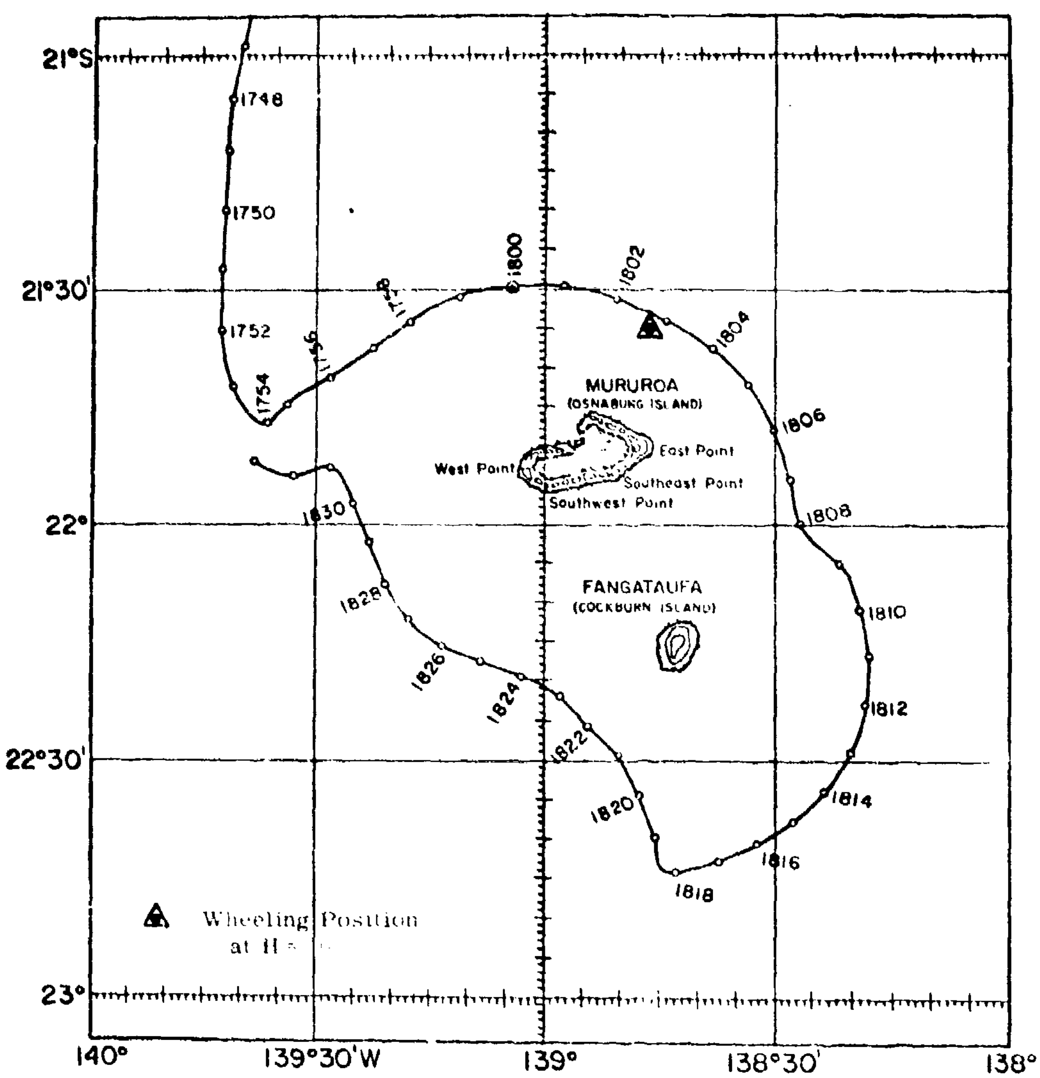

Figure 1 (S). Ground Track of LASL Aircraft for Fr 47 Event (S)

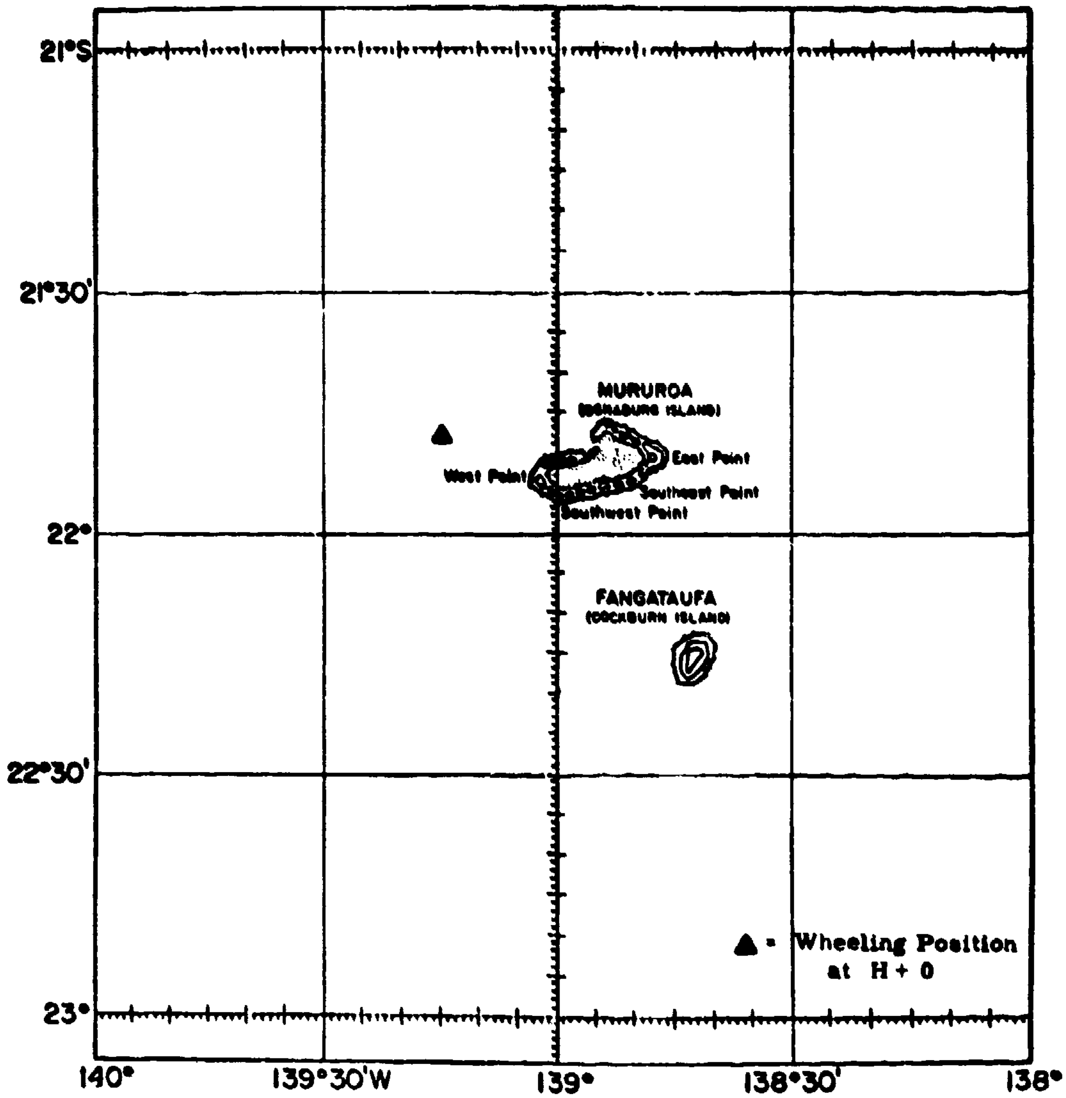

Figure 2 (S). Position of USNS Wheeling for Fr 48 Event (S)

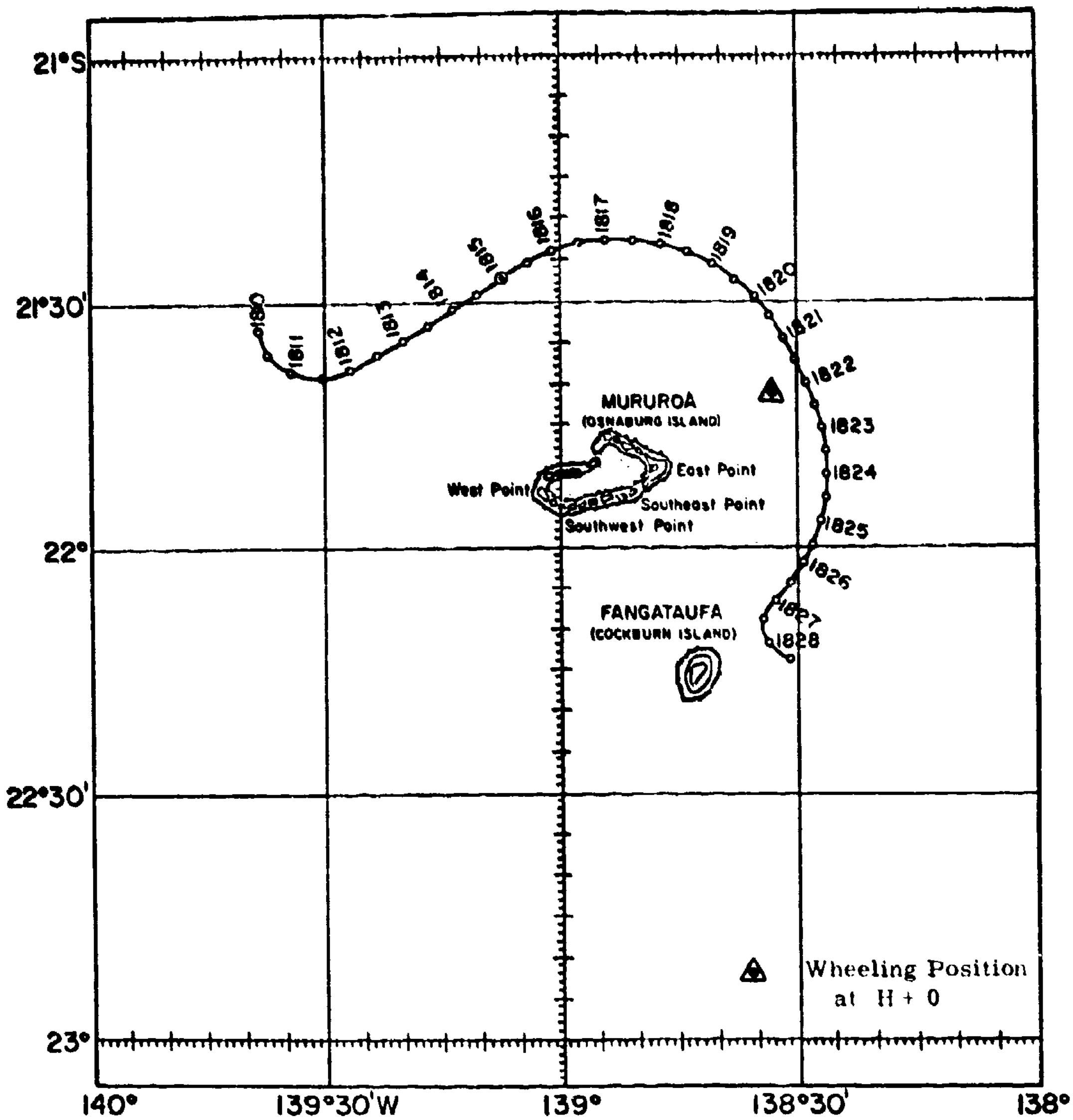

Figure 3 (S). Ground Track of LASL Aircraft for Fr 49 Event (S)

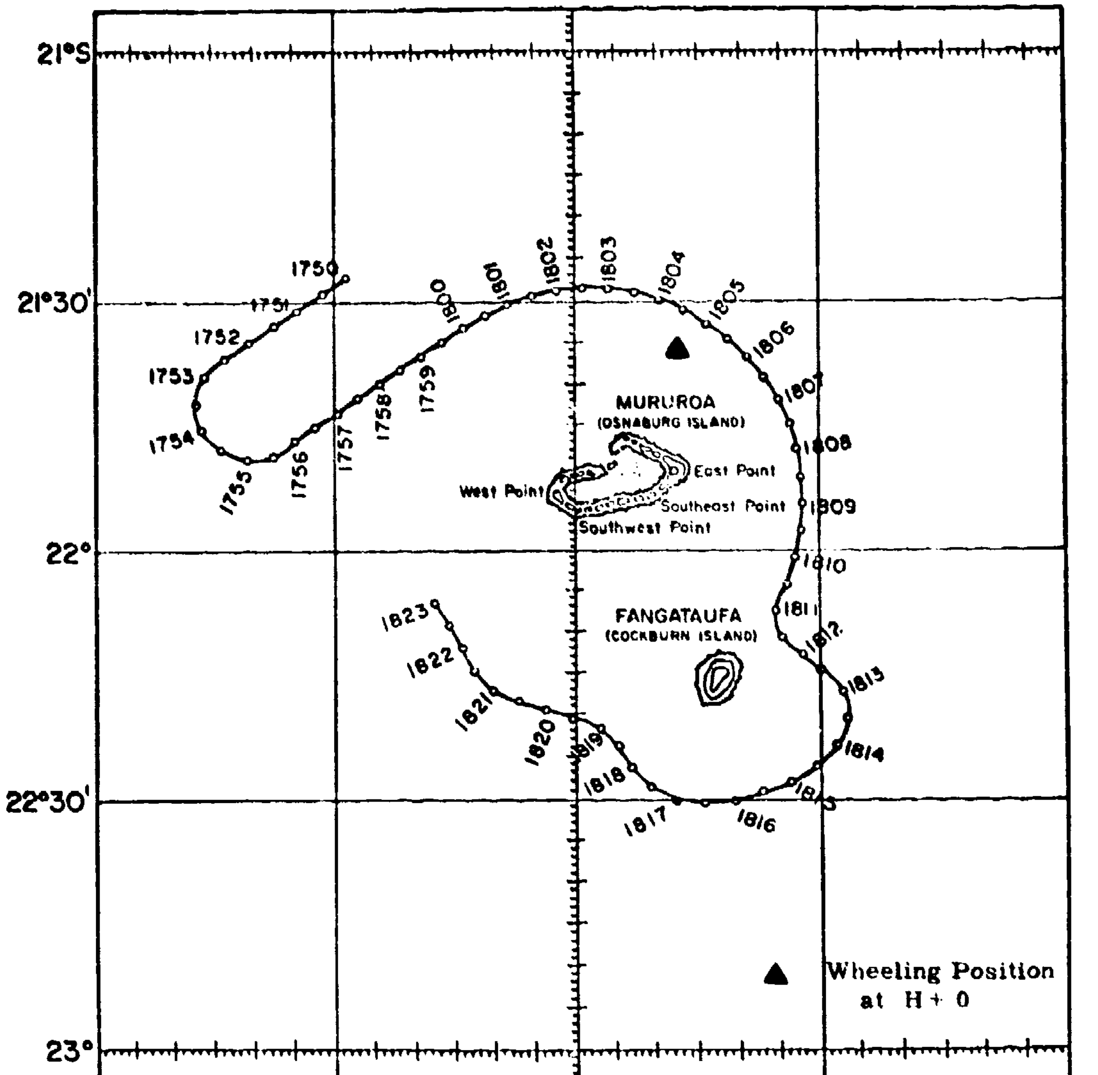

Figure 4 (S). Ground Track of LASL Aircraft for Fr 50 Event (S)

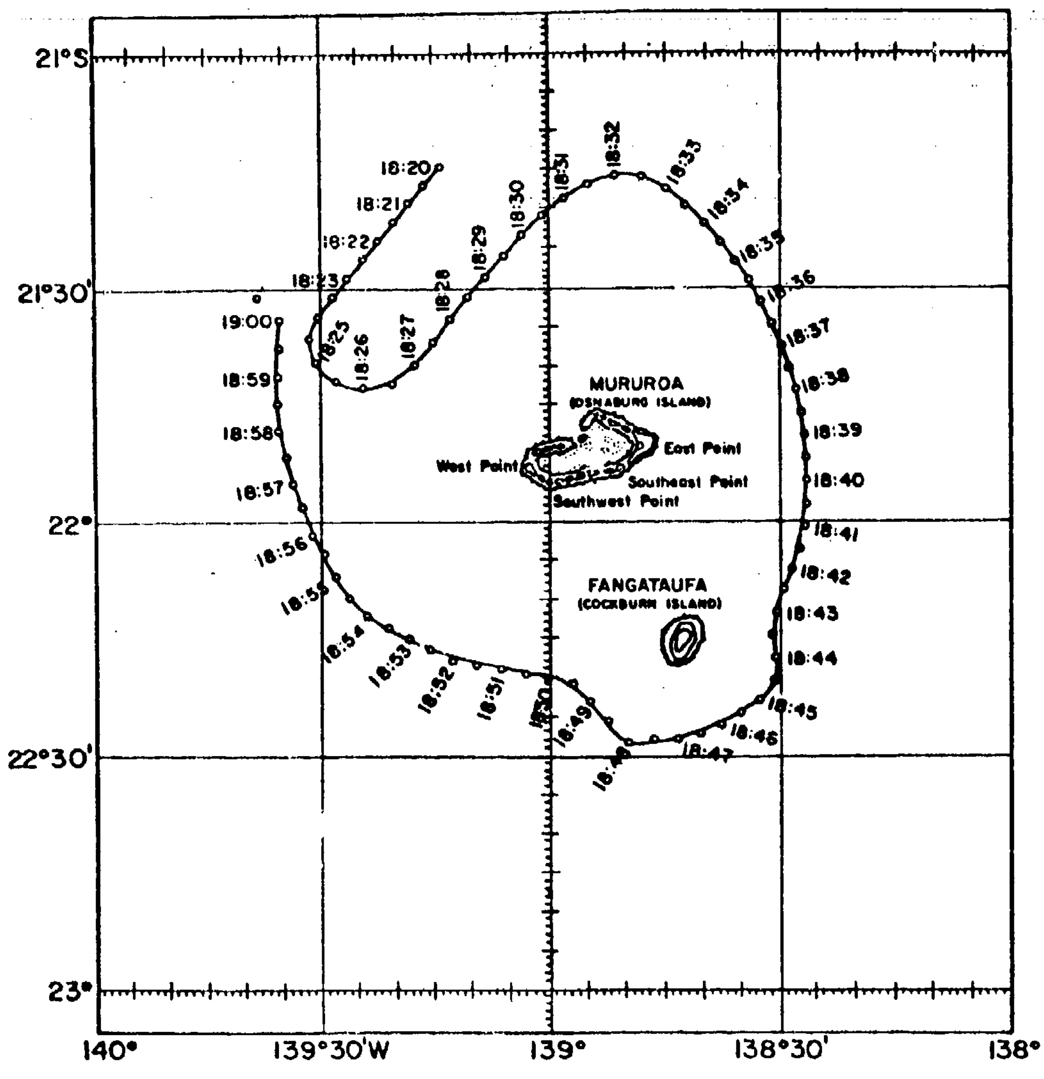

Figure 5 (S). Ground track of LASL aircraft for Fr 51 Event (S)

TABLE II (S)

PLATFORM POSITION PARAMETERS AT DETONATION TIMES (U)

Event	Fr 47	Fr 48	Fr 49	Fr 50	Fr 51
Detonation Site	West	North	North	West	Airdrop
USNS Wheeling (1)					
Range (nautical miles)	20.78	19.97	19.83	19.81	-
Event azimuth (deg. true)	215.93	88.18	251.16	215.96	-
Latitude (deg. S)	21.586	21.802	21.685	21.599	-
Longitude (deg. W)	138.778	139.248	138.555	138.787	-
USS Corpus Christi Bay (1)					
Range (nautical miles)	--	--	22.0	22.3	-
Event azimuth (deg. true)	--	--	114.9	59.7	
Aircraft 369 (2)					
Ground Range (nautical miles)	25.0	1578	25.0	25.2	26.0
Event azimuth (deg. true)	170.21	158.50	148.32	144.26	201.21
Altitude (ft.)	22180	--	26080	26550	26370

(1) USNS Wheeling and USS Corpus Christi Bay position parameters from J. Depp, SRI.

(2) Aircraft 369 position parameters from J. Malik, LASL

1.3 (S) Optical Instrumentation (U)

(U) A variety of photographic and electro-optical instrumentation systems were deployed to gather the data required to achieve the objectives of the Operation Hula Hoop program. Large format (5" and 9 1/2" film sizes), long focal length, pulsed cameras were used to obtain the high resolution data necessary for spatial structure analyses for radar clutter correlation. Shorter focal length (wide angle), large format, pulsed instrumentation provided documentation of late time cloud morphology.

(S) The acquisition of early time fireball development and radiometric data was achieved by the use of high speed, high resolution cine systems which utilized 16mm and 35mm film formats. These instruments produced similar sized images within the smaller film frames and were therefore located on a trainable mount system in order to maintain the source within the field of view. Some of the high speed cameras were filtered to either decrease the density of the exposure or emphasize a particular region of the source spectrum for better definition of certain early time phenomenology. Special spectrographic systems were employed to allow data collection over broad ranges of the optical spectrum. Thus, the overall spectral distribution of the source incident at the sensor was obtained.

(U) In addition, several video systems were employed as pointing controls for the optical systems located on the trainable mount and for post-event analysis of general phenomenology. The complete instrument plan is contained in Appendix A.

