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History

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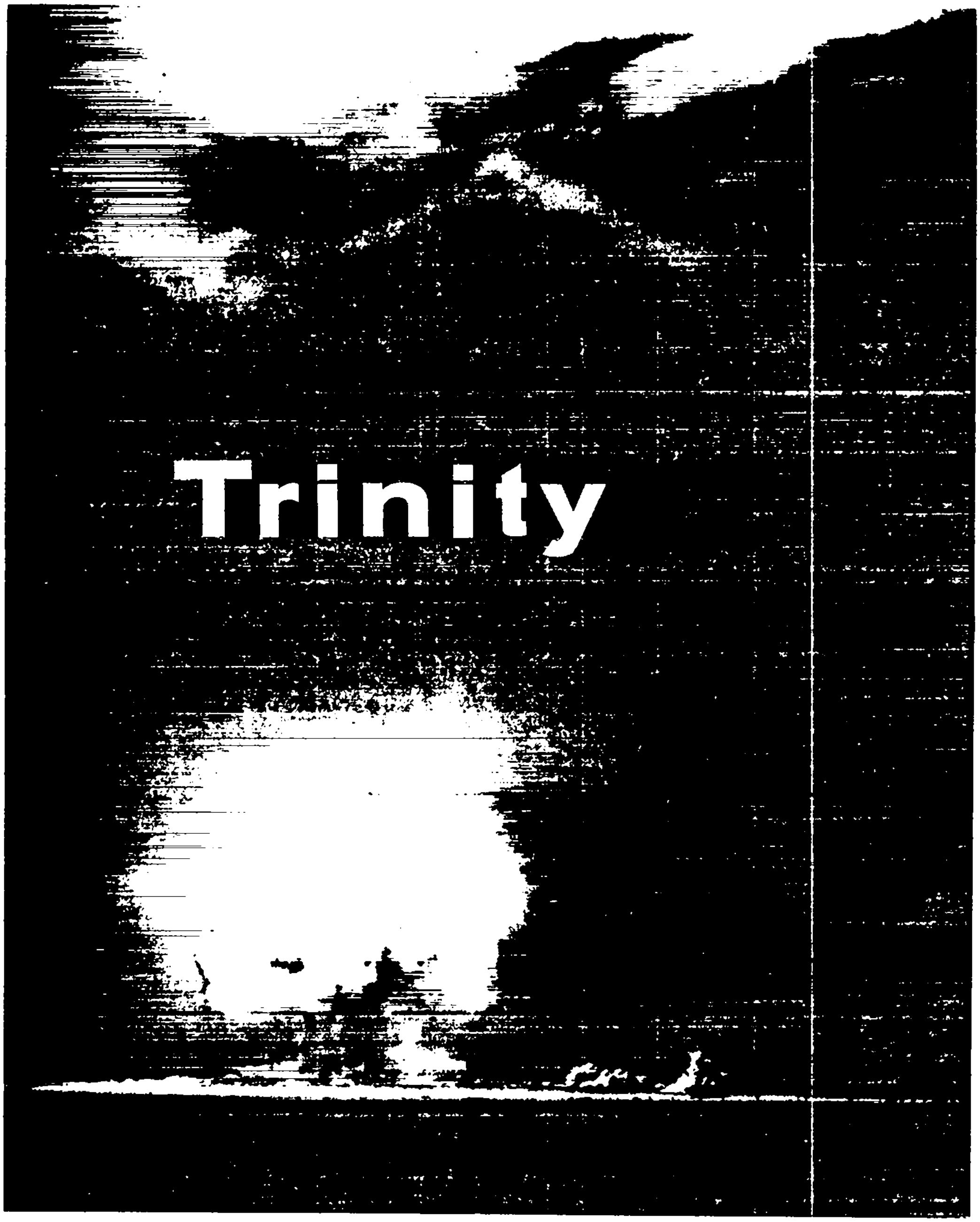

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LA-6300-H
History
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Trinity

by

K. T. Bainbridge

FOREWORD

The world's first atomic explosion occurred July 16, 1945 at the Trinity test site in southern New Mexico.

This account of the organization at Trinity, the experiments, and the results, under the direction of K. T. Bainbridge, was written shortly after completion of the test.

Because few deletions were required from the original (secret) report, this unclassified version contains almost all the original text previously published as LA-1012. The Appendix has been added to provide a short photographic account of this historic event.

Robert D. Krohn
Technical Information Group
Los Alamos Scientific Laboratory

PREFACE

This report is intended as a comprehensive record of the July 16, 1945 atomic bomb test at the Alamogordo Air Base. Sections 1-5 describe in detail the events leading up to "Zero," the moment the bomb was detonated. Section 6, which was originally intended as a summary only of the radiation observations at Trinity, was not written until the summer of 1946. During the intervening time, the airburst test at Bikini was made, and it was considered useful that a comparison be included between this later test and the Trinity data.

Sections 7-10 summarize all other experimental observations made at the Trinity test. Section 11, by the editor of this report, is relative to possible future atomic bomb tests that might be scheduled to investigate the behaviour of bombs of a design different from the Model 2 Implosion Bomb used at Trinity, Nagasaki, and Bikini.

K. T. Bainbridge

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TRINITY

by

K. T. Bainbridge

1. INITIAL PREPARATIONS FOR THE TEST (K. T. Bainbridge)

1.1. Introduction

Preparations for the Trinity test were started in March 1944 and culminated in a 100-ton rehearsal shot on May 7, 1945 and the final gadget test shot on July 16, 1945. The main purpose of this volume is to aid in the planning for any future test by furnishing a review of the preparations for and results of the above tests. The reports on results are included in their complete form, because the purpose of this report can only be met by supplying complete details of the equipment design and calibration with the results obtained. The main editorial work has been done by D. Inglis, who has acted as editor for all LA and LAMS reports.

The purposes of this report are:

- To put on record the development, scope, and type of operations involved in the July 16, 1945 atomic bomb test with recommendations for future operating procedure;
- To collect in one place all the reports relating to the apparatus and results, planning, and administration.

A test of the atomic bomb was considered essential by the Director and most of the group and division leaders of the Laboratory because of the enormous step from the differential and integral experiments, and theory, to a practical gadget. No one was content that the first trial of a Fat Man (F.M.) gadget should be over enemy territory, where, if the gadget failed, the surprise factor would be lost and the enemy might be presented with a large amount of active material in recoverable form. The only thing that could finally settle the many questions current before the test was an actual experiment with full instrumentation. Plans were made for yields from 100-10 000 tons with the most probable value 4000 tons (July 10, 1945). The safey of personnel and structures was insured for yields as great as 200 000 tons. The final functioning of the bomb showed that the prior work had been excellent in every respect and no vital factor had been overlooked.

1.2. Test Planned

The first formal arrangements for preparations for an atomic bomb test were made in March 1944, when Group X-2 was formed in the Explosives Division headed by G. B. Kistiakowsky. The duties of the X-2 group under K. T. Bainbridge included making preparations for a field test in which blast, earth shock, neutron and gamma radiations would be studied and complete photographic records would be made of the explosion and any atmospheric phenomena associated with it. This work was set up under Section X-2C with L. Fussell, Jr., in charge. Ensign G. T. Reynolds and D. F. Hornig of Division 2 of the National Defense Research Council (NDRC) were recruited to head the work on blast and earth shock measurements. D. L. Anderson had charge of the work on meteorological measurements and equipment for entering the crater area to recover samples of radioactive materials. P. B. Moon was in charge of the preparations for nuclear measurements. The section grew to a total of 25 members. All optical and photographic studies were prepared by J. E. Mack's group in another division.

The first systematic account of the test plan is given by a memorandum dated September 1, 1944, by Fussell and Bainbridge. These plans were based on the assumption that a large steel vessel (Jumbo) would enclose the gadget so that the active material could be recovered in the event of a complete fizzle. The planned tests included provision for a yield of 200–10 000 tons. The following outline lists these experiments. See Sec. 10 for additional information.

I.	Blast Measurements	Sec. 10, Part III, Blast
	a. Piezo electric gauges	(1)
	b. Paper diaphragm gauges	(4d)
	c. Condenser blast gauges	(2a)
	d. Barnes' boxes	Not used
	e. Condenser gauge blast measurement from plane	(2b)
II.	Ground Shock Measurements	III, Earth Shock
	a. Geophones	(1)
	b. Seismographs	(4)
III.	Neutron Measurements	
	a. Gold foil	(2b)
	b. Fast-ion chamber	Not used in this form
IV.	Gamma Rays	
	a. Recording in plane, dropped "gauges"	Not used
	b. Gamma-ray sentinels	V. (1)
V.	Nuclear Efficiency	II. (3a)
VI.	Photographic Studies	
	a. Fastaxes at 800 yd.	IV. General Phenomena (1a), (b), (c)
	b. Spectrographic studies. Radiation characteristics	IV. Radiation Characteristics (1a), (b)
	c. Photometric	IV. Radiation Characteristics (3a)
	d. Ball of fire studies	IV. General Phenomena (2a), (3a)
VII.	SCR-584 Radar	IV. General Phenomena (1f)
VIII.	Meteorology	VI

Additional nuclear measurements were considered by P. B. Moon who anticipated some of the experiments which were later adopted in March 1945.

1.3 Choice of a Site

Eight different sites were considered from map data.
1. Tularosa Valley
2. Jornada del Muerto Valley
3. Desert training area near Rice, CA
4. San Nicolas Island off the coast of southern CA
5. The lava region south of Grants, NM
6. Southwest of Cuba, NM and north of Thoreau
7. Sand bars, which form the coast of southern TX, located 10 mi from the main coast
8. San Luis Valley region near the Great Sand Dunes National Monument in CO

Scientific considerations required that the site be flat to minimize extraneous effects on blast. The large amount of optical information desired required that, on the average, the weather should be good, with small and infrequent amounts of haze or dust and relatively light winds. Ranches and settlements should be distant to avoid possible danger from the products of the fission bomb. Another major consideration was the requirement of minimum loss of time in travel by personnel and transportation of equipment between Project Y* and the site.

The main consideration of the Military Intelligence was the question of security and complete isolation of the activities of the test site from activities at Project Y.

The major problem of the military was the construction of a camp and facilities for living in whatever flat and desolate region was selected.

Auto trips were made to the regions north and south of Grants and Thoreau, the Tularosa basin, the Jornada del Muerto Valley, and the desert training area. Aerial surveys were made at low altitude by one or another of the group, K. Bainbridge, R. W. Henderson, Maj. W. A. Stevens, and Maj. P. deSilva, over the same areas. The choices finally narrowed to either the Jornada del Muerto region in the northwest corner of the Alamogordo Bombing Range or the desert training area north of Rice, CA.

The final choice of a site was made after consultation with Gen. Ent of the Second Air Force on September 7, 1944, who gave permission for a party to approach the Commanding Officer of the Alamogordo Bombing Base to seek an area within the base approximately 18 by 24 mi. Four locations were discussed, and finally the northwest corner of the Alamogordo Air Base was selected, latitude 33°28'-33°50', longitude 106°22'-106°41'. This permitted separation on the north and west of a minimum of 12 mi to the nearest habitation, which was great enough so that no trouble could be expected from shattering of ranchers' windows by the blast even under conditions of 100% yield. On the east the area under government control extended 18 mi and adjoined the "Malpais" area. The nearest towns in any direction were 27-30 mi away. The prevalent winds were westerly.

Arrangements were made with the Second Air Force for a 6 in.- to- the-mile mosaic to be made of a strip 6 by 20 mi including point 0 at the center to aid in locating stations. A transparent overlay was made for this map with 10 000-yd scaled arms so that the main instrument shelters could be rotated with respect to point 0, and the whole overlay could be shifted over the mosaic so that shelter positions that would not be in washes could be specified. A ground survey group, with this map, laid out points A and O and set a tentative location for point B, which was finally adopted following discussions with Col. Wriston of the Alamogordo Air Base.

The usefulness of aerial mosaics cannot be overemphasized, both for the exploratory work of the region and in the final precise planning. A great deal of time was wasted in land surveys because of inadequate maps; the good maps were not obtained in time to be of any use. Maps had to be requested through the Security Office, in June 1944, and in many cases were not received at all. The maps finally used were obtained by ordering all the geodetic survey maps for New Mexico and southern California, all the coastal charts of the US, and most of the grazing service and county maps for the state of New Mexico through other sources which normally had some use for maps. Aerial mosaics and land status maps were scrounged. This gave enough maps with which to work.

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*Project Y was the code name for Los Alamos.

1.4. Approval of Base Camp and Test Site

The original plans for the base camp were drawn up by Capt. S. P. Davalos, Bainbridge, and Fussell on October 10, 1944. A survey of the proposed scientific measurements at the site was given in a memorandum from G. B. Kistiakowsky to J. R. Oppenheimer dated October 13, 1944, giving justification for the construction and equipment requirements for the test. These two documents were transmitted to Gen. Groves on October 14, 1944, followed by a teletyped request for a decision whether or not a test would be run at all, and approval was sought for the proposed plans. The plans were approved, and early in November contracts were let through Maj. Stevens for the initial construction, which had to be expanded later (in May 1945) to take care of the expansion in activities planned for the final test shot in July. The camp was completed late in December 1944; and a small detachment, about 12 men, of Military Police under Lt. H. C. Bush took up residence there to guard the buildings and shelters before the completion of the mess hall and improvements in the roads. The choice of Lt. Bush as Commanding Officer of the Trinity Base Camp was a particularly fortunate one. The wise and efficient running of the Base Camp by Lt. Bush contributed greatly to the success of the May 7 and July 16 tests. It was a "happy camp," to borrow a Navy term. The excellent camp morale and military-civilian cooperation did much to ameliorate the difficulties of operation under primitive conditions.

1.5. Construction of Jumbo and Recovery Methods

In the winter and spring of 1944, the possibility that the first test bomb would not work at all was constantly in mind. Discussions had been held between S. Neddermeyer, G. B. Kistiakowsky, J. R. Oppenheimer, and others to consider the construction of a large pressure vessel that would be able to contain the active material and products of the explosion of a high explosive, if the operation of the first atomic bomb should be a complete fizzle. The need for the containing vessel was based on the uncertainties of the behaviour of the bomb and the desirability of conserving active material.

The engineering, design, and procurement of the pressure vessel Jumbo were handled by R. W. Henderson and R. W. Carlson of Section X-2A, among their other duties; and the testing was carried out by Lt. W. F. Schaffer, who headed Section X-2B and assisted in the measurements of pressures and deformations by G. M. Martin; T/3, B. Bederson; T/4, J. A. Hofmann, and T/4, K. W. Henderson of Fussell's section under P. B. Moon's direction. The early calculations by Bethe, Weisskopf, and Hirschfelder of the behaviour of high-pressure vessels were not fully sustained by experiment, as the best obtainable machine steel vessels could not contain more than about 50% of the predicted charge. R. W. Carlson[1] made a more complete analysis of the dynamic mechanics of the vessel and of the stresses involved in the walls. R. W. Henderson completed the new, final detailed design for Jumbo, which ultimately was built by Babcock & Wilcox. Scale experiments proved the soundness of the new design. The 214-ton Jumbo was shipped to the test site and finally erected a week or two before the test (Fig. 1) at a point 800 yd from its original location, because by that time its use in the July test had been abandoned, for reasons to be considered later.

Other methods for recovery of the active material were explored by Lt. W. F. Schaffer. One method provided a sand pile covering the bomb which "contained" the explosion of high explosive (HE) required for the initiation of the bomb and would permit recovery of the active material from a dud shot. The amount of sand required would not be small in its muffling effects on a full-scale atomic explosion. All proposed blast, earth shock, and optical measurements would be seriously compromised or rendered entirely useless if any of the recovery methods should be used. Another method required making a cone in the ground, mounting the bomb, then filling the cone with sand, and finally covering with sand in a cone above ground level. This reduced the amount of sand required to half that in the previous case. A ratio of weight of sand to weight of explosive of 15 000 to 1 was required for the recovery of the material in this case.

Finally, a water recovery method was investigated in which model bombs surrounded by an air space were suspended in a cylindrical tank of water whose weight was 50-100 times the weight of the bomb's HE. The water recovery method was investigated in detail, because it was the only method which gave any hope of recovery of 25 in the event that a 25-28* gadget was used, because mechanically it gave promise of nonmixing and nonburning of the core in the event of a nuclear fizzle.

All chemical methods of recovery, whether from Jumbo or from sand, were studied by R. B. Duffield's Group, CM-10.

It is interesting to recall that had a dud shot been made in Jumbo, the active material dispersed in the condensed steam and tamped by Jumbo's walls could be supercritical if no boron were added to prevent the reaction.

All recovery methods were abandoned in March 1945, when it was no longer possible to make test plans that did not interfere: one set of plans for the case of firing with Jumbo, the other, for an air shot with no attempt at recovery of the active material in the event of a fizzle. Any straddle would have meant that neither test setup would be ready on time. Recovery methods were abandoned as the greater promised production of active materials made it less essential to save the material in the event of a failure. Also, confidence in the ultimate success of the bomb increased. A major factor in the decision was the increased protest against the use of a containing vessel, because the vessel proper would spoil a very large share of the measurements. Certainly blast data experiments would be greatly affected, and good blast information was one of the main objectives of the test. It was important to study the blast effects under conditions that could be translated into combat use conditions to obtain the maximum military effect of the bomb. Jumbo contained 214 tons of steel which would be vaporized for yield >500 tons; at these yields of the atomic bomb the steel would be vaporized and later burnt, producing pressure effects that could not easily be analyzed. If the explosion were in the region 100-300 tons, the fragments from Jumbo would be a hazard to gauge lines, equipment, and personnel; and the energy abstracted by the fragments would be uncertain and difficult to correct for in measuring the total energy yield.

1.6. Expansion of the Trinity Program, March-May 1945

Preference rating on the scientific measurements had gradually descended almost to zero starting in August 1944 and continued very low until the end of February 1945. This resulted from difficulties in the development of the detonating system for the F. M., which required more manpower on research and development work than could be provided by normal recruiting. The urgency was so great to produce a satisfactory detonating system for the F. M. that all but two men of Section X-2C were applied to the development of the detonating system and other jobs which had higher priority than the preparations for the test. Studies continued on condenser blast gauges, earth shock geophones, "paper" box blast gauges, and other equipment in preparation for the test, particularly the procurement of piezo electric gauges, radiosondes, radars, pilot balloon equipment, and Heiland recorders, so that much equipment was purchased for use in the test, but there was not sufficient manpower for all the development, calibration, and testing that were needed.

The detailed status of the preparations for the Trinity test was made by Fussell's group. This study summarized the basic layout to which experiments were added or new methods substituted as demanded by increased knowledge and predictions of the physical effects to be encountered. Fussell wrote a brief summary.

> "It has been suggested that I prepare a short description of the work carried on in E-9 and X-2C in the early stages of preparation for Trinity.
>
> "The layout of the test site had been determined, roads were constructed, and shelters for instruments and personnel had been built. Shelter design was by Carlson and Reynolds. Earth samples in the region of the craters had been obtained; this work was supervised by D. L. Anderson with the help of Blake, Breiter, Rohlfing and Fortine. Some meteorological equipment had been obtained through the efforts of Anderson who made a few test soundings.

*Code name for ^{235}U, from element 9<u>2</u>, isotope 23<u>5</u>, and ^{238}U, from element 9<u>2</u>, isotope 23<u>8</u>.

"A considerable number of blast gauges, of several varieties, had been obtained and calibrated by Reynolds, who also designed and built a number of special geophones. A study of the expected blast pattern by Reynolds had fixed the locations for the blast and earth shock instruments. A design for an airborne condenser gauge and radio informer had been worked out by Blake, Rohlfing, and Fortine; Hornig contributed to the condenser design.

"A number of cables were installed, to determine electrical and weather characteristics; this work was done by Blake, Breiter, Rohlfing, and Fortine.

"A considerable program of pressure measurement in scaled Jumbino models was supervised by Moon and performed by Martin, Bederson, Hofmann, Henderson.

"The status of the nuclear preparations is covered by memo from Moon to Manley dated 14 February 1945. Attention should be called particularly to the contributions by Hofmann and Breiter to the delayed ionization (sentinel program); to D. L. Anderson's work in obtaining, designing, and assembling M-4 tanks and lead (which was taken over later by H. L. Anderson); and to the many ideas and overall supervisory load carried by Moon."

No directive could be given for a test because of the loose ends cropping up in bomb development, and until those were taken care of there would not be a bomb in any case.

Finally, with the completion of almost all of the physics research essential to the bomb, J. R. Oppenheimer proposed in March 1945 that section X-2C complete the detonating system development and that the various groups in R Division should consider the completion of different phases of the test project, which was christened "Trinity" or "TR".

