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EDGERTON, GERMESHAUSEN & GRIER, INC.

PHOTOGRAPHY OF AN EXPLODING 100-TON TNT CHARGE

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Donald F. Hansen
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EG&G Report No. B-2528
Contract No. AF30(602)-2546

Prepared for

Rome Air Development Center
Air Research And Development Command
United States Air Force
Griffiss Air Force Base
New York

BOSTON, MASSACHUSETTS • LAS VEGAS, NEVADA
SANTA BARBARA, CALIFORNIA

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FOREWORD

This report describes the photographic portion of the EG&G measurements on a 100-ton TNT charge detonated at the Suffolk Proving Ground near Medicine Hat, Alberta Province, by the Canadian Government. The EG&G effort, which was sponsored by the Rome Air Development Center (RADC), consisted of two parts: (1) the measurement of the electromagnetic (EM) energy radiated or induced by the 100-ton explosion and (2) the simultaneous time-correlated photography of the detonation. Only the photographic results of the experiment are described in this report.

The assistance and cooperation afforded the EG&G field team in the performance of their work by the Canadian personnel at the Suffolk Proving Ground is gratefully acknowledged.

The excellent photographic measurements were made under adverse field conditions by Mr. Clifton Lilliott and Mr. Thomas Devlin of EG&G.

ABSTRACT

The detonation of a 100-ton TNT charge took place on 3 August 1961 at the Suffolk Proving Ground near Medicine Hat in Alberta Province, Canada. The EG&G effort on the explosion was intended to (1) measure the electromagnetic (EM) signals, (2) perform high speed photographic measurements to assist in the analysis of the EM data. This report contains only a description of the photographic phase of the effort.

A 35 mm Fastax framing camera operating in a conventional manner, and a similar instrument modified for streak camera operation were used. Both cameras operated in nearly every respect as intended. The record for the framing camera lasted for 4.5 seconds, however at +30 msec, the entire field-of-view was filled by the fireball. The streak camera recorded for a similar length of time but useful radius vs time data could only be obtained during the first 18 msec of the explosion, at which time the streak camera's field-of-view was filled by the fireball.

The fireball radius vs time was found to obey an expression of the form

$$r = a + bt^{0.539}$$

for the time period 0.5 msec to the end of the streak record at 18 msec.

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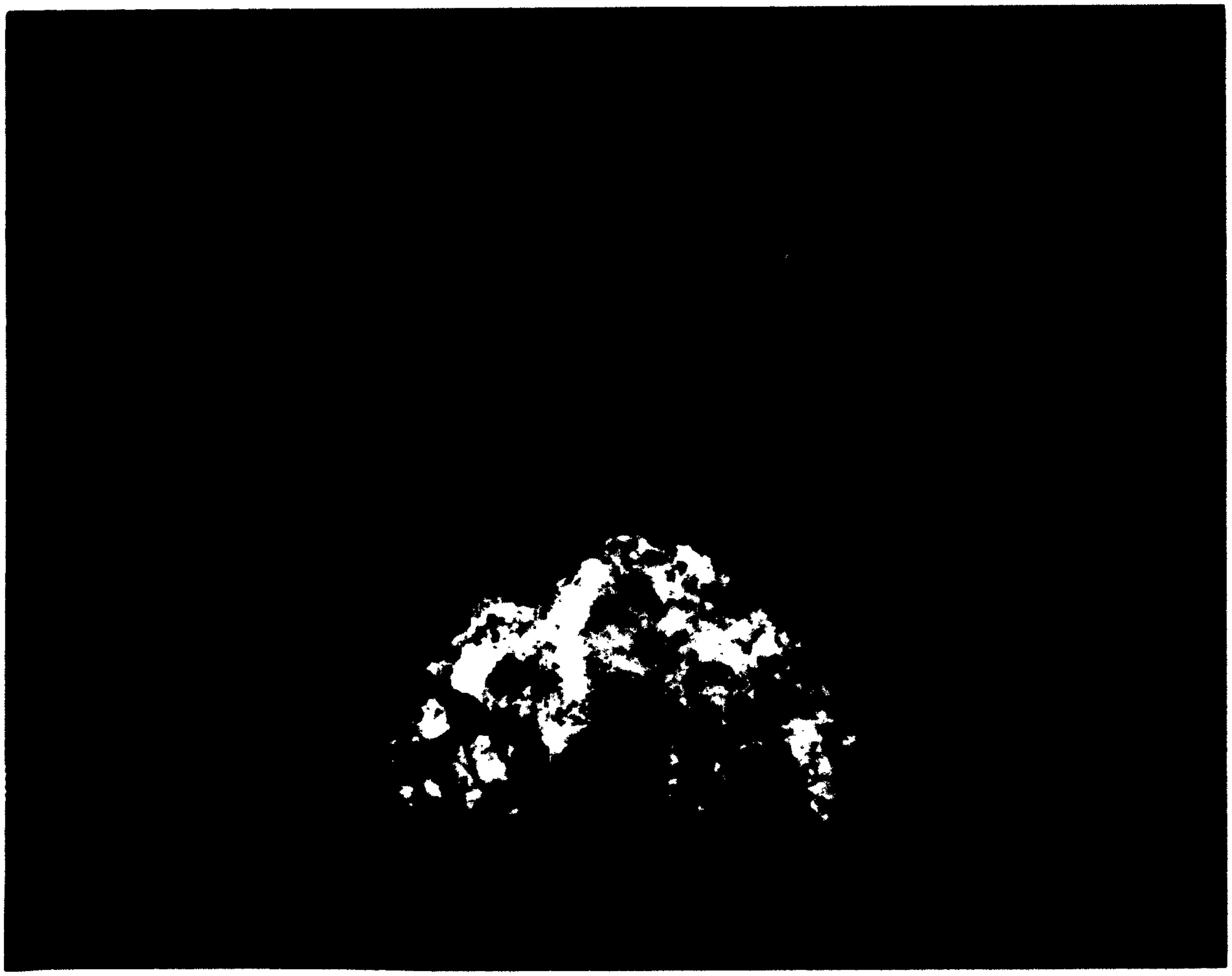


Frontispiece. 100 Tons Of Exploding TNT.

1.0 INTRODUCTION AND BACKGROUND

The work reported herein was done by EG&G in conjunction with a 100-ton TNT detonation which took place on 3 August 1961 at the Suffolk Proving Ground near Medicine Hat in Alberta Province, Canada. EG&G's main responsibility in the overall program was the measurement of the EM signal. To assist in the analysis of this signal, EG&G also instrumented to obtain high-speed photographic records of the high-explosive phenomena. Time correlation between the EM and photographic equipment was utilized. The EG&G EM studies have been reported separately and represent an effort to augment the existing body of knowledge [1, 2, 3] in this area. Since the photographic results have a significance beyond their application to the EM study, this report is published for use by those interested in the early time behavior of fireballs created by large chemical explosions.

The charge was a hemispherical mound of stacked blocks of molded TNT (see Fig. 1) having a radius of approximately 10 ft located in a shallow valley within the proving grounds. A few days prior to the detonation, the equipment used for recording the measurements was flown from Boston to Calgary. The EG&G team installed the equipment in a hastily improvised field station, using a rented truck as an instrument van and a tent as a storage facility. As only twenty-two days elapsed from project conception until completion, no more permanent facilities were available.

A 35 mm Wollensak Fastax framing camera operated in conventional manner, and a similar instrument modified to operate as a streak camera were employed by EG&G to record the explosion. The cameras were mounted in the instrument truck located on a gently rising hill overlooking the test area some 8000 ft from ground zero.