2.0 (S) EVENT DESCRIPTION SUMMARY (U)

(S) High resolution photographic data was obtained by TIC from the USNS Wheeling and the USS Corpus Christi Bay for all four balloon supported French nuclear events, hereafter referred to as Fr 47, Fr 48, Fr 49 and Fr 50. A fifth nuclear detonation (Fr 51), an airdrop, was unobserved by either of the two ship platforms, but approximately 8 minutes of Fr 51 event data was collected from the airborne LASL platform, AC 369. Data was also obtained aboard the aircraft during events Fr 47, Fr 49 and Fr 50. A schematic presentation, Figure 6, summarizes the optical data collection periods from each platform for the four near-surface events. This figure includes the specific categories of coverage obtained by the USNS Wheeling.

(S) As part of the Hula Hoop analysis effort TIC has produced a technical pictorial history report for each of the four events observed by the Wheeling (Ref. 1). Each report presents a high resolution photographic summary of event morphology with special emphasis on early time fireball and debris cloud development. Scaled photographic plates in these histories were printed from original high resolution cine and large format data records from both ship borne and airborne platforms. Detailed explanatory and descriptive text supports the photographic data presented for each event. Since these reports were distributed among the user agencies and their contractors, only representative photographs are included in this report, along with a summary description of each event.

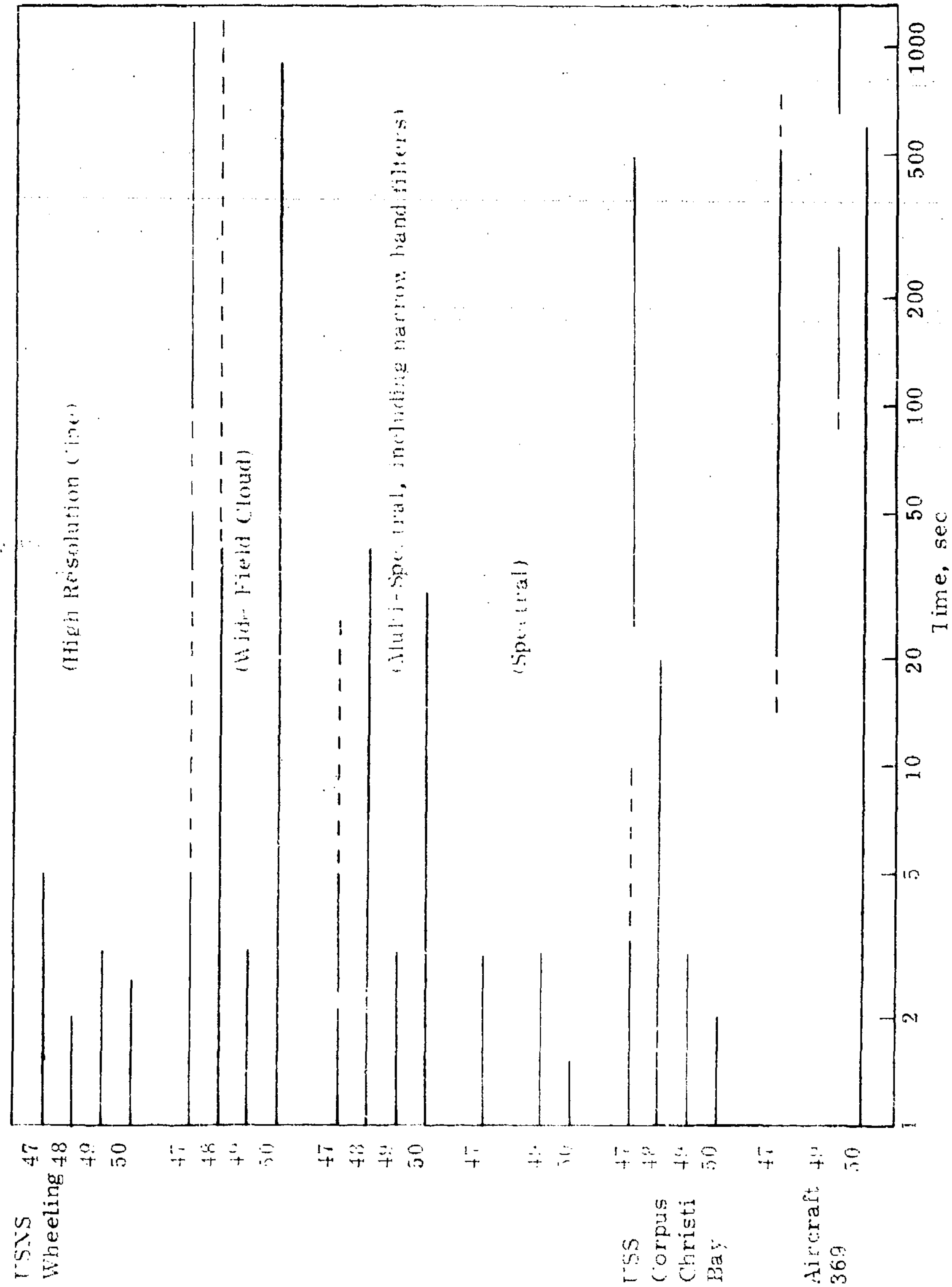

Figure 6 (S). Optical data acquisition period (U).

2.1 (S) Event Fr 47 (S)

(S) The first balloon supported device in the 1973 series was detonated at approximately 200 ± 10 meters above the water surface with an estimated yield of 13.5 ± 2.0 kt in the west site area of the Muroroa Atoll (21 July 1973 - 0900 local). Scattered clouds and showers intermittently blocked the platforms views of the event. Time-to-minimum occurred at about 12 msec., followed by the development of an atmospheric condensation cloud and formation of a typical turbulent mushroom cap rising into a natural cloud layer at about 4.5 sec. After reappearing above the first ambient cloud layer, a brownish-orange color had been distributed throughout the nuclear cloud cap. By 3 minutes after zero, an ice cap had formed over the still brownish cap. Figure 7 is a representative photograph depicting the fine structure of the overlapping ice cap layers. (The solar vector is from the left.) Ice cap dimensional characteristics are presented in Table III as related to time after zero. Gradual dissipation of the event was photographically observed out to 24 minutes.

2.2 (S) Event Fr 48 (S)

(S) The detonation of Fr 48 occurred at a burst height of approximately 260 ± 10 meters in the north site area under generally clear skies (28 July 1973 - 1400 local). This small 0.05 to 0.1 kt yield event was unobserved by the aircraft platform. Following rapid, asymmetrical fireball expansion, the color of the nuclear cloud very slowly changed from gray to white. No brownish-orange coloration nor ice cap formation was observed. Moreover, the usual stem was not evident throughout the data collection period of approximately 20 minutes. Figure 8 depicts the structural fireball characteristic of this event.

Figure 7 (S). Event Fr 47, H + 3 min 28 s. Scale ____ = 420 m (S)

TABLE III (S). EVENT FR 47 - ICE CAP DIMENSIONS (S)

Time (H+)	Top Height (m)	Vertical Thickness (m)	Width (m)	No. of Layers
3m 12.5s	6928	152	1970	1
3m 28s	7231	265	2424	5
3m 44s	7419	492	2538	3
3m 59s	7685		2652	approx. 4
4m 15s	7836			

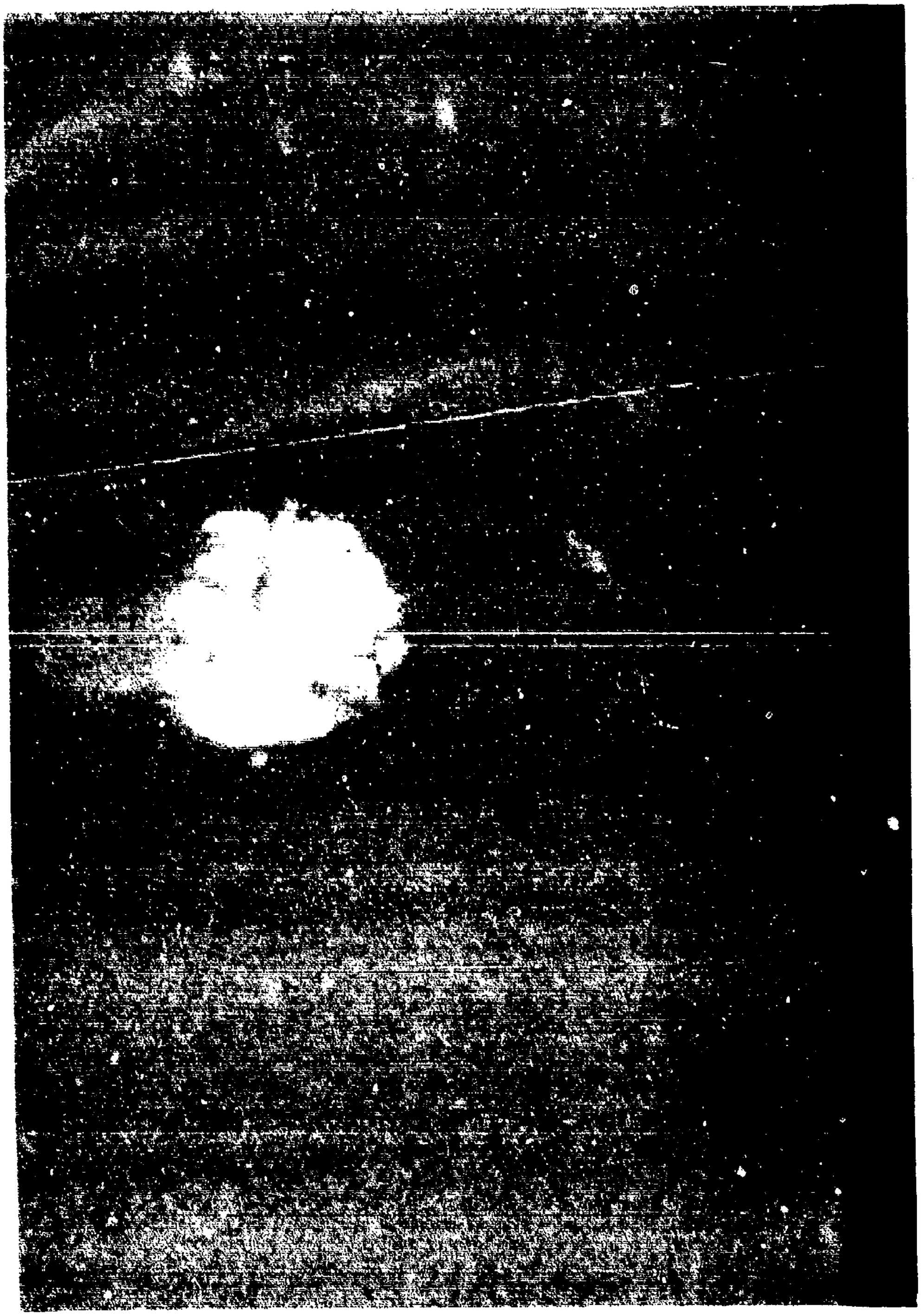

Figure 8 (S). Event Fr 48, H + 1.5 s, Scale ___ = 60 m (S)

2.3 (S) Event Fr 49 (S)

(S) Extensive cloud cover obscured data collection from both ship platforms after a few seconds of this 4.3 ± 0.6 kt event which was detonated at a height of 245 ± 10 meters in the north site area (18 August 1973 - 0915 local). Photographic images from the ship platform exhibited distinct surface brightness irregularities up to approximately 2.5 sec. after which observations were obscured by natural cloud cover. Slightly more than 6 minutes of photographic data was recorded from the aircraft platform during two passes between 1 and 12 minutes after zero. Some radial asymmetry was evident during very early fireball expansion prior to minimum time which occurred at about 8.5 msec. Figure 9 shows the stemmed toroidal mushroom cloud as seen from the aircraft after portions of the cap had taken on a brownish-orange coloration. Later TIC optical coverage from the aircraft recorded the drift and dissipation of the brownish cloud.

2.4 (S) Event Fr 50 (S)

(S) Clear weather and 100% visibility enabled excellent ship and aircraft observations of the last balloon borne device of this series (24 August 1973 - 0900 local). This event was detonated in the west site area at a height of 195 ± 10 meters with a yield estimated between 0.125 and 0.2 kt. Asymmetrical morphology and surface structure variations characterized the initial expansion of the Fr 50 fireball, along with a surrounding condensation cloud formation. Subsequently, the rising debris cloud with its twisted stem exhibited a coloration change from predominantly brown to white as it drifted laterally, finally reaching an early stabilization height as shown in Figure 10.

Figure 9 (S). Event Fr 49, H + 96 s, Scale ——— = 170 m (S)

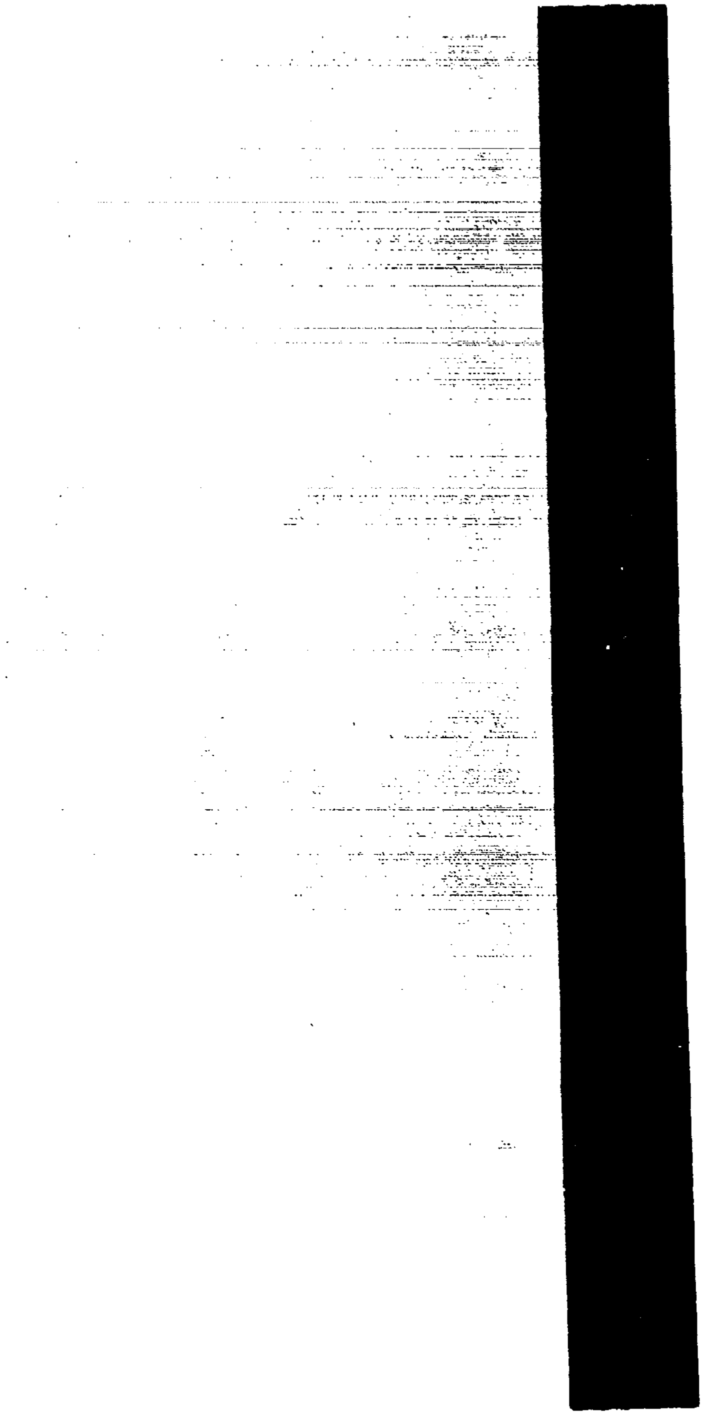

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Figure 10 (S). Event Fr 50, H + 6 min 52.5 s. Scale ___ = 200 m (S)

2.5 (S) Event Fr 51 (S)

(S) The last French nuclear test in the 1973 series was an airdropped device with an estimated yield of 6.6 kt (28 August 1973 - 0930 local). Only minimal photographic data was acquired with a TIC camera on board AC 369 for 7-8 minutes starting approximately 2.75 minutes after zero. Figure 11 is representative of optical coverage of the dissipating debris cloud as viewed from the aircraft during this period.

2.6 (S) High Explosive Safety Experiment (U)

(S) No flash was perceived at the time of detonation of this non-nuclear tower shot as the event was geometrically below the optical horizon from the ship (13 September 1973 - 0642 local). A very small cloud was discernible just above the horizon ten seconds later and persisted for about 50 seconds more.

Figure 11 (S). Event Fr 51, H + 3 min 42 s, Scale _____ = 520 m (S)

3.0 (S) CLOUD DEVELOPMENT HISTORY (U)

(S) The high resolution photographic records obtained for the Defense Nuclear Agency during Operation Hula Hoop have been analysed to provide spatial information on the cloud height, width, and other selected geometric features. Expansion rates have been derived from the cloud dimension versus time curves. Also included in this section are the initial (pre-zero) parameters for the events as observed from the DNA surface platform, the USNS Wheeling.

(U) A short discussion on the data reduction techniques used to obtain the spatial information is presented as a prefix to the data results.

3.1 (S) Data Reduction Technique (U)

(S) Photographic records of three events, Fr 47, 48, and 50, were analysed to determine the spatial characteristics of the fireball and debris cloud as a function of time. These records were made from the USNS Wheeling platform. The determination of the physical size or dimension of an object observed on a photographic image is obtained by a simple trigonometric calculation assuming a known range to the object as follows:

$$(\text{object size}) = (\text{image size on film})\frac{(\text{range to object})}{(\text{focal length of lens})}$$

Vertical dimensions should be corrected for:

a) Earth's curvature geometry, E

b) Height of observer (Incorporated in a) above)

c) Atmospheric refraction, A

(S) The correction, E, for the earth's curvature geometry and the correction, A, due to atmospheric refraction are discussed at length in Appendixes B and C respectively. The earth's curvature correction will be affected to a small degree by the roll of the ship, the size of the ocean swells, and the position of the ship on these swells. Atmospheric refraction makes objects appear higher in altitude than they actually are. The actual height above sea level, H, of an object, including the above corrective terms, is given by

$$H = H_o \times \left(\frac{\text{range}}{\text{focal length of lens}}\right) + E - A$$

where H_o is the measured image height. The actual burst height can usually be determined within ± 10 meters. Table IV gives a summary of the correction values for both earth's curvature and atmospheric refraction used for calculating the geometric dimensional characteristics for the four events Fr 47, 48, 49 and 50. These correction values were determined using the equations in Appendix B and C. It should be understood that although the range to the event is known at zero time, the subsequent motion of the debris cloud upward and laterally with prevailing winds will cause larger errors in the determination of late-time spatial characteristics.

3.2 (S) Pre-Event Parameters (U)

(S) Table V gives range information at zero time for both the ship and aircraft platforms for each of the four events Fr 47, 48, 49 and 50. The aircraft platform was not on station for Fr 48 and, therefore, no range data is given in the table. Also shown in the table is the balloon-device separation and height of burst. Within experimental error the value for the balloon-device separation is constant for all four

TABLE IV (S). SOURCE HEIGHT CORRECTION SUMMARY (U)

EVENT	RANGE (nautical miles)	EARTH'S CURV. CORRECTION (meters) [1]	REFRACTIVE CORRECTION VS. ALTITUDE [2]					
			250m	500m	1000m	2000m	5000m	10,000m
FR 47	20.78	-49 (± 3)	-12	-14	-15	-16	-16	-13
FR 48	19.97	-44 (± 5)	-14	-14	-14	-15	-15	-12
FR 49	19.83	-43 (± 4)	-13	-13	-14	-14	-14	-12
FR 50	19.81	-43 (± 2)	-14	-15	-15	-15	-14	-12

(1) Height of eye approx. 30' (average).

(2) Height corrections for photographically determined values are the net sum of earth's curvature correction and the appropriate refractive correction at the altitude of interest.

TABLE V (S). PRE-EVENT PARAMETERS (U)

EVENT	RANGE FROM USNS WHEELING (nautical miles)	GROUND RANGE FROM A/C 600369 (nautical miles)	BALLOON/DEVICE SEPARATION (meters)	HEIGHT OF BURST (meters)
47	20.78	25.0	32	200 ± 10
48	19.97	----	36	260 ± 10
49	19.83	25.0	36	245 ± 10
50	19.81	25.2	37	195 ± 10

(S)

events. Fr 48 and 49 appear to have been detonated at a slightly higher altitude than Fr 47 and 50. The values calculated for balloon-device separation and heights of burst are similar to values obtained from the previous tests Fr 44, 45 and 46.

(S) To adequately reduce and interpret information on the photographic records, it is essential to know both the pre- and post-event weather conditions in the vicinity of the platform. Table VI gives the pertinent local weather conditions at sea level for the four events. Included in the table are sea water temperature and the period and height of local sea and swell waves. Note that this information applies only to local conditions at the ship as opposed to the area between the ship and atoll. For events 49 and 50 rain showers in the vicinity led to some uncertainties in the atmospheric transmission values between the observation platforms and detonation point. Appendix D lists the detailed weather conditions as a function of altitude for both pre- and post-event. Included in this listing are the wind parameters that were available for each of the four events.