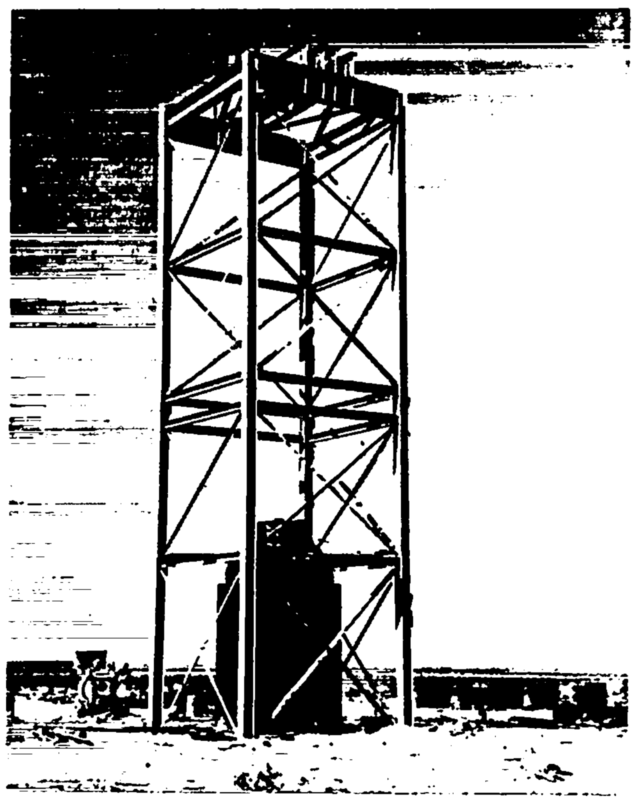

Fig. 1.
Jumbo.

2. 100-TON TNT CALIBRATION AND REHEARSAL SHOT (K. T. Bainbridge)

2.1 Plan and Organization

A 100-ton shot was proposed in the summer of 1944 to accomplish a dual purpose: (1) to provide a full dress rehearsal in preparation for the later gadget test and (2) to provide calibration of blast and earth shock equipment. Very little was known experimentally from prior work of blast effects above a few tons of HE. The results on blast and earth shock would aid in determining proper structures for withstanding these effects for the final shot by using proper scale factors. The center of gravity of the 100-ton stack was made 28 ft above the ground in scale with the 4000-5000 tons at 100-ft height expected in the final test.

The organization outlined below was set up and was expanded rapidly. This group served for the May 7, 100-ton shot.

PROJECT TR

K. T. Bainbridge	Director, Project TR
Lt. H. C. Bush	C. O., Trinity Camp
Lt. R. A. Taylor	Security
Capt. S. P. Davalos	Engineer Detachment, Trinity
W. G. Penney	Consultant, Shock and Blast
V. Weisskopf	Consultant, Nuclear Physics Problems
S. Kershaw	Safety Committee Advisor
Lt. W. F. Schaffer	HE Tower and Stacking
TR-1 J. H. Williams (R-2)	Services
	Radio and Telephone
	Construction
	Communications
	Transportation
TR-1 E. Marlowe	Timing
	Locking
	Remote Control Circuits
TR-1 R. J. Van Gemert	Purchase and Follow-up
TR-2 J. H. Manley (R-3)	Shock and Blast
TR-2 W. C. Bright	Condenser Gauges
TR-2 R. L. Walker	Piezo Gauges
TR-2 J. C. Hoogterp	Paper Box Gauges
TR-2 T. Jorgensen	Mechanical Impulse
TR-2 H. H. Barschall	Excess Velocity
TR-2 J. H. Coon	Earth Displacement and Crater Dimensions
TR-2 J. H. Coon	Geophones and Seismographs
TR-3 R. R. Wilson (R-1, R-4)	Nuclear Measurements
TR-3 P. B. Moon	Consultant
TR-3 R. R. Wilson (R-1)	Prompt Measurements
TR-3 J. H. Williams (R-2)	Delayed neutrons
TR-3 E. Segre (R-4) and	Delayed gammas
TR-3 P. B. Moon	
TR-3 Dr. L. H. Hempelmann	Health
TR-3 H. L. Anderson (F-4)	Conversion

TR-4 J. M. Hubbard	Meteorology
TR-4 Lt. C. D. Curtis	SCR-584 Radar and Ball of Fire Plotting

ASSOCIATED GROUPS OR TEAMS

TR-5 J. E. Mack (G-11)	Spectrographic and Photographic
TR-6 B. Waldman (0-4)	Airborne Measurements

In addition, the following were associated until their work could be transferred from the old section X-2C.

F. G. Blake, Jr.	Condenser
Ens. G. T. Reynolds	Shock and Blast
D. L. Anderson	Meteorology and Sample Recovery

2.2. Firing of 100-Ton Shot

The complete cooperation and unselfish devotion of all to the work at hand enabled the 100-ton shot to be fired on May 7, 1945. The scheduled date had been May 5 but extended to May 7 to allow installation of additional equipment.

Several requests for an additional time extension had to be refused. Any delay in starting the additional wiring, shelter construction, and completion of roads in preparation for the main show would have delayed the atomic bomb test and put intolerable burdens on the whole group to be prepared for the July test. To keep the schedule for the main test within the bounds of human capabilities it was essential to get the May 7 shot out of the way.

The greatest strain falls on those responsible for timing services, as the trials of signal lines, remote actuating circuits, and test calibrations must continue for long periods and at all hours. The relay system designed by Marlowe accomplished accurately all of the timing and actuating functions required. The final timing of equipment in the last 45 s was performed by a combination of a rotating drum and pin-actuated switch mechanism designed by J. L. McKibben and electronic timing devices provided by the Electronics Group.

The actual time of the explosion was 4:37:05.2 ± 0.1 s MWT,* May 7, 1945. The location of the blast was latitude 33°40'0", longitude 106°28'0".

The "Arming Party" responsible for the final closing of the firing line switches and for the safety of all personnel comprised K. T. Bainbridge, TR Head; Lt. H. C. Bush, C.O.; E. W. Marlowe, Timing; Sgt. W. Stewart, HE; and John Anderson, Security. There were three M.P. guards who came in from N-10 000, W-10 000, and S-10 000 at 2:00 a.m. and returned to the shelters to make a final check on personnel in the field who might be trying to do last-minute work.

The switches at S-10 000 were not closed until *every single individual* who had been allowed within the test area was accounted for and had been checked in at his post of duty. The checking took about 30 min for the May 7 shot and 15 min for the July 16th shot under the system set up by Lt. Bush and Bainbridge.

The keys to the three locked boxes at Zero, S-1500, and S-10 000 were in Bainbridge's possession as the responsible head of the operation.

2.3. Results of the 100-Ton Shot

R. C. Tolman wrote on May 13, 1945 a memorandum to General Groves that is a concise summary of the results of the "First Trinity Test." Excerpts follow from this report. The outline

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*Mountain War Time.

follows that presented in a Tuesday night colloquium by Bainbridge summarizing Trinity plans. The relation of the 100-ton test to the July 16 test is given in tabular form in Sec. 10 of this report. Detailed reports are indexed in the tabulation.

Report on First Trinity Test (R. C. Tolman)

2.3.1. Purpose of Test. This memorandum gives a brief description of results obtained in the first Trinity Test carried out on 7 May 1945. The purpose of this test was to obtain preliminary information, from the detonation of 100 tons of ordinary HE, regarding the success to be expected from observational methods and from administrative procedures proposed for the final test with nuclear explosive.

The section headings in this memorandum agree with those in the memorandum of 17 April 1945 on the "Program for Trinity Test," to which reference may be made for a clearer understanding of the purpose of the whole program. The present memorandum is written at a time when the data provided by the first test have, for the most part, not been worked out, but when it is possible to give an overall picture of the character of the test, and to state which measurements appear to have failed or succeeded.

2.3.2. General Character of the Test. The test was carried out with 100 tons of HE stacked on the platform of a 20-ft tower as described in more detail in the previous memorandum. The stack of HE was provided with tubes containing radioactive solution to simulate, at a low level of activity, the radioactive products expected from the nuclear explosion.

Measurements of blast effect, earth shock, and damage to apparatus and to apparatus shelters were made in general at "scaled-in" distances as compared with the distances proposed for the final shot. Measurements to determine "crosstalk" between circuits, and photographic observations were in general carried out at the full distances proposed for the final shot.

The scheduling of the test was advanced from the original date, 5 May, to 7 May to allow for further introduction of apparatus. On the basis of continuing weather forecasting, the time selected for the shot was 4:00 a.m., and it was actually pulled off with a delay of only 37 min to allow the observation plane to get properly ranged for dropping its airborne instruments.

The detonation was evidently high order. It led to the production of a highly luminous sphere, which then spread out into an oval form. This was followed by the ascent of the expected hot column which mushroomed out at a height of some 15 000 ft, at a level where atmospheric instability was indicated by meteorological observation, and then drifted eastward over the mountains, the illumination and sound were detected at the Alamogordo Air Base 60 mi away, by an observer who had been prewarned. Earth shock was imperceptible at 10 000 yd and at the base camp 10 mi away. The explosion seems to have aroused little comment in neighboring towns.

2.3.3 Program of Measurement and Observation. As described in more detail in the previous memorandum, the primary measurements and observations to be taken in the final test may be grouped under the following four headings:

1. Behaviour of the Implosion
2. Nuclear Energy Released
3. Damage Effects Produced
4. Overall Behaviour of the Explosion and Its After Effects

In this preliminary test, which involved neither an implosion nor nuclear explosive, only subsidiary experiments could be carried out in connection with the first two headings.

In addition to the program of primary measurements and observations, there were also programs of measurement in connection with meteorological observations and health control.

2.3.4. Organization for Carrying Out the Program. The organization for carrying out the program was substantially as described in the previous memorandum. Including military personnel, it involved a total of approximately 200 men. In view of the circumstances, that the test was carried out on a very tight time schedule and was to be regarded as a trial run, the organization functioned with considerable success.

The tightness of the schedule was affected by delays in procurement and transportation. This meant that some apparatus arrived only at the last moment and involved feverish night work for many persons on one or more nights preceding the actual test. We hoped to cure this in the final test (a) by a more realistic scheduling allowing for time delays in procurement, (b) by the provision of additional transportation, part of which will be assigned to individual groups who will then be responsible for its upkeep, (c) by improvements in key roads which will reduce transportation breakdown, and (d) by the setting of a definite date, sufficiently in advance of the test, beyond which further apparatus cannot be introduced into the experimental area.

In connection with scheduling, it should be remarked that the tightness of the time schedule for this preliminary test has the advantages of emphasizing the need for a less hurried procedure in the final test and of providing a longer interval of time to prepare for the final test.

There was some criticism in connection with arrangements for intercommunication and timing. Radio communication was often weak and subject to interference. We planned to cure this by installing more telephone communication, by obtaining better radio sets, and if possible by obtaining more than a single radio frequency for use. The arrangements for sending time signals to various apparatus stations actually worked well but involved a large amount of last-minute work by an emergency group. It is possible that a separate group, TR-7, will be set up to take charge of radio, telephone, and timing problems.

The organization is a temporary one set up specially for the Trinity Tests and involves placing heavy responsibilities on younger men, including SED* members. This means a certain looseness in the organization and inexperience on the part of some of the operators. In spite of this, the organization functioned as well as could be expected and has been through a good shakedown preparatory to the final test.

We may now turn to a brief but more detailed description of the different measurements and observations that were made, using the same headings as in the previous memorandum.

2.3.5. Behaviour of the Implosion

a. Detonator Simultaneity. No measurements of detonator simultaneity were made in this test, which did not involve thirty-two detonation points as in the final bomb. Such measurements are standard at Los Alamos.

b. Time Interval Between Detonator and Nuclear Action. No measurements of time betweer detonator and nuclear action were possible.

c. Determination of Alpha for the Nuclear Reaction. The cable and recording apparatus to be used by Wilson in the measurement of alpha were tested for crosstalk. The accidental signal level was a few millivolts so that the final apparatus will be designed to give its true signal at a level of about 1 V.

2.3.6. Nuclear Energy Released

a. Delayed Neutrons. Williams's equipment for measuring delayed neutrons was installed at a "scaled-in" distance and suffered no damage.

b. Delayed Gamma Rays. Moon's apparatus for measuring delayed gamma rays was installed and gave records. Tests were made on equipment for Segre's method, which withstood air blast and earth shock.

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*Special Engineering Detachment.

c. Conversion of 49 to Fission Products.* The Hanford slug was successfully dissolved and introduced into the pile which then had a beta-ray activity of 1000 Ci and a gamma-ray activity of 400 Ci. On the basis of simple scaling up of the RaLa** shots, it would be calculated that 10% of this activity would remain in the soil within a 300-ft radius after the shot. Actually only 2% was found in the radius, indicating as might be expected that simple scaling laws do not properly allow for the increase in updraft with increased charge. A distribution formula for the activity as a function of distance was determined. It was also determined that the local distribution in the soil was such as to permit alpha-particle counts without difficult chemical separation. The rocket method for obtaining soil samples from the crater was tested and found satisfactory, and the use of shielded tanks in connection with the final sampling was also tested.

2.3.7. Damage Effects Produced

a. Blast Pressure at Ground Level from Piezo Gauges. Eleven quartz blast gauges were installed, and nine records were obtained. These have not yet been analyzed in detail. Some of them show crosstalk, but a certain amount of reliable data will certainly be obtained.

b. Blast Pressure at Ground Level from Condenser Gauges. Eight condenser gauges were planned for use, but only one actually was installed, and it gave no record. In view of the success of a similar airborne gauge, some success in the final test is to be expected.

c. Blast Pressure at Ground Level from Excess Velocity. Six receivers were installed to pick up the blast wave and record its time of arrival. These worked well on the small calibration shot but gave evidence of much crosstalk hash on the main shot. It is not yet known whether the records can be satisfactorily analyzed. Improvement might be introduced by lowered sensitivity for the main shot as compared with that needed for the calibration shot, and by leading the signals into separated rather than a single amplifier.

Forty-seven flash bombs to be operated by arrival of the blast were installed. Photographic observation was then to be used to determine blast pressure from excess velocity. Only two flash bombs went off because personnel failed to provide enough batteries.

d. Peak Pressure at Ground Level from Paper Gauges. Twenty-nine box gauges, each with twelve holes covered with aluminum foil, were introduced to measure peak pressure at different distances, and they functioned successfully.

e. Blast Impulse at Ground Level from Piston Acting on Fluid. Five Los Alamos designed instruments were planned, and one was satisfactorily installed, for measuring blast impulse by following the action of a piston in forcing water through a set of constrictions. A good record was obtained, but without timing marks; it can probably be analyzed as a consequence of the constancy of speed of the motor used to drive the recording disk. One British designed instrument did not operate entirely satisfactorily, perhaps from sand in the bearings, because it showed a velocity that increased during the passage of the blast wave.

f. Blast Pressure at Higher Levels from Condenser Gauges. Three condenser gauges for measuring blast pressure were dropped over the target from a height 15 000 ft above ground by the observation plane. One radio receiver in the plane was known to be out of order because of a fire, and one recording instrument failed. The other gave an excellent pressure-time record. The three parachutes had to be dropped in salvo instead of successively, as planned, because of failure in the bomb-release mechanism. The plane used was a B-29 assigned to the project. Hardly any shock was felt by the plane when the blast wave reached it at a distance of about 4 mi.

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*Code name for ^{239}Pu, from element 9<u>4</u>, isotope 23<u>9</u>.

**Radiolanthanum, a radioactive isotope of ^{140}La.

g. Earth Shock. Six converted geophones were used for measuring velocities of earth motion and gave satisfactory records, which have not yet been analyzed. Survey is now being made to determine the permanent displacement of stakes driven into the ground around the point of explosion. The crater was about 5 ft deep and 30 ft in diameter, which was smaller than expected. This may be partly due to the effect of the heavy concrete footing for the tower.

2.3.8. Overall Behaviour of the Explosion and Its After Effects

a. Size, Shape, Behaviour, and Path of the Ball of Fire. Three out of three Fastax cameras (1000 frames/s) at 800 yd, and two out of two at 10 000 yd, operated satisfactorily. Two Mitchell cameras at 10 000 yd operated satisfactorily, one for 30 s and the other for the full 1000 s planned. Films have been sent out for development.

b. Radiation and Temperature of Ball of Fire. Two out of two Hilger spectrographs were in operation; there was some uncertainty about the focusing of one of these. The films are being developed. The Bausch & Lomb spectrograph and the movie camera with filters were on low priority for this test and were not installed. The drum camera with photocells gave no record because of crosstalk. The thermocouples and galvanometers appeared to function satisfactorily.

c. Behaviour of Hot Column. Three Fairchild Aero Cameras were installed. The two at 10 000 yd north and south did not operate because personnel failed to push the necessary buttons. The one at 35 000 yd continued to take pictures until 9:00 a.m.

d. Mach Wave and Air Velocity. The proposed photographs of a suspended primacord were not obtained because of failure to launch the balloons from which it was to be suspended. The poor quality balloons burst and a low helium supply prevented additional attempts. Photographs of a horizontal stretch of primacord appear to have been obtained. The primacord detonation was dimmed rather than brightened by the blast.

2.3.9. Meteorological Observations. Meteorological observations are being continuously undertaken to obtain a good idea of behaviour in the particular location. They would be greatly assisted by the proposed installation of a teletype weather service, which has still not come through.

In connection with the present test, excellent meteorological service was provided. On 23 April it was successfully forecast that 7 May would fall in a good weather period. On 3 May, successful forecast was made as to the surface wind direction, upper air flow, and visibility to be expected at 4:00 a.m. on 7 May. Similar forecasts were made on 5 May, and at 5:00 p.m. 6 May, which gave 4:00 a.m. and also 9:00 to 10:30 a.m. as operationally possible.

Temperature, humidity, and wind velocities at all levels up to 30 000 ft were measured with the help of radiosondes and radar at 1:30 a.m., 3:00 a.m., and 4:37 a.m., on 7 May, before and just after the explosion.

P. E. Church arrived in time for the test and was helpful in discussing meteorological methods and problems.

2.3.10. Health Control. Radioactive monitoring was carried out by Hempelmann during the processes of slug solution and introduction into the pile. Monitoring after the explosion in the neighborhood was carried out by Hempelmann and checked by Anderson. The level of activity in the final crater was low enough to be safe for several hours' exposure.

The dissolving unit is to be covered with fresh earth and surrounded by a guard fence.

2.3.11. Conclusion. The test appears to have been successful as a trial run. In the final test, it is to be hoped that a larger proportion of the measurements will be successful, but even if this were not the case sufficient data would be provided to answer a considerable proportion of the necessary questions.

There is common agreement, among those concerned, regarding the steps suggested that should be taken to insure greater success in the final test. Among these suggestions, one of the most important is that of setting an advanced date beyond which further apparatus, especially electrical apparatus, cannot be introduced into the experimental area. This will allow time for plenty of dry runs and elimination of crosstalk. Improvement in transportation equipment and key roads should be sought. Special attention should be given to the early procurement and testing of those very important kinds of apparatus that could not be tried in the present partial test.

2.4. Post 100-Ton, Suggestions for Improved Facilities and Procedure: Suggestions for Improvements

A few days after the shot, while the experiences of the personnel were still fresh in peoples' minds, Bainbridge called a meeting in which all gripes could be aired and suggestions made for improved operating procedure. Written suggestions from J. E. Mack and from members of J. H. Manley's group were particularly valuable.

The 100-ton test pointed up the following requirements:

1. Better roads were needed to protect personnel and instruments from the effects of dust—essential to meet the schedule. About 20 mi of blacktop road were laid, and an area in the vicinity of the tower was also blacktopped.
2. More vehicles were required per group. Additional cars, weapons carriers, and carryalls were obtained by purchase or loan to help in correcting the deficit, but there was never a surplus. Thanks to the continued hard work of D. Greene and emergency loans from Maj. Miller, the transportation problem was licked. The final list of vehicles comprised approximately 15 sedans, 16 weapons carriers, 32 carryalls, and 11 jeeps, to which possibly 30 more cars were added the last week by the monitoring and G-2 groups.
3. More repair men were needed, and night servicing was required to aid in keeping up with the vehicle demand. Arrangements were made with Maj. Stevens and Capt. Davalos for additional help. The car parking and checking system, set up by Greene, and the improved roads aided in decreasing the amount of repair work per car.
4. Wire communications were overloaded, so that plans were made for more telephone lines, address systems in all shelters, and more Motorola radios in field cars and at shelters. The telephone system later was installed by Lt. Comdr. T. M. Keiller of J. H. Williams's group. Eighteen vehicles were equipped with 25-W Motorola* FM radios. Their convenience was great and more could have been used with profit, possibly an additional ten, before the radio traffic became congested.
5. The need for additional help on procurement, shipping, and stock management at Trinity could be anticipated with the scheduled increased activity for the July shot. A teletype was installed for "in the clear" communication between Y and TR. More stock men at TR and longer hours open schedules were used at Fubar Stockroom. D. P. Mitchell was able to furnish alternates or "stand-ins" for key men such as Van Gemert and Harry Allen at Y so that the absence of one or the other on other work for a short time would not slow down the solution of Trinity problems.
6. A Town Hall was finally built at Trinity so that the regular nightly meetings on construction and occasional technical meetings or administrative meetings could be properly housed. The ranch house office furnished a central point for mail and bulletins of general interest.
7. The hardness of the water at Trinity made it difficult to maintain ordinary sanitary requirements in the mess hall. Water-softening equipment was installed but some error occurred in the analysis of a sample of typical water, and the unit was entirely too small to handle the gypsum and lime content encountered. The addition of a steam bath for trays solved the grease and sanitary problems. More help in the mess hall was finally obtained so that 18-h working days were no longer the rule for the chefs and KP help.