2.0 INSTRUMENTATION

The principal task of the photographic effort on the Canadian 100-ton TNT detonation was to correlate fireball radius vs time with any EM signal which might be obtained. The fireball radius vs time information was acquired with a 35 mm Wollensak Fastax camera which had been modified for slitted streak operation by removing the rotating prism mechanism used for normal framing operation, and inserting a narrow slit close to the film.

Some months prior to the Canadian detonation, EG&G had occasion to photograph a 500-pound pentolite explosion[4] from a distance of 1200 ft utilizing a slitless streak camera to measure fireball diameter vs time. The reduction of the data was tedious since a continuously changing correction factor had to be calculated and applied to obtain the true fireball diameter. Slitless streak photography was necessary at that time because a wide field-of-view was required to encompass a moving object. As the Canadian 100-ton TNT detonation was a stationary object located at a moderate distance, and in order to simplify the data reduction task, it was decided to avoid the use of the slitless streak camera and to employ instead the slitted camera method. An unmodified 35 mm Wollensak Fastax camera having normal framing operation was used as a backup in case the slit camera failed.

The study of the EM phenomenon required that the EM signal be correlated to the fireball radius to within an accuracy of ±10 μsec. Such an accuracy is beyond the capability of the Fastax framing camera, and moving film framing cameras in general. The maximum framing rate of the Wollensak Fastax is 2500 frames per

Figure 1. View From EG&G Station Overlooking Detonation Site

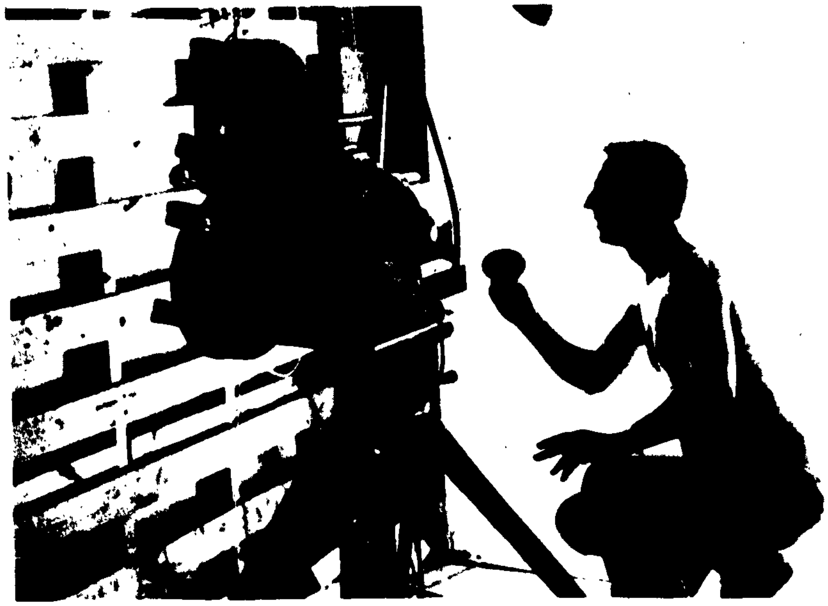


Figure 2. Wollensak 35 MM Fastax Framing Camera Equipped With 20-Inch Fototel Lens

Figure 3. Wollensak 35 MM Fastax Camera Modified For Streak Camera Operation With A 40 Inch Mirrotel Lens

second. At this framing rate an exposure duration of 80 μsec is obtained. A conventional fast streaking image camera was not available; however it also would have presented difficulties because of the rewrite problem when operating in daylight. The only available solution for obtaining fireball radius vs time to the accuracy desired was the conversion of a moving film camera to streak operation.

The Fastax framing camera, Fig. 2, employed a 20-inch Wollensak Fototel lens giving a field-of-view of approximately 254 ft vertical by 396 ft horizontal at the charge. The streak camera, Fig. 3, used a 40-inch Wollensak Mirrotel lens. In order that the streak camera follow the radial growth of the fireball in the vertical direction, the streak camera was rotated 90 degrees and operated on its side. Since these cameras are designed to operate in either position no particular difficulties were encountered.

The field-of-view of each high speed camera are pictured in Fig. 4 where the approximate position of the 100-ton TNT charge is also shown. Figure 5 illustrates the principles involved in streak camera operation and the time correlation method employed in this particular experiment. In Fig. 5a the 40-inch focal length Mirrotel lens images the object on the film which is pulled through the focal plane by a sprocket drive wheel. The distance, s, which the film travels in time t is s = vt, where v is the film velocity. By definition, the time resolution Δt of a slitted streak camera is:

$$\Delta t = \Delta s/v \qquad (1)$$

where Δs = width of the slit.

The time resolution of a streak camera is thus the time required for the film to move one slit width.

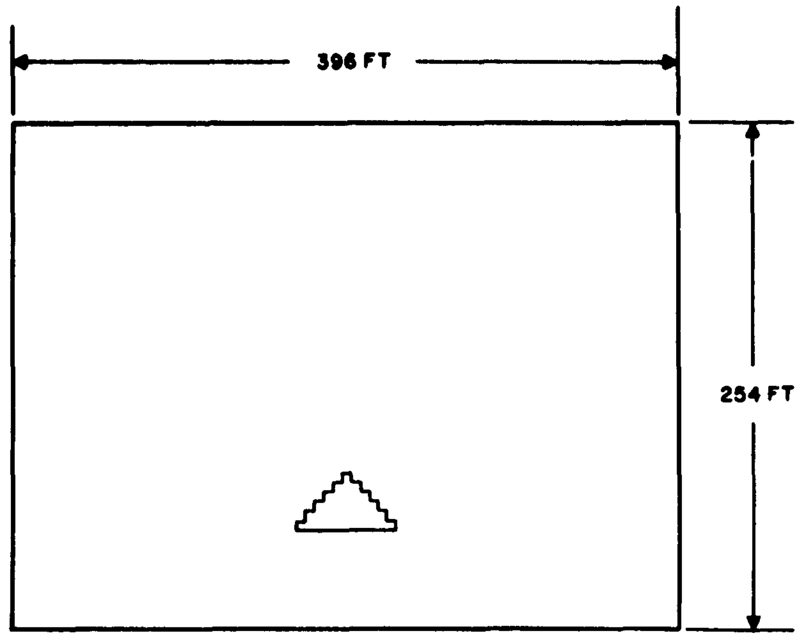
A photoelectric fiducial unit (Fig. 5a) is triggered by light from the explosion. This unit sends simultaneous pulses to a miniature glow lamp located near the film plane of the camera and to a recording head of a magnetic tape recording unit in the EM equipment. Thus, on the record of each equipment, there occurs a specific point indicating a common time.

Figure 6 depicts the fiducial trigger units which were used for time correlation between the EM and photographic equipments. The outputs of the two units were connected in parallel for backup in case of the failure of one unit.

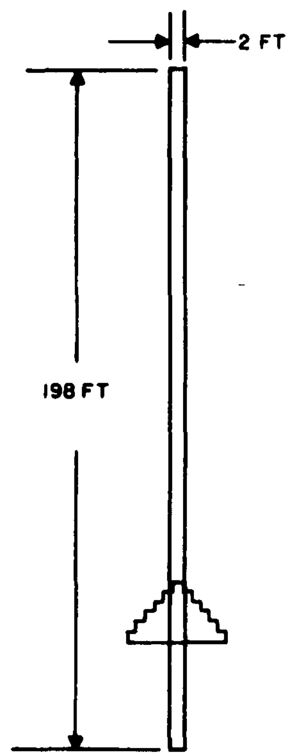
Ordinarily, when time correlation is employed with a slit camera the fiducial marker is allowed to illuminate the film through one edge of the slit. Any positional difference which occurs on the film between the time correlating mark and the appearance of light from the phenomenon indicates that the fiducial system did not trigger at the appearance of first light but at some later time. In this case the fiducial mark on the EM equipment is delayed by a corresponding amount of time.