3.3 (S) Dimensional Characteristics (U)

(S) Detailed late-time geometric data out to approximately ten minutes after detonation was obtained for the three events Fr 47, 48, and 50. The debris cloud from Fr 49 was visually obscured in less than one minute by natural clouds, while for Fr 51 the USNS Wheeling was not on station to observe the event. Early-time spatial data (1-30sec) was also obtained for events Fr 48 and 50. The photographic records used in this analysis were obtained from high resolution cameras recording data at 10-30sec intervals and having a spatial resolution at the source of approximately 2-5 meters. Appendix A has the pertinent

TABLE VI

WEATHER OBSERVATION DATA AT H=0

EVENT	WINDS Direction	WINDS Force	SURFACE VISIBILITY	PRESSURE	TEMP.	SEA TEMP.	DEW POINT
	(deg. true)	(knots)	(miles)	(millibars)	(Dry°C/Wet°C)	(°C)	(°C)
47	015	10	10	1014.5	24.4 / 22.2	24.4	21
48	130	9	10	1018.4	23.5 / 20.1	23.9	22
49	125	10	10	1019.6	22.6 / 20.3	23.4	19
50	083	8	10	1023.2	23.8 / 22.3	23.9	22

EVENT	CLOUDS Amount	CLOUDS Height	CLOUDS Type*	WEATHER	SEA WAVES Period	SEA WAVES Height	SEA SWELLS Direction	SEA SWELLS Period	SEA SWELLS Height
	(tenths)	(feet)			(sec)	(feet)	(deg. true)	(sec)	(feet)
47	9	2000	C, AC, Ci	None	4	1	010	12	7
48	5	2500	C, SC	None	4	1	090	10	10
49	8	2000	C	Distant Rain	3	2	120	6	6
50	7	2500	C, AC	Rain Showers	3	1	050	2	4

*Cloud Types: C = cumulus; AC = alto-cumulus; Ci = cirrus; SC = strato-cumulus.

(S)

details of these camera systems.

(S) The objectives of the spatial analysis effort were to determine the cloud dimensions both in the vertical and horizontal plane, expansion rates, and dimensional characteristics of other selective geometric objects such as the ice cap observed in the Fr 47 event. In general, color film records were selected for analysis in order to enhance the discrimination of cloud structure. For determining dimensions of fine structure within the debris cloud black and white records were studied since they have higher spatial resolution qualities.

3.31 (S) Event Fr 47 (S)

(S) Fr 47 was the largest yield event, 13.5 kt, of the Hula Hoop series, detonated at an altitude of 200 meters.

(S) High resolution photographic records yielded spatial data coverage from zero to approximately 10 minutes after detonation. At early times (1-30sec) the debris cloud was partially obscured by natural clouds. Good weather conditions prevailed with the exception of the low cloud bank at about 2000 ft. altitude (see Table VI). After thirty seconds the debris cloud was above the natural clouds and good dimensional data was obtained. Measured values for both cloud height and width versus time are plotted in Figures 12 and 13 respectively. The upper curve in Figure 12 is a plot of the height of the top of the debris cloud, determined visually as a function of time; the lower curve is a plot of the height of the bottom of the debris cloud, not including the stem. The top of the cloud appears to begin stabilizing at four minutes at an altitude of about 7,500 meters. By 10 minutes the cloud height is seen to have reached 9,500 meters.

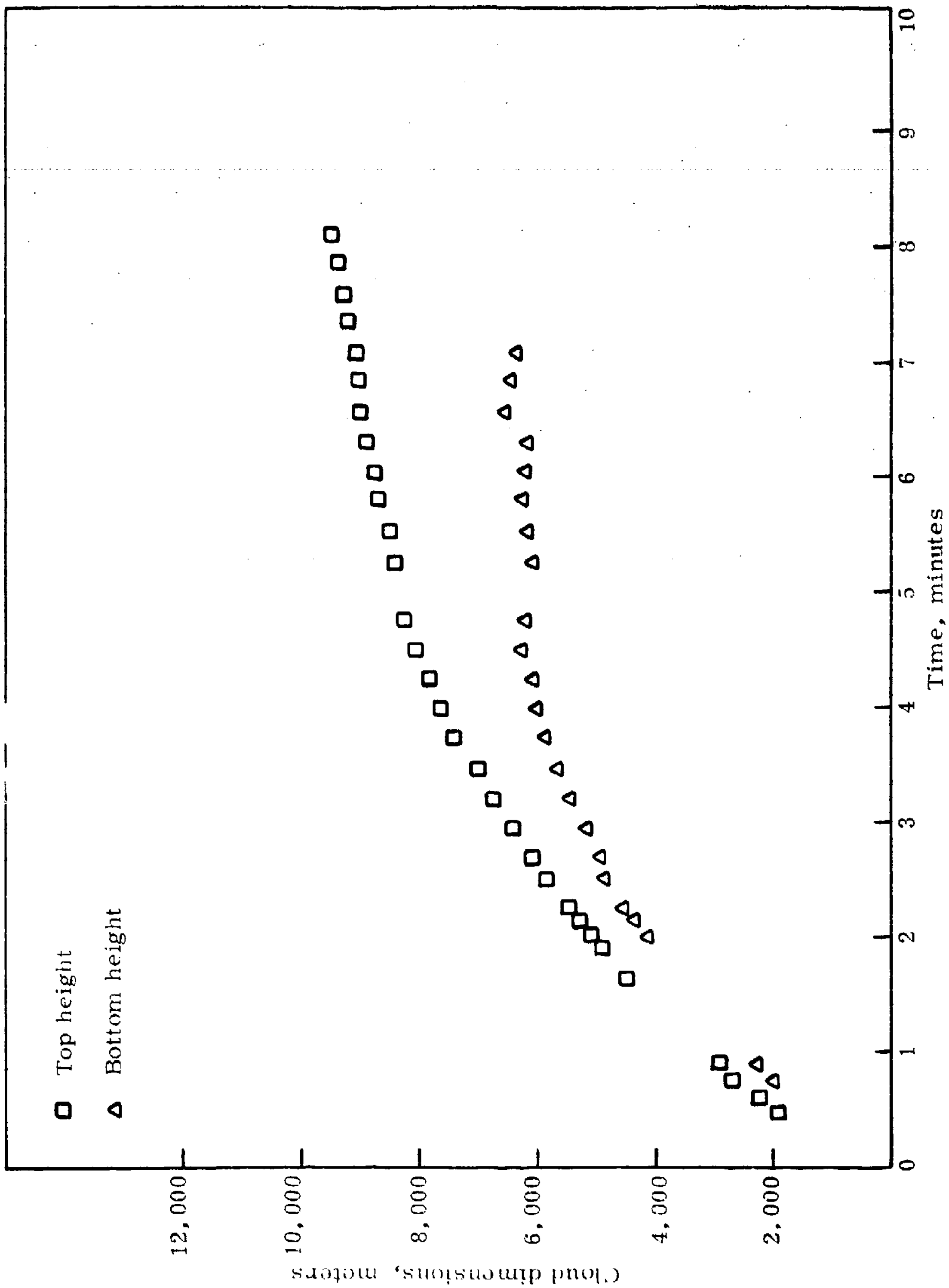

Figure 12 (S). Event Fr 47 - Cloud height vs. time (S).

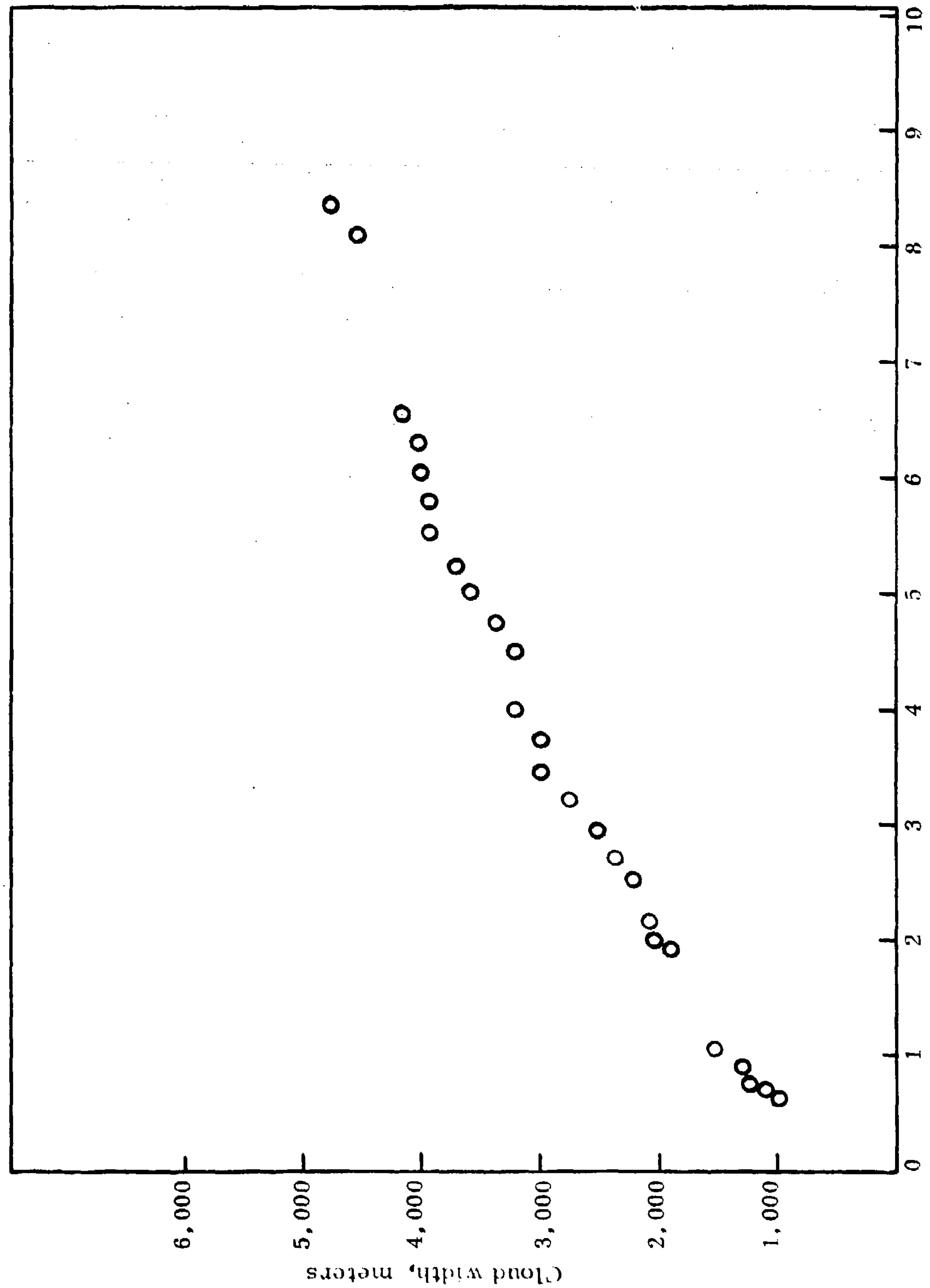

Figure 13 (S). Event Fr 47 - Cloud width vs. time (S).

(S) Consistent with the cloud top height, the height of the bottom cloud is seen to have reached a maximum height (of about 6,000 meters) by four minutes also. The vertical rise rate for the top height of the cloud was calculated to be 24 m/sec over the time interval H = 0 to H + 2.5 min. At later times the vertical rise rate decreased to less than 6 m/sec as the cloud height began to stabilize. The vertical cloud dimension, top to bottom, at 5 minutes is approximately 3,000 meters. This corresponds fairly well with the cloud width at the same time (see Figure 13). The expansion rate in the horizontal direction, obtained from Figure 13, is 22 m/sec at H + 20 sec and 11 m/sec at H + 2.5 min. In determining the values presented in Figures 12 and 13 a constant range was assumed for all times and no correction was made for horizontal motion of the cloud. The wind profiles and cloud width dimensions should be studied to approximate variations in true slant range. In the data plotted in Figures 12 and 13 the small variations from a continuous or smooth curve are probably due to instrumental effects.

(S) A comparison of the Fr 47 event with that of Fr 46 from the previous year indicates that even though the height of burst and yield were approximately the same (Fr 46; HOB = 215 km, yield = 6.5 kt), at roughly H + 5 minutes the debris cloud from Fr 47 expanded in a horizontal direction 4 times greater than that of the debris cloud from Fr 46. The vertical expansion and rise rates show no large differences between the two events.

3.32 (S) Event Fr 48 (S)

(S) This event was the smallest yield (0.05 kt) experiment of the Hula Hoop program and was detonated at approximately 260 meters.

(S) Good photographic coverage of this event was obtained from zero time to approximately H + 10 minutes with a small gap in the coverage between three and five minutes due to natural clouds. Values for both the debris cloud height and width as a function of time as determined from the photographic records are plotted in Figures 14 and 15 respectively. The upper curve in Figure 14 is a plot of the apparent height of the visual top of the debris cloud and the lower curve is a plot of the bottom height of the debris cloud. It is seen from the figures that stabilization is reached at about 4.5 minutes at an altitude of approximately 2,100 meters. After 8 minutes the cloud height has reached an altitude of 2,400 meters, with the cloud body having dimensions of 900 meters in the vertical direction and 1300 meters in the horizontal direction. It should be pointed out that in Fr 47, a much larger yield event, the vertical and horizontal dimensions of the cloud were about equal at its stabilization altitude of roughly 9000 meters. Stabilization times, for the two events, appear to be equal.

(S) Figures 16 and 17 plot the early-time cloud development for Fr 48 from H = 0 to H + 30 sec. Plotted in Figure 16 is the visual top and bottom heights of the cloud and Figure 17 gives the cloud width as a function of time. The data in both figures are smooth and slowly changing. The calculated vertical rise rate from Figure 16 is 14.0 m/sec at H + 10 sec. The horizontal expansion rate at this time as determined from the slope of the curve in Figure 17 is 10.6 m/sec. At H + 20 sec the horizontal expansion rate has decreased to 6.3 m/sec. The vertical rise rate has remained constant at 14.0 m/sec over this relatively short time interval. At later times, H + 2.5 minutes, the vertical rise rate is calculated to be 4.7 m/sec, with a horizontal expansion rate of 2.9 m/sec.

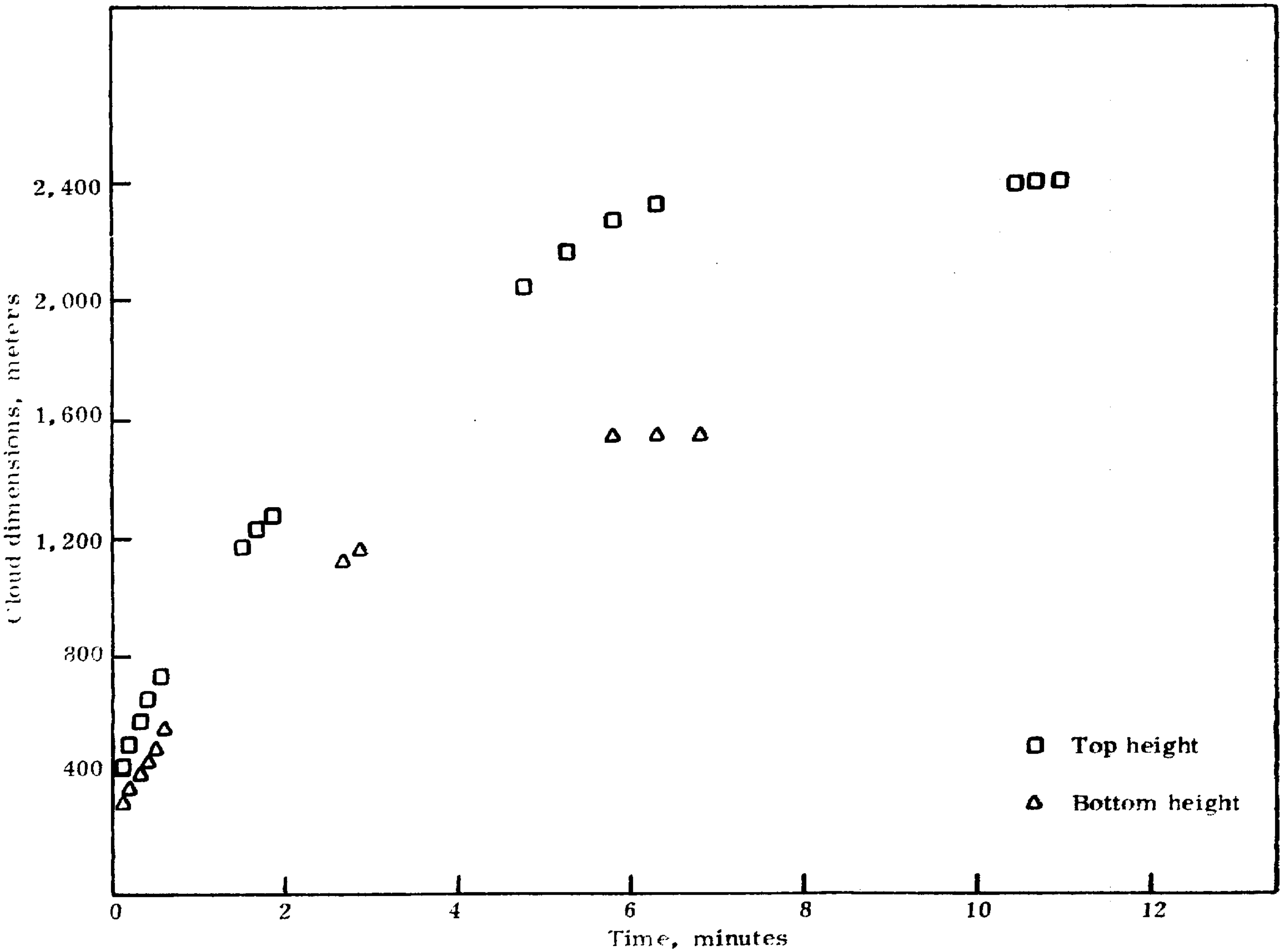

Figure 14 (S). Event Fr 48 - Cloud height vs. time (S).

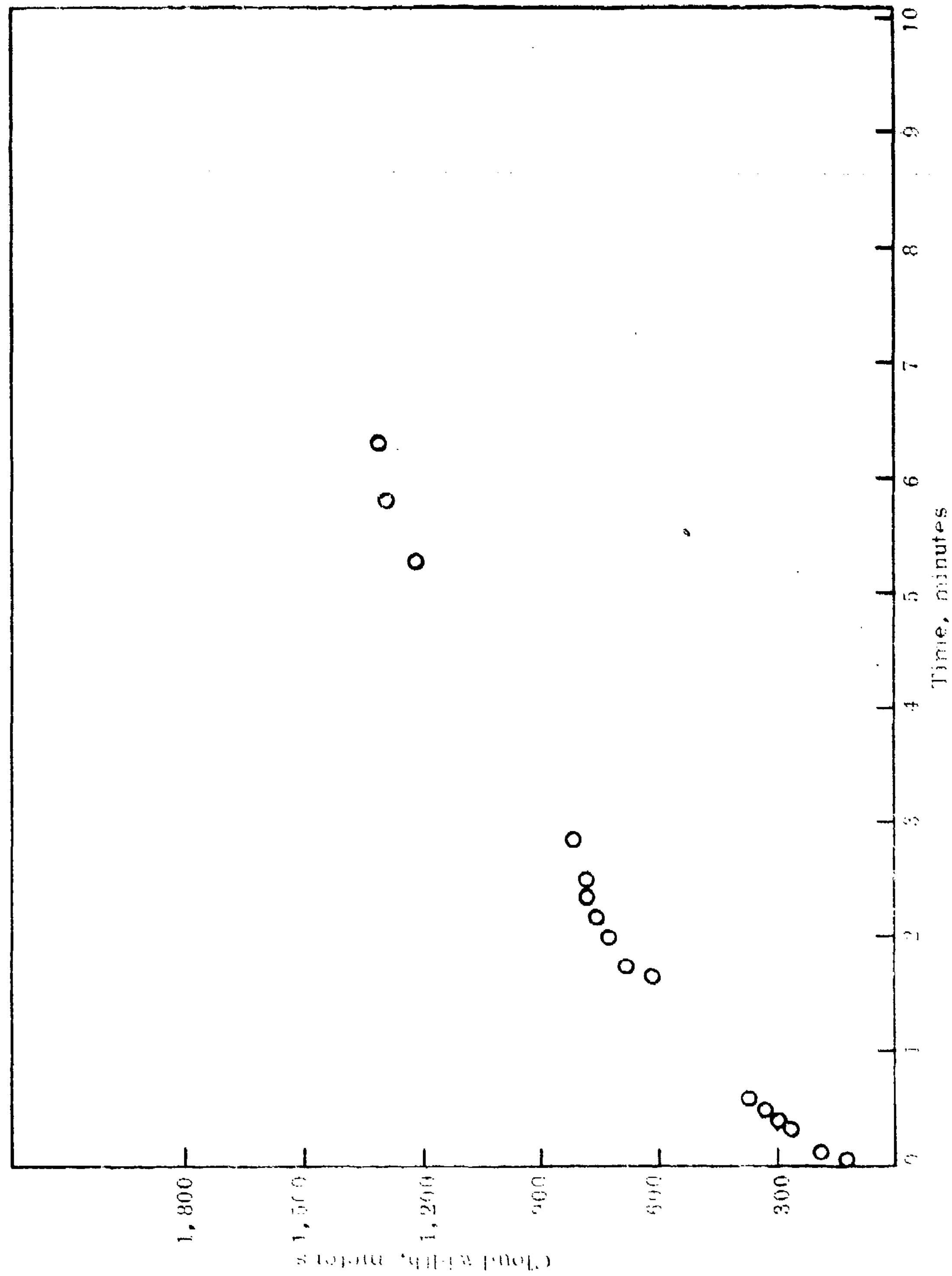

Figure 15 (S). Event Fr 48 - Cloud width vs. time (S).