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the US Energy Research and Development Administration to the exclusion of others that may be suitable.

8. The guarding rules during the 12 h preceding the shot were too rigid. A nose counting system had been set up so that everyone could be accounted for 2 h before the shot until after the shot. Emergencies arose in which an electronics expert, for example, would have to proceed from the S-10 000 to the N-10 000 yd shelter at minus 2-1/2 h. If he had not been on the N-10 000 guard's list, some telephoning was required before he could be admitted. Considerable time was wasted in emergencies of this sort or because other personnel trips had not been anticipated fully. In the final arrangement for July 12 and succeeding rehearsals, and just before the July 16 shot, *anyone* having legitimate business outside the Base Camp had free access to all parts of the test area. Free access was feasible as by mutual agreement; each respected the others' problems, wiring troubles, and need for unhampered work in getting the job done. As a matter of safety, everyone was asked not to kibitz at the tower during assembly, hoisting, checking, i.e., any time after assembly started.

2.5. Conclusions Concerning the 100-Ton Test

The original purposes for which the 100-ton test had been planned were accomplished. Those who had no prior experience in field work were familiarized with the difficulties and tribulations associated with work away from a well-equipped laboratory. The atomic bomb test could be approached with more confidence after the shakedown test. The calibration of instruments was valuable, particularly for blast measurements, where the 100-ton data furnished a useful calibration point of greater value than extrapolation from tables prepared from 66-lb shots. The earth shock data gave a reference point which was greatly superior to extrapolations from various short-range laws which varied in their predictions for large ranges over tremendous factors. The design of shock-proof instrument shelters could proceed with confidence. The gaps in equipment and organization pointed out by the test could be corrected or plans altered to give a smoother operation in the main show.

The 100-ton pile was spiked with 1000 Ci of fission products derived from a Hanford slug. This part of the test conducted under H. L. Anderson was of particular value in giving information on the probable amount of material which would be deposited on the ground and its distribution. Both sets of information were essential to the planning of the July 16th shot with respect to recovery of equipment, the measurement of the efficiency of the gadget, and preparations for the protection of personnel.

The high percentage of successful measurements in the final July 16th test may be attributed in large measure to the May 7th rehearsal shot practice that gave an improved framework on which to build.

3. PREPARATIONS FOR THE JULY 16 TEST (K. T. BAINBRIDGE)

3.1 Introduction

The preparations for the bomb test were greatly increased in intensity starting in March, when a July 4 date was set for the gadget test.* In the final 2 wk about 250 men from Y were engaged in technical work at Trinity, and many more contributed to theoretical and experimental studies at Y and in the construction of equipment. The very difficult work of providing in time the wiring, power, transportation, communication facilities, and construction needed for the test was ably carried out by J. H. Williams and his group. The whole-hearted support of other groups in Project Y made the test possible. In addition to the work of R-1, R-2, R-3, R-4, F-4, G-11, and O-4, groups effectively transferred full time into the Trinity Project, groups T-3 under Weisskopf and T-7 under Hirschfelder gave full time to the consideration of nuclear and radiation effects or to damage phenomena which would be associated with a successful shot. R. F. Bacher generously gave the support of G Division by the loan of personnel or by supplying special equipment for the test preparations. Heavy demands were made upon W. A. Higinbotham's Group G-4. He assigned his best personnel to strategic points, and his group manufactured the greater part of the electronic amplifying and recording equipment and all the main electronic timing equipment. The very important and punishing job of supplying the timing and remote operating signals was well done by J. L. McKibben for the relay and safing circuits and by E. W. Titterton for the electronic timing and detonating circuits.

3.2. Organization

The detailed organization chart must be included here to be read because it gives the most concise view of the responsibilities and number of people necessary to conduct a test. In many cases an individual took part in the preparation of several experiments and went from one job to another as required. The list given conforms to the situation the last week or possibly 2 wk leading up to the test. For the period 4 wk before the test, only two-thirds to three-fourths of the people listed were engaged full time, and only one half for the prior 4 months.

ORGANIZATION CHART FOR PROJECT TR

K. T. Bainbridge	Administrative head. Overall responsibility. Veto power on suggested experiments. Planning and coordination. Arming Party.
Barbara S. Anderson	Secretary.
J. H. Williams (TR-1)	All services as given under TR-1 below. Alternate for Bainbridge.
F. Oppenheimer	Administrative aide. Planning. Safety. Emergency roving center.
Lt. H. C. Bush	Commanding Officer of Trinity Camp. Responsible for camp matters, barracks, mess, road maintenance, guarding, camp hygiene, etc. Arming Party.
Lt. R. A. Taylor	Security for Trinity at Y.
John Anderson	Security for Trinity at TR.

*On June 30 the Cowpuncher Committee finally agreed to July 16 as the earliest possible date.

Capt. S. P. Davalos	TR U.S. Engineer Detachment Operations.
Lt. R. D. Wholey	U.S. Army Contracts.
Sgt. W. Stewart	Responsible for HE for all instrument calibration tests, velocity of sound charges, etc. Arming Party.
Consultants	
R. W. Carlson (X-2)	Design of structures. Installation of tower.
P. E. Church	Meteorological problems, particularly the dilution of active gases.
E. Fermi (F Division)	All nuclear physics measurements.
J. O. Hirschfelder (T-7)	All problems affecting damage which arises after the nuclear reactions have stopped.
S. Kershaw	Proper safety regulations and procedures.
L. D. Leet	Earth shock problems particularly at distant points.
W. G. Penney	Blast, earth shock, and permanent earth displacement problems.
Ens. G. T. Reynolds	Structures.
V. Weisskopf	All nuclear physics measurements and radiation problems. Chairman of Nuclear Measurements Committee.
TR Assembly	All problems connected with assembly of the gadget.
Comdr. N. E. Bradbury (X-1, X-6)	Head.
G. B. Kistiakowsky, Alternate	Arming Party.
Pit Assembly (G-1)	
M. G. Holloway P. Morrison	Pit Assembly overall responsibility.
R. F. Bacher	Advisor.
R. E. Schreiber H. K. Daghlian	Certification.
L. Slotin B. D. McDaniel C. S. Smith	Mechanical Assembly (check later on tower).
M. G. Holloway	Mechanical Assembly at base of tower (check later on tower).

L. Slotin H. K. Daghlian	Monitoring.
B. T. Feld	Checking.
Sgt. H. Lehr	Assembly.

Detonator Unit (X-5)

D. F. Hornig T/4 R. J. Brown T/3 W. Vogel	Raytheon unit. Wiring of detonators. Test of stand-in unit.

Asimultaneity (X-7)

K. Greisen J. C. Anderson T/3 V. Caleca R. W. Williams	Installation and check of special switches and circuits. E. W. Titterton on recording mechanism at W-800. Testing of HE-actuated switches.

HE Assembly and Detonators (X Division)

R. S. Warner, Jr. R. W. Henderson H. Linschitz Lt. W. F. Schaffer T/3 L. Jercinovic A. B. Machen T/3 A. D. Van Vessem E. J. Lofgren	HE and mechanical assembly. Installation of detonators. Test of detonators.

Services

<u>TR-1</u>

J. H. Williams (R-2)

<u>TR-1A</u>

Lt. Comdr. T. M. Keiller, Head	Construction.
T/4 A. H. Jopp, Supv. Pvt. A. L. Brehm, Supv. Pvt. L. Jackson Pvt. V. Guess T/5 J. Mather T/4 S. Friedman Pvt. B. Doyle T/5 A. Martinez	Electrical construction and telephone services. Motor generators.

<u>TR-1B</u>

J. L. McKibben, Head T/3 W. Treibel Pfc. R. Moore R. Perry	Timing, all timing and remote control signals. Arming Party.

C. L. Bailey L. Guttman	(Later searchlight group).
E. W. Titterton T/3 V. Fitch T/3 R. Lowry G. Mathis C. R. Linton	Electronic time signals.

TR-1C

R. J. Van Gemert, Head	Procurement at Y.
T/5 T. Montgomery	Stock.
T/5 E. Percy	Stock.
T/5 C. Pettis	Y Shipping to S-45 (TR).
Additional unloaders and clerks	

TR-1D

D. Greene, Head 1 SED to assist Greene	Transportation at TR.
Sgt. Margaret Swank, Head	Transportation at Y.

TR-1E

F. Stokes, Head T/3 G. Curl	Radio communications.
T/4 D. Miller	SCR-299 at S-10 000 No. 1 unit.
T/5 A. Giordano Pvt. R. B. Hart Pvt. W. D. Braden	SCR-299 at S-10 000 No. 2 unit.

TR-1F

Capt. B. B. Geery Pvt. G. Merrigan Pvt. A. W. Reinert	Balloon flying.

TR-1G

H. S. Allen T/5 A. Newell T/4 E. Utzig T/4 J. A. Rice W. Case	High iron work and special jobs.

TR-2

J. H. Manley (R-3) W. G. Penney, Consultant H. H. Barschall, 1st Alternate T. Jorgensen, 2nd Alternate	Air blast and earth shock. Responsible for all measurements below in TR-2 group.

Air Blast

TR-2A

R. L. Walker H. Sheard, Consultant D. Littler, Consultant W. D. Kennedy, Consultant R. Babick (from A-1) T/3 M. Battat T/4 H. Courant E. Lennox W. Nyer M. Sands (from G-4) Pfc. C. Simons (from GM-13)	Piezo gauges.

TR-2B

W. C. Bright V. Anderson T/4 R. Dye (from G-4) W. Hane (from G-4) T/4 K. Kupferberg T/4 D. Leed (from G-4) P. Olivas	Condenser gauges.

TR-2C

H. H. Barschall R. W. Davis W. Elmore (from G-4) G. M. Martin	Excess velocity measurement.

TR-2D

T. Jorgensen Pvt. D. W. Rhoades R. Sherr	Impulse gauge.

TR-2E

H. Sheard, D. Littler C. Janney W. Lawrence	Maximum pressure gauge.

TR-2F

J. C. Hoogterp Pfc. F. Michaels	Box gauge.

Earth Shock

L. D. Leet, Consultant

TR-2G

H. M. Houghton J. Coon, Alternate Pvt. C. D. Jones R. Nobles T/5 O. Seborer	Velocity geophone

TR-2H

L. D. Leet	Displacement seismographs (Tularosa).
H. Gewertz, Alternate	9000 N
J. A. Crocker	9000 N
T/3 A. Hershey	Elephant Butte
T/5 D. Garrett	Elephant Butte
T/3 C. Crumb	San Antonio
T/4 J. Lepman	San Antonio
T/4 S. Calvert	Tularosa
Elizabeth R. Graves	Carrizozo
A. C. Graves	Carrizozo
Pfc. G. Hall	

TR-2I

W. G. Penney W. G. Marley F. Reines Surveyors	Permanent earth displacement.

Physics

TR-3

R. R. Wilson (R Div.)
E. Fermi, Consultant
V. Weisskopf, Consultant

TR-3A

R. R. Wilson (R-1) J. DeWire, Alternate S. Barnes H. Bridge W. Caldes P. Balch T/5 R. Fortenbaugh T/5 W. S. Hall L. Lavatelli W. Schaefer T. Snyder R. Sutton W. Woodward	Prompt measurements. α and shock wave transmission time (shock wave transmission time, Froman at Y).

B. Rossi, Consultant and Head	Prompt Measurements, α.
T/4 J. Alexander J. Allen B. Diven J. Fox J. Fredricks A. Grubman S. A. Kline C. Menz D. Nicodemus Corp. R. E. Sherman	Cooperating with R-1 on M.I.T. fast oscillograph.

<u>TR-3B</u>

H. T. Richards J. M. Blair D. Frisch J. Hush E. Klema R. Krohn R. Perry C. Turner	Delayed neutron measurements.

<u>TR-3C</u>

E. Segre (R-4)	Delayed gamma rays.
C. Wiegand	Electrical part.
M. Deutsch	Ionization chambers and calibrations.
O. Chamberlain	Shelter design.
J. Aeby G. W. Farwell G. A. Linenberger W. Nobles T/4 A. H. Spano T/5 C. Wahlig	

<u>TR-3D</u>

P. B. Moon S/Sgt. W. J. Breiter Ens. I. Halpern T/4 J. A. Hofmann J. Hughes T/5 M. J. Pincus	Gamma-ray sentinels and delayed gamma rays.

<u>TR-3E</u>

H. L. Anderson (F-4)	Conversion.
C. W. Snyder	C.I.T. rocket consultant.

G. L. Weil	Rocket sampling.
D. E. Nagle H. Heskett	Tank sampling.
Sgt. J. Twombly	Radio maintenance.
Sgt. N. Smith	Tank driver.
Sgt. J. Brothers	Tank driver
T/5 F. J. Tucci	Tank maintenance.
Sgt. G. Banas	Tank maintenance.
L. D. P. King	Survey.
A. Turkevich	Survey.
V. Cannon	Gross counting.
N. Wilkening	Alpha counting.
J. Tabin	Beta counting.
A. Novick N. Sugarman	Gamma counting. Chemistry.
D. Engelkemeir M. Kahn J. Miskell	49 Chemistry.
S. Katcoff J. Seiler L. Winsberg	Fission product chemistry.
Sgt. C. Schwob Sgt. E. Hoagland	Sampling at Y.
A. Goldstein WAC Technicians M. Young M. Wirz S. Lozier S. Corl	Counting room at Y.

Meteorology

TR-4

J. M. Hubbard

TR-4A

Lt. C. D. Curtis Pvt. F. K. France T/5 T. Harlowe Pvt. R. L. Heller Pvt. G. F. Mason Pvt. G. Meyers	Radar.

TR-4B

Sgt. J. C. Alderson Sgt. J. M. Lobel Sgt. J. G. Taylor	Pilot balloons (**Arming Party**).

TR-4C

Sgt. P. A. Tudor Sgt. L. Caskey Sgt. I. E. Rosenthal	Radiosonde.

TR-4D

Sgt. W. Blades	Base weather and records.

Spectrographic and Photographic Measurements

TR-5

J. E. Mack (G-11) B. Brixner, Alternate N. Bifano, Alternate at Y T/3 N. York (permanently at TR and in charge in absence of Mack and Brixner)	
T/5 E. D. Wallis	Photographer (and stockeeper until Shue's arrival).
T/4 B. C. Benjamin T/5 G. E. Economou F. E. Geiger R. Loevinger T. S. Needels	
T/5 K. J. Shue	Stockkeeper.
T/3 G. W. Thompson	Photographer.
T/4 J. Wahlen	Wiring liaison.
D. Williams P. Yuster	Total radiation.

Airblast—Airborne Condenser Gauges

TR-6

B. Waldman (0-2)
L. Alvarez
H. Agnew
R. Dike
T/5 R. Alhbrand
T/5 W. Goodman
L. Johnston
T/3 E. Karas
T/3 J. Wieboldt
W. Stroud

Medical group

TR-7

Dr. L. H. Hempelmann
Capt. J. F. Nolan, Head at TR
Col. S. L. Warren, Consultant
J. Hoffman, Consultant

TR-7A

R. Watts W. Scivally L. Brown	Instruments.

TR-7B

P. Aebersold	Monitor Group.
Capt. H. L. Barnett Lt. J. H. Allen Capt. P. O. Hageman	N-10 000 W-10 000 S-10 000
A. Anderson Sgt. J. Green J. O. Hirschfelder J. Hoffman Sgt. R. Leonard Sgt. P. Levine J. Magee	Road Monitors.
Lt. J. S. Brooks Lt. A. M. Large	Emergency medical aid

Special Assignments

Capt. M. Allen L. Reiser, Assistant	Searchlight plotting.
Pvt. J. H. Fuqua Paul Hough T/5 C. Wright	L-2 crew at W-10 000.
C. L. Bailey D. Barton T/5 D. Miller	L-3 crew at N-10 000.
A. Breslow I. Rehn R. White	L-7 crew NE of 0.
J. Blair M. Kupferberg A. Nedzel	L-8 crew NNE of 0.
S. K. Allison	Ground-to-plane communication and shelter announcer.

Col. D. N. Yates Col. B. Holzman	Weather consultants to Gen. Farrell.
J. Mattingly	Meteorological observer for P. E. Church and consultant on dilution problems.

A total of 125 men, under Lt. H. C. Bush's command, were charged with the responsibility of guarding and maintaining the camp.

An additional 160 men were located north of the test area, under the command of Major T. O. Palmer, with sufficient vehicles to be able to evacuate ranches and towns if the products descended in dangerous amounts.

At least 20 men associated with Military Intelligence were in neighboring towns and cities up to 100 mi away. Eighteen were provided with recording barographs as described in Ref. 2. These instruments and the remote seismographs were for getting permanent records of blast and earth shock at remote points and in neighboring towns.

Distinguished Visitors, July 10-16

J. R. Oppenheimer
R. C. Tolman
V. Bush
J. B. Conant
Brig. Gen. T. F. Farrell
Maj. Gen. L. R. Groves
C. C. Lauritsen
I. I. Rabi
Sir Geoffrey I. Taylor
Sir James Chadwick

3.3. Coordination of Preparations

3.3.1. Consultants. The advice and predictions of V. Weisskopf on the behaviour of the gadget and its radiation effects, of J. H. Manley and W.G. Penney on shock and blast effects, and of J. O. Hirschfelder on postshot phenomena were of the greatest importance in defining the operations at Trinity and their preparation. R. W. Carlson and Ens. G. T. Reynolds aided in advising on structures and blast phenomena. Major contributions and aid also were frequently furnished by H. A. Bethe, E. Fermi, and J. R. Oppenheimer.

3.3.2. Weekly Meetings. One- or two-hour meetings were held every week for consideration of new experiments, correlation of work, detailed scheduling, and progress reports. The members who regularly attended were the consultants and group and section leaders who held great responsibilities in the test and preparations for it. The members were:

K. T. Bainbridge	Chairman
H. L. Anderson	TR-3E Conversion measurements
H. H. Barschall	TR-2 Alternate Group Leader
E. Fermi	Consultant on nuclear physics problems
L. H. Hempelmann	TR-7 Medical problems
J. M. Hubbard	TR-4 Meteorology
Lt. Comdr. T. M. Keiller	TR-1A Construction and electrical services
J. E. Mack	TR-5 Spectrographic and photographic measurements
J. H. Manley	TR-2 Shock and blast
J. L. McKibben	TR-1B Timing services

F. Oppenheimer	TR Administrative and technical aide
W. G. Penney	Consultant, shock and blast
H. T. Richards	TR-3B Delayed neutron measurements
E. Segre	TR-3C Delayed gamma-ray measurements
E. W. Titterton	TR-1B Electronic timing services
B. Waldman	TR-6 Airborne measurements
V. Weisskopf	Consultant on nuclear physics
J. H. Williams	TR-1 Services
R. R. Wilson	TR-3 Physics measurements

3.3.3. Acceptance of New Experiments. It was essential to get the most out of the test and to meet the date, which required that all proposed experiments should be studied critically. If a new experiment was approved by the designated examining group, it was presented before the Monday meeting for consideration with respect to the program as a whole.

The first examining groups were:

J. H. Manley and W. G. Penney R. R. Wilson, E. Fermi, V. Weisskopf	Blast and earth shock nuclear measurements
J. E. Mack, V. Weisskopf	Spectrographic and photographic measurements
B. Waldman and appropriate consultant	Airborne measurements

K. T. Bainbridge served ex officio on all examining groups.

It was also essential that the proponent should carry out his plans on paper far enough so that the proposal would appear in its right size, shape, and degree of complexity. One must know how much will be involved if the proposed experiment should be included in the program.

The following minimum requirements had to be answered before the proposal could be considered at a Monday meeting.

1. Object or relationship to energy release, damage, etc.
2. Estimates of accuracy expected, calibrations needed.
3. Number and recommended positions of gauges, chambers.
4. Position of recorders, type of recorders, availability of recorders.
5. Design and location of recorder chambers, amount of shielding, date needed for completion, in place, ready for occupation.
6. Signal lines required and type.
7. Actuating, timing, calibrating lines needed.
8. Timing signals and allowed probable variation acceptable.
9. Estimate of number of men required at site for installation, and names if possible.
10. Personnel, if any, required at the time of the shot who will have to be in recorder shelters W-10 000, S-10 000, or N-10 000.
11. Machine shop construction time, checked by E. Long or G. Schultz.
12. Electronics development time, checked by W. Higinbotham, particularly if it involves key circuit designers.
13. Electronics shop time not involving development by key circuit designers.

With the above information at hand, a satisfactory picture was presented of just how much a new experiment involved so that a decision could be reached rapidly on the experiment's suitability for the program and the possibilities of its successful completion in view of the test schedule and the laboratory limitations on machine shop and electronics time.

3.3.4. Prompt Dissemination of General Information. The large number of personnel of many groups with responsibilities in the test made it mandatory that all information of general usefulness should be circularized. J. H. Williams's early suggestion that this circularization should be done saved time for all concerned and was indeed the only way in which one could be sure of complete coverage.