The mechanical construction of the Fastax camera made it impossible to place the time correlating light at the slit aperture without rendering a large fraction of the slit unusable for photography. To surmount this difficulty, the fiducial light was centered in the film plane (Figs. 5b and 5c) but placed a distance s_o ahead of the slit in the time axis. In this situation a true time scale of events as measured from the fiducial timing mark on the film is found from the relation.

$$t = (s - s_o) / v \qquad (2)$$



(a) FRAMING CAMERA



(b) SLIT CAMERA

Figure 4. Field Of View Observed

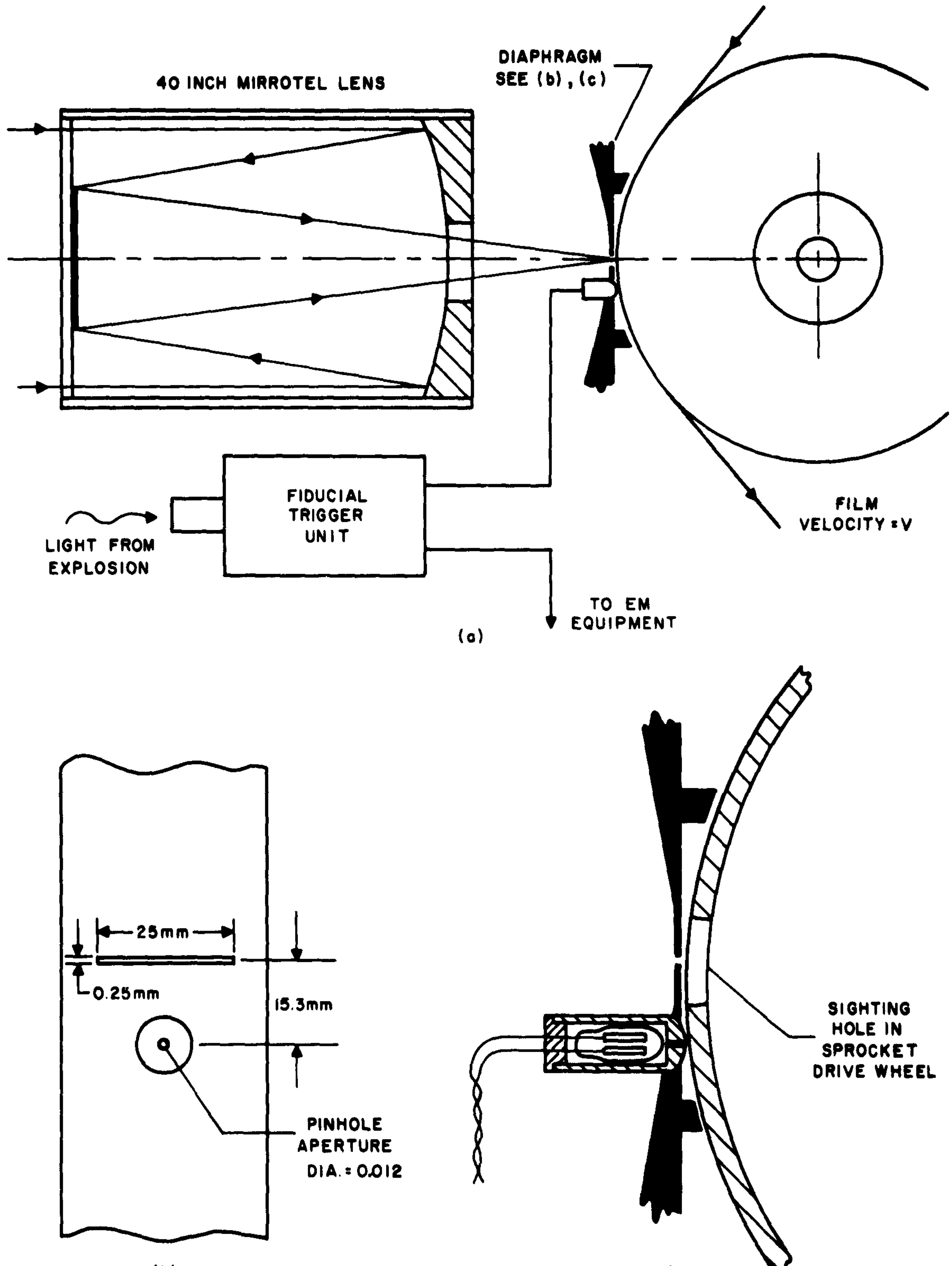


Figure 5. Streak Camera Principles

If on the data film the first light from the phenomenon occurs at a distance $s = s_o$ from the timing light mark, then the fiducial system triggered on the first light mark, and no further compensation need be made to the time scales of the photographic or EM records. A delay in triggering is indicated by a positive initial value of t. This initial non-zero value, if it occurred, would be applied to the EM record with reverse sign. It would be placed ahead of the time correlating mark on the magnetic tape in order to find the point of the EM record corresponding to the appearance of first light on the film.

Detailed operating characteristics of the two cameras and other pertinent information are given in Tables 1 and 2. It had been hoped that the new high-speed superior resolution Eastman Double-X film could be employed as the photographic recording medium. However, film of this emulsion type could not be obtained with high speed perforations in time to be used. Eastman Tri-X film was used as an alternative with some reduction in the resolution which it was hoped to obtain.

As optical lines of sight over long paths close to the ground are severely affected by a layer of turbulent air near the ground, it turned out that the factor limiting resolution was not the film but rather atmospheric "boil". A resolution test chart, Fig. 7 was erected 500 ft in back of the TNT charge at a height of 12 ft so that it was visible from the camera locations over the top of the charge. It was calculated to be easily within field depth of both cameras for 20 lines per millimeter resolution at the film. The largest resolution patterns were

TABLE 1

Characteristics Of The 35 MM Fastax Framing Camera As Used On The Canadian 100-Ton TNT Detonation	
Camera	Fastax Type
Mode of operation	Framing
Objective Lens	Wollensak Fototel
(a) f/number	f/6.3
(b) Focal Length	20 inches
Film	
(a) Size	35 mm
(b) Type	Eastman Tri-X
(c) Length	400 ft.
Resolution (Spatial)	20 lines/mm
Duration of record	4.5 sec
Format	16 mm x 25 mm
Frame rate	1416 fr/sec
Exposure time	140 μsec
Attenuation	None
Object distance	8040 ft.
Magnification	2.07×10^{-4}
Field-of-view	254 ft. x 396 ft.
Depth of focus	0.157 mm
Depth of field	3300 ft. to ∞

TABLE 2

Characteristics Of The 35 MM Modified Fastax Streak Camera As Used On The Canadian 100 Ton TNT Detonation	
Camera	Modified Fastax Type
Mode of operation	Streak
Objective lens	Wollensak Mirrotel
(a) f/number	f/6.3
(b) Focal length	40 inches
Film	
(a) Size	35 mm
(b) Type	Eastman Tri-X
(c) Length	400 ft.
Resolution (Spatial)	20 lines/mm
Duration of record	5-1/2 sec
Slit width	0.25 mm
Slit height	25 mm
Film speed	0.0219 mm/μsec
Time resolution	11.4 μsec
Attenuation	None
Object distance	8040 ft.
Magnification	4.14×10^{-4}
Field-of-view	198 ft. x 2 ft.
Depth of focus	0.157 mm
Depth of field	5700 ft. to 13,300 ft.