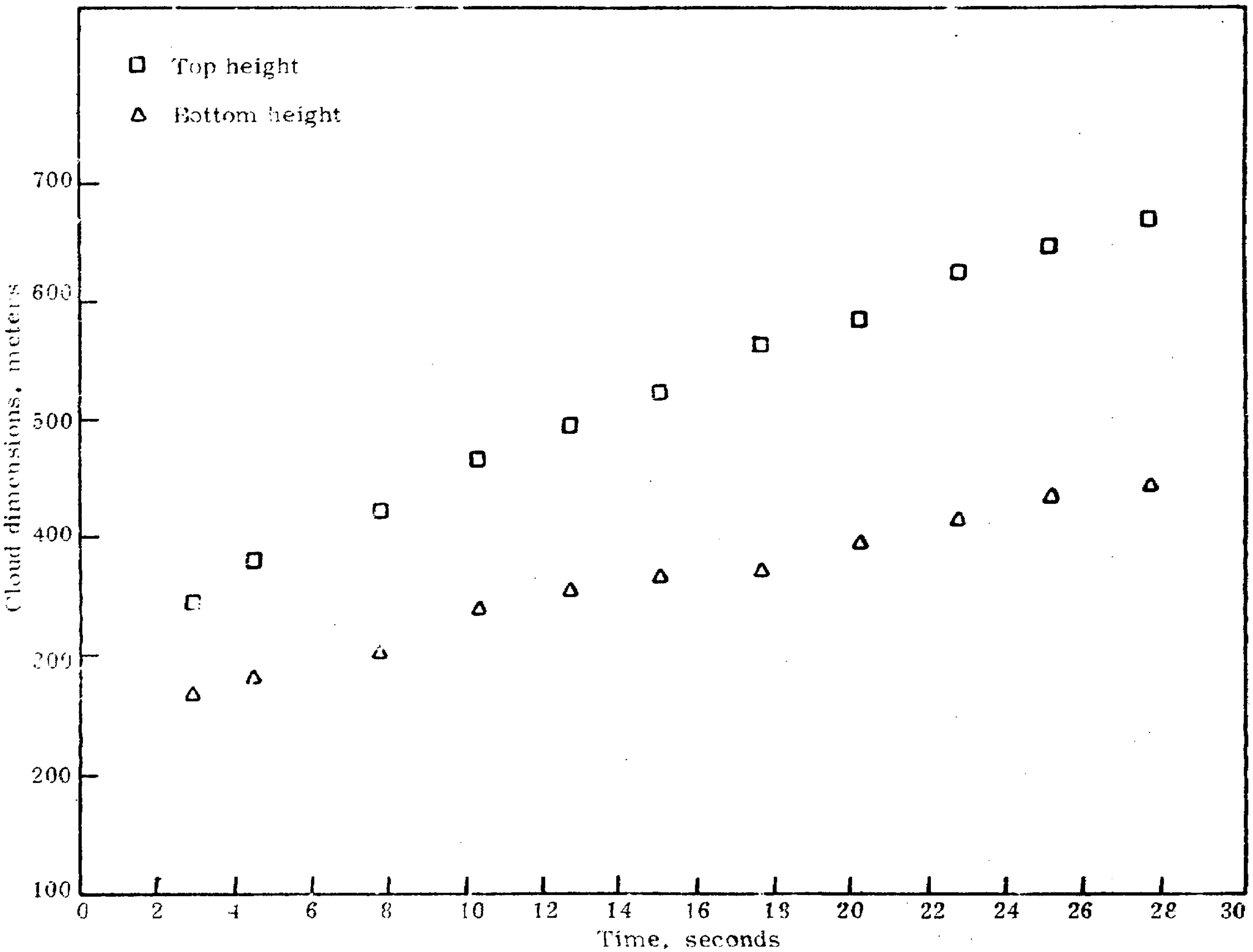

Figure 16 (S). Event Fr 42 - Early cloud height vs. time (S).

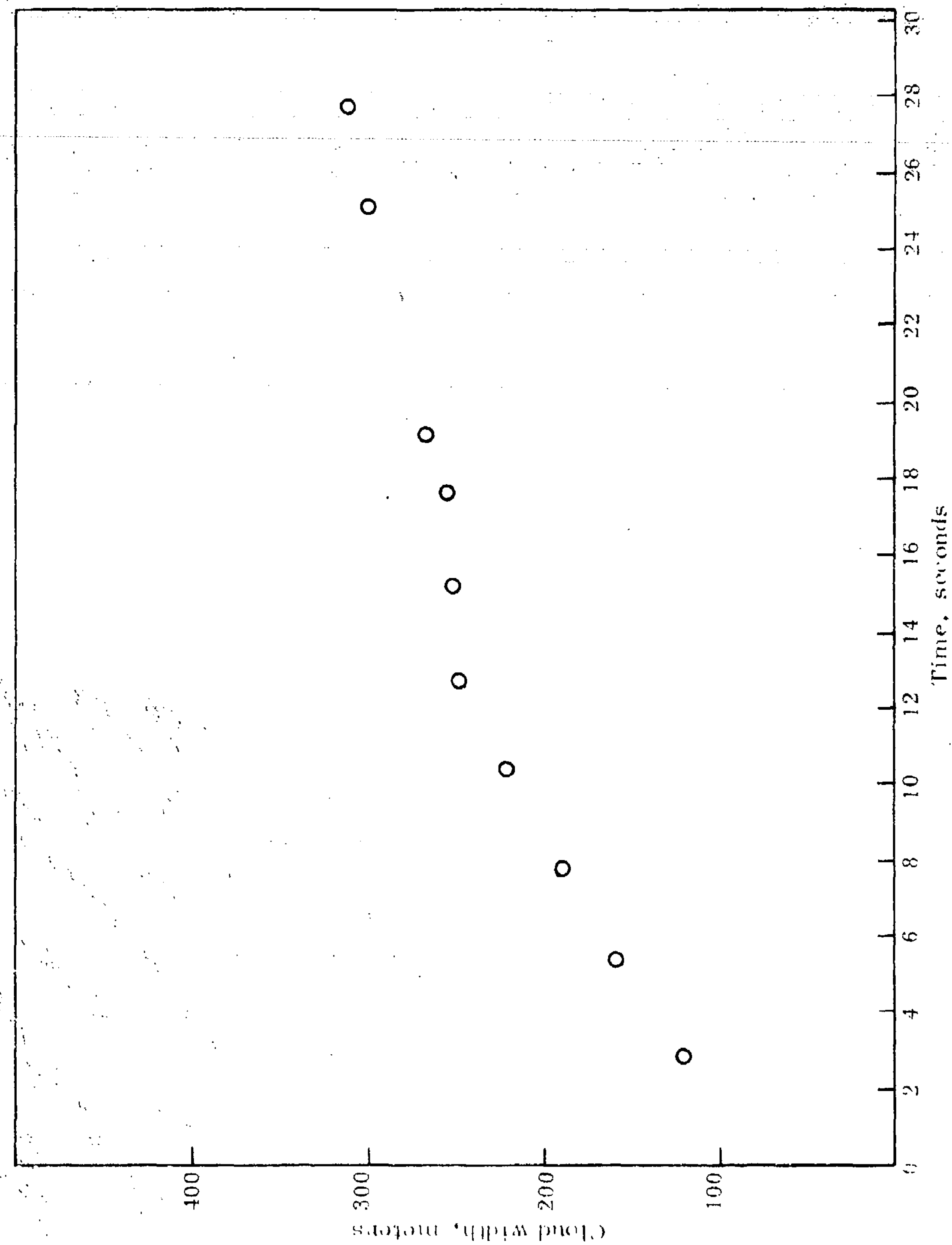

Figure 17 (S). Event Fr 48 - Early cloud width vs. time (S).

3.33 (S) Event Fr 49 (S)

(S) The Fr 49 detonation occured at an altitude of 245 meters with a yield of 4.3 kt, the third largest of the Hula Hoop series. The weather conditions in the area between the USNS Wheeling and the detonation point consisted of localized showers and scattered clouds with a ceiling of about 2000 ft. The extremely poor visibility allowed optical data acquisition during only the initial few seconds from the ship platform.

(S) Early-time high resolution photographic coverage was obtained of the fireball and partially self-luminous debris cloud out to a time of about 2.5 seconds. Beyond this point the cloud rose into or behind the ambient low-lying natural clouds. The debris cloud was no longer of sufficient contrast with the surroundings to be clearly defined on photographic records obtained from the ship platform.

3.34 (S) Event Fr 50 (S)

(S) The Fr 50 event was detonated at an altitude of approximately 195 meters and had a yield of 0.125 kt. The yield of this event was about twice that of Fr 48 but considerably smaller than that of Fr 47 and 49.

(S) High resolution photographic coverage of this event extended out to about H + 13 minutes. The debris cloud dimensions have been plotted in Figures 18 and 19. Figure 18 shows the visual top and bottom heights of the debris cloud as a function of time. In Figure 19 the cloud width is plotted as a function of time. (Irregularities in the curves are probably due to instrumental effects.) Stabilization time

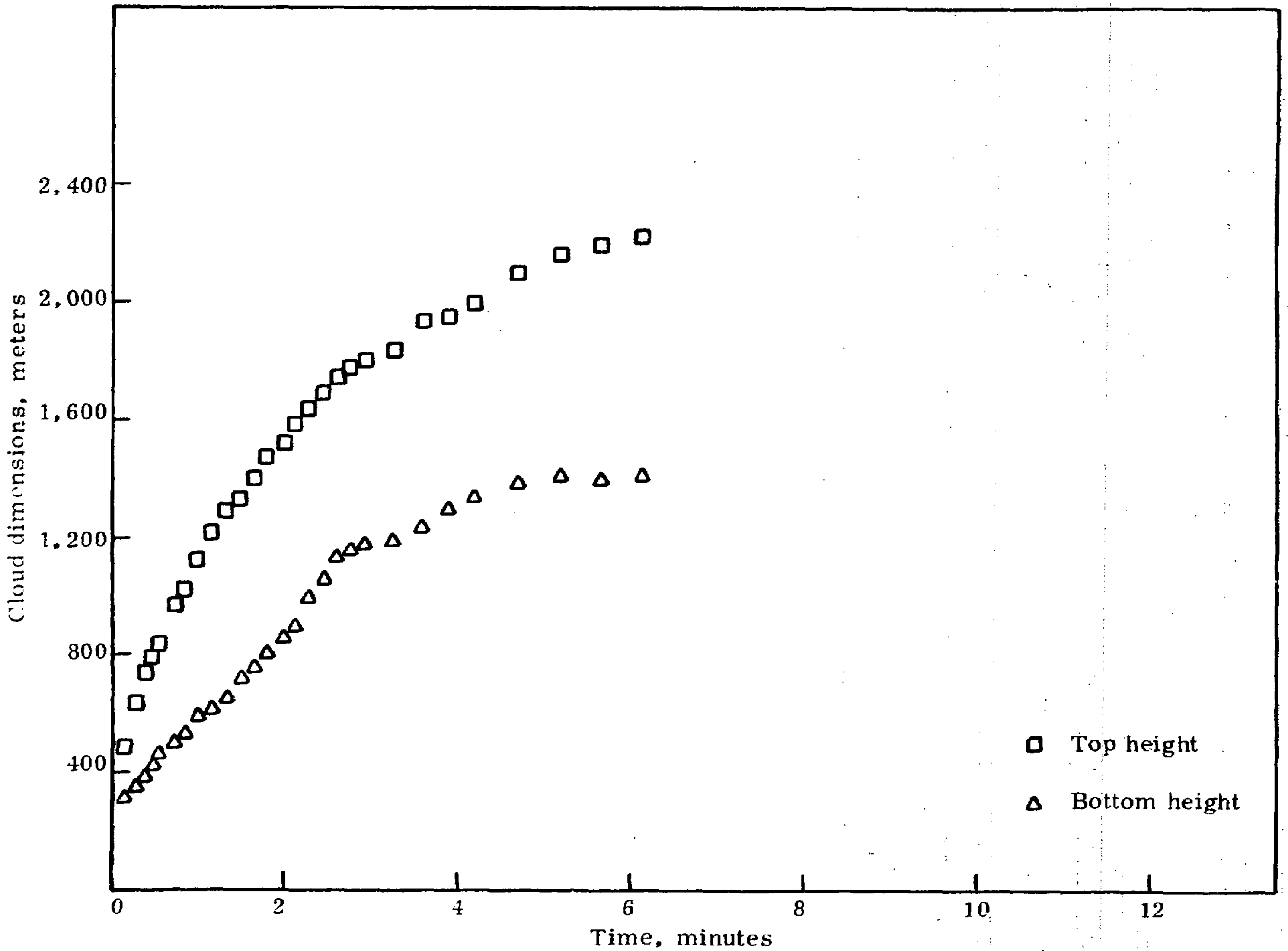

Figure 18 (S). Event Fr 50 - Cloud height vs. time (S).

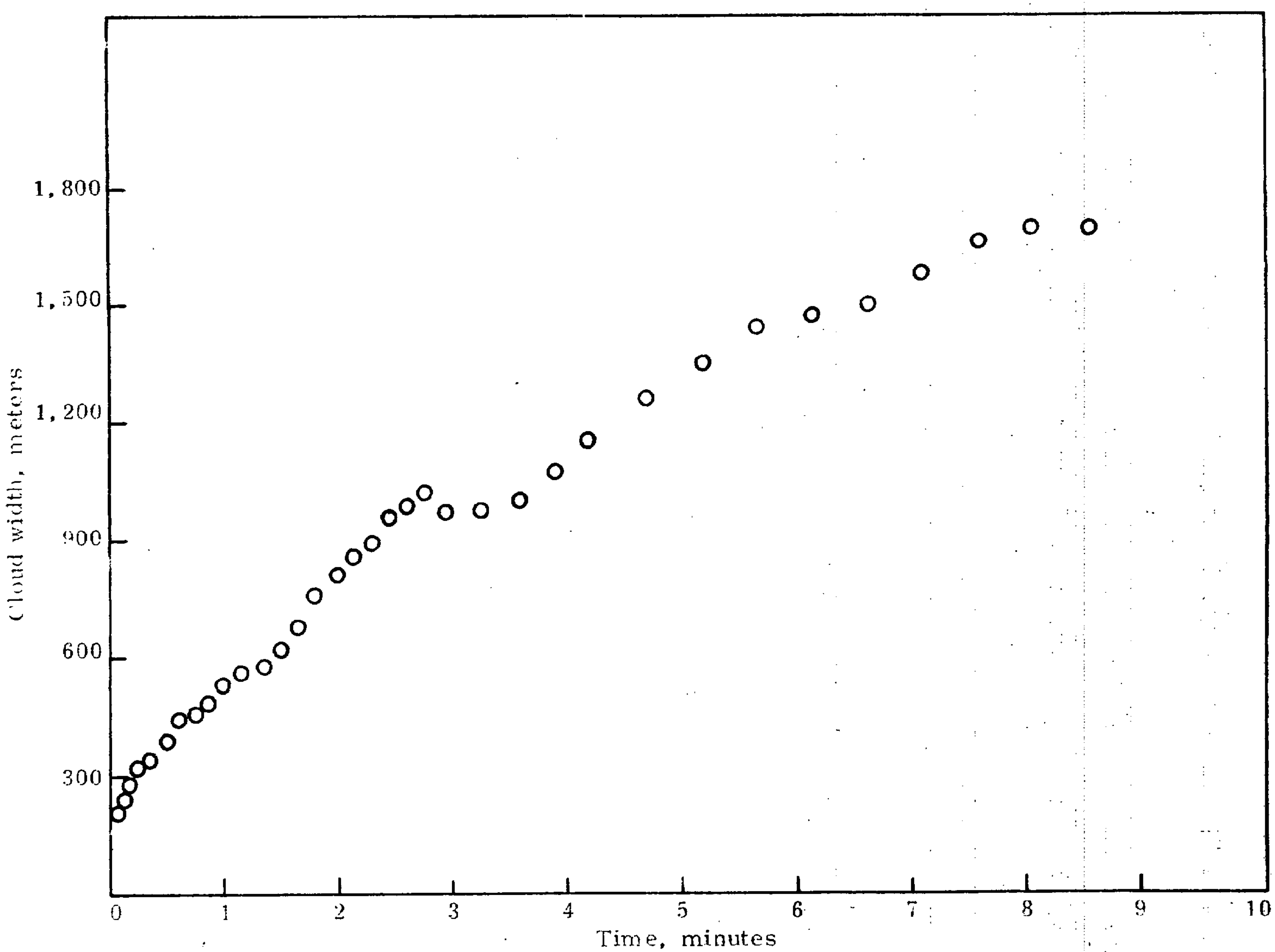

Figure 19 (S). Event Fr 50 - Cloud width vs. time (S).

(S)

appears to occur roughly at 4.5 minutes comparable with those of Fr 47 and Fr 48. Stabilization altitude was measured to be about 2000 meters with a slow drift upward to 2200 meters by 6 minutes. At 6 minutes the debris cloud has a vertical dimension of 800 meters and a width of 1700 meters. These values are similar to those of the Fr 48 event where vertical and horizontal dimensions at late time were 900 and 1300 meters respectively. The early-time (0-30sec) cloud heights and widths are plotted in Figures 20 and 21 respectively. The visual top of the debris cloud is plotted in the upper curve in Figure 20 and the lower curve is the bottom dimensional height of the cloud.

(S) The vertical rise rate, as determined from Figure 20, was 19.3 m/sec at H + 10 sec. The horizontal expansion rate at this same time was 11 m/sec decreasing to 7 m/sec at H + 20 sec. At H + 2.5 minutes the debris cloud's vertical rise rate had decreased to 5 m/sec. The horizontal expansion rate at H + 2.5 minutes was 3 m/sec. The rise rate and expansion rate values for Fr 50 are seen to be similar to those observed for Fr 48.

(S) Table VII lists the vertical rise rates and the horizontal expansion rates for the three events Fr 47, 48, and 50. By comparison it can be seen that Event Fr 47 rises and expands more rapidly than either Event Fr 48 or Fr 50 as would be expected. The expansion and rise rates of Events Fr 48 and Fr 50 compare extremely well considering the slight differences in yield and height of burst.

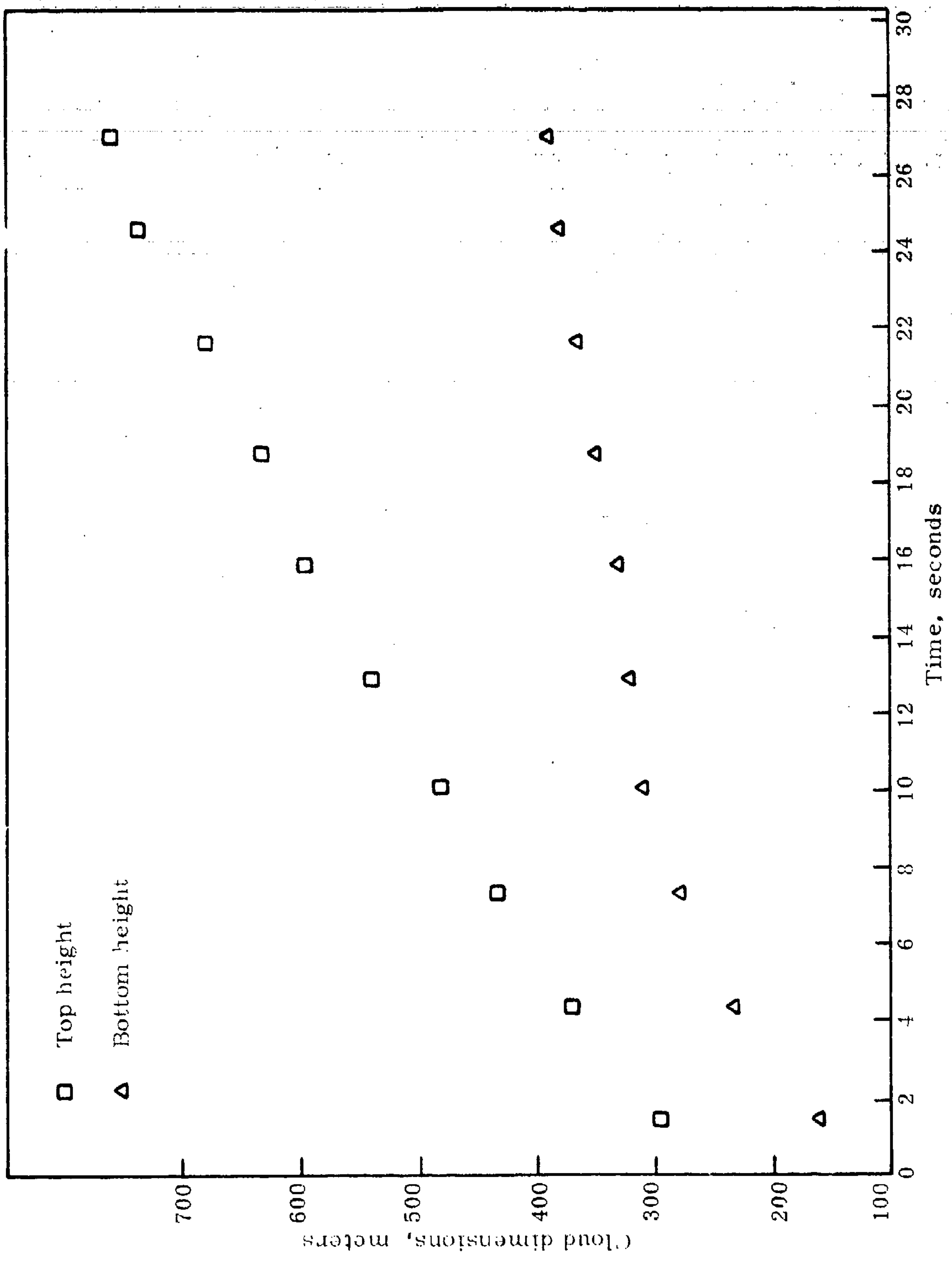

Figure 20 (S). Event Fr 50 - Early cloud height vs. time (S).