3.3.5. Coordination of Construction. Approximately 1 month before the July 16th shot and during a similar period before the May 7th shot, J. H. Williams held nightly meetings to hear reports on field construction progress and to plan the assignment of men for the following day. As finally developed, J. H. Williams with J. L. McKibben, Lt. Comdr. Keiller, Sgt. Jopp, and F. Stokes would meet directly after supper with Capt. S. P. Davalos or Sgt. Gibson, representing the Engineer Detachment, and all interested group or section leaders who had field construction work under way. Construction help was assigned based on the needs and priority of the experiments that had been accepted for the test.

The correlation of the construction program and the proper and successful designation of construction aid was exacting work requiring "superior judgment," as the Army says, and long hours of hard work. This was done supremely well by J. H. Williams, to whom the TR Project owes much for the successful completion of the July 16th operation.

4. FINAL PREPARATIONS FOR REHEARSALS AND TEST (K. T. BAINBRIDGE)

4.1 Schedule

During the period from June 9 to June 30, the test date was set for July 13 with a first rehearsal July 8. This fixed the schedules for everyone participating in the Trinity test. S. K. Allison as chairman of the Cowpuncher Committee had the responsibility of integrating the efforts of the entire Project Y and the receipt of material from Hanford.

On June 30 a review was made of all schedules at the Cowpuncher Committee meeting where all division leaders submitted the earliest possible date at which their work could be ready. The earliest date for the Trinity shot was changed to July 16 as required for the inclusion of some of the more important experiments, and the same date followed from X-Division considerations on June 30. (Later it was found that their schedule for assembly was more conservative than was proven by the actual work, so that a day was shaved from their schedule. However, this could not be taken advanage of by the TR group and indeed was not even mentioned to them, because the TR schedule was tight enough on a July 16 basis.)

Commitments had been made in Washington for firing the test as soon after July 15 as possible. This was accomplished by firing the shot the morning of July 16 at the first instant weather conditions were at all suitable. The predictions of J. M. Hubbard were for more nearly ideal weather on the 18th or 19th, with July 16 only a possible date.

The schedule which was broadcast July 1 and circulated July 3 is given below. The afternoon rehearsals had to be changed to morning rehearsals because the daily afternoon thunderstorms interfered with the flight of the B-29 planes cooperating in the test and also produced electrical interference and pickup on lines. The second rehearsal was held the late morning of July 12, and the third the late morning of July 13, with the final rehearsal held at 11:59 the evening of the 14th.

TR SCHEDULE

The earliest date is July 16, 4:00

Date	Time	All Circuits	V-Sound 5 lb. Chg.	Gadget 1/2 lb. Chg.	Plane	Guards	Medical	G-2	Remote Seismograph
7/10	0400 0445								Radio test
7/11	1200	Freeze							
7/11	1600	x	x	x	x				
7/12	(No test. Chase down pickup troubles.)								
7/13	1600	x	x	x	x				
7/14	2359	x	x	x	x	x	x	x	x
7/15	(No rehearsal)								
7/16	0300	*This will be it if weather permits*							
7/17	0400	x	x	x	x	x	x	x	x

ASSEMBLY RUNS

The following dates for the TR Dry Run were set before June 30 and were adhered to.

Monday, July 2	Load inert assembly on truck; test by driving around mesa.

Tuesday, July 3	Truck leaves for TR at 0500; arrives TR sometime in afternoon. If during daylight, truck is unloaded at this time.
Wednesday, July 4	Unload truck (if not previously done), trap door, reassemble, and lift. (Note that wiring people should be available for work by 1300 of this day for tower top operations.)
Thursday, July 5	Complete tower top wiring, disassemble, and lower.
Friday, July 6	Unit returns to Y.

A summary of all the problems connected with the F. M. assembly is given by Capt. Schaffer in Sec. 5, together with the firm dates for the TR Hot Run, with final assembly starting Friday, July 13, at 1300.

4.2. Timing and Wiring Layout—Electronics

The detailed location of measuring equipment was given on two maps. A complete list of the apparatus turned on by the control system is given in McKibben's report[3] to which reference should be made for details of the safety and indicating features incorporated in the control circuits to all equipment, and the firing circuits. Details of the electronic timing circuits and firing circuit are given in Titterton's report[4].

4.3. Shelter Chiefs

It worked out well having one senior man act as Shelter Chief at each of the three main shelters. The Shelter Chiefs:

1. Are in charge of the technical personnel, military and civilian, with the exception of the M.P. guards. The Medical Officer is the alternate Shelter Chief.
2. Are responsible for shelter discipline.
3. Are responsible for the proper parking of vehicles in preparation for a quick exit and checking of vehicles before the shot to see that they have sufficient gasoline and oil.
4. Are responsible for the assignment of personnel to vehicles.
5. Will on the advice of the Medical Officer enforce the orderly evacuation of the shelter in the direction recommended by the Medical Officer, except for the radar, searchlight, and optical crews at W-10 000 or N-10 000.
   a. The Shelter Chief will lead the convoy. The Medical Officer's assistant will take the last car in the convoy.
   b. At W-10 000 and N-10 000 where there are searchlight and optical crews (and a radar crew at W-10 000), the Medical officer will remain with the units, if no radiation is encountered, until their work is completed and then will convoy them out as recommended by the senior Medical Officer at S-10 000, or by the local Medical Officer if communications are unsatisfactory.
   c. In the event of an emergency evacuation, the Shelter Chief will lead the convoy and the Medical Officer will take the last car, after all personnel have been evacuated.
6. Will aid the guard in checking personnel lists.
7. Will post weather reports transmitted from S-10 000.
8. Will check that all personnel are wearing respirators.
9. Will check that the shelter doors are off and properly stacked against the wall.

In explanation of the evacuation rules, it should be stated that if no fission products were encountered at the shelter proper, the searchlight, optical, and radar crews were to remain to obtain data on the cloud position and continue with the planned plotting and photographic work. The other personnel required not more than 20 min to shut down equipment and extract photographic records. Then they were to leave either to the Base Camp or to Site Y and would be followed by the searchlight, optical, and radar crews when their work was completed.

Because of the possibility of contamination on the roads, the Medical officer was to define the routing, because he would receive the detailed information required to make a decision from the Base Camp headquarters and from the S-10 000 headquarters. The Shelter Chiefs were ordered to go first because they were most familiar with the roads in the country and the driving conditions. The Medical Officers were asked to go last with their monitoring equipment in accord with their responsibility for the health of the group.

In the event of radiation rising in the immediate vicinity of the shelter, all personnel were to be evacuated on an emergency basis. This actually was required when a low cloud passed over N-10 000 but did not deposit much on the ground, as shown by measurements made approximately 2 h later (<0.02 R/h). The Shelter Chiefs and Medical Officers were R. R. Wilson and Capt. H. Barnett at N-10 000, J. H. Manley and Lt. J. H. Allen at W-10 000, and F. Oppenheimer and Capt. P. O. Hageman at S-10 000.

4.4. Arming Party

K. T. Bainbridge	Checked arming routine as responsible head.
J. L. McKibben	In charge of timing and control circuits.
G. B. Kistiakowsky	To check Bainbridge and McKibben in the arming operations. Aided Mack in focussing cameras and spectrographs by manipulating a portable searchlight at the first platform level on the tower.
Sgt. W. Stewart	Rigged the 5-lb. Comp. B charge for the velocity of sound measurements.
Sgt. J. C. Alderson	Responsible for getting weather data at Point 0 until withdrawal of the party.
Lt. H. C. Bush and one guard	Lt. Bush took over from Lt. Richardson the responsibility for preventing sabotage of the bomb or its auxiliaries. The arming party did not withdraw until searchlights L-2 and L-3 were focussed on the tower to discourage any possible saboteur.

The arming party remained at the base of the tower until just before 5:00 a.m. when the weather reports from Hubbard by phone began to look satisfactory for a shot. Sgt. Stewart was released to S-10 000 before 5:00 a.m.; his job had been completed. The drive out to S-10 000 was not made above 35 mph, contrary to rumors. Original plans were for the entire party to return at 2:00 a.m. to S-10 000 where J. R. Oppenheimer, Gen. Farrell, J. M. Hubbard, and K. T. Bainbridge would decide at t_0-1/2 h whether or not the test should be run. One dissenting vote was sufficient to call off the shot. Sunday afternoon discussions of possible sabotage of the bomb made it reasonable for the arming party to guard the tower until the last possible moment.

The final OK for the 5:30 a.m. shot was given at 5:10 a.m. because 20 min were needed for preparation in the three main shelters.

4.5. Location and Time of Shot

The location of Point 0 was latitude 33°40'31", longitude 106°28'29", based on New Mexico Map No. 44, Grazing Service, Albuquerque Drafting Office.

The time is known only very poorly because of difficulty in picking up station WWV for a time check. The best figure is July 16, 1945, 5:29:15 a.m. MWT plus 20 s minus 5 s error spread.

4.6. Protection Against Radiation—Base Camp

The following instructions were issued by Col. S. L. Warren dated 15 July 1945.

Directions for Personnel at Base Camp at Time of Shot

1. Do not leave the main group at the camp where there will be monitoring and evacuation facilities. There will also be contact by radio with the planes, the shelters, and area monitors.
2. No one should remain in camp who can view the show from the mountains to the north and then leave immediately for Site Y. A minimum number of vehicles should be taken away from camp.
3. Persons will not be permitted to leave along Broadway until all danger of contamination has passed and the monitors have declared it safe. This may take several hours.
4. We do not expect danger to the Base Camp, but all personnel will conform with the following safety regulations.
   a. At a *short* signal of the siren at minus 5 min all personnel whose duties do not specifically require otherwise will prepare to face the south, looking in the direction parallel to the long axis of the barracks buildings.
   b. At a *long* signal of the siren at minus 2 min all personnel whose duties do not specifically require otherwise will lie prone on the ground or in an earthen depression, the face and eyes directed toward the south.
   c. After the south hills light up, one may look toward zero with the eyes covered by a welder's filter, which will be issued to camp personnel by Fubar's supply room.
   d. Do not arise before the blast wave arrives, which takes about 50 s.
   e. At *two short* blasts of the siren, indicating the passing of all hazard from light and blast, all personnel will carry on, thereafter conforming with directions that may be announced over the loudspeaker.
5. In event that evacuation becomes necessary, directions for this action will be broadcast on the loudspeaker and carried out in orderly fashion according to prepared plans.
6. Any possible hazard from uv light injuries to the skin is best overcome by wearing long trousers and shirts with long sleeves.

4.7 Health and Monitoring Organization and Preparations* (Louis H. Hempelmann, M. D.)

4.7.1. Introduction. It is the purpose of the Medical Department to anticipate possible dangers to the health of scientific personnel, residents of nearby towns, and of casuals, to provide means of detection of these dangers, and to notify proper authorities when such dangers exist. It is also necessary to obtain records which may have medico-legal bearing for future reference.

The medical group will act in an advisory capacity and avoid direct orders to personnel except in cases of emergency. It is the responsibility of the Trinity Project Director to confirm or deny activities to scientific personnel which may be hazardous to them. It has been advised that no person should (of his own will) receive more than 5 R at one exposure.

Evacuation of towns or inhabited places will be carried out by G-2 personnel if necessary on advice from the Medical Department. Contaminated areas will be adequately marked and guarded until decontaminating procedures can be carried out.

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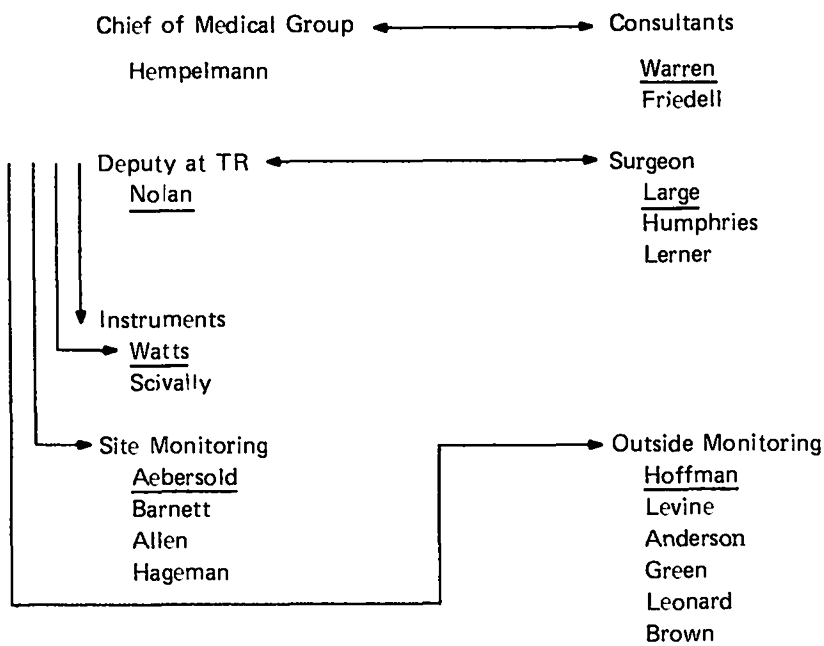
*As of 20 June 1945.

4.7.2. Organization of Medical Group (TR-7)*



The Duties of Medical Group Personnel

1. Hempelmann: Generally in charge of operations. To have no regularly assigned duties, but to be ready at Base Camp for consultation.
2. Nolan: To plan for medical personnel and equipment. To acquaint all personnel as to activities of Medical Group. To instruct medical personnel to their duties and responsibilities. To inform Trinity director as to Medical Hazards.
3. Watts: To construct and install all monitoring devices. To instruct monitors as to their equipment and duties.
4. Monitors: To carry out readings and recordings as instructed.
5. Medical officers: To be available in case of catastrophe and to act as temporary monitors.
6. Consultants: To be available at Base Camp for receipt of monitoring reports and to advise as to necessity of evacuation of contaminated areas.

Stations of Medical Group Personnel

1. At base camp: Hempelmann, Nolan, Watts, Warren, Large, Aebersold.
2. At 10 000 yd shelters: Barnett, Allen, Hageman.
3. At range camp—Lava Bed: Levine.
4. At Highway 54: Anderson.
5. At Highway 285: Green.
6. At Highway 85: Leonard.
7. At locations 3-6-Roving Monitor: Hoffman.
8. In airplane: Members of Alvarez's Group.
9. In Albuquerque: Friedell.

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*Underlined names designate person in charge.

4.7.3. Equipment of Medical Group

Transportation

1. Ambulances
   a. Panel type
   b. Field type
2. Four-wheel drive
   a. Command car
   b. Carryall
3. Sedan
4. On loan—Two four-wheel drive vehicles for taking scientific personnel into contaminated area. All available four-wheel drive vehicles for evacuating base camp.

Protective Clothing

100 Coveralls—for people in shelters, Medical Group, Tank-Group, and in-going personnel.
100 Caps, surgical
100 Booties. various
100 Gloves. cotton

Gas Masks

12 Positive pressure type—Tank Group
30 Smoke-resistant type—in-going group
30 Regular gas masks—Shelter Group
40 Respirators—all personnel at base

Instruments

15 Portable gamma meters
20 Portable alphameters
10 Filter Queens
12 Recording gamma meters (Esterline-Angus)*
1 Hand and Swipe counter
200 Regular pencils
3 Chargers
12 Resistant pencils
100 Film badges—catastrophe
200 Film badges—for towns

4.7.4. Plans for Monitoring—Before Shot

Transportation of Material

1. Courier to wear pencil and catastrophe badge.
2. Container to be checked with small portable gamma and alpha meters.

Assembly

1. Dry box maneuvers to be checked with portable gamma meter.
2. Protective clothing and respirator worn before tamper is in place.
3. Check hand and nose counts of Pit Man.

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the US Energy Research and Development Administration to the exclusion of others that may be suitable.

Raising of Material and HE

Area to be cleared of unessential personnel before, during, and after this procedure.

4.7.5. Plans for Monitoring—Time of Shot

At 10 000 Yd Shelters

1. All persons to remain inside shelters.
2. One member of Medical Group at each shelter.
3. Instruments and equipment.
   a. one portable gamma meter
   b. one portable alpha meter
   c. pencil chambers or film badges for each person
   d. ordinary gas mask for each person
4. All personnel to leave for base camp within 30 min using gas masks.
5. a. Evacuate before 30 min if gamma reading outside shelter reaches 0.1 R/h.
   b. Put on gas masks and evacuate if alpha reading reaches 5 c/min.
6. Adequate transportation to be checked by members of Medical Group.

At Base Camp

1. All persons to be outside of buildings.
2. Observers of shot to wear protective goggles and avoid direct vision.
3. To stay at Base until contaminated area is ascertained—6h.
4. Member of Medical Group to be in communication with town monitors by phone and with plane monitors by radio.
5. Instruments and equipment.
   a. portable gamma meter
   b. portable alpha meter
   c. respirators
   d. adequate transportation for all personnel for evacuation
   e. tolerances—same as above

At Range Camp (Lava Bed)

1. Observe cloud and trail with radar and direct vision.
2. Instruments and equipment.
   a. portable gamma meter
   b. portable alpha meter
   c. respirators
   d. transportation
3. Tolerances—same as above.
4. Communications—radio to Base Camp.

Member of Medical Group at Highway 54

1. Check recording meters (alpha and gamma) at Carrizozo, Oscura, Three Rivers, and Tularosa.
2. Observe cloud visually and record course.
3. Observe readings of portable alpha meter beneath cloud.
4. Follow cloud towards east and continue with meter readings.
5. Communicate with Albuquerque by phone as to course, intensity of readings, etc.

Member of Medical Group at Highway 285

1. Check recording meters (alpha and gamma) at Carlsbad and Roosevelt.
2-5. As listed above.

Member of Medical Group at Highway 85

1. Check recording meters (alpha and gamma) at San Antonio.
2-5. As listed above.

Roving Town Monitor (Hoffman)

1. Station himself at Carrizozo at time of shot.
2. Follow cloud visually and with portable meters.
3. Direct station and activities of ground monitors.
4. Confer with Albuquerque (W. Friedell) in case of need of evacuation at any point.

4.7.6. Plans for Monitoring—After Shot

At Shelters 10 000 Yd

1. Evacuate area as soon as possible returning all personnel to Base Camp.
2. Check wearing of gas masks and pencil chambers.
3. Report on meter readings.

At Base Camp

1. Receive reports from plane and surface monitors. (Nolan)
2. Send consultation group to dangerous areas if need be. (Nolan)
3. Check equipment, calculate dosage, instructions to personnel entering contaminated area to retrieve equipment. This is to be done by a board consisting of Kenneth J. Bainbridge, Victor Weisskopf, and James F. Nolan with the aid of information obtained by Tank Team and from gamma sentinels of Moon. Men to wear coveralls, caps, boots, smoke masks, film badges, and direct reading electroscopes. (Nolan)
4. Record gamma and alpha readings at Base Camp and evacuate if necessary. This must continue until all of Base Camp can be evacuated after 4 to 7 days.
5. Check equipment of Tank Team before and after their activities.
6. Map out area of gamma contamination to tolerance limit (0.1 R/8 h).
7. Map out area of alpha contamination to tolerance limit (5 c/min on ground).
8. Set up windsocks at various locations for ground wind direction.

At Highways and Lava Bed

To report at Base after recording devices are secured and after cloud and trail have passed. Be prepared to proceed in direction of cloud if necessary. Return to base when advised to watch for and retrieve film badges dropped through cloud by plane.

Plane

This to be performed by members of Alvarez's group and to be instrumented to carry out the following measurements.

a. size of cloud
b. shape of cloud
c. course of cloud
d. gamma intensity by direct reading at distance
e. gamma intensity by dropping film through cloud at intervals

Additional Measures

Film to be sent to post offices of surrounding towns and picked up by G-2 man and recorded.

4.7.7. Immediate Hazards

Blast. Hirschfelder's calculations 10 June 1945 for an efficiency of 100 000 tons would yield at 10 000 m 0.69 p.s.i. and at 10 000 m—0.34 p.s.i. With such pressures (less than 1 p.s.i.) bodily injuries will not occur. Ear injury may occur from 1 to 5 p.s.i.

Fragments. It has been calculated by Zimmerman that the danger from fragments would be maximum in the case of a relatively small explosion of 50 - 500 tons. In this case, a fragment with a range of 10 000 yd would have to have an initial weight of from 230 to 500 lb. A fragment of such a size would only result in the case of a nonsymmetrical explosion using Jumbo. Even here, the maximum would probably be less than 10 000 yd.

Heat. According to Hirschfelder, the rise in temperature produced by the blast wave will probably be 40° instantaneously and within 1 s will be only 1° at 10 000 yd.

Light Equivalence.

10 000 tons at 10 000 m	1 sun for 1 ms. 1/10 sun in 1 s.
100 000 tons at 10 000 m	10 suns at 1 ms. 1 sun at 1 s.
100 000 tons at 10 mi	5 suns at 1 ms. 0.5 sun at 1 s.

Observers within 10 mi will not be injured and will be specially protected by smoked glasses.

Gamma Rays. According to Weisskopf's maximum estimate of immediate gamma radiation, the amount delivered immediately would be 10^{-4} at 10 000 m.

Neutrons. At 10 000 m the peak neutron flux would be less than 1 n/cm^2, which is far below tolerance.

We find that all personnel housed in the shelters at the time of the shot will be adequately protected. However, premature detonation will be quite dangerous. For these reasons, persons working around the tower after the charge and pit are in place will wear "catastrophe badges," and precautions will be taken for the evacuation of injured persons and the treatment of blast injuries.