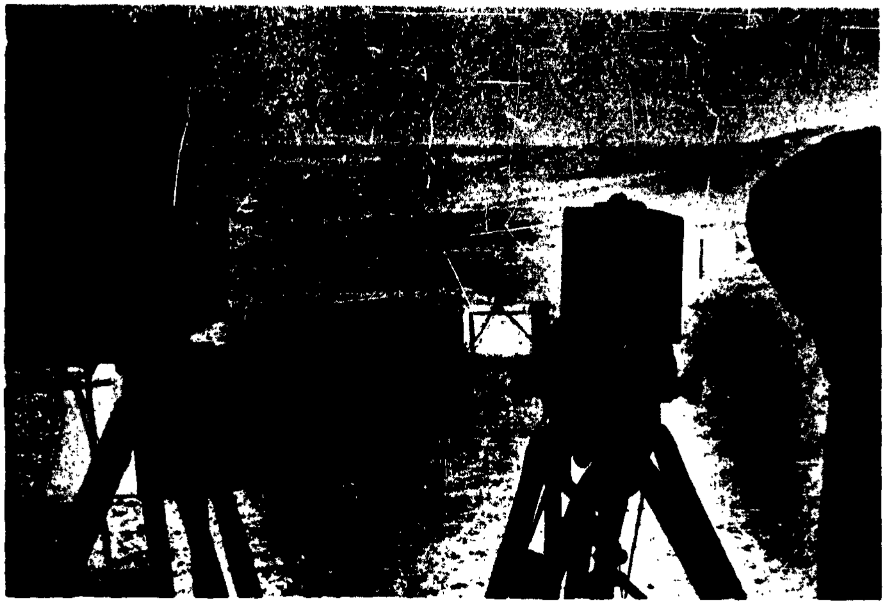


Figure 6. Fiducial Trigger Units Used For Time Correlation Of The EM And Photographic Equipments

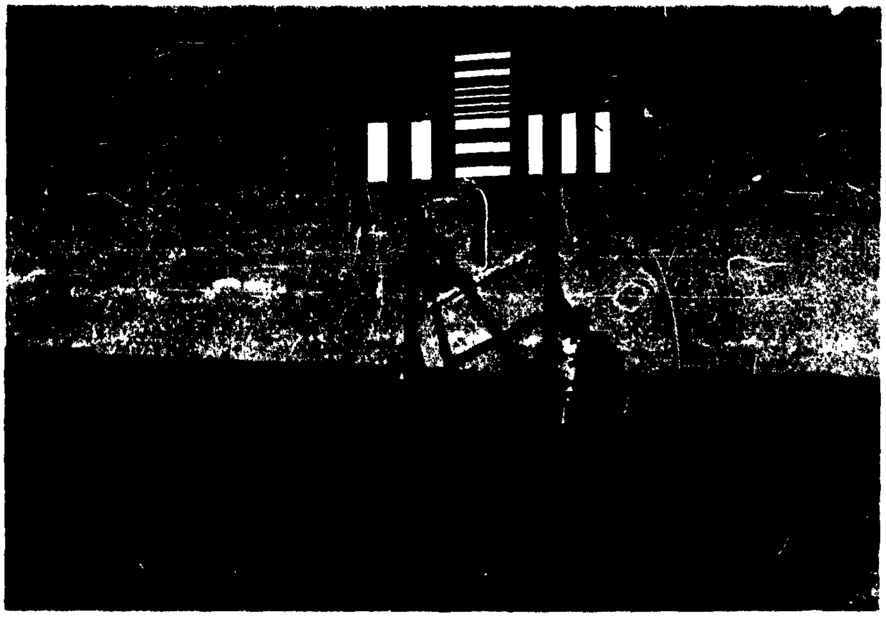


Figure 7. Resolution Chart For Checking The Overall Resolution Of Camera, Film And Atmosphere

distinguishable throughout most of the day, but only at dawn and dusk were the smallest patterns distinguishable.

3.0 RESULTS

The detonation of 100-tons of TNT proved to be a spectacular event as can be witnessed by the frontispiece and other candid photographs shown in Appendix A. A blast effect equivalent to a 20 kiloton nuclear explosion at 8.9 miles was felt by the observers at their 8000-ft station.

The cameras were manually started at minus two seconds from voice countdown signals. Both cameras operated in nearly every respect as intended. Selected sequence pictures from the framing camera record are shown in Fig. 8. The first of the sequence shows the TNT charge as it appeared a fraction of a second prior to the explosion. Background details of the remaining photographs have been sacrificed in heavy printing exposures in order to bring out graticulation details on the fireball. Since the framing camera photographed at an actual frame rate of once every 700 μ sec, the first and all succeeding frames after detonation have an inherent error of approximately this same amount with respect to true zero time. By the time 30 milliseconds had elapsed, the fireball had filled the entire field-of-view of the camera. The entire record of the framing camera lasts for 4.5 seconds.

The streak camera recorded the explosion for a similar period of time. Useful radius vs time data could be obtained only during the first 18 milliseconds at which time the fireball filled the field-of-view of that instrument. Because of the larger focal length lens used on the streak camera, its field-of-view was encompassed by the fireball earlier than that of the framing camera.

Figure 9 shows a contact print of the first few milliseconds of the streak record and an enlargement of the very early portion of the record. The time correlating mark is apparent slightly ahead of the earliest portion of the fire-ball expansion. A measurement of the distance between the time correlating mark and the first light of the fireball indicates, to within the order of accuracy of the measurement, that the fiducial system triggered at the instant the detonation wave reached the surface of the hemispherical TNT charge.

Striations are shown in Fig. 9 even at very early times. These early striations are indicative of uneven burning or turbulence which is apparent in the framing camera photographs. A number of reference lines were scribed on the streak film in order to simplify the data reduction task. These lines may be apparent in the reproduction as fine lines perpendicular to the time axis.

The shape of the initial brightness profile is a feature of this explosion worthy of consideration. It is intuitively obvious that if the detonation wave were perfectly hemispherical, it would reach all surface points of the charge at the same instant of time. The result would be manifested on the streak record as an initial straight line brightness profile. The actual streak record shows a definite slope with the detonation wave reaching the upper surface of the charge at a time later than at the lower portion of the charge. In addition to the sloping initial profile strong striations are apparent on the initial profile which we have not attempted to explain.

4.0 ANALYSIS AND CONCLUSIONS

The object of the EG&G photographic effort was the correlation of fireball radius with any EM signal which might be observed. The EM signal is however the subject of a separate report. It is our intention to present here only an analysis of the streak camera record, obtaining as a result the fireball radius vs time over that period for which it remained in the field-of-view of the camera.

Since a slitted streak camera measures the fireball radius vs time directly, the reduction of the data was comparatively simple. Measurements of the radial dimensions on the film were made visually using a precision comparator. Measurements of this type are subject to a slight error because of the ambiguity in defining the true fireball position in the presence of a strong edge gradient of densities. The accuracy achieved by the comparator technique was quite sufficient for the purposes for which the measurements were made, therefore more elaborate data reduction techniques were not applied to the problem.