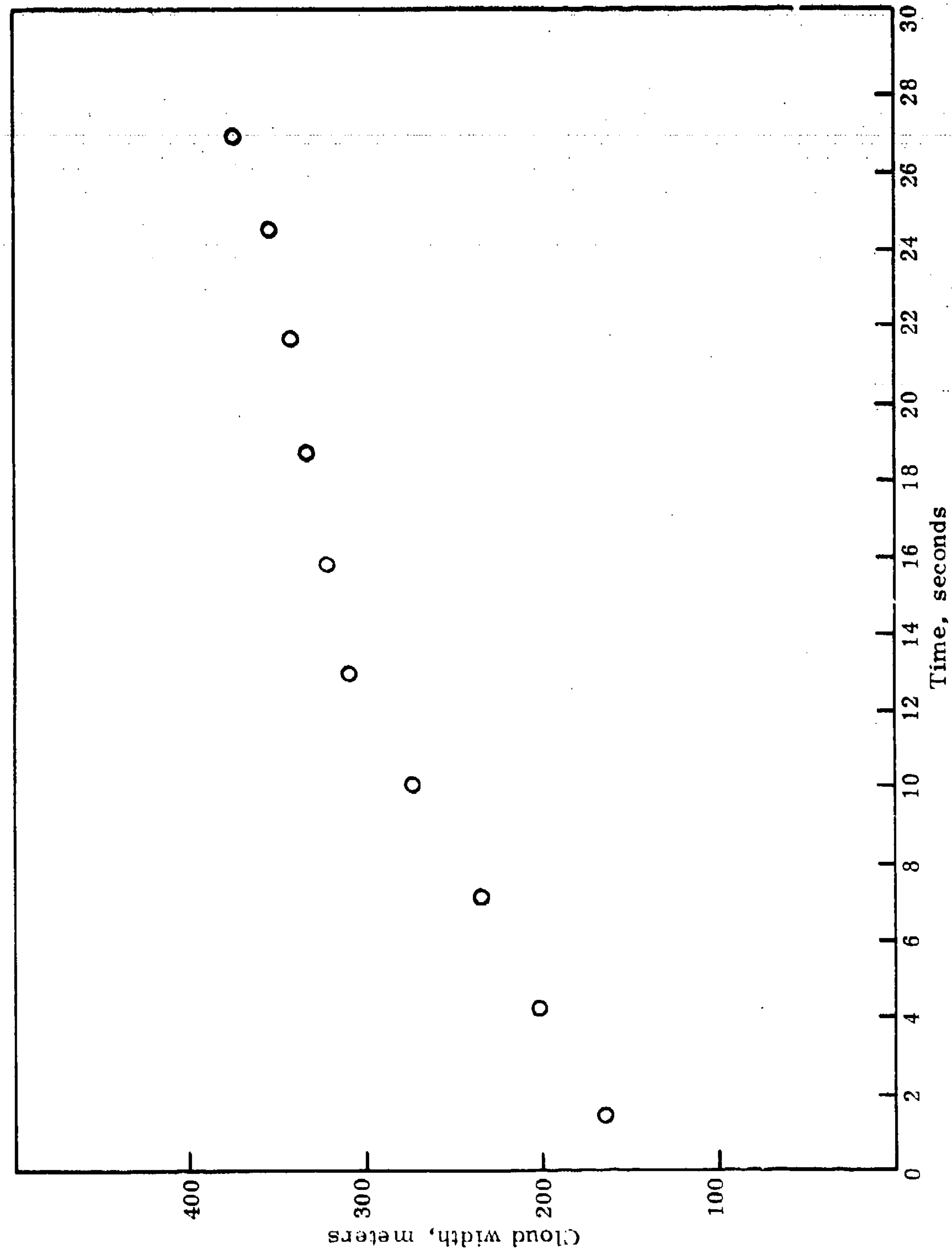

Figure 21 (S). Event Fr 50 - Early cloud width vs. time (S).

TABLE VII (S). CLOUD GROWTH RATES (U)

EVENT	VERTICAL RISE RATE (meters/second)		HORIZONTAL EXPANSION RATE (meters/second)		
	@ H + 10 sec	@ H + 2.5 min	@ H + 10 sec	@ H + 20 sec	@ H + 2.5 min
47	--------	24.2	--------	22.1	10.6
48	14.0	4.7	10.6	6.3	2.9
50	19.3	4.7	10.7	7.2	3.3

4.0 (S) RADIOMETRIC MEASUREMENTS (U)

(S) In addition to the extensive spatial measurements made by TIC in support of Operation Hula Hoop, a limited number of photographic records were made to provide a photometric data base for the early luminous phase of the nuclear experiments. In general it is possible to measure radiometrically the yield related parameters of time to minimum and time to second maximum (except for high altitude detonations), as well as the integrated brightness or optical power of the radiating source in the photographically visible region of the optical spectrum. The first two parameters are independent from the absolute brightness of the source whereas the latter parameter is dependent upon a properly calibrated photographic (or electro optical) imaging system.

4.1 (S) Photographic Film Calibration (U)

(U) In order to determine the relative or absolute brightness (or radiance) of a radiating source using photographic recording techniques, the film must be processed using appropriate sensitometric control methods. (In addition, the atmospheric transmission must also be known -- as a function of spectral wavelength.)

(S) Kodak Plus-X Pan black and white film was selected for the Hula Hoop radiometry measurements because of its wide exposure latitude with linear photographic response. Calibrated densitometric step wedges were exposed on the same unexposed film stock with a xenon flash sensitometer for event records from Fr 47 and Fr 48 and with the aid of an absolute calibrated tungsten sensitometer in addition for event records from Fr 49 and Fr 50. From the latter calibrated scales a plot of density vs. (log)

(S)

exposure was generated with both a specular (narrow beam) and diffuse (hemisphere) type densitometer, the specular being used for data analysis and the diffuse being used for correlation of the processing control of the records and step-wedge controls.

(U) Having determined the D log E response curve of the film record, the exposure energy associated with a measured density from a particular area of the record image can be readily obtained. The radiance of the source image can then be calculated as described in the following section.

4.2 (S) Source Radiance Calculation Procedure (U)

(U) The measured image density on a film record can be related to an absolute energy at the film plane as described in section 4.1 above. This procedure is generally used (and is in this analysis) to relate density to effective exposure assuming that the spectral sensitivity of the particular film emulsion employed is constant over the useful exposure range. The radiance calculation, however, must take the source spectrum into account; initially to account for the variation in atmospheric attenuation as a function of wavelength and ultimately to relate the source surface brightness to temperature.

(U) The effective exposure on a photographic film, E_{eff}, produced by a distant source near the optical axis of the imaging system is given by

$$E_{eff} = \frac{10^7 \pi t}{4(f/n)^2} \int N(\lambda)T(\lambda)S(\lambda)d\lambda \quad \text{ergs/cm}^2 \qquad (1)$$

(U)

where f/n = f -- number of the imaging optics

t = exposure duration in seconds

$N(\lambda)$ = source spectral radiance in watts/cm^2 - ster - A

$T(\lambda)$ = combined spectral transmittance of the atmosphere and all optical elements, e.g. lenses, filters, etc.

$S(\lambda)$ = relative film spectral sensitivity (obtained from published Kodak data)

(U) Since it is desired to calculate the (spectrally) integrated source radiance N_{ab} (over the wavelength interval a to b), it is necessary to determine a suitable expression for this term. First, N_{ab} is defined as

$$N_{ab} = \int_a^b N(\lambda)d\lambda \qquad \text{watts/cm}^2 \text{ - ster} \tag{2}$$

The finite integral can be further expressed by redefining

$$N(\lambda) = N_o n(\lambda) \qquad \text{watts/cm}^2 \text{ - ster - A} \tag{3}$$

where N_o = $N_{max}(\lambda)$, the maximum value of the source spectral radiance in watts/cm^2 - ster - A

$n(\lambda)$ = relative source spectral distribution

Substituting equation (3) into equation (1) and solving for N_o yields

$$N_o = 4(f/n)^2 \, E_{eff} \left(10^7 \pi \; t \int n(\lambda)T(\lambda)S(\lambda)d\lambda\right)^{-1} \tag{4}$$

$$\text{watts/cm}^2 \text{ - ster - A}$$

(U) Further substitution into equation (2) derives the desired expression for the integrated source radiance

$$N_{ab} = \frac{4(f/n)^2 \; E_{eff} \int_a^b n(\lambda) d\lambda}{10^7 \pi \; t \int_a^b n(\lambda) T(\lambda) S(\lambda) d\lambda} \quad \text{watts/cm}^2 \text{ - ster} \qquad (5)$$

(S) The effective spectral coverage of the Hula Hoop film records was essentially 4000 to 7000 A. The relative source spectral distribution $n(\lambda)$ was obtained by the use of a scanning spectrometer which recorded the source strength as a function of wavelength and time. Figure 22 is a reproduction of the spectrometer display at H + 0.166 sec for the Fr 47 event. The upper curve represents the product $n(\lambda)T_a(\lambda)$, where $T_a(\lambda)$ is the integrated atmospheric transmission between the source and the recording system. The lower curve represents the sky background observed just prior to the Fr 47 event.

(U) The source spectrum, $n(\lambda)$ used in equation 5, above, is obtained by dividing the apparent spectrum $n(\lambda)T_a(\lambda)$ by $T_a(\lambda)$ which in this analysis is derived by calculational procedure as a function of discreet wavelength intervals.

(U) The atmospheric transmission, $T_a(\lambda)$, in the spectral range 4000 to 7000 A was calculated by considering the effects of atmospheric molecular scattering, water vapor absorption, and aerosol scattering and absorption over a 37 km horizontal maritime ray path.

(U) Values for the molecular absorption and scattering coefficients were obtained from Allen (reference 2) and Valley (reference 3). The contributory effect due to aerosols was estimated on the basis of measured continental environment effects. The largest contribution to

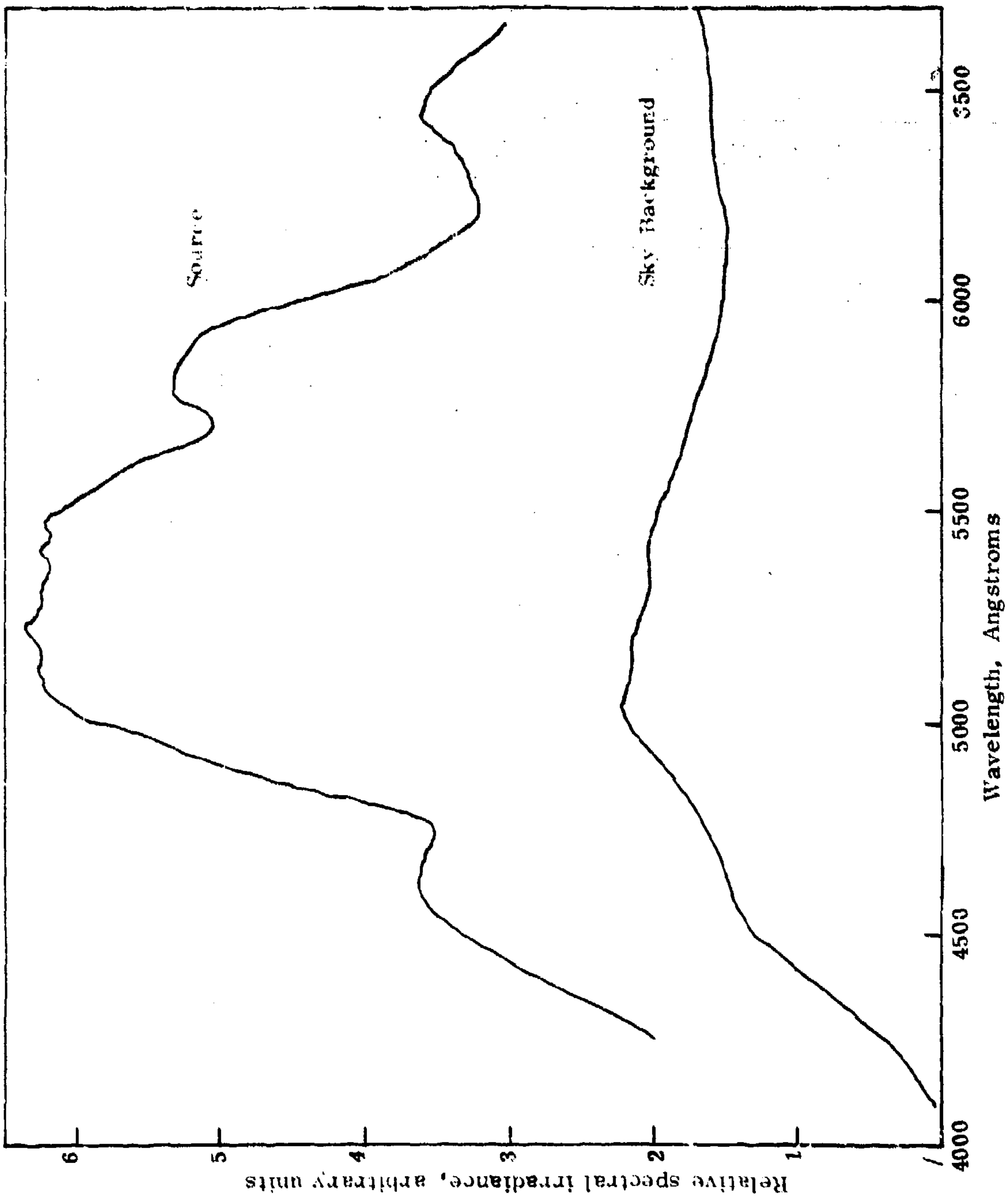

Figure 22 (S). Event Fr 47 - Spectrometer trace at H + 0.166 sec (S).

(U)

optical attenuation in continental air is due to aerosols and other suspended particles such as dust and fog. Attenuation of visible light by aerosols is considered to be proportional to the concentration of large aerosols, i.e., particles of 0.1 to 1.0 microns in diameter. Calculations described in DNA 3396 (reference 4) indicate that the concentrations of large particles in maritime air may be 1/20 the large particle concentration in the normalized "clear" continental atmosphere model. On this basis, the aerosol absorption and scattering coefficients used in the present calculation were derived by multiplying the "clear" model coefficients given in ref. 3 by the factor 0.05. Resultant atmospheric transmission values were calculated in consideration of all of the above pertinent effects as a function of 500 A wavelength intervals and are presented below.

Wavelength, A	Transmission $T_a(\lambda)$
4000	.109
4500	.227
5000	.324
5500	.422
6000	.493
6500	.545
7000	.623

(U) Dividing the upper curve shown in Figure 22 by the applicable transmission terms shifts the energy distribution $n(\lambda)$ more toward the blue end of the spectrum with peak spectral radiance occuring around 5000 A. The derived relative spectral energy distribution, $n(\lambda)$, is plotted in Figure 23.

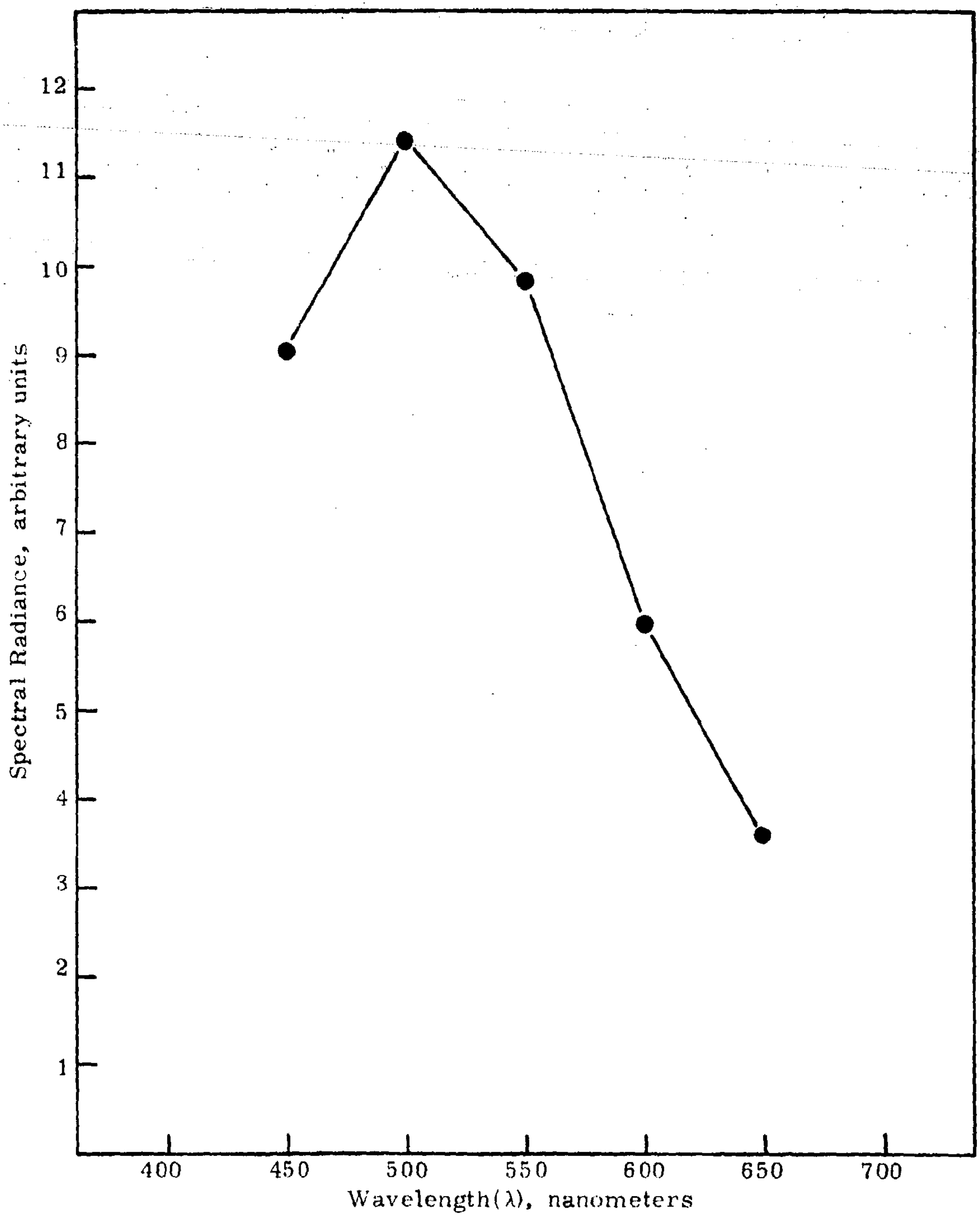

Figure 23 (S). Event Fr 47 - Relative spectral energy distribution at H + 0 166 sec. (S).

(U) Using the derived n(λ) data, equation 5 was then used to calculate the integrated source radiance, N_{ab}. The integrals in this equation were computed numerically over the wavelength range 4000 to 7000 A. The exposure time, t, and lens aperture, f/n, were known instrumental parameters. The values for effective exposure, E_{eff}, were obtained from the calibrated D log E film response curves generated for each film data record.

(U) The source radiance values presented in this report are in fact peak source radiance values corresponding to the most dense regions from each frame used for data analysis.

4.3 (S) Results of Peak Radiance Measurements (U)

(S) Using the methods described above the peak source radiance time history has been determined for each of the observed Hula Hoop events. Figures 24 through 27 are plots of the peak radiance history of events Fr 47, Fr 48, Fr 49 and Fr 50 respectively. The maximum measured radiance values of these four events are seen to be within the same order of magnitude. The decay of the radiance curves is more rapid for events Fr 48 and Fr 50 as would be expected with significantly lower yields.