4.7.8. Delayed Hazards.

Ground Contamination. Because of the necessity of retrieving scientific apparatus for records after the shot, the ground contamination becomes important. The alpha-contaminated area will be appreciable, but will not be dangerous if the correct protective clothing is worn. The gamma-contaminated area will be appreciable, but will shrink due to decay of the fission products. Although these areas must be measured at the time in question, estimates of their size have been made to facilitate the placement and removal of apparatus. Calculations by Weisskopf and data reported by Anderson from the 100-ton shot are used.

Because the area of the crater will be contaminated with alpha particles and will be closely associated with fine particles of dust on the surface of the ground, it will be necessary to bind the dirt in this area rather closely and bury it later. Local winds are variable, and danger from breathing contaminated air will be ever present unless this is done. This area of alpha contamination will represent an "attractive hazard" to the curious even though it will be fenced off and adequately marked.

The area of alpha contamination will be monitored by Anderson's dirt samples from the tank; also, the area of contamination will be marked by the Medical Group in the following manner. A portable alpha meter designed by Watts, which can accurately read 5 c/min, will be wheeled into the area. Dirt scooped up in a measured plate that gives this reading will indicate that if all the dirt in this area were dispersed in the air, one would inhale the tolerance dose of 49 in 15 min. People entering this area will wear protective clothing and smoke masks.

Calculations:

1 μg = tolerance dose = 140 000 dis/min.
= 70 000 c/min.
Respiration = 15 000 cm^3/min (100% retention assumed).
Meter window 2-cm by 9-cm with 8-mm-thick wall window.
Alpha range in air = 4 cm in air or 3 cm in front of window.
Volume measured by meter = 2 x 9 x 3 = 54 cm^3 = 1/20 liter.
Effective geometry = 30%.
Best practical reading = 5 c/min.
In air — 4 c/min in 50 cm^3.
= 1500 c/min in 15 000 cm^3.
= $\frac{1500 \times 3}{70\,000}$ = 1/16 tolerance dose/min.
or tolerance dose 1 μg in 16 min.

The gamma-contaminated area will be measured by Anderson and Moon's sentinels. These figures will be used by Weisskopf to calculate time and duration of entrance of personnel. Also, the Medical Group will outline the region of the tolerance level 0.1 R/8 h with portable gamma meters.

Cloud Contamination. The activity of the cloud will vary with the efficiency of the explosion, and measures to monitor it until it is dispersed must be taken because it represents a possible dangerous hazard to the population of the surrounding territory. Also, definitive measurements must be obtained for medico-legal reasons. However, the size, shape, and activity of the cloud have been calculated. A description of the monitoring by airplane will be furnished by Alvarez and Waldman, who are undertaking the procedure.

Trail Contamination. There is a probability that loose dust from the crater and surrounding area,which will be drawn upward by the hot air currents, may form nuclei upon which radioactive materials will condense. It has been calculated by Hirschfelder from actual measurement of the TR dust and the surface area afforded by the particles that if this dust should rise to 10 000 ft and then fall at a normal rate there may be danger to towns 30 mi away. His calculations are based on pessimistic assumptions, but the possiblity of this happening cannot be excluded. The calculated amount of radiation resulting is 7 R/h for fission products and 1 μg of 49 in 22 h at normal respiratory rates.

It is most probable that there will be a selectivity of particles by the updraft, so that only dust of small diameters ($\leq 100\mu$) will reach this height. Also, it is probable that the cloud will ascend higher than 10 000 ft,resulting in greater dispersion and dilution if these particles should fall. It is also probable that these particles will not fall at a normal rate, but will be held together by electric forces. Also, the probability that the cloud will pass over populated places is not certain.

In any case, this possibility will be watched for by the town monitors and steps will be taken to evacuate the town if danger is imminent. As the decay rate procedes as 1/t, there should be adequate time to evacuate after contamination is noted. The ultimate decision will be made by the medical consultants with the complete information at hand after the shot.

4.7.9. Meteorology. The TR No. 2 shot will occur during a time when meteorological conditions are similar to the May 7th shot. As far as the medical considerations go, the main planning for monitoring the surrounding territory has been with this in mind. J. Hubbard has reasonably assured all concerned that these conditions are predictable at least 6 days in advance.

A summary of the conditions to be expected and their bearing on the cloud is as follows.

1. The humidity will be low enough to exclude the causation of a thunder shower by the blast and heat effects of the explosion. Such a thunderstorm would be dangerous in that it might cause the precipitation of the active material over a small area which could not be controlled.

2. There will be a small temperature inversion over the site and surrounding territory from 1000-1700 ft high. This will retard heavy particles in traveling any great distance and impede lighter particles which have penetrated the inversion from falling back through it. The latter effect will tend to protect the nearby towns until the morning thermals have mixed the active material more thoroughly.

3. Above the inversion there will be at least a 30-mph wind towards the southeast. This will carry the cloud beyond the nearby towns, giving the active material time to diffuse somewhat and become more dilute.

4. Five miles from the site there is a range of mountains 4000 feet above terrain. With the winds in the southeast direction this range will cause an increase in the velocity of winds above it to 10 000 ft. This will give a shearing effect to the trail at the bottom of the cloud. What material from the trail that is not deposited on the west face of these mountains will be diffused by the high turbulence of the winds. Some 50 mi from the site there is another range of equal height which by the same effect will spread and diffuse material that may have started to fall from the cloud.

5. There will be a slightly stable atmospheric lapse rate. The effect of this will be to allow the ball of fire to ascend until stopped by a higher inversion. This higher inversion is expected to be from 20 000-25 000 ft. In the 100-ton shot, the height reached was from 12 000-14 000 ft because of a slight inversion at the height. The energy of the TR No. 2 shot will probably be enough to exceed such a slight inversion as this one was, but all calculations as to the action of the cloud have been on the basis of 12 000 ft. The higher the cloud ascends, the less danger from heavy active particles falling on a small area. We are assured that the lapse rate will exclude any possibility of the cloud descending.

6. The usual heating of the earth at about 9:00 a.m. will start the general movement of air in an ascending manner as the inversion is broken. Besides this, there will be rather large updrafts or thermals. The effect will be to disperse the cloud in the matter of a few hours. The cloud's station at this time will be about 250 mi from the site, and again we have been reassured that no local thunderstorms will form which could "suck in" the entire cloud and deposit it over a small area.

7. Hubbard finds it conceivable that contaminating material thrown in the air will remain at high altitudes until thoroughly mixed and may be suspended for a matter of weeks (for example, the volcanic dust and surface dusts from the interior of China).

5. WORK PRECEDING AND INCLUDING ASSEMBLY AT TRINITY (CAPT. W. F. SCHAFFER)

5.1. Preliminary Tests

The assembly of the HE charge in its case for the Trinity bomb was preceded by certain tests at Site Y. These tests were made to study method of loading and effects of transportation. In the first part of the test, an inert unit was used and the method evolved for loading the unit in the truck was to set the unit on an assembly tub that had been bolted to the truck bed, with the polar cap up. Then the sphere was fastened in place by 1/4-in. steel cables running from each ellipsoid attachment lug to eyebolts on the truck bed. This method worked satisfactorily, and on July 3 the unit was driven to Trinity without any difficulty. The truck was maintained not to exceed 30 mph on smooth highways and slower speed as the condition of the road indicated. Periodic half-hour inspections of the lashings were made.

The complete procedure which was anticipated for the hot run was followed through in a dry run. The procedure for the final assembly of the bomb at the base of the tower was carefully planned in advance by all parties concerned. The procedure decided upon was followed step by step, and note was made of desirable changes for the hot run. The dry run was completed and the unit was returned to Site Y by July 6.

On July 7 a mockup HE charge with four actual lens charges was delivered from S-Site for assembly. The charges were prepared and the assembly was made on July 8. On July 9 this unit was driven for 8h over a rough course to determine what effect transportation to Trinity might have on the actual lens charge. It should be stated at this point that until now there had been insufficient full-scale lens castings made to make a complete charge. After 3-h driving time, the top polar cap was removed for inspection and the charge was found to be in excellent condition. The next day the unit was completely disassembled and each casting was inspected to determine its condition. Inspection proved satisfactory and revealed that all charges had withstood the test and were in perfect condition.

5.2. Preparations at Y

On the evening of July 10 castings for two assemblies were received. These castings were to make up the Trinity charge and the Creutz charge. G. B. Kistiakowsky and N. E. Bradbury, together with all S-Site personnel concerned with the inspection of charges, held a conference in which all records were reviewed and disposition of the castings was made according to their quality. The following day the castings were personally inspected by Kistiakowsky and Bradbury for chipped corners, cracks, and other imperfections which were undesirable. Only first-quality castings which were not chipped or which could be easily repaired were used for the Trinity assembly. The remainder of the castings were diverted to the Creutz charge.

On July 12, two groups, one at V-Site under Capt. Schaffer and one at Pajarito Canyon under H. S. North, began assembling their respective charges. Until this point there was considerable controversy over the effect of small air spaces between castings. Grease was advocated by some to take care of the possible air voids left by the spacer materials. However, grease was undesirable from the standpoint of assembly technique and its effect on castings under undeterminable storage conditions prior to field use. Because the procedure used for Trinity would have to be the same as the one used for the first field use of the gadget, the use of grease would introduce a serious problem. Because the HE components were G. B. Kistiakowsky's responsibility, he, with the concurrence of N. E. Bradbury, made the decision not to use grease on the basis that the castings assembled were much better than any previously made and that the air spaces left by the spacer materials were insignificant.

By midafternoon of the 12th, the Trinity charge was complete. With the interested personnel present, an inspection of the charge was made by removing each polar cap. Because of the specially prepared case, further inspection of the charge was possible. This case had been drilled with 1-in. holes located at the corner intersection of each casting. The charge was found to be as satisfactory as possible according to our best knowledge at the time. The case was then closed, all booster holes were sealed, and the unit was wrapped in a Butvar*(waterproof wrapping material) bag, sealed and lashed firmly to the truck in preparation for the haul to Trinity. The castings which were to be used in place of the dummy trap door plug were boxed together with one spare casting of each type. At midnight of July 12, the preassembled bomb started on its way to Trinity. G-2 escort cars preceded and followed the bomb. Before noon on July 13 the charge arrived at the base of the tower, and assembly operations began at 1300.

5.3. Procedure for Final Assembly

The procedure used for the final assembly of the bomb is probably best given by the memorandum from N. E. Bradbury, which gives the procedure to be followed, as discussed by all members concerned, and that was evolved from the dry run.

TR HOT RUN

by N. E. Bradbury

Saturday, 7 July, 1700	Schaffer Shake Test ready to deliver.
Sunday, 8 July, 0830	Assemble Shaffer Shake Test, load on truck.
Monday, 9 July, 0830	Schaffer Shake Test charge given 8-h road test. Remove polar cap and dummy plug and inspect top of charge only after 3-h riding.
Tuesday, 10 July, 0830	Completely disassemble charge and inspect each casting for condition. Verbal report of charge condition by 1630 Tuesday. Reassemble and remove.
Wednesday, 11 July, 0830	Information will be furnished as to which charges will be used in TR shot and which in Creutz shot. Separate charges. Complete papering of TR charges. Complete papering of Creutz charges (use separate groups—request additional personnel as needed.)

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the US Energy Research and Development Administration to the exclusion of others that may be suitable.

Wednesday, 11 July, 1730	Both charges completely papered. Work another night shift if necessary to complete this job. Request personnel as necessary. This job must be done so that assembly of both charges can start on Thursday, 12 July, at 0830.
Thursday, 12 July, 0830	Use two groups—one at V-Site to assemble TR charge (Lt. Schaffer supervises), and one at Pajarito for Creutz charge (North supervises). Tamper needed by 1000 at V-Site.
Thursday, 12 July, 1500	Assembly of TR charge complete. Notify interested personnel that it is ready for inspection if desired.
Thursday, 12 July, 1600	Seal up all holes in case; wrap with Scotch wrap (time not available for strippable plastic). Start loading on truck. Tie down to truck body.
Thursday, 12 July, 1600	Box charges, inner and outer, with two spares for each. Stow on truck so they cannot shift and are padded from truck bottom.
Friday, 13 July, 0001	TR charge starts on its way to TR. G-2 escort cars fore and aft. G. B. Kistiakowsky to ride in fore car.
Friday, 13 July, 1200	TR charge arrives at base of tower. Following personnel to be at base of tower by 1300. N. E. Bradbury G. B. Kistiakowsky R. S. Warner H. Linschitz Lt. W. F. Schaffer T/3 Jercinovic T/3 Van Vessem A. B. Machen
Friday, 13 July, 1300	Assembly starts.

Unloading at TR

1. Truck backs up to base of tower.
2. Tarpaulin is removed, cradle and assembly unlashed.

3. Main hoist lifts sphere off cradle with spreader bar or tongs.
4. Drive truck out from under sphere.
5. Place new cradle under hoist and lower sphere suspended by tongs into it with main hoist.

Assembly at TR

1. Sphere is now resting on cradle with *polar cap up*.
2. Detach main hoist; pick up gently with hook, lower, pull out over gadget and secure.
3. With jib hoist, remove polar cap and dummy plug. Special polar cap and funnel put in place. Gadget now belongs to tamper people (at about 1400 on Friday). Before their taking over, a 15-min period will be available for generally interested personnel to inspect the situation. After this time, only G-engineers and two representatives from the assembly team will be present in the tent.
4. G-engineers work till 1600 with active material insertion.
5. Light must be available to work in tent at night.
6. At 1600 dummy plug hole is covered with a clean cloth and explosives people take over. Attach tongs to tent peak by chain. Place tongs on trunnion. Lift sphere and turn over with jib hoist for HE insertion. Return sphere to cradle.
7. Place hypodermic needle *in right place*. (Note: Check this carefully.)
8. At this point another 15-min period will be available for inspection by generally interested personnel.
9. Insert HE—this is to be done as slowly as the G-engineers wish. Have on hand extra paper, if charges are slightly small, grease, and hypodermic needle grease gun. Be sure glass tape and/or shim stock shoe horn is on hand.
10. When HE has been inserted and explosives people and G-engineers are satisfied that all is OK, another inspection period of 15 min will be available.
11. Lift sphere with tongs by chain to tent peak. Return to polar cap up position. Remove special polar cap with jib hoist; replace with regular polar cap.
12. Turn sphere over with tongs, chain and tent peak so that lug is up.
13. Place sphere in special cradle for tower top, and attach cradle firmly to sphere. Remove all tongs, chains, etc., and generally clear deck.
14. Leave tent in place till morning.

NOTE: The HE vacuum cup has arrived and appears to be extremely useful in handling HE charges. It is possible that the entire assembly may be done in the vertical position using the jib hoist and vacuum cup to lower the HE as slowly as the G-engineers wish. This would then require no handling between tent peak and tongs, and the sphere will be left overnight with the *cap up* and in a small dishpan.

15. It is anticipated that we will leave the tent (guarded) at about 2200.

Saturday, 14 July, 0800, *Lift to tower top*

1. Remove tent with main hoist.
2. Turn over with main hoist and place on special cradle. (This operation necessary only if not previously done as it would not be in a vertical assembly.)
3. Rig guide lines.
4. Lift to tower top. Ready for X-unit at 0900.
5. Bring up G-engineer footstool.

Saturday, 14 July, 0900, *Operations aloft*

1. Wiring of X-unit proceeds under the direction of and by explosives people. Note that X-unit should have cables attached to cone before this time.
2. Detonators are staked to coax by Caleca of detonator group.
3. Detonators are placed by Caleca to conform with requirements of informer switches. HE people stand by to criticize potential rough handling.
4. Detonators and informers in place, verified by Greisen.

5. X-unit and informer unit safed, verified by Bradbury or Kistiakowsky.

6. X-7 will provide all detonators, informer switches, informer cables (adequate length), informer apparatus. (Where they get it is their business.) X-5 will supply prepared detonator cables. X-6 will obtain detonator springs and other necessary gear from appropriate sources. X-6 will supply all fittings for wiring. Schaffer to check that all mechanical parts (nuts, bolts, etc.) are supplied.

7. Note that once detonators are on sphere, no live electrical connection can be brought to X-unit, informer unit, or anywhere else on sphere. Hence all testing must be done before sphere is lifted to tower. After that it is too late.

Saturday, 14 July, 1700,	*Gadget complete*
Sunday, 15 July, all day	Look for rabbit's feet and four-leaved clovers. Should we have the Chaplain down there? Period for inspection available from 0900-1000.
Monday, 16 July, 0400	Bang!

General Notes

The same responsibility for procurement of items exists as in the dry run. Machen to check his list for parts left down there. Could they have been stolen? Schaffer to get vacuum cup and two pumps ready to go down. Have glass tape handy to tie charge to hook of jib hoist to guard against vacuum failure.

It is assumed that the following will have been done at TR.

- Guide wire hold-down improved.
- Method of holding down tent improved.
- Ionization chambers either not connected to pipe coax or off to one side. Wilson's chamber to be connected later; Rossi's chamber to be pulled off to wall side.
- Rig a roped-off area about base of tower allowing 20-ft clear space. Provide "Keep Out" signs (Oppenheimer). All spectator personnel stay outside this area except at inspection times.

The following points were noted in the dry run assembly. Personnel listed should take appropriate steps.

- Shim stock shoe horn was missing. (Machen)
- Longer screws needed for X-unit cable clamps. (Schaffer)
- Sphere not grounded. (Schaffer)
- All detonators off floor; all detonators cables off floor. (Greisen)
- Shorter screws could be used for detonator leaf springs. (Schaffer)
- Washers needed for informers. (Greisen)
- Cable lengths too short? (Hornig)
- Headless screws to protect screw holes (not necessary with Scotch wrap).
- Need good cover for HE hole while turning over. (Schaffer)
- Need proper clevis for attaching tongs to main hoist. (Henderson)
- Need better method of erecting tent and securing. (Henderson)
- Upper platform should be tested with concrete weight. (Oppenheimer)

It will not be possible to permit any personnel on the assembly platforms other than those actually engaged in assembly operations. However, personnel may observe the operations from beyond the roped-off area, and may inspect the assembly at times as noted in the above operations list.

(Signed) N. E. Bradbury

Distribution

J. R. Oppenheimer
F. Oppenheimer
G. B. Kistiakowsky
Major Ackerman
R. W. Henderson
R. S. Warner
Lt. Schaffer (2)
A. B. Machen
Morrison
Holloway
R. F. Bacher
N. Ramsey
K. T. Bainbridge
Lt. Comdr. Keiller
K. Greisen
D. Hornig
H. Linschitz
R. W. Carlson
John Williams
B. Rossi
R. Wilson

6. RADIAL DISTRIBUTION OF NEUTRONS, GAMMA RADIATION, AND THERMAL RADIATION (JOHN L. MAGEE)

6.1. Introduction

In this chapter we shall present the Trinity experimental data on the radial and time dependence of radiation intensities. These data are not very extensive, and we shall supplement them in places with results obtained in the airburst test at Bikini (Test "Able"). Radiochemical evidence shows that these two bombs were identical in efficiency; so a direct comparison is indicated. The experimental results will be accompanied by a limited amount of comparison with theoretical expectation and interpretation.

Theoretical predictions were made for neutrons and gamma radiation by Weisskopf before the Trinity shot. These predictions were very useful in planning experimental measurements, and the agreement obtained was good. The only pre-Trinity discussion of thermal radiation was made by Magee and Hirschfelder. A more complete discussion of radiation phenomena connected with air blasts appears in this Technical Series.[5]

6.2. Neutrons

6.2.1. Fast Prompt Neutrons. The cross section for the sulphur (n,p) reaction is almost a step function, rising from ~0 to 0.2 b at 3 MeV. This reaction presents an excellent method for measuring the radial distribution of fast, prompt neutrons above 3 MeV in energy. Delayed neutrons all have energies about 0.6 MeV and thus do not interfere. One measurement was made by E. Klema[6] at Trinity and many were made by Linenberger and Ogle at Bikini.

The experimental results are all given in Fig. 2. The ordinate is distance squared times activity of sample (in arbitrary units) and the abscissa is distance. Klema's Trinity point is only corrected for the difference in atmospheric density, because most of the scattering is done by nitrogen, and the humidity does not matter.

Figure 2 is difficult to understand. If the average neutron of the high-energy group were degraded below 3 MeV on its first collision, the curve would be a straight line, its intercept at R = O giving the number of high-energy neutrons penetrating the bomb materials. The experimental curve has such great curvature that it would seem to mean that the average neutron of this group must be scattered many times (six or more) before being degraded below 3 MeV. At present this result is not explained.

The absolute number of fast neutrons represented by Klema's Trinity point is 6.5×10^{21} neutrons through the sphere at 200 m. It is impossible to make a theoretical estimate of the number of fast neutrons per fission which should penetrate the bomb, so an estimate of the efficiency cannot be made from these data.

6.2.2. Slow Neutrons—Space and Time Relations. Slow neutrons come from two sources. (1) Prompt neutrons are first slowed down in the high explosive to about 300 eV and then discharged into the air about 30-50 μs after the nuclear explosion. These have an average penetration of about 280 m in air before being absorbed as epithermals by nitrogen, i.e., the average value of r^2 is $(280)^2$. (2) Delayed neutrons are emitted from fission products. The half-lives of these neutron emitters is on the order of 1 s or so. These neutrons have an energy of about 0.6 MeV and thus have farther penetration, about 450 m.