Figures 10 and 11 present linear plots of the reduced data. Figure 10 is a plot at the early portion of the fireball expansion using an arbitrary origin. The curved initial profile of the explosion is apparent in this data plot. In order to have a monotonically increasing behavior for the fireball radius it was necessary to set the origin of the time scale as beginning 18 μsec after the first appearance of light at the bottom of the charge. Using this point as the origin of the time scale, the complete fireball radius vs time record is given in Fig. 11. The same data is replotted on a log-log plot in Fig. 12 in order to establish a power law governing the rate of expansion. The fireball radius as a function of time is thus found to be given by an expression of the form

$$r = a + bt^{0.539} \tag{3}$$

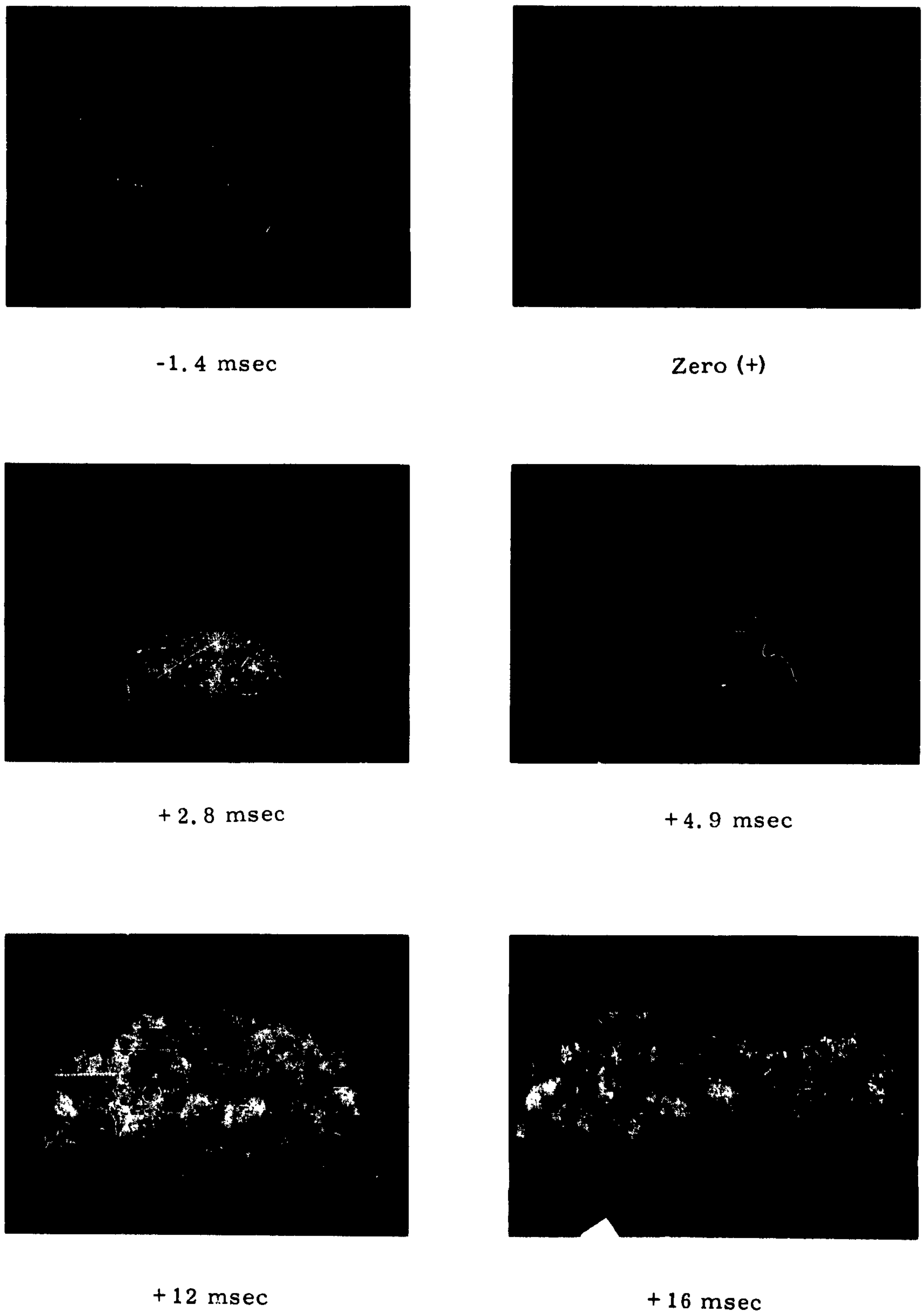
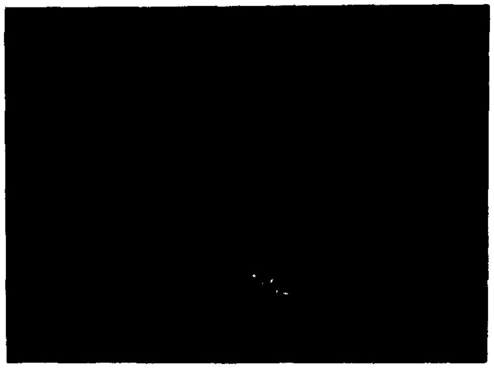


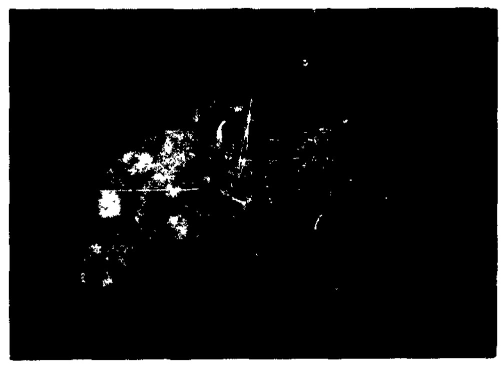
Figure 8a. Selected Sequence Of Photographs Of 100-Ton TNT Explosion