(S) Of the four events for which radiometric time history data was obtained three exhibited reasonably well defined second maxima in the plotted data. (Time to minimum was not resolvable in these data records because of their relatively slow framing rate.) The second maxima occur at times of 0.14 sec, about 0.07 sec, and 0.02 sec for Fr 47, Fr 49, and Fr 50 respectively. The value of 0.07 for the Fr 49 event is

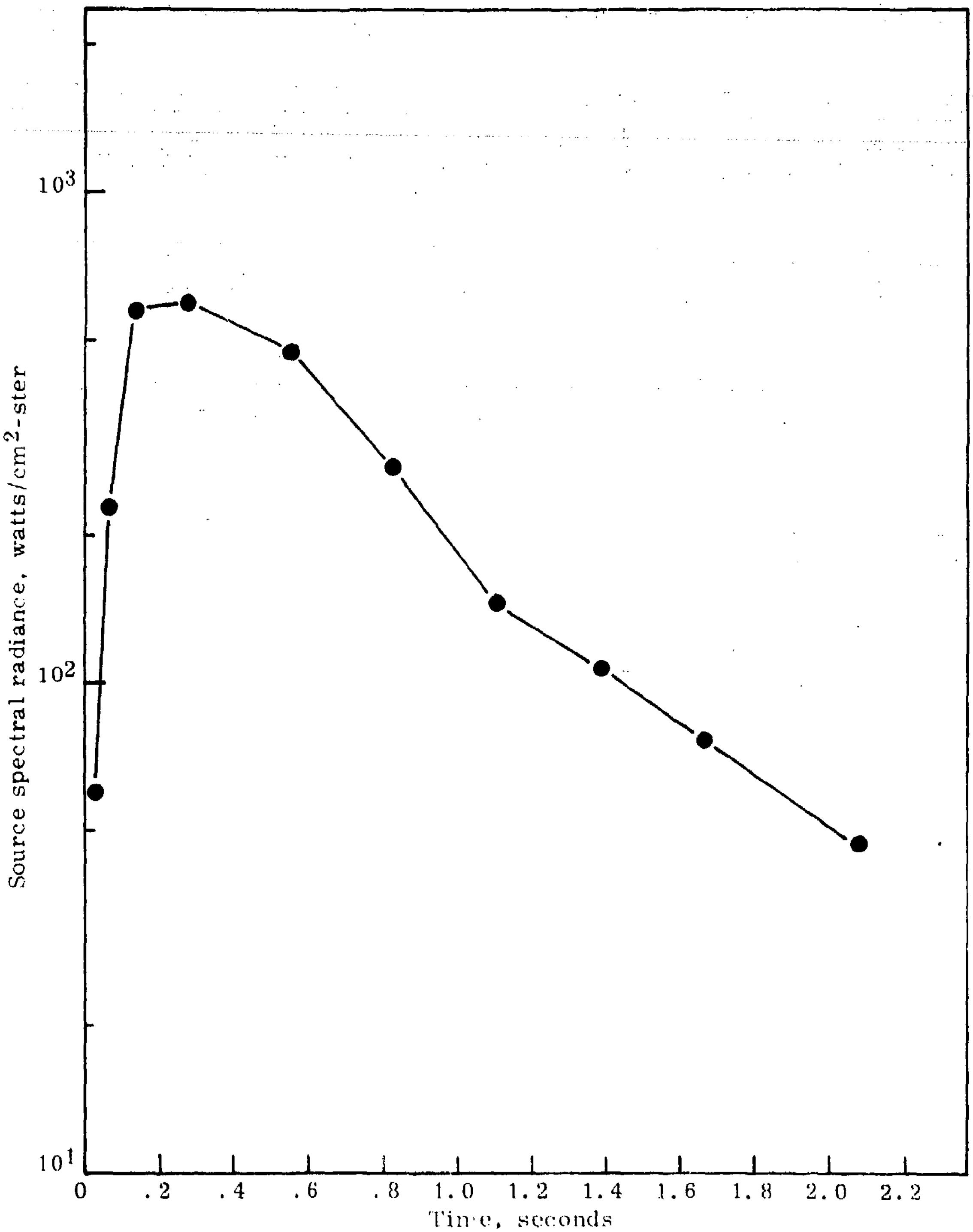

Figure 24 (S). Event Fr 47 - Source spectral radiance vs. time (S).

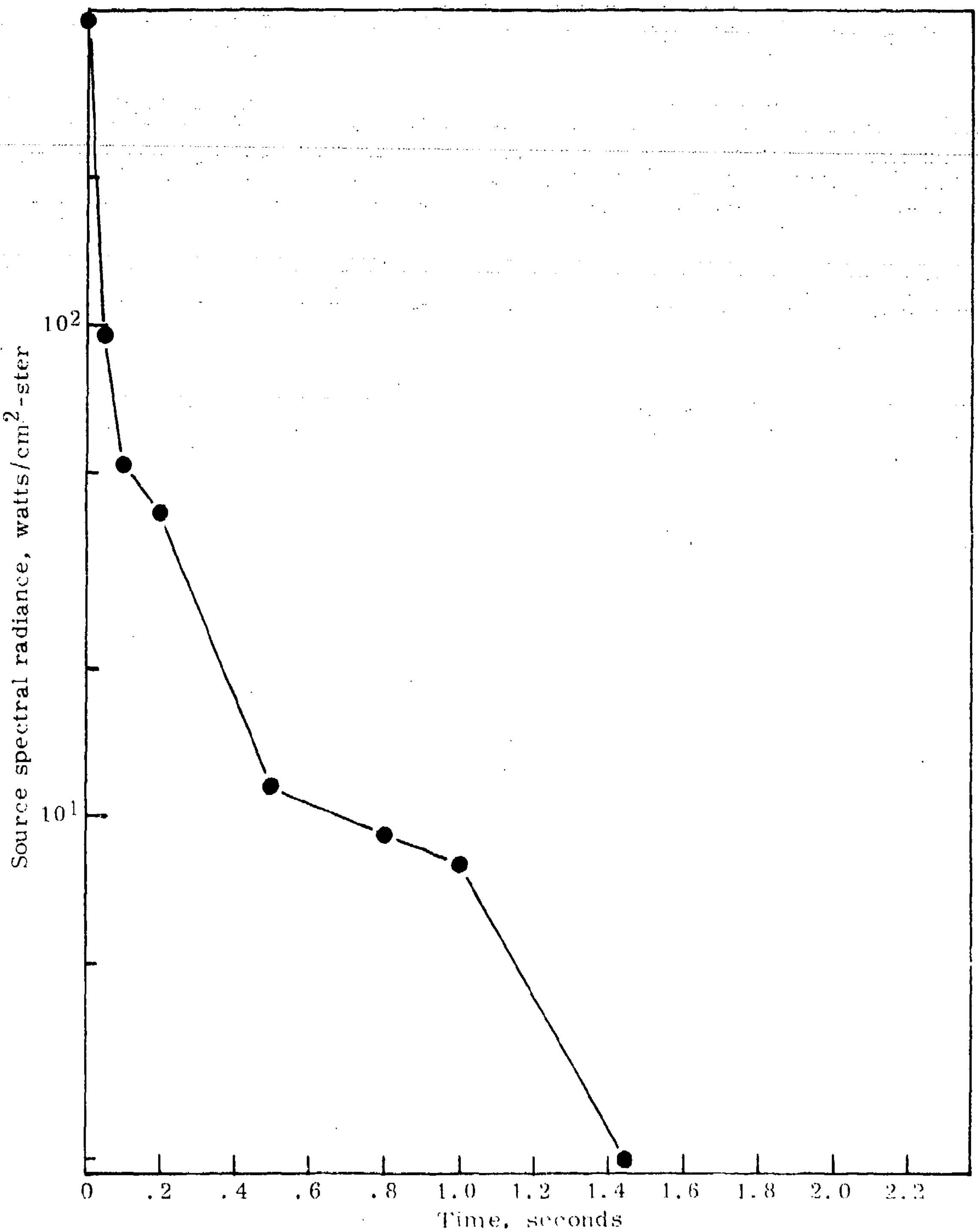

Figure 25 (S). Event Fr 48 - Source spectral radiance vs. time (S).

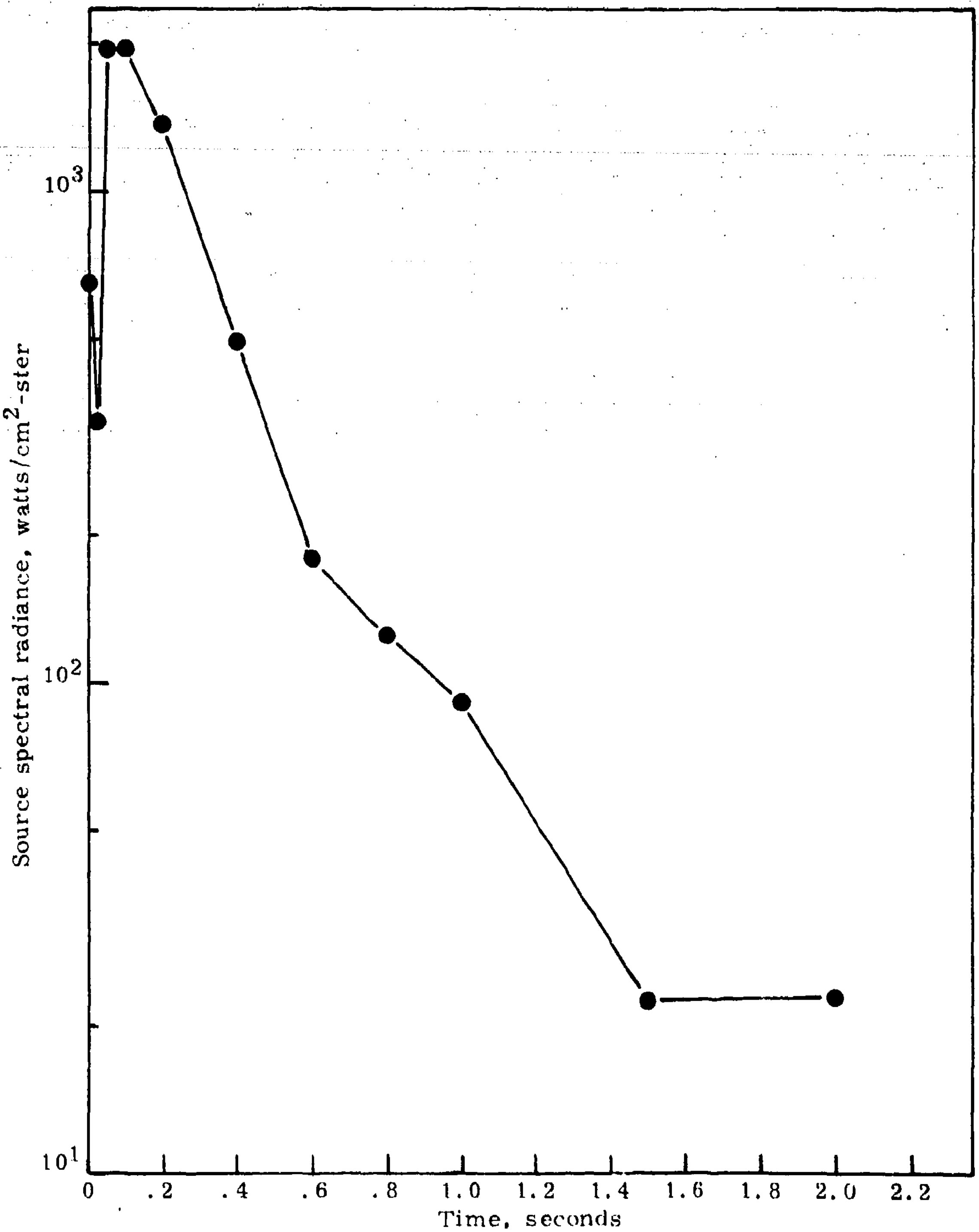

Figure 26 (S). Event Fr 49 - Source spectral radiance vs. time (S).

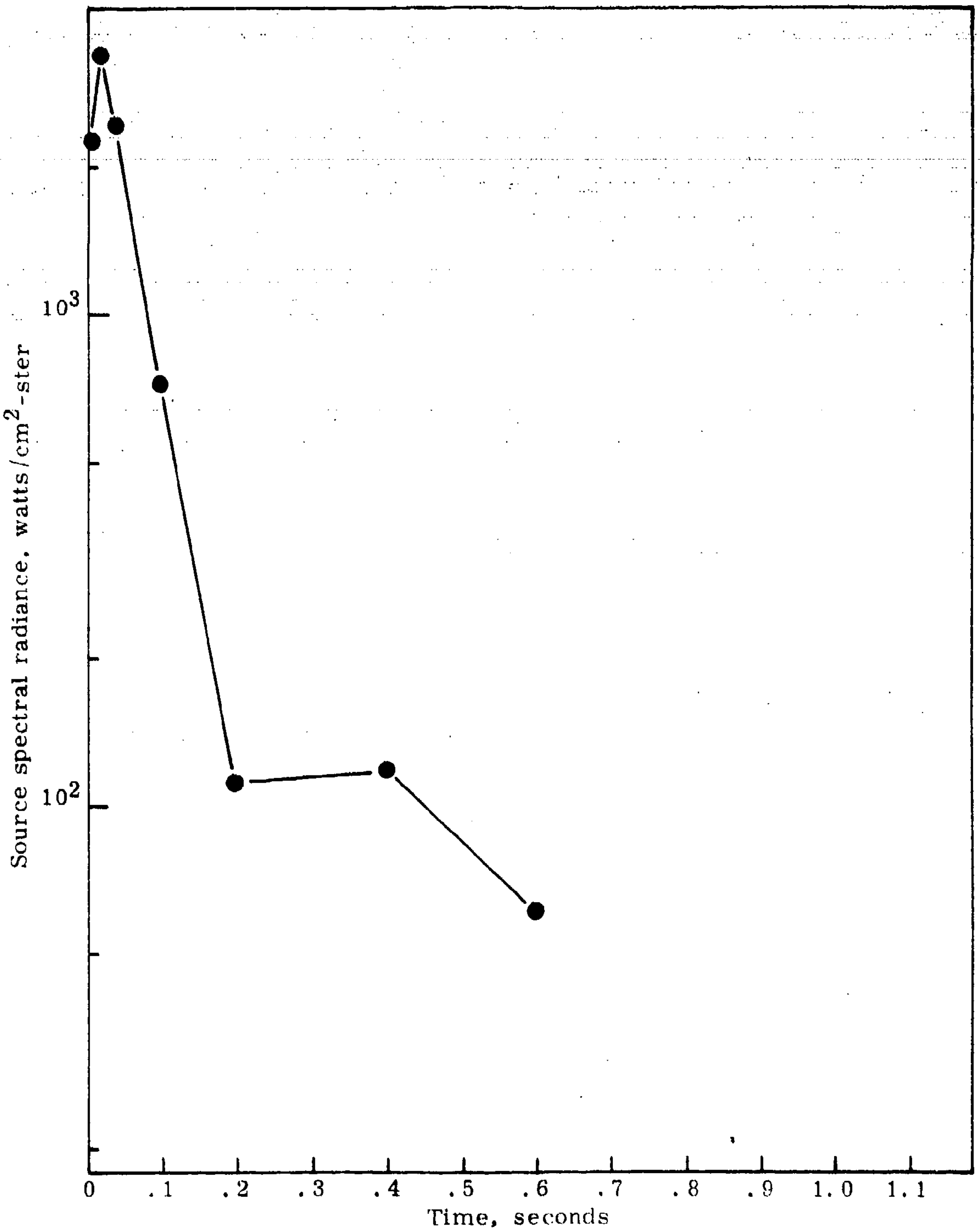

Figure 27 (S). Event Fr 50 - Source spectral radiance vs. time (S).

(S)

approximate since the data images are overexposed during this time and thus represent a lower bound on the magnitude of the peak radiance in this time regime.

(S) Structure was visible in all of the source images from the Fr 48 event. This fact indicates that the generally opaque shock front was optically transparent by the time of the first data frame -- or about 0.01 sec.

(S) The yield, time of second maximum, and initial peak radiance of the four observed Hula Hoop events are summarized in Table VIII. Although the temporal resolution of the data records is not sufficient for definitive analysis of the early time brightness characteristics, qualitative differences are apparent in comparing the data. The larger yield event, for example, exhibits a less bright intensity peak (but broader radiance curve) than the smaller yield events as would be predicted. (Fr 48 is not considered large enough to be included in the scope of the previous statement.) In general, however, the influence of the weather in the detonation area and throughout the 20 nautical mile range to the observation platform is not fully assessable and this would have to be weighed in interpreting the resultant data.

(S) A typical isodensity contour graph made from a two-dimensional isodensitometer scan is shown in Figure 28, from event Fr 47. This type of density map is used directly in calculating the (spatially) integrated radiance or optical power of a given image. The density contours shown in Figure 28 were measured on a frame taken at H + 1.5 sec. At that time a Wilson cloud had formed just above the horizon while the twin-lobed fireball was seen above the Wilson cloud.

TABLE VIII (S). INITIAL PEAK RADIANCES (U)

EVENT	YIELD (kt)	TIME OF SECOND MAXIMUM (seconds)	PEAK RADIANCE (watts/cm^2-ster)
Fr 47	13.5	0.14	6×10^2
Fr 48	0.05 - 0.1	—	4.2×10^2
Fr 49	4.3	0.07	2×10^3
Fr 50	0.125 - 0.2	0.02	3.4×10^3

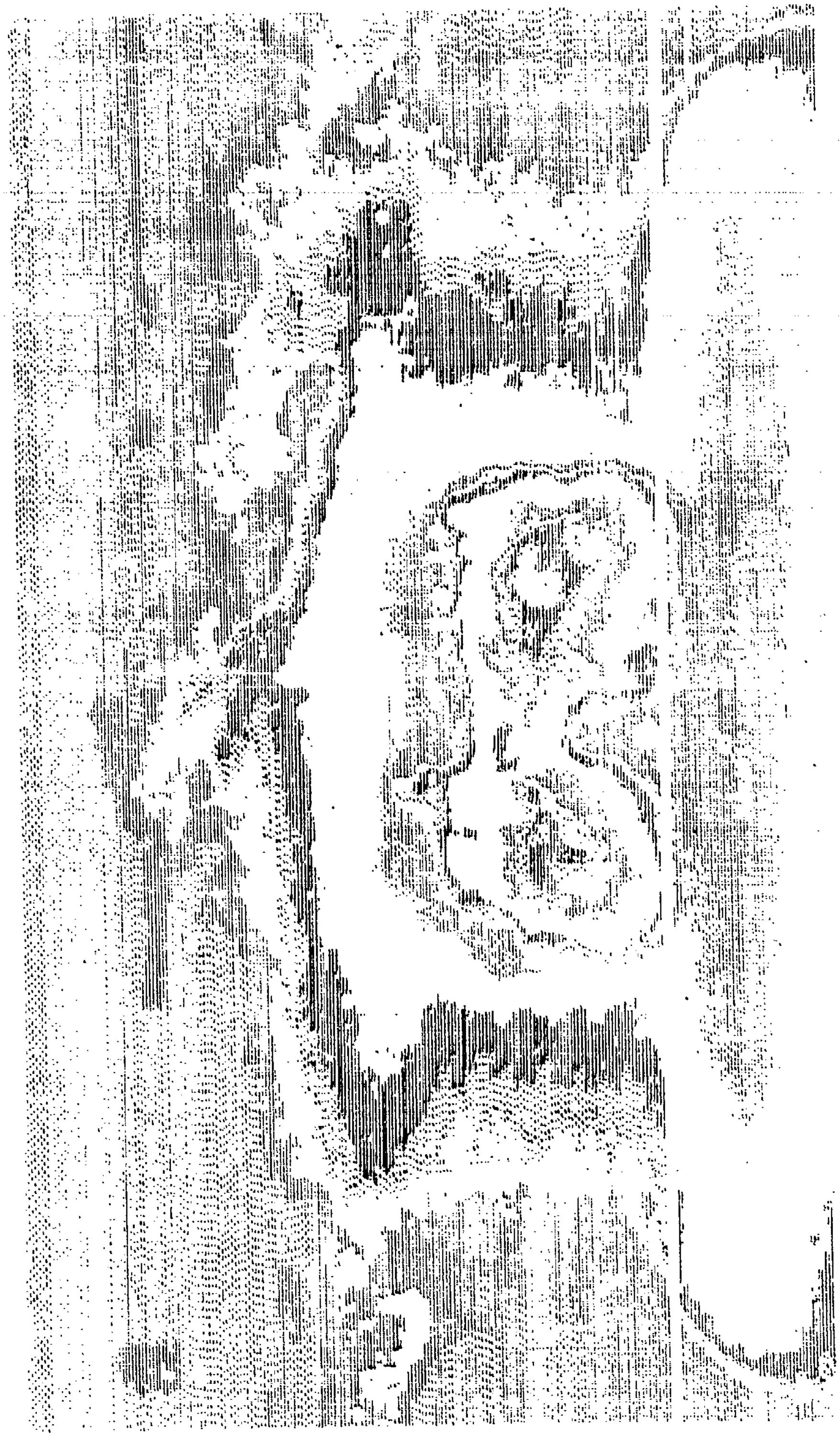

Figure 28 (S). Event Fr 47, Isodensity Contour Graph at H + 1.5 s (S)

4.4 (S) Spectral Data Results (U)

(U) A rapid scan Czerny-Turner video spectrometer was operated on the first four 1973 series events as mentioned earlier in this section. In general, this instrument covered the first second or two after detonation and provided an indication of the spectral distribution of the main radiating source for calculating source brightness during this early period.

(S) In addition to the rapid scan spectrometer, a two dimensional spatially resolved spectrograph was operated in the wavelength region of 5000 to 8700 A. The optical system incorporated a twenty element slit matrix with a transmission grating spectrograph. An effective field of view of about 2° x 2° was obtained by this system. For the Fr 47 event the spectrographic system provided spatial information over a 1.4 km x 1.4 km region of the luminous debris could. Each of the slits had an equivalent image of a 38 meter x 3.8 meter rectangle on the cloud. Figure 29 shows a typical series of spectra obtained from Fr 47.