The total flux of slow neutrons per unit logarithmic energy interval as a function of distance was measured by E. Klema[7] at Trinity using activation of cadmium-covered gold foils. His results are given in Fig. 3. The slow neutron intensity-time relation was measured by Blair, Frisch, and Richards at one 600-m station using a cellophane "catcher camera." Their results are shown in Fig. 4.

Figure 4 shows the space and time discrimination against the first group of neutrons which was expected at 600 m. Only 20% of the total number are from the prompt neutrons, and their contribution is negligible after 0.5 s. According to expectation, however, the prompt neutrons should have lasted only about 0.5 s. This discrepancy is not understood at present.

The increase in intensity at 0.6 s is due to the arrival of the shock wave at 600 m. The deviation of the observed curve from the "expected" in the region 0.6-3.5 s must be associated with air motion, but a detailed explanation has not been made.

Due to the presence of the ground and the tenuous ball of fire, it is difficult to make absolute calculations of neutron intensities. A model experiment, however, did demonstrate that the ground and ball of fire effects almost cancel.

Calculations on the ground effect and neutron intensities in the air as a function of time have been made by Marshak et al.[8,9]

6.3. Gamma Radiation

6.3.1. Radial Distribution of Total Radiation. The total gamma radiation at a number of positions was measured by E. Segre and others using x-ray film and paper. Their results are given in Table I.

Weisskopf has pointed out the difficulties in interpreting these results. In some cases the values (for the same shielding) multiplied by the distance squared increase with distance, whereas there should be exponential attenuation. In some cases the absorption coefficient in lead seems to be as small as 0.1 cm^{-1}; the smallest coefficient for lead at any gamma-ray energy is 0.45 cm^{-1}.

Fortunately, a more extensive set of measurements using film was obtained at the Bikini airburst test and these are available.* Because the two bombs were found by radiochemical means to be identical, a direct comparison was made. The experimental points are plotted in Fig. 5. The ordinate gives distance squared in yards times Roentgens, and the abscissa is distance in yards. The film was not covered with absorbing material as had been done at Trinity. Varying the degree

*The measurements were made by Dessauer and Rouvina of the Radiological Safety Section. The writer is indebted to Rouvina for the results.

TABLE I

TOTAL RADIATION IN ROENTGENS

Shielding[a] (cm Pb)	400 mS[b]	600 mS	760 mS	1000 mS	600 mN[c]	800 mN
0.			15000 ±4000	2100 ±300		
0.95		4000 ±1000	2100 ±300	920 ± 90		1400 ± 140
1.9	19000 ±6000	1600 ±200	1300 ±130	820 ± 80	12000 ±2500	1000 ± 150
3.8	3200 ±600	1100 ±110	650 ± 70	380 ± 60	2600 ±400	510 ± 60
5.7	1900 ±500		360 ± 50	200 ± 30	1150 ±100	380 ± 50

[a] Several different thicknesses of lead shielding were used at each station.
[b] Meters south.
[c] Meters north.

of shielding presumably accounts for most of the scattering of points, because the films were placed all over the ships and had various and unknown thicknesses of iron between them and the gamma-ray source. This being the case, one should expect that at a particular distance the unshielded radiation intensity is given by the highest reading. One should like to have asymptotically an expression of the form

$$D^2R = \text{Const}\, e^{-D/F} ,$$

where D = distance, R = Roentgen, and F = mean free path.

The straight line drawn in the figure gives what we shall call an "experimental" curve for unshielded radiation intensities at large distances. The point at 3500 yd far above the line was taken from a ship that suffered fire damage, and the film was probably ruined by heat.

The two unshielded Trinity film results (see Table I) are also plotted. They are indicated by T. In plotting these points, allowance has been made for the more tenuous character of Trinity air.

There was an x-ray film found at Hiroshima by Philip Morrison in a hospital at 1550-m horizontal distance from the burst (or 1815 yd short range). There is considerable uncertainty in the amount of radiation this film received, because it was rather poor quality and the shielding was not certain. We have plotted the point (marked with an H) on the figure after correcting for the different fission yield (8000 ton is assumed).

The equation of the straight line in Fig. 5 is:

$$D^2R = 3.70 \times 10^{10} \times 10^{-D/850}.$$

This curve established that the mean free path of the radiation at large distances is about 370 yd or 340 m. Gamma radiation having such a long mean free path in air of normal density must have an energy in the vicinity of 5 MeV. This point will be discussed later.

6.3.2. Time **Dependence of Radiation** at **Distant Points**. E. Segre and others attempted to measure the time dependence of the gamma radiation at two stations with ionization chambers. One, on the ground at 550 m, gave a result; the other instrument was destroyed by thermal radiation. Their instruments were designed for a lower yield than was obtained, and thus, they got saturation for early times. For later times, 10 to 20 s, they obtained significant readings. Taking into account the motion of the ball of fire and assuming that all the intensity was coming from fission products, they accurately calculated the fission yield of the bomb. They did not present their data in terms of radiation intensity as a function of time.

More extensive measurements of the time variation of radiation intensity was made by J. Tuck at the Bikini airburst test. These results indicate that the delayed gamma radiation is due to the fission products. In Fig. 6 one of Tuck's records is compared with expectation. The "calculated" curve is obtained from the laboratory measurements of the rate of gamma emission and the observed rate of rise of the ball of fire. The mean free path was taken as 340 m in accordance with the experimental observation, and a point source was used. The experimental curve is adjusted to agree with the calculated at 1 s. The agreement between the curves is good considering the roughness of the calculation. It seems to indicate that the radiation having the long mean free path must be coming from the fission products throughout the time of interest.

6.3.3. **Spectrum of** Gamma **Radiation**. It was mentioned earlier that to have a mean free path of 340 m the energy of a gamma ray must be in the vicinity of 5 MeV. This observation only depends upon the validity of the Klein-Nishina formula for the scattering of gamma radiation, because a primary beam of initially homogeneous radiation in a few mean free paths will come into equilibrium with its scattered radiation. A careful consideration of the possible sources of this high-energy radiation leads to the fission products as the most likely source. To account for observed intensities, one needs about 0.72 MeV per fission in this energy region. Before the rising of the ball of fire takes the source of radiation away, there is a total of 1.8 MeV per fission given off. Thus about 40% of the early fission gammas must be in the 5-MeV region.

6.3.4. Capture Gamma and Contamination. Some of the features of the Trinity Test were due to the location of the point of burst near the ground. During the first fraction of a second an appreciable amount of gamma radiation, for points close to the burst, was due to neutron capture in the ground. No measurements bearing on this point have been made, so it will not be discussed further. Estimates of this effect have been made by Weisskopf, and calculations of Marshak[8,9] on the rate of neutron absorption in the ground are pertinent.

Because of the presence of the dust around the detonation point, a large region of the countryside was contaminated with fission products. This topic is discussed by Hirschfelder et al.[10]

A total of about 1% of the fission products was left in the crater and vicinity. The gamma activity due to this contamination is reported by Aebersold and Moon.[11]

6.4. Thermal Radiation

6.4.1. Total Radiation. The total radiation was measured by D. Williams and P. Yuster,[12] using a thermopile technique. They obtained a value of 3060 metric tons TNT equivalent for the total; the measurement was made at 10 000 yd.

6.4.2. Radiation Intensities—Space and Time Relations. There was no good measurement either of the brightness of the ball of fire or the illumination as a function of time at any distance at Trinity. Measurements of the brightness using the absolute density of fastax film and rough estimates of the temperature by means of a record obtained on a recording spectrograph indicate roughly solar brightness, with little variation as a function of time.[13] These measurements were admittedly unrealiable. The theoretical expectation had been that the temperature of the radiating surface should be several hundred thousands of degrees for the first few microseconds, drop to a minimum of about 4500° at about 15 ms.[5] increase for less than a second to 10 000° and then cool off more slowly. The minimum was corroborated, but the initial high temperatures were not found.

The theory of the radiating body was further developed.[5] The high temperatures initially seemed to be essential, and they were kept in the theory. The theory for the radiation after the first few milliseconds is not in a very good state, and here the "theory" was adjusted to give the correct total radiation as measured by Williams and Yuster.[12] At the Bikini Able test the existence of the extremely high temperatures was verified by measurements of Brian O'Brien.

In Fig. 7 the illumination as a function of time is presented. The ordinate is distance squared times "suns," where the sun ʘ, is a unit of illumination rather than brightness. The temperatures of the radiating surface are indicated along the curve. This curve calculates radiation intensities at all distances and times, insofar as atmospheric absorption can be neglected.

6.4.3. Incendiary Effects. Measurements on the incendiary effects were made at Trinity by Marley and Reines.[14] They found that no fires were started in wooden materials which were appreciably outside the fire zone, but that charring occurred to beyond 1000 yd. Fir timber was slightly scorched to distances of 2000 yd.

In an attempt to understand scorching and charring, let us consider a constant source of heat on a surface. It can be shown rather easily that the surface temperature is raised after a time by the amount $T_s = \frac{2}{\sqrt{\pi}} \; \frac{Q \quad t}{K \, \rho \, C}$ *,

where Q = strength of heat source (cal/cm^2 s)
K = thermal diffusivity (cm^2/s)
ρ = density (g/cm^3)
C = specific heat (cal/g degree).

The above formula shows that the source strength comes in directly, whereas the time is a square root. It is thus relatively better to have an intense source for a short time. It seems reasonable to expect a scorching or charring process to have a temperature criterion, either occurring or not depending upon the temperature, and relatively unsensitive to application time.

**Sic*. This equation and the following text appear as in the original report.

Let us apply this formula to pine wood, using Fig. 7. The constants are taken as $K^2 = 1.4 \times 10^{-3}$, $\rho = 0.5$, and $C = 0.42$. Assuming that the value of $D^2\Theta$ is constant at 4.5×10^9 for 20 ms and then drops abruptly to zero, we get $\Delta Ts = 9.2 \times 10^8 °C/D^2$ (for distance in yards). This is for absorption of all of the radiant energy. If 400° C is selected as a charring temperature we get D = 1520 yd. This is about the limit to which there was an appreciable effect observed.

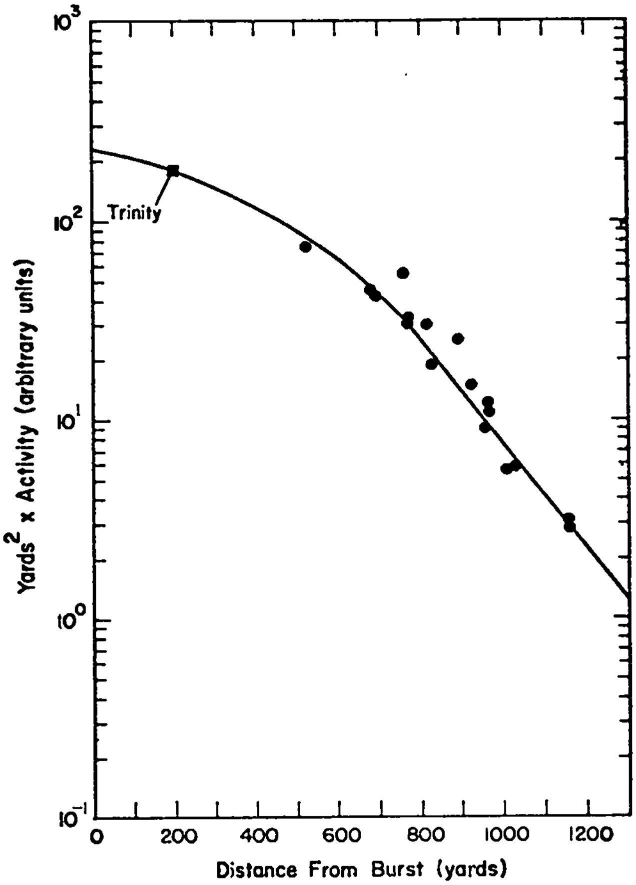

Fig. 2.
Experimental results of prompt neutron measurements.

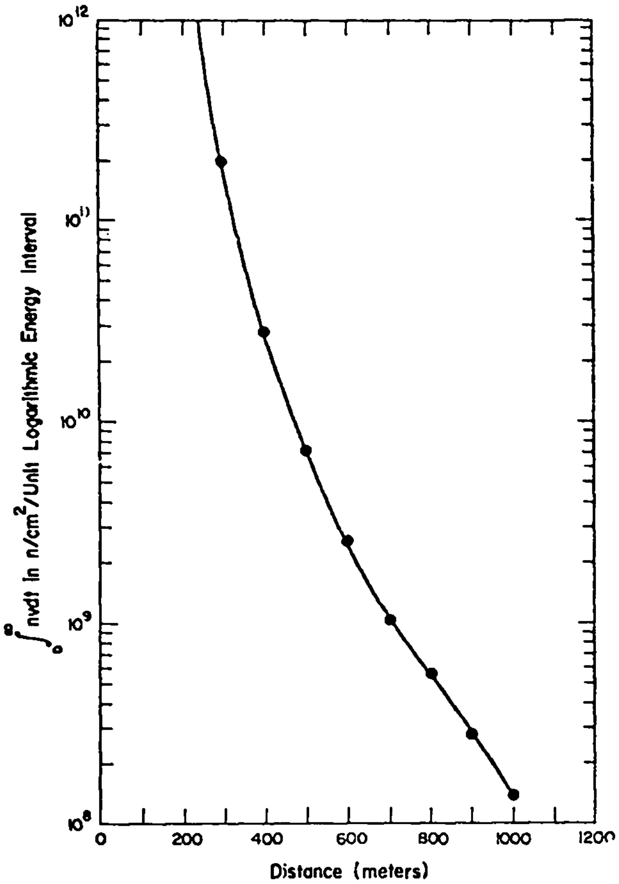

Fig. 3.
Slow neutron flux vs. distance.

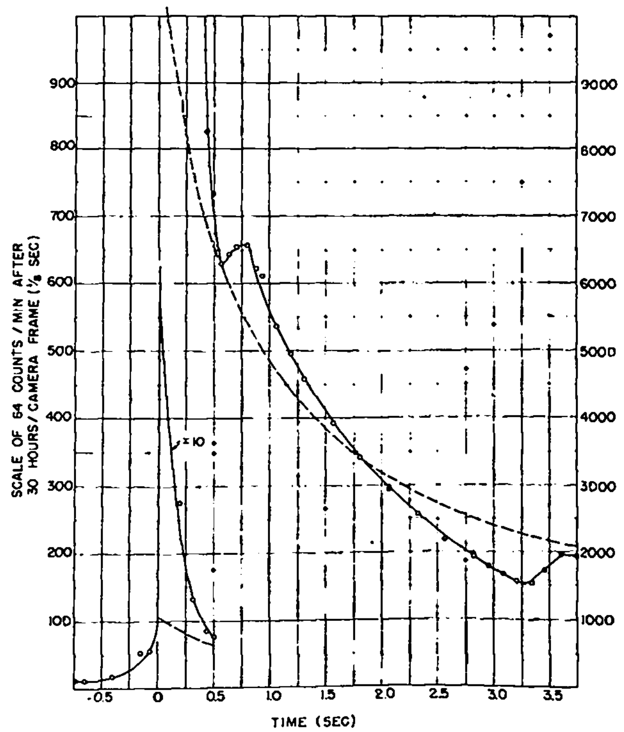

Fig. 4.
Slow neutron flux vs. time.

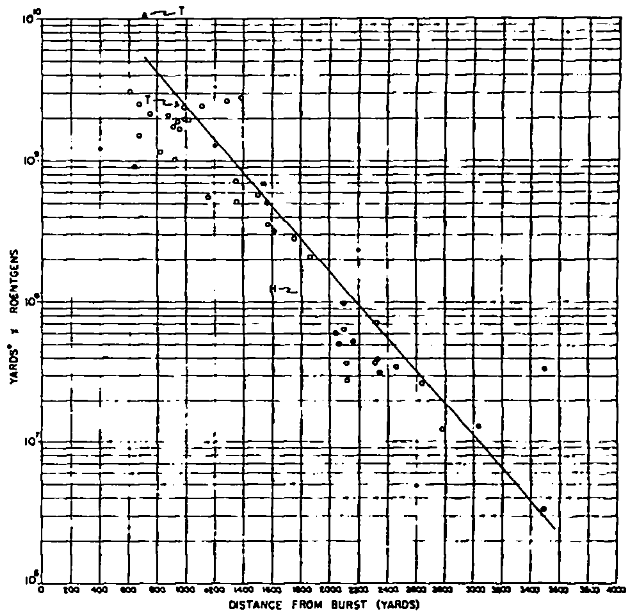

Fig. 5.
Bikini and Trinity radiation film results.

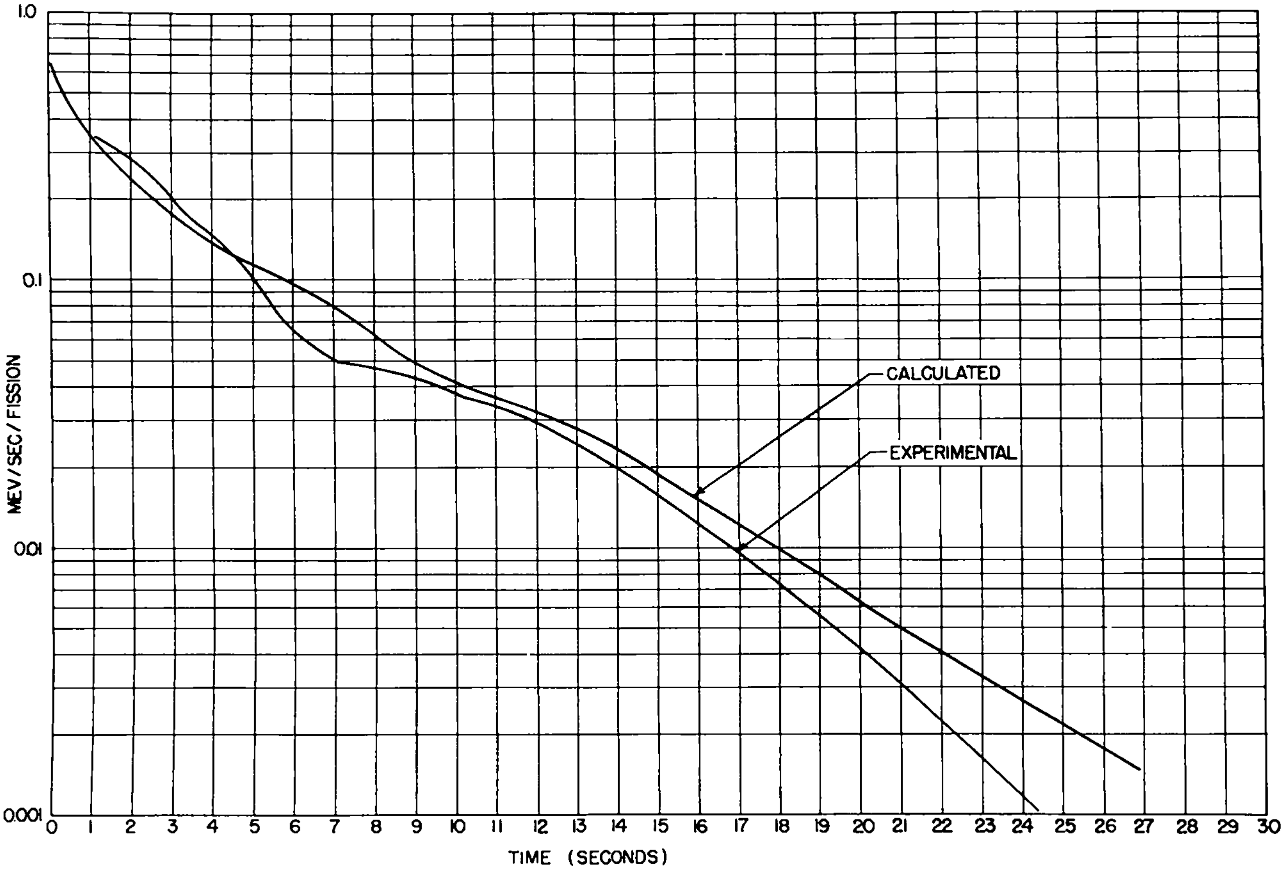

Fig. 6.
Calculated and experimental measurements of radiation intensity vs. time.