+.7 msec

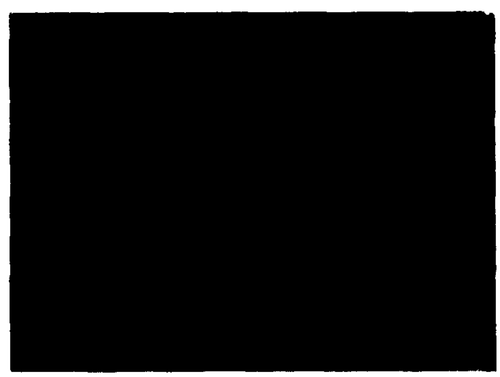
+1.4 msec

+7.1 msec



+9.2 msec

+22 msec



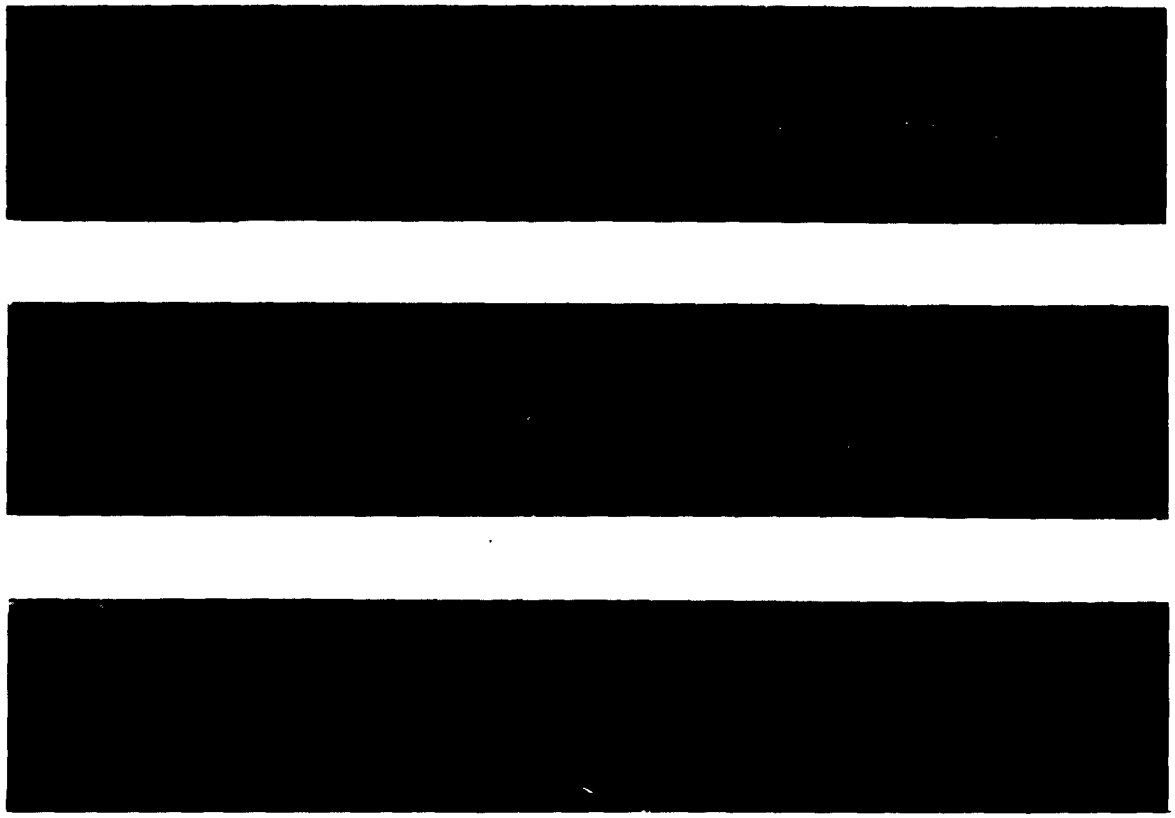
+30 msec

Figure 8b. Selected Sequence Of Photographs Of 100-Ton TNT Explosion

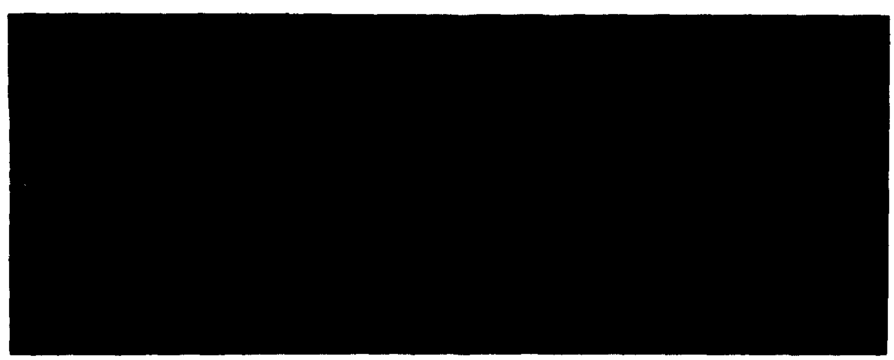
Equation 3 applies only for that interval of time during which the growth becomes a straight line on the log-log plot. This expression is of interest in comparison with the shock radius vs time law given by strong shock theory for point source explosions in the atmosphere.

$$r = bt^{0.4} \tag{4}$$

A comparison of the EG&G experimental results with the semi-empirical shock wave results of Goodman[5] is shown in Fig. 13. For comparison purposes it was necessary to assume a 200-ton charge in the case of the BRL data since their results are tabulated in terms of complete spherical charges of pentolite. The EG&G data represents fireball radius only, whereas the BRL data gives the position of the shock wave front. The shock front remains attached to the fireball only for a short period of time and after detachment runs ahead at a faster rate than the fireball growth. The EG&G cameras did not record against a background suitable for defining shock position, hence no trace of the shock front is seen on the films.



(a)



(b)

Figure 9. Streak Camera Record Of The 100-Ton TNT Explosion. (a) Contact print of the streak record; (b) Enlargement of the early portion of the record, showing uneven initial arrival of the detonation wave at the surface of the charge, and striations due to heterogeneities in the fire ball

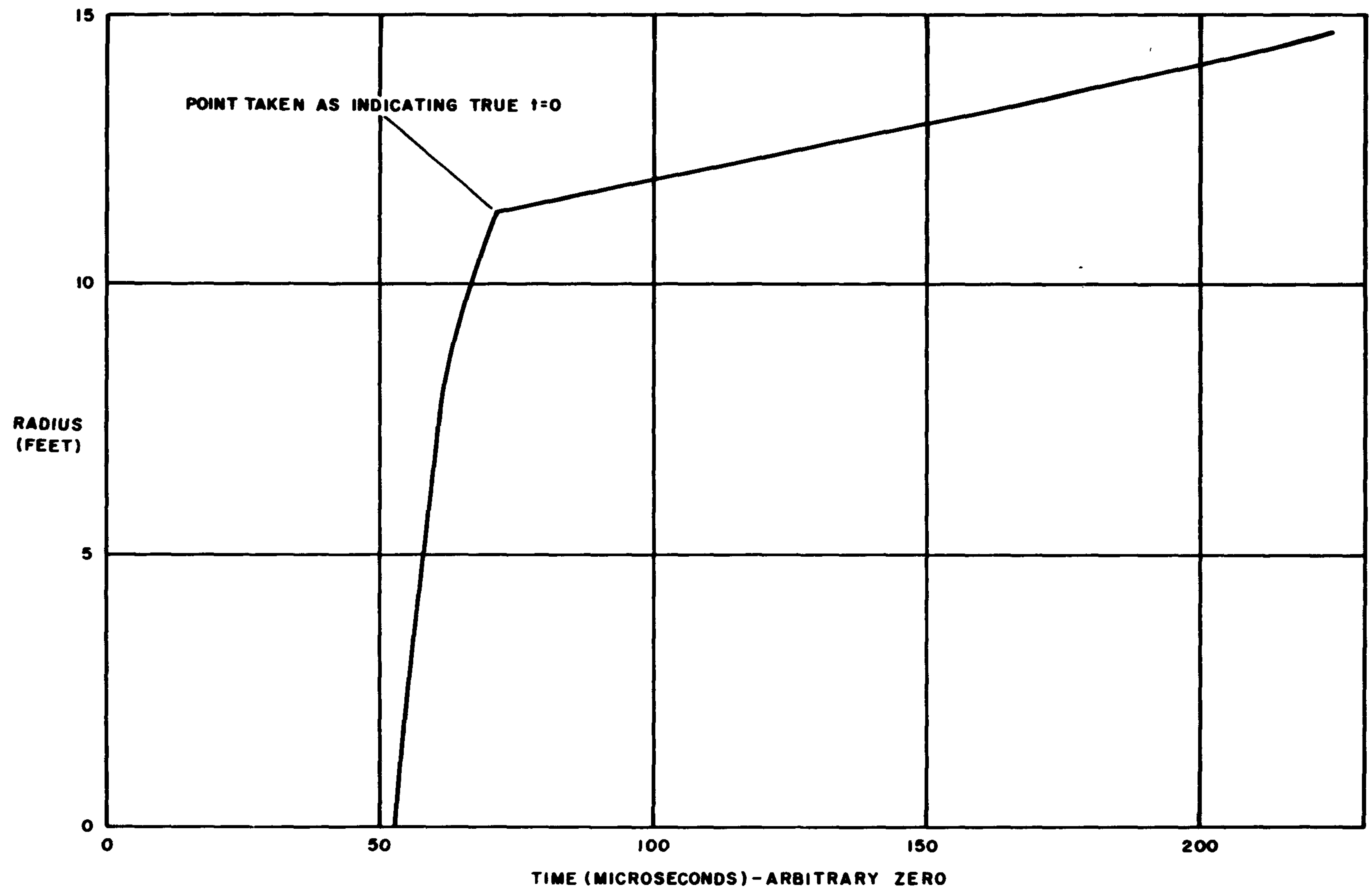


Figure 10. Early Portion Of The Fireball Radius Vs Time From The 100-Ton TNT Explosion