(S) The twenty slits were aligned in four diagonals with five slits on each diagonal. Figure 30 shows a densitometer trace through a single spectrum from the Fr 47 event. Some of the major atmospheric absorption lines have been assigned and are so specified. The spectrograph was employed so that for small-yield detonations a comparison of the event and surrounding air mass spectra could be obtained and for larger yield events, or long lasting phenomena, spatially resolved spectra could also be obtained.

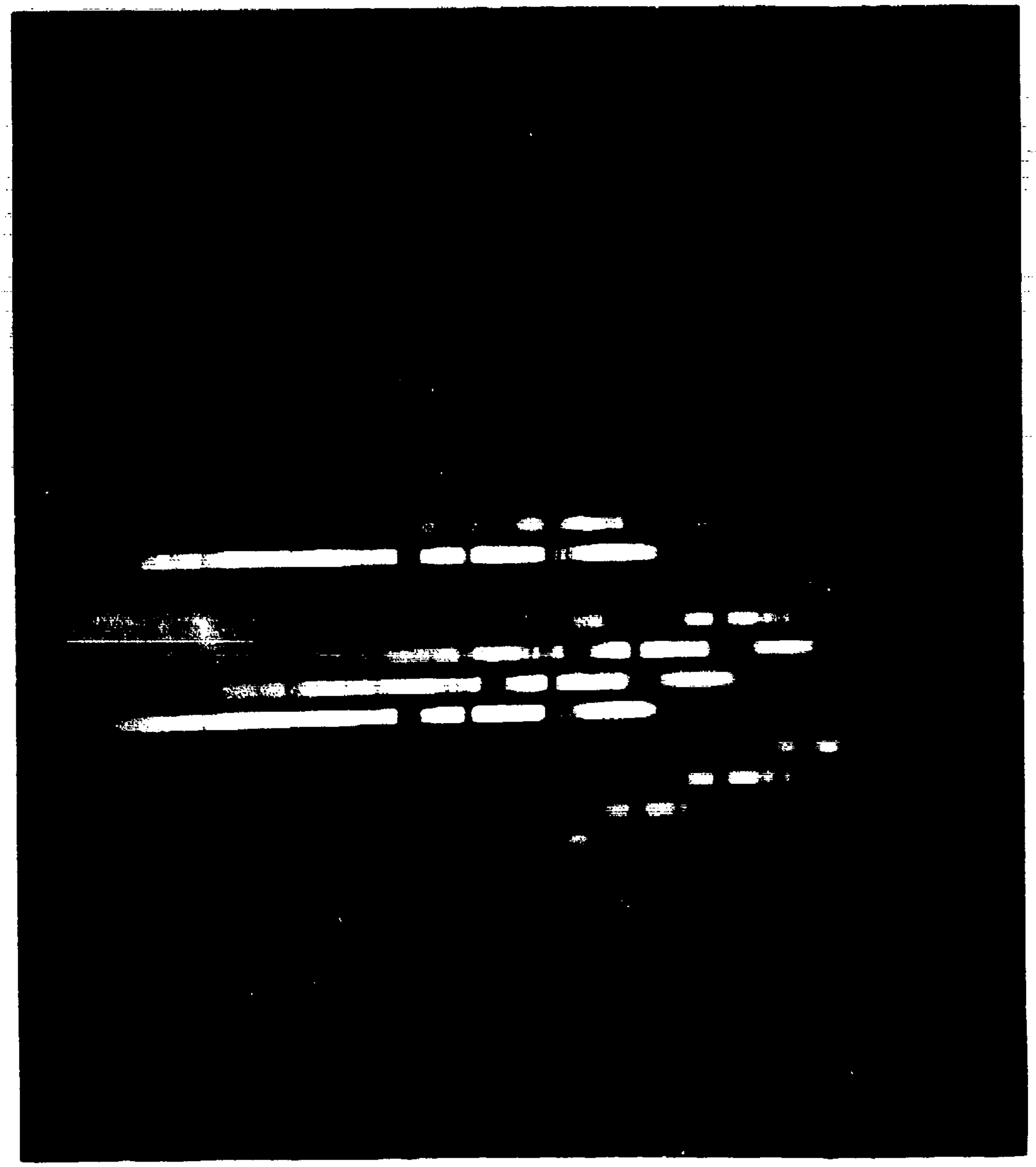

Figure 29 (S). Event Fr 47 - Typical multi-slit spectra (S)

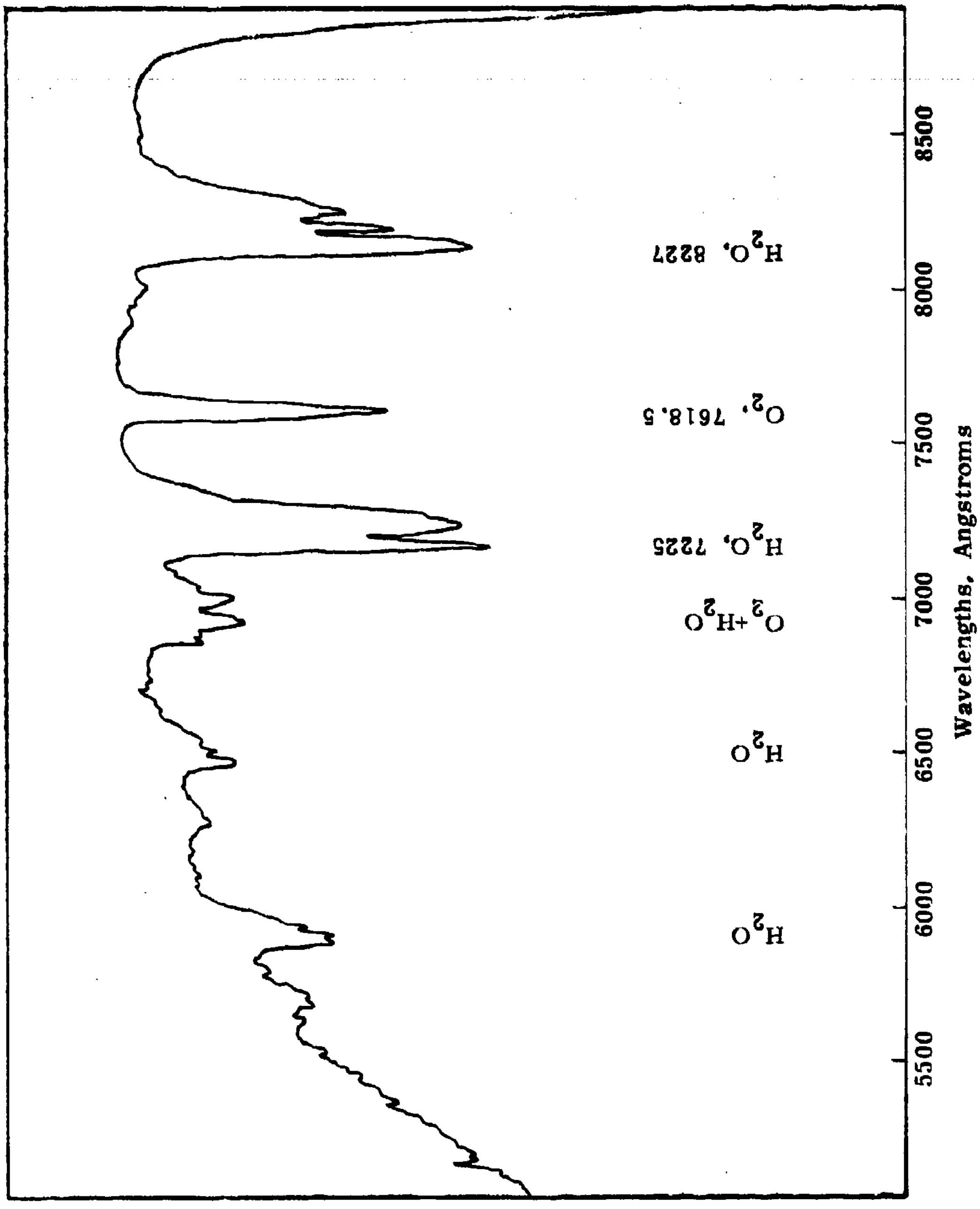

Figure 30 (S). Event Fr 47 - Relative intensity profile of typical multi-split spectrum (S).

5.0 (S) DISCUSSION OF OPTICAL OBSERVATIONS (U)

(S) The 1973 Pacific test series consisted essentially of small primary type devices, two of which were so small as to preclude an accurate determination of their yield (~100 tons). Of the three nominal size events detonated the two balloon borne devices were photographed by the ship at H = 0. One of these (Fr 47) was also photographed for a significant period from the LASL aircraft. Both the Fr 47 and Fr 49 events were of sufficient yield to permit significant radar type measurements.

(S) The clearly defined formation of a series of layered ice caps above the main debris cloud cap of the Fr 47 event (see section 2.0) is descriptive of nominal (10 - 20 kt) and larger yields detonated near the surface with appropriate weather conditions prevailing. Thus, this experiment was useful from the overall DNA point of view inasmuch as it was representative of the effects of moderate and larger detonations.

(S) A second aspect of the Fr 47 event was clearly documented in the color data records. The distribution of the reddish-brown colored regions of the debris cloud was especially well recorded for this event. In particular the fact that significant amounts of this NO_x type substance were observed as a residual constituent of the debris cloud stem as well as the evolving debris cloud cap is important to have established for future modeling estimates of the distribution history of the NO_x chemistry.

(U) In summary, the optical data resulting from observations made from both the surface and airborne platforms provide appropriate and pertinent results for expanding the phenomenological data base on such

(U)

detonations as well as supporting the other experimenters participating in the DNA effects program.

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APPENDIX A

HULA HOOP INSTRUMENT PLAN

TECHNOLOGY INTERNATIONAL CORPORATION

INSTRUMENT PLAN

OPERATION: Hula Hoop **DATE:** Summer 1973 **STATION:** Prime Surface

EVENT: ALL **LOCATION:** OPAREA **PROJ/ENGINEER:** Deuel/Ronnholm

POSITION	INSTRUMENT	FOCAL LENGTH	FILTER	FILM	NOMINAL RUNNING TIME	SHUTTER/RATE	REMARKS
31	B-C/D	360mm	-	EMS 70x100'	60 m	1.2 sec	9x12°, Clock
32	B-C/D	360mm	-	EMS 70x100'	60 m	2.0 sec	9x12°, Clock
33	K-17D	508mm	-	MSA 9.5"x200'	60 m	2.0 sec	25x25°
34	K-17D	915mm	W 12	AIR 9.5"x200'	60 m	1.2 sec	14x14°
35	K-17D	915mm	-	MSA 9.5"x200'	60 m	1.2 sec	14x14°
36	K-22	1500mm	W 25 (1)	PXA 9.5"x250'	60 m	2.0 sec	8.6x8.6°
37	K-17	150mm	-	MSA 9.5"x125'	29 m	2.0 sec	74x74°

ADDITIONAL INFORMATION: (1) For events 50 and 51, the film was changed to MSA and the W 25 filter removed.

TECHNOLOGY INTERNATIONAL CORPORATION

INSTRUMENT PLAN

OPERATION: Hula Hoop **DATE:** Summer 1973 **STATION:** Prime Surface

EVENT: ALL **LOCATION:** OPAREA **PROJ/ENGINEER:** Deuel/Ronnholm

POSITION	INSTRUMENT	FOCAL LENGTH	FILTER	FILM	NOMINAL RUNNING TIME	SHUTTER/RATE	REMARKS
01	PS-16 1B	150mm	-	XRM 16x400'	20 sec	800 fps	3x4°
02	PS-16 1P	150mm	W 85	CNF 16x200'	40 sec	200 fps	3x4°
03	PS-16 1P	150mm	W 12	IE 16x100'	40 sec	100 fps	3x4°
04	HS MITCHELL	360mm	-	PXN 35x400'	lm 04 sec	100 fps	3x4°
05	PS-10A	600mm	-	EMS 70x400'	lm 43 sec	20 fps	5.5x5.5°
06	PS-10A	800mm	-	XRM 70x400'	51 sec	40 fps	4.1x4.1°
07	KS-67A	500mm	-	CPS 70x85'	65 sec	6 fps	6.6x6.6°
08	KS-67A	500mm	-	EMS 70x85'	65 sec	6 fps	6.6x6.6°
10	EL-500	500mm	W 12	AIR 70x15'	54 sec	1.5 fps	6.6x6.6°
11	EL-500	500mm	W 88A	IRA 70x20'	54 sec	1.5 fps	6.6x6.6°
12	EL-500	500mm	4554A	TXA 70x20'	54 sec	1.5 sec	6.6x6.6°
13	EL-500	500mm	4278A	TXA 70x20'	54 sec	1.5 fps	6.6x6.6°
14	KS-72A	2000mm	-	MSA 5"x300'	60 m	5 fps	2° dia.
15	KS-72A	900mm	-	ACN 5"x300'	60 m	5 fps	7.2x7.2°
16	KS-72A	900mm	W 88A (1)	IRA 5"x300'	60 m	5 fps	7.2x7.2°
17	M-S Spectrograph	500mm	(Minus Blue)	IRA 70x15'	lm 12 sec	1 fps	5000-9000 A
18	Spectrometer		-	VTR 1/2"	60 m	20 ms	4000-10,000 A
19	IVC-90	Zoom 50-300mm	-	Color-VTR 1"	60 m	30 fps	9°x12° -1.4°x2.0°
20	HV-15S	500mm	W 88A	B/W*-VTR 1"	60 m	30 fps	7000-12,000 A .8x1.2° FOV
21	HV-15S	Zoom 75-260mm	W 25	B/W*-VTR 1/2"	60 m	30 fps	Pointing Camera 6°x9° -1.6 x2.3°

ADDITIONAL INFORMATION: (1) For events 50 and 51 a W 25 filter was added.

* Tivicon - Texas Instruments electron scanned silicon-diode-array image tube spectral response 0.35 to 1.1μ; with W 88A filter 0.74 to 1.1μ.

TECHNOLOGY INTERNATIONAL CORPORATION

INSTRUMENT PLAN

OPERATION: Hula Hoop **DATE:** Summer 1973 **STATION:** A/C

EVENT: ALL **LOCATION:** OPAREA **PROJ./ENGINEER:** Boquist

POSITION	INSTRUMENT	FOCAL LENGTH	FILTER	FILM	NOMINAL RUNNING TIME	SHUTTER/RATE	REMARKS
41	KS-72A	898mm (1)	-	MSA 5"x300'	24 min	5 fps (2)	7.2x7.2°
42	1000F/CL-5	1250mm	W 12	AIR 70x15'	-	Manual	2°
43	DBM-55 (3)	300mm	-	XRM 16x400'	32 sec	500 fps	1.4° x2°

ADDITIONAL INFORMATION:
(1) Changed to 460mm for events 50 and 51.
(2) Framing rate changed to 1 frame per 5sec. at approx. H + 15 sec.
(3) Included for events 49, 50 and 51.

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TECHNOLOGY INTERNATIONAL CORPORATION

INSTRUMENT PLAN

OPERATION: Hula Hoop **DATE:** Summer 1973 **STATION:** Secondary Surface

EVENT: ALL **LOCATION:** OPAREA **PROJ/ENGINEER:** Sp/4 Faour, U.S.Army

POSITION	INSTRUMENT	FOCAL LENGTH	FILTER	FILM	NOMINAL RUNNING TIME	SHUTTER/RATE	REMARKS
51	KS-67A	500mm	-	EMS 70x85'	23 min	5 fps	6.6x6.6°
52	EL 500	250mm	W 25	PXP 70x15'	2 min	2 fps	13x13°
53	EL 500	250mm	-	CPS 70x15'	6 min	1 fps	13x13°

ADDITIONAL INFORMATION:

APPENDIX B

CORRECTION FOR EARTH'S CURVATURE

(U) The curvature of the earth limits the distance at which near surface objects can be seen. Bowditch (Ref. 5) states that the range of the visible horizon (R) is dependent upon the height of the observer (h) through the following relation:

$$R = 1.144\,(h)^{1/2}$$

for h in feet and R in nautical miles. This equation must be applied twice, once for the height of the observer and once for the height of the object above its local sea level. A total correction of 44 meters is found for typical values of event ground range of 20 nautical miles and an observing height of 30 feet. Thus to correct for the earth's curvature, 44 meters must be added to the horizon-object vertical separation distance as calculated from the data frame.

(S) The earth curvature correction is subject to errors in range and observation height. If the ground range to the target is increased, for example, by one nautical mile, the correction is increased by 6 meters. For events Fr 47 to Fr 50, the ground range to the burst point was determined by radar ranging to within a few yards and did not contribute a significant error to burst height determination.

(U) Observation height, and therefore the value of the curvature correction, varies with the ship's roll and vertical movement due to swells. The effect of these height variations was calculated for the sea conditions encountered during each event and included in Table IV as the error in the earth's curvature correction. The maximum error was $\pm$ 5 meters.

APPENDIX C

CORRECTION FOR ATMOSPHERIC REFRACTION

The effect of atmospheric refraction is to bend light rays towards the horizon causing the observer to perceive a target altitude higher than its true geometrical position. Figure C-1 illustrates that although the actual position of the target is T, it will appear to be at A, along a line tangent to the curving ray at the position of the observer, O. The correction AT must be calculated, therefore, to determine the actual target altitude above sea level.

The radius of curvature, R, of a light ray within the atmosphere is given by the equation (Ref. 6):

$$R = \frac{1.266 \times 10^4 T^2}{P(34-\Gamma)} \quad \text{km} \qquad (C.1)$$

where P is atmospheric pressure in millibars

T is temperature in $^{\circ}$K

Γ is the negative of temperature change with height in $^{\circ}$K/km (lapse rate)

In Figure C-2 the refraction correction, s, is given by the equation:

$$s = R\ (\sec \alpha\ - 1) \qquad (C.2)$$

where the value of α in radians is:

$$\alpha = \frac{OT}{R}$$

In the case being considered, the distance OT can be approximated by the known distance from the observer to ground zero, OI. The error in the calculation of α introduced by this approximation is less than .01%. The refraction correction equation (C.2) then becomes