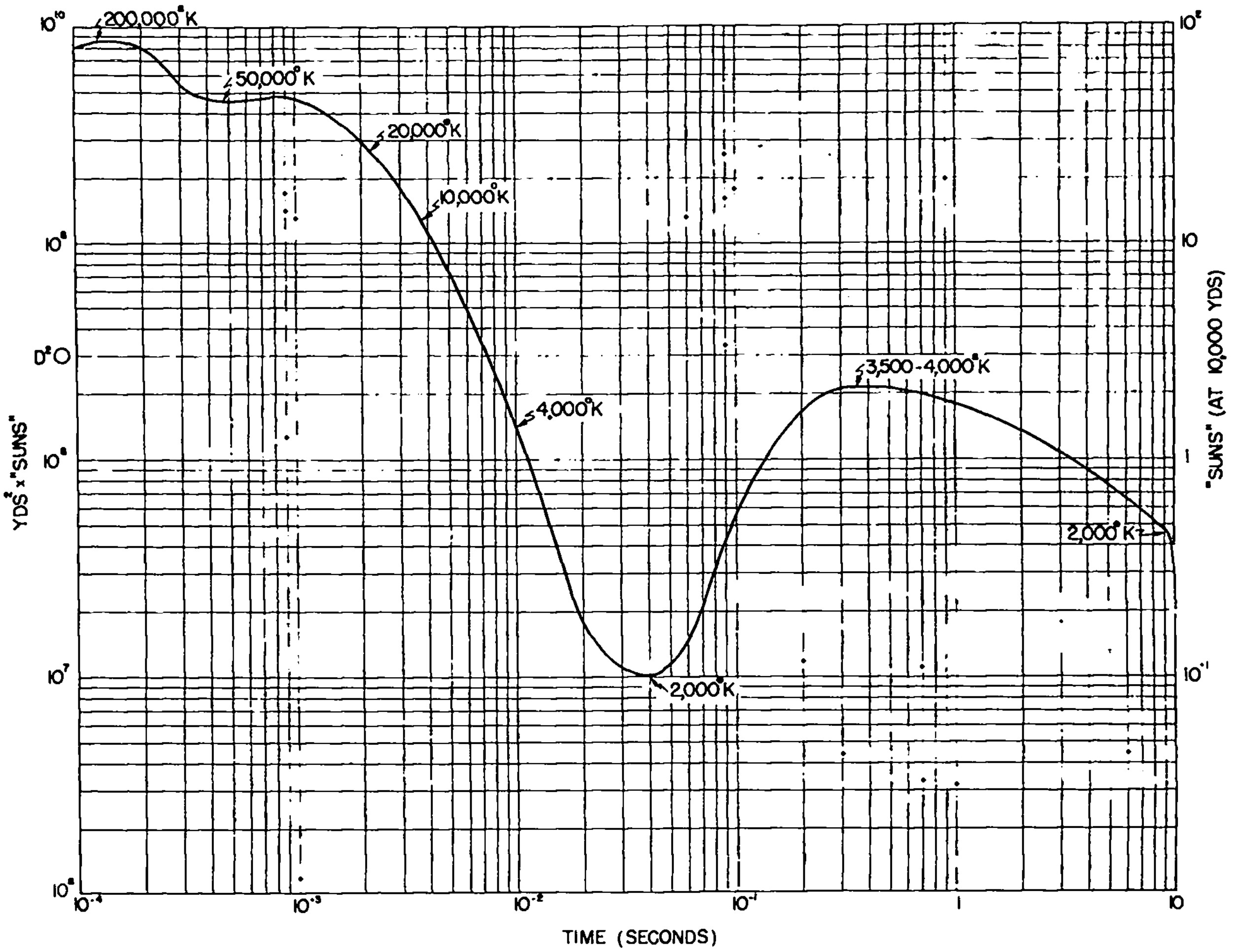

Fig. 7.
Illumination as a function of time.

7. SUMMARY OF NUCLEAR PHYSICS MEASUREMENTS (ROBERT R. WILSON)

The immediate purpose of the nuclear physics measurements was to determine the efficiency of the fast chain reaction to be tested at Trinity. The experiments were also designed in a manner that would give the greatest insight into the nuclear phenomena occurring during the explosion. Particularly in the event of a failure or of a resulting low efficiency would such measurements be crucial.

The experimental problems posed were extremely difficult. Most measurements were designed to give results for an efficiency varying from that equivalent to an energy release from 10 000 to 50 000 tons of TNT. It was necessary to place most of the equipment in a position where it had to withstand the heat and shock wave from the bomb, or alternatively to send its data to a distant recording station before it was destroyed. We can understand the difficulty of transmitting signals during the explosion when we consider that the gamma rays from the reaction will ionize the air and other material within hundreds of yards. Fermi has calculated that the ensuing removal of the natural electrical potential gradient in the atmosphere will be equivalent to a large bolt of lightning striking that vicinity. We were plagued by the thought that other such phenomena might occur in an unpredictable or unthought of manner. All signal lines were completely shielded, in many cases doubly shielded. In spite of this many records were lost because of spurious pickup at the time of the explosion that paralyzed the recording equipment. Much of the recording was done photographically in reinforced concrete, earth-covered shelters placed about 1000 yd from the bomb. Deeply buried shielded cables brought the signals to the shelters. Even here the tremendous gamma-ray emission blackened the photo plates except where the plates were surrounded by thick lead shields within the shelters. In many cases the dirt was blown from the shelters by the outgoing wind.

It was difficult to keep the number of experiments within bounds. Most physicists yielded to temptation and conceived experiment after experiment. A screening board consisting of E. Fermi, V. Weisskopf, and R. Wilson considered each proposed experiment with respect to its feasibility and possibility of giving cogent information. Even so, considering the short time in which to prepare the experiments, perhaps too many were attempted.

The theoretical work by V. F. Weisskopf on what nuclear phenomena might be produced by the fast chain reaction was of great assistance to those designing the experiments.

It was recognized from the beginning that the most promising measurement of the nuclear efficiency would come from the radiochemical determination, and hence the greatest effort was put into this experiment under Anderson's direction. Experimental details will not be given here.

Segre's group made observations on the delayed gamma rays from the fission products by means of ionization chambers several milliseconds after the explosion. They had two stations: one on the ground at 550 m from the bomb and another one at the same distance but lifted by a balloon to an elevation such that the line joining the balloon with the bomb made a 45° angle with the horizontal. The purpose of the latter station was to get away from the effects due to the earth thrown into the air by the explosion. Unfortunately the airborne detector was destroyed by the initial radiation flash before a record was obtained. In addition to the ionization chamber measurements they also made measurements of the total radiation in gamma units at various distances from the bomb and under several amounts of lead shielding, using the blackening of photographic materials.

Moon also made measurements on the delayed gamma rays at longer times,[11] particularly for the purpose of giving information to parties entering the radioactive region after the explosion. He also made an attempt to photograph the distribution of fission products in space as a function of time using the gamma rays from the products and pinhole camera.[15]

The radiant energy was successfully measured by D. Williams and P. Yuster using a thermopile technique.[12] They found 3060 metric tons of TNT equivalent as the value for the total radiant energy emitted.

The members of J. William's group made measurements on the number of delayed neutrons from the fission products resulting from the explosion. Their technique consisted of measuring the activity of a cellophane tape that had been passed rapidly between two ^{235}U plates. The activities of the fission fragments caught in the cellophane gave a time-differentiated neutron record. Three cellophane catcher cameras were constructed. One was airborne 300 m out and 300 m up: the other two were ground stations, one at 300 m and the other at 600 m from the bomb. Only the 600-m station survived the radiation and the blast to give record.

The low and unknown density distribution in the ball of fire and the large soil effect at 600 m made difficult the interpretation of the observed neutron density in terms of efficiency. A scaled mockup of the ground plus ball of fire hole has been studied, and the results indicated that at 600 m the hole produced by the ball of fire nearly compensated for the reduction in intensity produced by the soil.

E. Klema determined the number of neutrons per square centimeter per unit logarithmic energy interval as a function of distance from the bomb by measuring the activation of cadmium-covered gold foils which had been calibrated in a graphite block. His values were in good agreement with those obtained by the catcher camera technique after the latter had been integrated over the time. Klema also measured the number of fast neutrons from the nuclear explosion at a point 200 m distant using sulphur as the detector.

Both in the case of delayed neutron measurements and of delayed gamma-ray observations, more reliable results would have been obtained had the nuclear efficiency been somewhat lower.

8. SUMMARY OF MECHANICAL EFFECTS (J. H. MANLEY)

8.1. 100-Ton Test and July 16th Nuclear Explosion

To have a summary of mechanical effects for easy reference, the data from various reports on both the 100-ton test and the July 16th nuclear explosion have been collected in Tables II and III. These data are also shown graphically in Fig. 8.

The data have been selected in the sense that uncertain values have been omitted, and in some cases of apparently equal weight an average has been used in tabulation. Occasionally more than one value by a single method appear at a given radius. These derive from equipment at different directions from the explosion. The difference in results for these cases is not great enough to suggest a significant asymmetry in the explosion. For complete details and description of the instrumentation, the orginal reports as indicated in Tables II and III should be consulted.

TABLE II

AIR BLAST

July 16th Nuclear Explosion		100-Ton Test
Mechanical Impulse Gauge:		
Radial position	1200 yd	200 yd
Peak pressure	9.4 ± 15% psi	15 psi
Impulse	1.77 ± 6% psi-s	0.426 psi-s
Duration	0.65 ± 5% s	0.130 s
Condenser Gauge:		
Radial position	6000 yd	No record
Peak pressure	0.58 ± 0.03 psi	
Impulse	0.45 psi-s	
Microbarographs:		
Radial Position (10^{-3} yd)	**Peak Pressure (psi)**	
10.0	0.47	Not used
13.4	0.31	
15.5	0.13	
48.3	0.03	
50.0	0.11	
60.5	0.04	
63.3	0.03	
78.	0.008	

July 16th Nuclear Explosion	100-Ton Test

Piezo Gauges:

July 16th Nuclear Explosion: No record

100-Ton Test:

Radial Position (yd)	Peak Pressure (psi)	Impulse (psi-s)
150	20.4	---
180	14.2	---
230	8.2	.470
230	9.0	.556
320	5.9	.346
740	1.6	.172
1500	0.73	.073
9200	0.13	.015

Excess Velocity:

July 16th Nuclear Explosion:

Radial Position (yd)	Peak Pressure (psi)
448.7	45.2
593.2	25.3
593.3	27.2
838.4	14.0
838.4	12.2
1185.1	7.0
1184.9	7.1

100-Ton Test:

Radial Position (yd)	Peak Pressure (psi)
164	16.2
204	10.2
204	11.0
272	6.3
498	2.2

Piston Gauges:

July 16th Nuclear Explosion:

Radial Position (yd)	Peak Pressure (psi)
367	>60
500	24 - 26
567	<18
1000	2.6 - 6.7
1500	3.5 - 4.0
2000	>2.8

100-Ton Test: Not used

July 16th Nuclear Explosion

Foil Gauges:

Radial Position (yd)	Peak Pressure (psi)
800	6.18 - 7.35
814	6.18 - 7.35
1000	6.18 - 7.35
1190	5.09 - 6.18
1250	6.18 - 7.35
1250	5.09 - 6.18
1320	5.09 - 6.18
1360	6.18 - 7.35
1360	5.09 - 6.18
1400	3.96 - 5.09
1400	5.09 - 6.18
1445	5.09 - 6.18
1445	6.18 - 7.35
1490	3.96 - 5.09
1490	5.09 - 6.18
1550	5.09 - 6.18
1550	6.18 - 7.35
1620	3.96 - 5.09
1710	3.96 - 5.09
1800	2.97 - 3.96
1800	3.96 - 5.09
1920	2.97 - 3.96
1920	3.96 - 5.09
2050	2.97 - 3.96
2250	2.10 - 2.97
2550	2.10 - 2.97
2675	2.10 - 2.97

Crusher Gauges:

Radial Position (ft)	Max. Pressure (tons/sq. in.)
327	1.10
328-1/4	1.34
320-1/4	1.26
322	1.36
208	4.95

100-Ton Test

Foil Gauges:

Radial Position (yd)	Peak Pressure[a] (psi)
195	10.5 - 11.8
220	10.0 - 11.2
270	7.4 - 7.7
360	4.0 - 4.6
520	2.0 - 2.6

[a]Range given in lowest value of Table V, column 6 to highest value Table V. column 7, p.10 of LA-354.

Crusher Gauges: Not used

TABLE III

EARTH MOVEMENT

Geophones:

July 16th Nuclear Explosion: Radial Position (yd)	Max Displacement (cm) Hor.	Max Displacement (cm) Vert.	100-Ton Test: Radial Position (yd)	Max Displacement (cm) Hor.	Max Displacement (cm) Vert.
800	---	1.2	800	.030	.033
1500	.75	---	1500	.010	.018
	(.52)[a]	(0.36)			
9000	.019	.02	9000	.0018	---
				(.0033)	(.0028)

[a]Values in parentheses were obtained at approximately 150° from other values listed. These are derived results (from velocity and periods) and are accurate to about 50%.

Seismographs:

July 16th Nuclear Explosion: Radial Position (yd)	Max Displacement (cm)	100-Ton Test
	Hor.-Radial	Not used
9000	0.068	

The most extensive data on *both* explosions was obtained from the excess velocity measurement and from foil gauges. Neither method gives as precise information as desired: the velocity method involves an average between two distances, the foil method involves discrete pressure increments. However, by scaling the results of the 100-ton test (108-tons TNT equivalent neglecting any effects of wood boxes) one has:

Method	Nuclear Explosion, TNT Equivalent (tons)
Foil gauges	9900 ± 1000
Excess velocity	10 000 ± 1000

Measurements of earth motion show that earth shock is unimportant as a damage-producing agent in comparison with air blast. Different methods of scaling test results give values from 3000 to 15 000 tons TNT equivalent for the nuclear explosion.

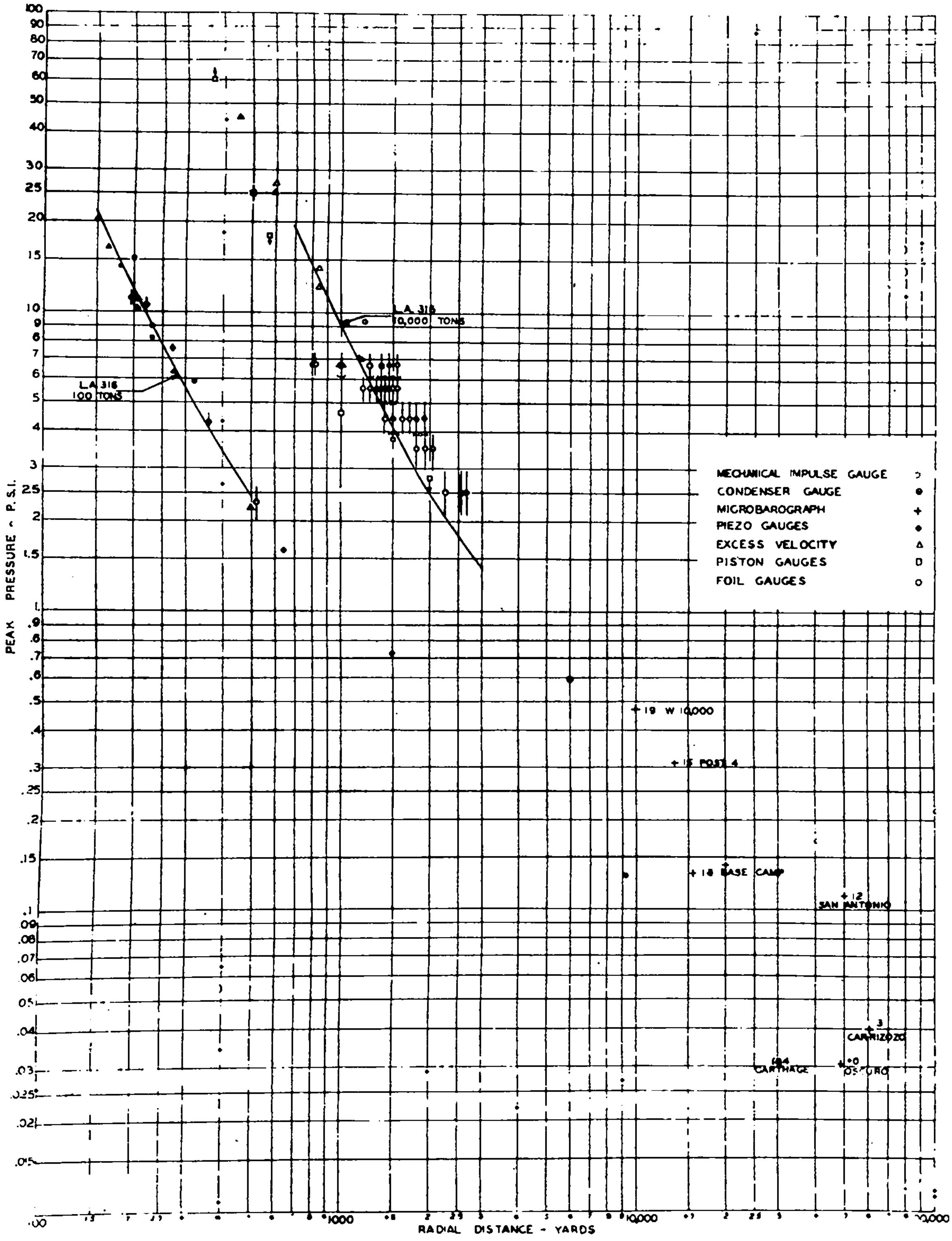

Fig. 8.
Data for 100-ton test and for the July 16th nuclear explosion.

9. JULY 16TH NUCLEAR EXPLOSION—SUMMARY OF OPTICAL OBSERVATIONS (JULIAN MACK)

9.1. Introduction

The observations of the Optics group fall roughly into two categories: space-time relationships[16] and the analysis of the emitted light.[12] A semipopular account of the explosion, in titled pictures, has been issued.[17]

9.2 Space-Time Relationship

For the determination of space-time relationships, approximately 10^5 photographic exposures were made, almost all of them motion picture frames. Most of the resultant data are shown in Fig. 9 (Ref. 16). A summary of the events observed follows. The expansion of the ball of fire before striking the ground was almost symmetric, following the relationship

$$R = 616\, t^{2/5}$$

where R is the radius in meters and t is the time in seconds, except for the extra brightness and retardation of a part of the sphere near the bottom, a number of blisters, and several spikes that shot radially ahead of the ball below the equator. Contact with the ground was made at 0.65 ± 0.05 ms. Thereafter the ball became rapidly smoother. From 1.5-32 ms the time dependence of the shock radius closely followed the relationship

$$R = 564\, (t + 4 \times 10^{-4})^{2/5}$$

At 3 ms there appeared at the bottom of the ball an irregular line of demarcation, below which the surface was appreciably brighter than above. This line rose like the top of a curtain until it disappeared at the top of the ball at about 11 ms. Shortly after the spikes struck the ground (about 2 ms) there appeared on the ground ahead of the shock wave a wide skirt of lumpy matter and within and above the skirt a smooth belt (interpreted as the Mach wave), originally brighter than the main wave but rapidly growing dimmer. Two successive visible fronts dropped behind the well-defined shock wave. The brighter but less sharply limited ball of fire fell behind it at about 16 ms (105 m). At about 32 ms (144 m) there appeared immediately behind the shock wave a dark front of absorbing matter, which traveled slowly out until it became invisible at 0.85 s (375 m). The shock wave itself became invisible at about 0.10 s (2.4×10^2 m) but was followed thereafter to 0.39 s (460 m), first by its light-refracting property and later by the momentum it imparted to a balloon cable.

The ball of fire grew even more slowly to a radius of about 3×10^2 m, until the dust cloud growing out of the skirt almost enveloped it. The top of the ball started to rise again at 2 s. At 3.5 s a minimum horizontal diameter, or neck, appeared one-third of the way up the skirt, and the portion of the skirt above the neck formed a vortex ring. The neck narrowed, and the ring and fast-growing pile of matter above it rose as a new cloud of smoke, carrying a convection stem of dust behind it. A boundary within the cloud, between the ring and the upper part, persisted for at least 22 s. The stem appeared twisted like a left-handed screw. The cloud of smoke, surrounded by a faint purple haze, rose with its top traveling at 57 m/s, at least until the top reached 1.5 km. The later history of the cloud was not quantitatively recorded.

Data not shown in Fig. 9 include quantitative measurements on the refraction of light and the material velocity behind the shock front, in certain intervals; the former can be made to yield the material density as a function of radius behind the shock front.[16]

9.3 Analysis of the Emitted Light

For the analysis of the emitted light, we have density readings on motion-picture negatives, quartz-prism spectrograms for the first few milliseconds with time resolution of the order of 10^{-5} s and for the first 1/5 s with lower resolution, photocell records (partly usable) of the light intensity for the first second, and thermopile records showing that the total radiant energy density received at 10^4 yd was 1.2×10^7 ergs $cm^{-2} \pm \sim 15\%$.

The following observations, among others, seem to deserve special notice.