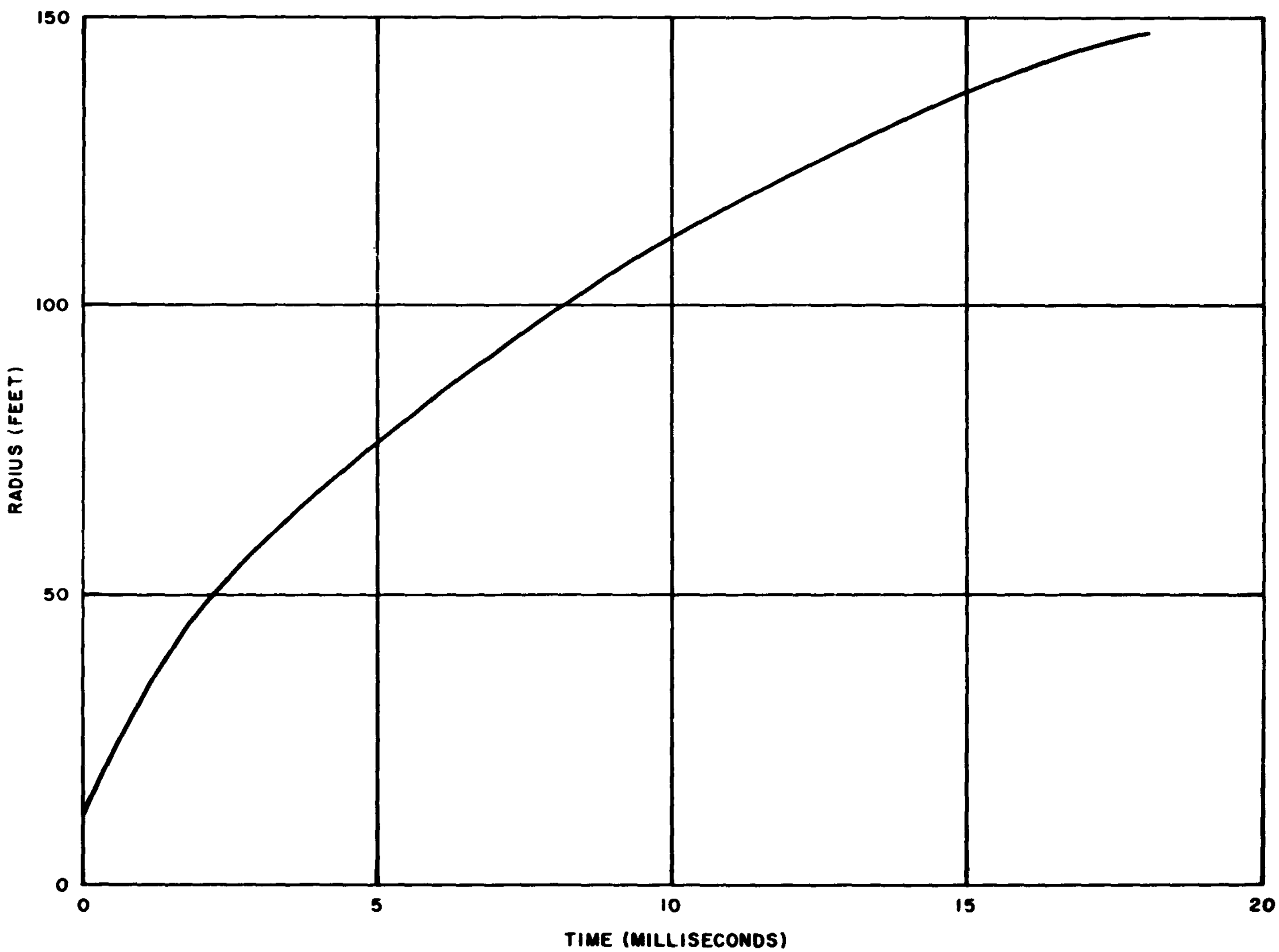


Figure 11. Complete Fireball Radius Vs Time Record From The 100-Ton TNT Explosion

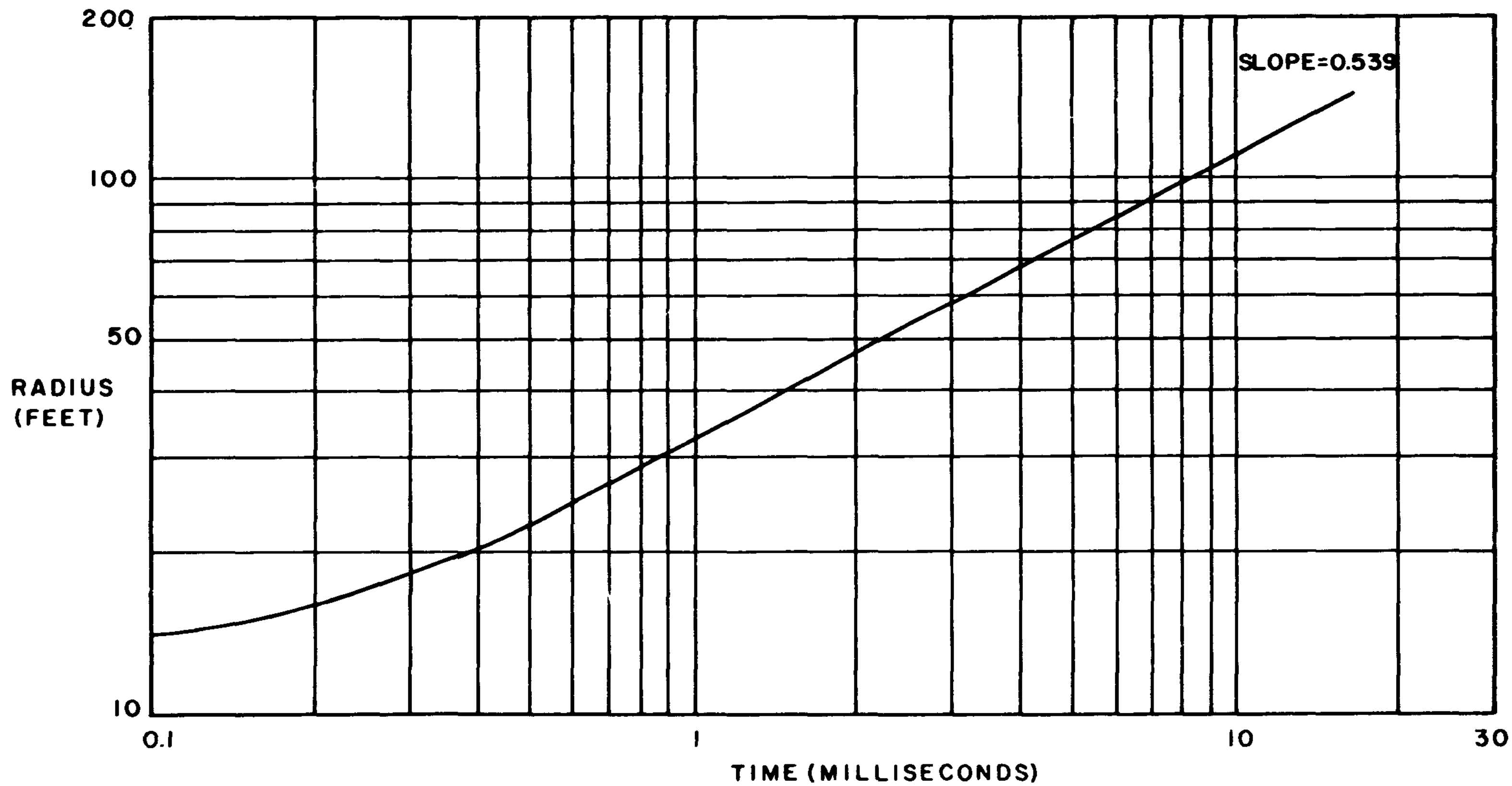


Figure 12. Logarithmic Plot Of Fireball Radius Vs Time Record From The 100-Ton TNT Explosion