$$s = R \quad \sec \frac{OI}{R} - 1 \qquad (C.3)$$

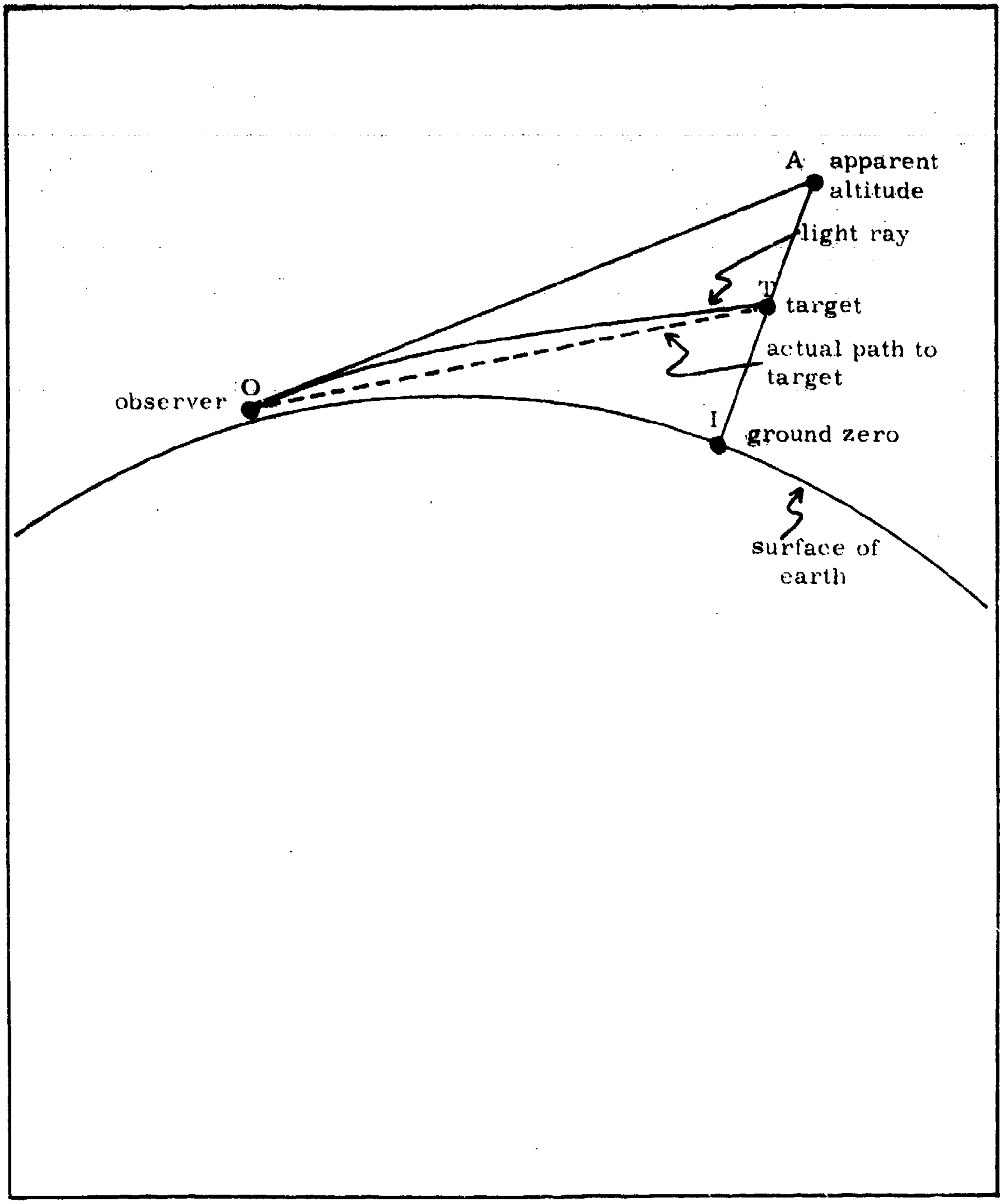
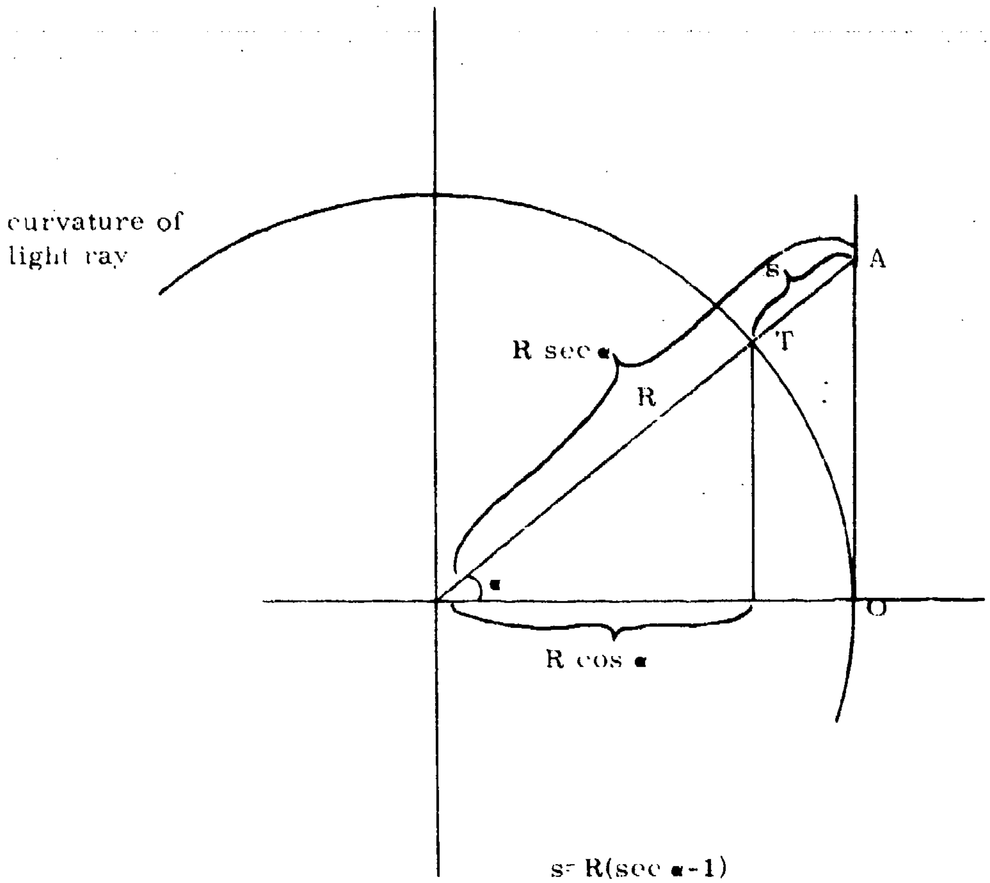


Figure C-1 Geometrical model for terrestrial refraction calculation



$s = R(\sec \alpha - 1)$

Figure C-2 Geometry used for refractive correction calculations

The radius of curvature will change as a function of altitude and atmospheric conditions. Using the appropriate atmospheric temperature and pressure information to solve for the radius of curvature, the resulting apparent optical separation can be determined from equation (C.3), assuming the light ray is subject to the conditions of one altitude regime for its entire path. Since the true light path passes through many of these layers, one may average the corrections from each layer as the light ray passes from the surface to the target. These averages, computed from actual event day conditions and weighted to include the length of the total path spent in each layer, are listed in Table IV for the events of interest.

APPENDIX D

SUMMARY OF PRE- AND POST-EVENT WEATHER CONDITIONS

TABLE D-1 (S)

PRE-EVENT WEATHER OBSERVATION DATA

FR 47 21 July 1973 1000Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (Deg.)	WIND SPEED (knots)
1016	0	23.4	18.8	050	26
1000	148	21.0	17.4	060	23
964	480	17.8	16.6	--	--
946	600	16.0	14.7	--	--
905	1025	14.6	10.6	--	--
850	1528	10.8	8.0	345	13
834	1725	9.6	8.0	--	--
807	2000	9.4	3.6	--	--
787	2200	11.6	-10.4	--	--
739	2725	11.0	3.2	--	--
700	3143	9.0	-17.0	280	12
640	3900	3.4	-13.6	--	--
524	5500	-8.7	-28.7	--	--
500	5830	-9.9	-31.9	265	33
452	6650	-13.3	-28.3	--	--
437	6875	-14.7	-32.7	--	--
421	7175	-16.7	-25.7	--	--
400	7530	-19.7	-27.7	280	45
334	8875	-29.1	-34.1	--	--
300	9610	-35.3	M	265	53
289	9900	-37.1	-41.5	--	--
250	10840	-44.7	M	255	60
200	12300	-56.5	M	260	75
170	---	-65.1	M	--	--
150 (trop)	14070	-67.7	M	270	75
100	16490	-71.5	M	280	63
70	18600	-69.3	M	285	43
50	20640	-63.1	M	275	35

TABLE D-2 (S)

PRE-EVENT WINDS ALOFT

FR 47 21 July 1973 1000Z (S)

ALTITUDE (m)	DIRECTION (degrees)	SPEED (knots)
0	050	26
305	025	25
610	055	20
914	020	12
1219	355	12
1524	345	13
1829	340	13
2134	320	13
2438	315	13
2743	315	13
3048	280	12
3658	290	18
4267	285	22
4877	275	27
5486	265	33
6096	265	40
7620	280	53
9144	275	53
10668	265	61
11887	260	72
13106	260	73
14021	270	75
14935	270	67
15850	280	70
16764	275	67
17983	295	45
18288	290	46
19507	280	26
20422	280	35

TABLE D-3 (S)

POST-EVENT WEATHER OBSERVATION DATA

FR 47 21 July 1973 2100Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)
1015	0	24.4	21.4
1000	136	22.0	19.4
950	560	17.8	16.1
892	1080	14.8	11.9
850	1526	12.8	5.8
832	1650	12.8	-6.2
775	2270	11.8	-18.2
700	3140	7.2	-20.8
500	5820	-10.1	-28.1
488	5990	-11.5	-27.5
400	7510	-19.5	-31.5
338	8720	-28.5	-41.5
318	9180	-32.7	-39.7
300	9590	-35.3	-43.3
294	9720	-34.7	-42.7
281	10020	-38.7	-45.7
250	10830	-44.7	---
200	12290	-57.1	---
161	13600	-69.5	---
150	14050	-71.1	---
100	16450	-70.9	---

NOTE: No Wind Direction and Speed values available.

TABLE D-4 (S)

POST-EVENT WINDS ALOFT

FR 47 21 July 1973 2000Z (S)

ALTITUDE (m)	DIRECTION (degrees)	SPEED (knots)
0	100	10
136	220	26
305	065	15
610	345	20
914	340	23
1219	335	23
1524	325	23
1829	315	18
2134	300	15
2438	280	13
2743	265	17
3048	300	13
3140	300	13
3658	320	17
4267	305	23
4877	305	25
5486	285	32
5820	285	32
6096	280	35
7510	270	53
7620	270	55
7925	275	65
9144	280	57
9590	280	55
10668	275	46
10830	275	45
11278	280	40
12290	280	43
14050	270	70
16450	277	53

TABLE D-5 (S)

PRE-EVENT WEATHER OBSERVATION DATA

FR 48 28 July 1973 1200Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (deg.)	WIND SPEED (knots)
1018	0	24.6	21.0	135	23
1000	162	20.0	16.3	125	22
955	525	16.0	16.0	--	--
850	1539	8.8	8.8	85	12
792	2125	4.8	4.8	--	--
785	2200	5.6	-10.4	--	--
770	2350	7.0	-14.0	--	--
700	3134	6.0	-15.0	175	5
533	5175	-7.9	-25.9	--	--
516	5400	-7.5	-25.5	--	--
500	5620	-8.1	-15.1	190	42
400	7310	-20.3	-33.3	210	33
334	8625	-31.1	-36.1	--	--
300	9370	-37.5	-44.5	205	58
250	10610	-45.9	--	210	87
200	12070	-52.5	--	195	78
158	13550	-60.5	--	--	--
150	13890	-61.3	--	240	47
138	14350	-61.1	--	--	--
119	15325	-64.1	--	--	--
100 (trop)	16340	-71.1	--	280	30
70	18500	-67.9	--	295	20
50	20550	-64.1	--	270	10
30	23730	-57.9	--	275	16
20	26300	-55.7	--	320	16
10	30770	-50.3	--	310	58
7	33100	-50.3	--	M	M

NOTE: No winds aloft data.

TABLE D-6 (S)

POST-EVENT WEATHER OBSERVATION DATA

FR 48 28 July 1973 2400Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (deg.)	WIND SPEED (knots)
1017	0	23.4	18.4	135	9
1000	152	22.0	17.6	130	10
927	750	16.2	15.4	--	--
902	1000	15.0	11.2	--	--
890	1150	14.0	12.3	--	--
850	1536	10.8	9.3	55	5
825	1800	8.6	8.1	--	--
811	1925	8.4	-16.6	--	--
791	2125	9.6	-16.4	--	--
700	3143	8.2	-17.8	170	7
662	3600	6.4	-18.6	--	--
602	4375	0.6	-22.4	--	--
500	5850	-6.5	-25.5	205	7
462	6475	-11.7	-19.7	--	--
451	6625	-12.1	-24.1	--	--
400	7550	-18.3	-28.3	220	20
379	7950	-21.5	-27.5	--	--
369	8150	-22.5	-33.5	--	--
300	9630	-34.5	-44.5	220	41
278	10150	-39.7	-49.7	--	--
250	10880	-44.1	--	220	65
242	11150	-44.5	--	--	--
232	11400	-44.5	--	--	--
200	12370	-48.3	--	195	65
164	13650	-55.3	--	--	--
162	13750	-57.5	--	--	--
150	14220	-59.3	--	210	33
135	14900	-64.3	--	--	--
100	16690	-68.9	--	220	17
70	18810	-67.9	--	260	10
50	20870	-60.9	--	230	5
30	24110	-51.1	--	275	23
20	26790	-43.9	--	280	13

NOTE: No winds aloft data.

TABLE D-7 (S)

PRE-EVENT WEATHER OBSERVATION DATA

FR 49 18 August 1973 1000Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (deg.)	WIND SPEED (knots)
1019	0	23.0	19.8	120	13
1000	166	20.8	18.7	125	12
850	1548	9.8	8.4	065	03
816	1875	9.2	3.1	--	--
759	2475	6.2	0.1	--	--
734	2750	4.6	-7.4	--	--
715	2950	3.6	-25.4	--	--
700	3146	4.4	-24.6	200	06
683	3325	4.4	-24.6	--	--
624	4075	0.6	-27.4	--	--
568	4825	-5.9	-32.9	--	--
500	5810	-11.3	-37.3	210	18
400	7480	-25.1	-48.1	255	28
317	--	-31.7	-55.7	--	--
300	9530	-34.1	-58.1	265	79
270	--	-39.7	-56.7	--	--
250	10780	-43.3	M	260	80
200	12240	-53.7	M	275	66
150	14060	-62.3	M	265	73
145	---	--	--	280	86
100	16520	-69.3	M	260	52
89 (trop)	---	-70.7	M	275	39

TABLE D-8 (S)

PRE-EVENT WINDS ALOFT

FR 49 18 August 1973 1000Z (S)

ALTITUDE (m)	DIRECTION (degrees)	SPEED (knots)
0	120	13
305	125	12
610	130	10
914	125	8
1219	90	4
1524	65	3
1829	60	4
2134	45	4
2438	140	3
2743	240	5
3048	200	6
3658	200	8
4267	180	9
4877	215	10
5486	210	18
6096	225	18
6706	250	22
7620	245	34
8534	265	59
9144	260	68
9754	255	85
11887	250	83
12192	275	66
13106	285	78
13411	280	86
14630	260	63
15240	290	51
15544	295	55
16764	265	43
17374	290	40
17983	300	40
18288	290	41

TABLE D-9 (S)

POST-EVENT WEATHER OBSERVATION DATA

FR 49 18 August 1973 2000Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)
1019	0	22.6	19.2
1000	162	21.0	18.8
850	1549	12.6	11.2
809	1900	11.0	4.6
788	2200	10.6	3.9
728	2800	6.6	-3.4
700	3161	6.8	0.4
680	3350	5.0	-2.8
623	4050	1.6	-6.2
583	4550	-3.1	-10.7
553	5000	-4.7	-12.4
500	5840	-8.9	-16.5
400	7530	-21.5	-28.8
367	8150	-24.3	-31.4
351	8450	-26.9	-32.7
343	8650	-29.5	-32.1
321	9050	-29.9	-34.3
308	9400	-32.1	-34.3
300	9600	-32.5	-37.2
272	10200	-36.1	-42.7
250	10870	-39.9	-46.8
200	12370	-48.7	---
150	14220	-57.1	---
100	16760	-62.9	---

NOTE: No winds available.

TABLE D-10 (S)

PRE-EVENT WEATHER OBSERVATION DATA

FR 50 24 August 1973 1000Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (deg.)	WIND SPEED (knots)
1020	0	23.2	21.3	115	18
1000	183	21.6	20.7	120	17
872	1375	13.8	13.4	--	--
850	1572	13.6	9.9	80	--
838	1725	13.4	7.4	--	--
811	2000	11.8	4.8	--	--
803	2075	11.8	6.8	--	--
759	2575	10.0	7.9	--	--
729	2900	8.4	-10.6	--	--
700	3189	5.4	-3.6	55	15
658	3725	2.4	-20.6	--	--
621	4200	2.0	-24.0	--	--
555	5075	-4.7	-27.7	--	--
534	5325	-4.7	-29.7	--	--
500	5870	-7.7	-31.7	60	27
469	6350	-10.3	-34.3	--	--
400	7570	-20.7	-39.7	85	31
386	7900	-23.9	-41.9	--	--
347	8675	-27.9	-46.9	--	--
300	9640	-34.9	-52.9	50	25
290	9950	-37.1	-54.1	--	--
250	10880	-45.1	--	110	29
200	12350	-53.3	--	140	10
191	12950	-55.1	--	--	--
181	13150	-55.3	--	--	--
150	14170	-62.1	--	200	16
117 (trop)	15875	-70.5	--	215	31
100	16610	-70.3	--	230	12
70	18730	-68.5	--	260	10
50	20770	-64.1	--	280	8
30	23960	-55.9	--	200	10

NOTE: No winds aloft data.

TABLE D-11 (S)

POST-EVENT WEATHER OBSERVATION DATA

FR 50 24 August 1973 1900Z (S)

PRESSURE (mb)	ALTITUDE (m)	TEMP. (°C)	DEW POINT (°C)	WIND DIR. (deg.)	WIND SPEED (knots)
1023	0	23.8	21.6	85	8
1000	207	22.0	21.5	M	10
850	1603	13.4	13.1	65	15
768	2450	10.6	1.6	--	--
744	2700	8.8	1.8	--	--
700	3221	5.8	-3.2	80	10
671	3550	3.6	3.6	--	--
653	3800	2.2	-8.8	--	--
641	3950	1.6	-14.4	--	--
617	4275	1.8	-15.2	--	--
585	4650	1.2	-15.8	--	--
551	5125	-2.9	-20.9	--	--
500	5910	-6.7	-23.7	50	25
400	7620	-18.1	-34.1	35	18
300	9700	-34.5	-48.5	45	15
272	10425	-39.1	-53.1	--	--
250	10960	-42.3	--	90	12
216	12000	-49.9	--	--	--
200	12430	-51.9	--	175	17
150	14280	-58.1	--	235	26
125	15525	162.7	--	--	--
109	16450	-63.2	--	--	--
100	16780	-66.7	--	245	18
70	18950	-62.7	--	250	14
50	21050	-56.5	--	250	15
30	24370	-46.3	--	10	12
20	27100	-41.3	--	325	7
10	31910	-36.1	--	M	M

NOTE: No winds aloft data.

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Defense Threat Reduction Agency
8725 John J Kingman Road MS 6201
Ft Belvoir, VA 22060-6201

TDANP/TRC

January 14, 2002

MEMORANDUM TO DEFENSE TECHNICAL INFORMATION CENTER
ATTN: OCQ-MR LARRY DOWNING

SUBJECT: DOCUMENT REVIEW OF SPECIAL MARKED DOCUMENTS

Enclosed is the Authority Letter removing the special notation on each document. Please have the documents listed, displayed and available for the Defense Community.

If you have any questions, please call me at 703-325-1034.

Ardith Jarrett
ARDITH JARRETT
Chief, Technical Resource Center

Defense Threat Reduction Agency
8725 John J Kingman Road MS 6201
Ft Belvoir, VA 22060-6201

TD December 28, 2001

MEMORANDUM TO THE TECHNICAL RESOURCE CENTER
ATTN: MS ARDITH JARRETT

SUBJECT: NOTATION AVAILABILITY

I have reviewed the following documents and determined that the following notation is no longer applicability and can be removed. The notation reads: "NOT TO BE ANNOUNCED IN DDC TAB. This document is not to be announced, abstracted, or cited in any announcement media, secondary publication, or general bibliography listing."

The documents reviewed are:

AFGL-TR-78-0017, Modified Infrared Skymapper Data Summary. (AD-C953729)
SPC-224, Comparison of ABM and ATBM Requirements. (AD-C953311)
DASA-2581, Experimental Mass Removal and Cn of Various Heat Shield Materials. (AD-594895)
DNA-3714F, Data Analysis of High Resolution Photographic Records From DNA Operation Hula Hoop 1973. (AD-C950226)
DNA-2894P2, Proceedings of the underground Nuclear Test Measurement Symposium. (AD-596335)
DNA-3604T, Excitation Temperature Measurements of a Low Altitude Nuclear Explosion-Album B 13KT Yield. (AD-C950195)
DNA-3670F, High Resolution Optical Measurements for DNA Operation Dice Game, Field Report. (AD-C950196)
DASA-2719, TV Material Handbook. (AD-595618)
DASA-625-IS-14, DoD Nuclear Weapons Effects Tests Summary. (AD-594572)
DNA-3625F-1, Technology Assessment for Strategic Options, Volume 1. (AD-C950300)
DNA-3393F, Operation Hula Hoop Optical Measurements HSS Field Program. (AD-C950053)
DNA-3625F-3, Technology Assessment for Strategic Options, Volume 3. (AD-C950302)
GE-TMP-69397, Refraction Panel Report. (AD-595538)
DNA-2894P1, Proceedings of the Underground Nuclear Test Measurements Symposium I. (AD-596403)
DASA-625-IS-13, DoD Nuclear Weapons Effects Tests Summary. (AD-399775)

DON LINGER
Deputy for Technology Programs

DEFENSE THREAT REDUCTION AGENCY
Defense Threat Reduction Information Analysis Center (DTRIAC)
1680 TEXAS STREET SE
KIRTLAND AFB, NM 87117-5669

OP-CSUI (505) 853-0644

11 March 2009

To: DTIC-OQ

Subject: Distribution Review

DTRA has reviewed the following unclassified documents and assigned Distribution Statement C, Admin and Operational Use:

AD-C950036
Optical Measurements for Operation Hula Hoop (U)
26 November 1974. DNA 3395F

AD-C950035
Operation Dial Flower Analysis of High Resolution Optical Data (U)
26 November 1974. DNA 3396F.

The following two documents have been assigned Distribution Statement C, Critical Technology with ITAR Caveat:

AD-C950196
High Resolution Optical Measurements for DNA Operation Dice Game – Field Report (U).
16 July 1975. DNA 3670F

AD-C950226
Data Analysis of High Resolution Photographic Records from DNA Operationa Hula Hoop – 1973 (U)
May 1975. DNA 3714F

Steven Bradford
Program Manager,
Defense Threat Reduction Information
Analysis Center (DTRIAC)

DEFENSE THREAT REDUCTION AGENCY
Defense Threat Reduction Information Analysis Center (DTRIAC)
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12 May 2009

To: DTIC-OQ

Subject: Distribution Review

DTRA has reviewed the following declassified documents and assigned Distribution Statement A, per FOIA Review, 28 April 2009:

ADC950035
Operation Dial Flower Analysis of High Resolution Optical Data (U)
26 November 1974. DNA 3396F

ADC950036
Optical Measurements for Operational Hula Hoop (U)
26 November 1974. DNA 3395F

ADC950196
High Resolution Optical Measurements for DNA Operation
Dice Game – Field Report (U)
16 July 1975. DNA 3670F

ADC950226
Data Analysis of High Resolution Photographic Records from DNA
Operation Hula Hoop-1973 (U)
May 1975. DNA 3714F

for Linda M Qassim

Steven Bradford
Program Manager,
Defense Threat Reduction Information
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