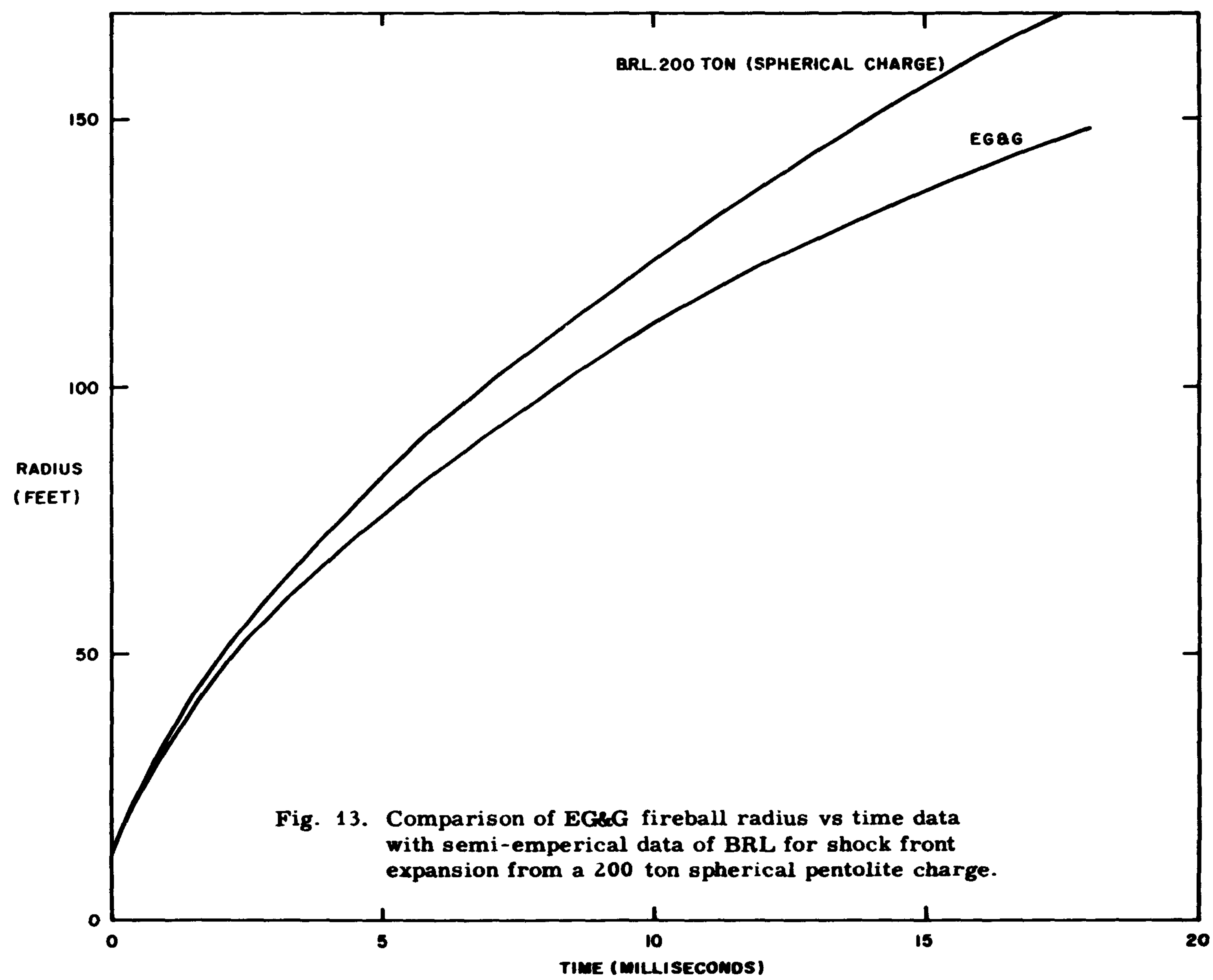


Fig. 13. Comparison of EG&G fireball radius vs time data with semi-emperical data of BRL for shock front expansion from a 200 ton spherical pentolite charge.

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APPENDIX A

The following are candid photographs taken at the Suffolk Proving Ground in connection with the detonation of the 100-ton TNT charge. These photographs may be of use to the reader interested in further details of the event.

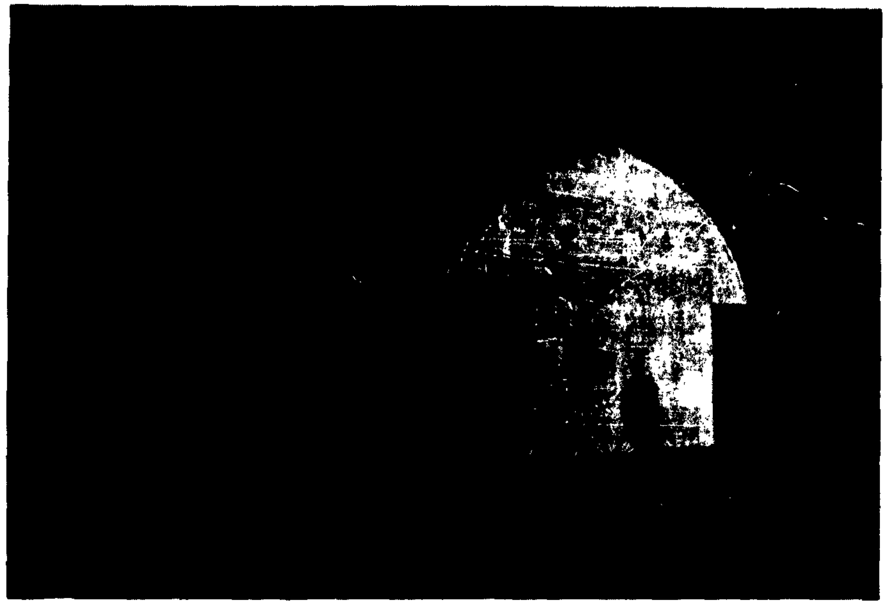

Figure A1. Shelter Which Protected The 100-Ton TNT Charge From The Weather Prior To The Detonation

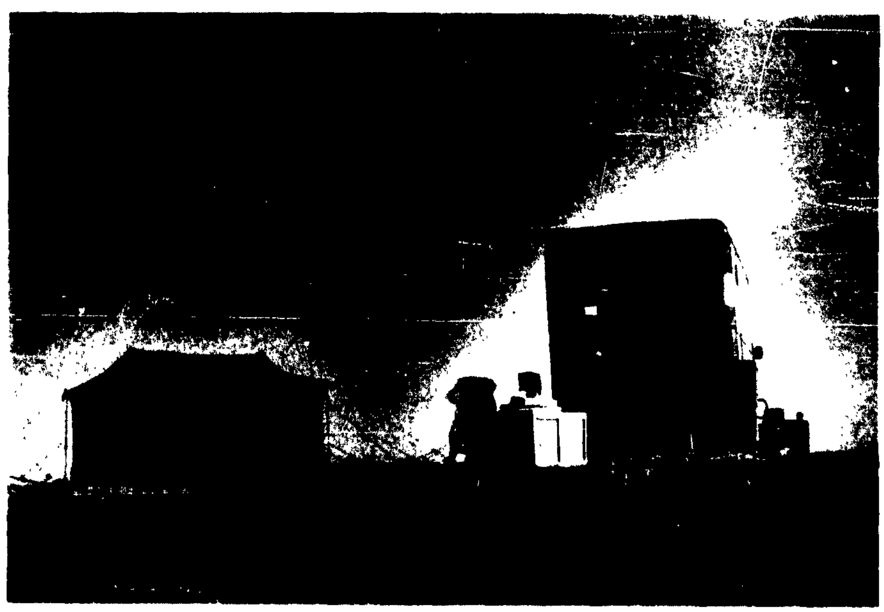

Figure A2. The EG&G Photographic Station Located Approximately 8000 Ft From Ground Zero

Figure A3. Close-Up View Of The EG&G Camera Station

Figure A4. Photograph Of Ground Zero Taken Seconds After Detonation

Figure A5. Smoke Ring Which Was Created In The Aftermath Of The Explosion