- During the earliest stages observed by us (radius α 10 to 100 m) the shock wave radius followed Taylor's two-fifths power law: radius times 2/5.
- The shock wave was markedly deformed by the platform: moreover, the radius in other directions was influenced by the presence of the platform.[5]
- A skirt of hot, lumpy matter, thus far unexplained, rose from the ground ahead of the Mach wave.
- The Mach wave was clearly discernible throughout the interval $\sim 10^{-2}$ to 10^{-1} s, and information is available on its kinematics and on its brightness, opacity, and material density.
- The dropping of the ball of fire behind the shock wave produced a minimum in the brightness curve, as predicted. (Theory discussed in Ref. 5.)
- The shock wave was followed, at an increasing time interval as its pressure and temperature decreased, by a sharply defined dark wave front of absorbing material, evidently consisting of one or more of the colored oxides of nitrogen; the dark wave broke away from coincidence with the shock wave at about 144 m, and grew asymptotically to a radius of about 360 m before it became indiscernible.
- The velocity of the shock wave unexpectedly remained nearly constant at twice sound velocity during the expansion in radius from 2.5×10^2 to 4×10^2 m, decreasing by only 15% in this interval instead of dropping nearly to the ordinary velocity of sound. Whereas a slight increase in sound velocity might have been expected from the sudden heating of the air around the ball of fire by radiation, the predominant cause of the observed maintenance of velocity appears to be radiant heating of the shock front by energy absorbed by the dark front as ultraviolet or visible radiation and transformed there to lower frequencies, as suggested by Magee.
- The emission spectrum had a violet cutoff that was a function of time: the highest wave number emitted at any time was $3.34 \times 10^4 cm^{-1}$, which coincides, within the error of the determination, with the cutoff characteristic of ozone formation.

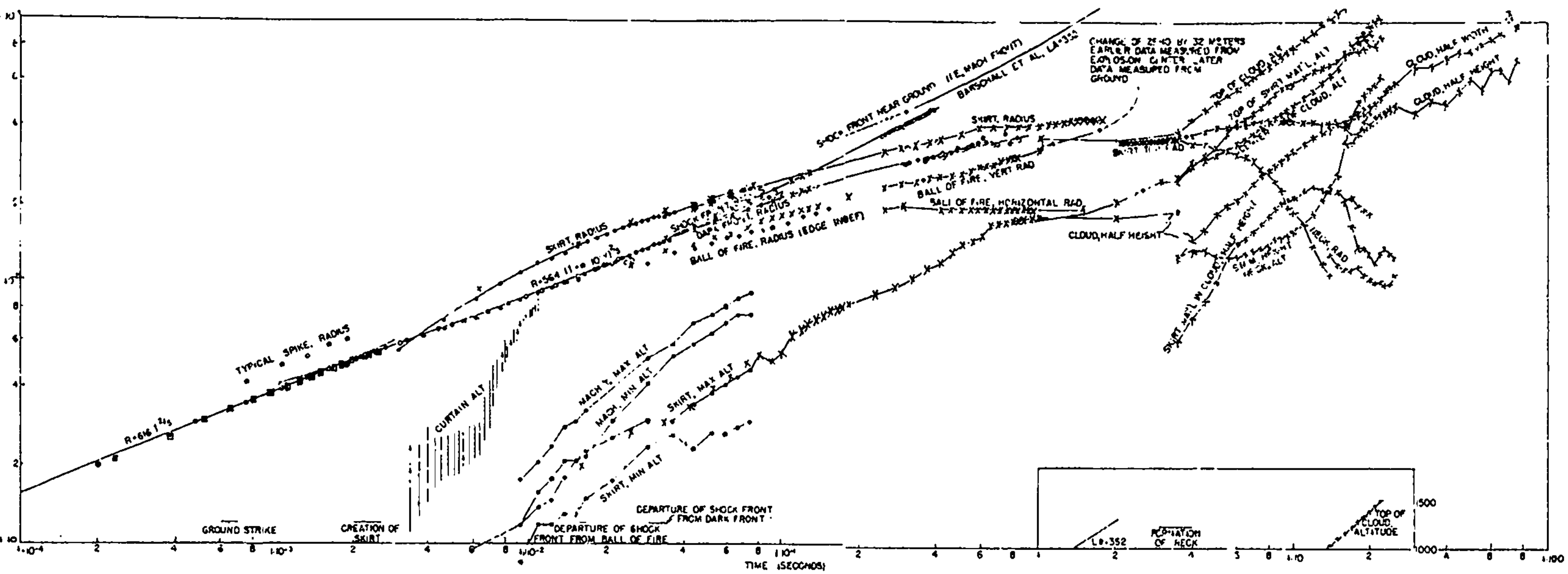

Fig. 9.
Summary of optical space-time data.

⊡ *8mm, 7110/s. W 800 F = 2 in.*
ʘ *16mm, 3560/s. W 10,000 F = 6 in.*
• *16mm, 655/s. N 10,000 F = 6 in.*
× *35mm, 107/s. N 10,000 F = 18 in.*
\+ *35mm, 24/s. N 10,000 F = 3 in.*
⊗⊗ *35mm, 119/s. W 10,000 F = 24 in.*

10. SUMMARY OF TRINITY EXPERIMENTS AND INDEX OF REPORTS (K. T. BAINBRIDGE)

TRINITY EXPERIMENTS

Measurements	In Charge	Equipment or Method
I. IMPLOSION		
(1) Detonator Asimultaneity	K. Greisen E. W. Titterton	Detonation wave operated switches and fast scopes
(2) Shock wave transmission time	D. Froman R. Sutton	Interval from firing of detonators to nuclear explosion recorded on fast scope
(3) Multiplication factor (α)	R. R. Wilson	(a) Electron multiplier chambers and time expander
	R. R. Wilson	(b) Two-chamber method
	B. Rossi	(c) Single coaxial chamber, coaxial transformers and direct deflection high-speed oscillograph
II. ENERGY RELEASE BY NUCLEAR MEASUREMENTS	R. R. Wilson	
(1) Delayed gamma rays	E. Segre	Ionization chambers, multiple amplifiers, Heiland recorders, ground and balloon sites
(2) Delayed neutrons	H. T. Richards	(a) Cellophane catcher and 25 plates, on ground and airborne
		(b) Gold foil detectors to give integrated flux
		(c) Sulphur threshold detectors 8 units
(3) Conversion of plutonium to fission products	H. L. Anderson	(a) Determination of ratio of fission products to plutonium
	D. Frisch J. M. Hubbard	(b) Collection of fission products and plutonium or 25 on filters from planes at high altitude
III. DAMAGE, BLAST, AND SHOCK	J. H. Manley	

Blast	J. O. Hirschfelder	
(1) Piezo	R. L. Walker	Quartz piezo gauges—22 units
(2) Condenser	W. C. Bright	(a) Condenser gauges, frequency modulation type C.I.T.—8 units
	B. Waldman	(b) Condenser gauges, C.I.T. type dropped from B-29 planes—6 units, 2 planes
(3) Excess velocity	H. H. Barschall	(a) Moving coil loudspeaker pickup—10 stations
		(b) From piezo time records
	J. E. Mack	(c) Optical method. Blast-operated switches and torpex flash bombs
	J. E. Mack	(d) Schlieren method—one station
(4) Peak pressure	H. Sheard D. Littler	(a) Spring-loaded piston gauges—8 units, intermediate pressure range 2.5- 10 psi
	H. Sheard D. Littler	(b) Same gauges—12 units, above ground and in slit trenches, 20- 150 psi in range
	W. G. Penney F. Reines	(c) Crusher-type gauges
	J. C. Hoogterp	(d) Aluminum diaphragm "box" gauges—52 units 1- to 6-lb range
(5) Remote pressure barograph recorders	J. H. Manley	19 Friez ML-3-A No. 792 barographs
(6) Impulse gauge	T. Jorgensen	12 mechanically recording piston liquid and orifice gauges, 4 each for 3 yield values
(7) Mass velocity	J. E. Mack	Suspended primacord and magnesium flash powder viewed by Fastaxes
(8) Shock wave expansion	(H. Bethe) J. E. Mack	Fastax cameras at 800-yd stations

Earth Shock	J. H. Manley	
(1) Geophone	H. M. Houghton	12 velocity-type moving coil strong motion geophones
(2) Seismographs - Leet	L. D. Leet	Five Leet three-component strong motion displacement seismographs
(3) Permanent earth displacement	W. G. Penney F. Reines	Steel stakes for level and vertical displacement measurements
(4) Remote seismographs	G-2	Tucson, El Paso, Denver observations
Ignition of Structural Materials		
(1) Roofing and wall materials	W. G. Marley F. Reines	Roofing, wood, and excelsior on stakes
IV. GENERAL PHENOMENA		
(1) Behaviour of ball of fire	J. E. Mack	(a) Six 8000 frames/s Fastaxes
		(b) Two 4000 frames/s Fastaxes
		(c) Two 800 frames/s Fastaxes
		(d) Fifteen color cameras, standard 16 mm
		(e) One Cline-Special 24 frames/s
	Lt. C. D. Curtis	(f) Two SCR-584 radars
(2) Rise of column	J. E. Mack	(a) Four 100 frames/s Mitchells. one 24 frames/s 16 mm
		(b) Two pinhole cameras
and ball of fire	P. B. Moon	(c) Two gamma-ray cameras
(3) Mushrooming and lateral movement	J. E. Mack	(a) Two Fairchild 9- by 9- in. aero view cameras at N-10 000 and W-10 000
		(b) Two Fairchild cameras 20 mi NE for stereo-photos

		(c) Two Fairchild cameras 20 mi E for stereo-photos
and rise of column	Capt. M. Allen	(d) Day or night position plotting by search-light equipment
(4) Blast cloud effects	F. Reines analysis	J. E. Mack photos J. Aeby photos
Radiation Characteristics		
(1) Spectrographic	J. E. Mack	Two Hilger high-time resolution 10^{-5}-s spectrographs Two Bausch & Lomb spectrographs
(2) Total radiation	D. Williams J. E. Mack	Two thermocouples and recording equipment
(3) Photometric	J. E. Mack	Two units—moving film and filters Six photocells and filters recording on drum oscillograph
V. POSTSHOT RADIATION MEASUREMENTS		
(1) Gamma-ray sentinels	P. B. Moon	Sixteen ionization chambers which recorded at 10 000 yd shelters
(2) Portable chamber observations in high-gamma flux region	H. L. Anderson	Observations were made from the tanks using portable ionization chambers. standard design
(3) Dustborne product survey	L. H. Hempelmann	Portable alpha. gamma ionization chambers and Geiger counters
(4) Airborne products	J. M. Hubbard D. Frisch	B-29 planes equipped with special air filters
(5) Detailed crater survey	P. B. Moon	Ionization chambers and Watts- type amplifiers
VI. METEOROLOGY	J. M. Hubbard	Complete instrumentation and weather information

RESULTS

Results	July 16 Nuclear Explosion Report	In Charge	100-ton Test Report
Records fogged by gamma rays.			
Equipment Test		M. Blair	
Record obtained from 600-m station. Energy release consistent with H. Anderson figure.			
Number of neutrons per cm^2 per unit logarithmic energy interval was measured for 7 stations, 300-1000 m.			
Two of 8 units recovered. Given flux for energies 3 MeV at 200 m			
Tracer Test 18 600 tons TNT		Anderson Sugarman	LA-282 LA-282A LA-290
No results from TR shot dust after it circled world. Indications from Hiroshima; nothing from Nagasaki.			
General blast considerations	LA-316	W. D. Kennedy	LAMS-247
No records. Traces thrown off scale by radiation effects.	LA-366	Walker	LA-286
No TR records. Shot had to be fired when planes out of position. 100-ton records and combat records		Waldman	
Obtained velocity of sound for a small charge and then excess velocity for bomb. Yield 10 000 tons		Barschall	LA-291
Blast pressure values low compared with all other methods		Not armed	
Highest pressure range	LA-431		

9900 ± 1000 ton TNT equivalent	LA-354	Hoogterp	LA-288
Consistent with 10 000 ton	LA-360		
Consistent with 10 000 ton	LA-355	Jorgensen	LA-284
19 000-ton *total* yield			
Extrapolation from small charge and 100-ton data gives 7000 ton	LA-351	Houghton	LA-287
Approximately 15 000 ton	LA-438	L. D. Leet prognosis	LA-439
10 000 ± 5000 ton	LA-365 LA-365A	Penney	LA-283 LA-292
No effect at these distances	None	See Leet report	LA-439
Risk of fire produced by radiant energy is small	LA-364		
(General prospectus)	LAMS-165 LA-531		
Two plots of cloud obtained. Radar reflection not favorable.	LA-430		
The first 18 mi of the main cloud path height was triangulated	LA-448 LA-531 LA-353	J. E. Mack	
These units were extremely valuable in giving the distribution of radioactive products immediately after the shot until safe stable conditions were assured		Moon	Trial for blast effects only
About 4 h after shot ionization data from the chambers were radioed back to the control shelter		Anderson Hempelmann	Trial of tanks and rockets

Local TR ionization and at remote points to 200 mi was measured for dust-deposited fission products	LAMS-277		
See Sec. 10, II. 3. b	LA-418		
After 4 wk, approx 15 R/h at edge of scoured crater, 0.02 R/h at 500 yd	LA-359	Anderson	LA-282 LA-282A LA-290
See complete report. Weather data obtained up to 45 min prior to shot at Point 0 to 20 000 ft and 25 min after shot. Low-level smoke studies made in event of a fizzle.	LA-357	Hubbard	LA-285

11. RECOMMENDATIONS FOR FUTURE OPERATIONS (K. T. BAINBRIDGE)

11.1 Measurements

These recommendations are made on the basis that the gadget under test incorporates some radical changes in design from the Model 2 used at Trinity and at Nagasaki. Therefore, the most important measurements of the test will be those concerned with the internal behavior of the gadget and the measurements of its energy release. Two cases should be considered—a ground test and an airdrop test over ground.

A ground test has the advantage of giving the maximum amount of information concerning the behaviour of the gadget, and it would permit fundamental physics experiments to be carried out which could only be conducted at great cost in time and personnel or could not be conducted at all if an airdrop test were made.

There have been newspaper accounts that the Navy has definitely decided on the tests of one or more gadgets from the stockpile. If this program goes through, then in addition to the measurements recommended for an airdrop test it would be useful to plaster the Navy ships inside and out with gold foil, sulfur, and ^{235}U neutron detecting equipment and equivalent films and automatic recording ionization chambers for gamma rays. These should be buoyant and recoverable in the event the ships so treated are sunk during the test.

11.1.1. Ground Test. The recommendations for experiments which should be included in the ground test are as follows (for details refer to the corresponding numbers in the chart on experiments for the July 16th nuclear explosion, Sec. 10).

Blast	Changes or Remarks
I. IMPLOSION	
(1) Detonator asimultaneity	---
(2) Shock wave transmission time	---
(3) Multiplication factor (b,c)	Three sets of equipment for maximum accuracy at different generation times.
II, ENERGY RELEASE (by nuclear measurements)	
Prompt gamma *and* delays. Total gamma irradiation	More for medical reasons. Not used in Trinity test.
(2) Delayed neutrons (a,b,c)	---
(3) Conversion of plutonium to fission products	---
a. On ground	---
b. In air	Extension over TR program
III. DAMAGE, BLAST, AND SHOCK <u>BLAST</u>	
(1) Piezo gauges	Thermally insulated by concentric aluminum foil shells

(2) Condenser gauges

a. On ground

b. Dropped from airplanes

The number cannot be increased over that planned for the TR test because of crowding of radio channels. If it is desired to increase the number of gauges, then considerable development will have to be done.

(3) Excess velocity

This was one of the most successful blast measuring methods (a)

(4) Peak pressure (a,b,c,)

Many more of these gauges should be used if they can be developed into reliable instruments

Inexpensive and reliable (d)

(5) Remote pressure barograph recorders

Necessary for legal reasons

(6) Shock wave expansion

From ground sites, and from airplanes for practice for future tests

EARTH SHOCK

(2) Seismographs—Leet

Necessary for legal reasons

(3) Permanent earth displacement

This is a simple measurement and is of interest because of the new phenomena encountered in the July 16 test

(4) Remote seismographs

The reverend seismographers will never forgive you if you do not give them a warning of the test.

IGNITION OF STRUCTURAL MATERIALS

The Army, the Navy, and de Seversky will want to define this.

IV. GENERAL PHENOMENA

(1) Behavior of ball of fire (a,b,c,d,e)

(2) Rise of column (a)

These photographic records are extremely valuable, and this part of the work should certainly be expanded

(3) Mushrooming and lateral movement (a,b,c,d,)

Radiation Characteristics

(2) Total Radiation

V. POSTSHOT RADIATION MEASUREMENTS	
(1) Gamma-ray sentinels	---
(2) Portable chamber observations in high-gamma flux region	---
(3) Dustborne product survey	---
(4) Airborne products	See II.3.b.
VI. METEOROLOGY	Vitally important, and the sooner the group starts at a new site, the better.

Additional suggestions by P. B. Moon follow.

1. "That ionization sentinels, signalling by radio instead of by line, be taken out and deposited in the field *after* the shot in addition to those of the previous type that were installed before the shot. In this way readings could be obtained from the area of the crater. The sentinels could be taken out by the lead-lined tanks. This suggestion was made to me by F. Oppenheimer.

2. "That in order to elucidate the remarkable fogging of films buried .5 ft underground, specimens of suitable neutron-activatable and gamma-activatable radioactive indicators be buried at various depths and distances and recovered for examination after the shot. This suggestion was appended by me to the LA-430 (Ref. 15) report on our attempts to obtain gamma-ray kinephotographs.

"Weisskopf has since suggested that photographic films might also be buried."

11.1.2. **Airborne Drop Test.** Recommendations for tests which from past experience could be accomplished for an airborne drop are as follows. Numbers correspond to those in Sec. 10.

Blast	**Changes or Remarks**
I. IMPLOSION	
(1) Detonator asimultaneity	This is difficult and was not licked in the period November 1944—July 1945.
(2) Shock wave transmission time	This could be handled by an amplitude-modulated transmitter. A continuous low-amplitude signal from the bomb would give a recorder something to tune on; the first detonator increases the amplitude; the explosion kills the transmitter entirely.
(3) Multiplication factor (α)	No airborne scheme has yet been suggested that could compete with the Rossi method on the ground or in the air. The two-chamber method might be feasible.

II. ENERGY RELEASE (by nuclear measurements)	
(3) Collection of fission products and plutonium or 25 on filters from planes at high altitude	See Ref. 18.
III. DAMAGE, BLAST. AND SHOCK	
BLAST	
(2) Condenser gauges (a,b)	---
(4) Peak pressure (d)—aluminum-diaphragm box gauges	This is an inexpensive and reliable method for blast measurement.
(5) Remote pressure barograph recorders	Necessary for legal reasons.
(8) Shock wave expansion	If possible, airborne and ground-located cameras.
EARTH SHOCK	
(1) Geophones	For scientific interest.
(2) Seismographs - Leet	For legal reasons.
IGNITION OF STRUCTURAL MATERIALS	
IV. GENERAL PHENOMENA	Important and should be expanded.
(1) Behavior of ball of fire (a,b,c,d,e)	
(2) Rise of column (a,b)	
(3) Mushrooming and lateral movement (a,b,c)	
V. POSTSHOT RADIATION MEASUREMENTS	
(1) Gamma-ray sentinels	One set in place; one set introduced afterwards.
(3) Dustborne product survey	---
(4) Airborne products	See II.3.b.
VI. METEOROLOGY	Extremely important.

11.2. Preparations and Administration

1. A firm directive should be obtained for a test at least 6 months in advance for operations within the continental limits of the United States. This assumes that a location for the test has been agreed upon.

2. A firm agreement should be obtained from the higher administration on personnel policy and the procurement of personnel. J. R. Oppenheimer gave 100% backing to the transfer policy he initiated.

3. It is essential to have a first-class man in charge of "services" and to have all services under one head. J. H. Williams did a supreme job in this work.

4. It is essential to have the base camp installations complete 4 months before the date of the test.

5. The wiring should be complete at the latest 1 month before the test, which means that 90% of the requirements should be known 4 months prior.

6. No new experiments should be introduced later than 6 wk before the test.

7. *No new equipment of any kind, electrical or mechanical, should be installed or removed after the first test rehearsal* except as required to minimize pickup and interference encountered in the first rehearsal.

8. An examination of the organization of TR-1, TR-2, TR-3, etc., will give a realistic estimate of the minimum number of men required per job and per experiment.

9. There should be increases in the timing staff. The large amount of testing and calibration made it very difficult for one man to carry the load. Both J. L. McKibben and E. W. Titterton were overloaded almost beyond human endurance for the period of 2 wk preceding the test. Eighteen hours a day, for 2 wk, is too much, and whoever takes their positions should have two aides with nothing else to do but keep up-to-date on the system and aid in the installation, test, and calibration work.

10. The same applies to whoever takes Sgt. Jopp's position: he was called upon day or night whenever any emergencies arose, such as broken wires, or when unauthorized and unreported splicing of wires was done by some irresponsible person in a hurry. Shooting is much too good for anyone who crosses up the wires. All changes in the wiring must be channelled through one office: in our case, Sgt. Jopp.

11. All shielding of equipment within a range of 1000 yd for a 20 000-ton gadget should be gas tight, and if earth covered, a concrete apron and shield must be provided. There is evidence at 300 yd that radioactive gases were blown into equipment and cooled and condensed there. At 800 yd earth embankments were scoured away, which decreased the shielding for delayed radiations.

12. Whoever has the overall responsibility for the test should insist on review power over any newspaper releases to make sure the facts, if any, are correct and to avoid the tripe and incorrect statements which appeared in the official release.

13. The FM Motorola radios are perfectly satisfactory day and night within a 15-mi radius, and there are many cases where they did good duty up to 40 mi. However, for any distances greater than 15 mi, sufficient radios of the SCR-299 type, or lighter models if possible, should be used.

14. All instruments should be started automatically by remote control. No one should have to throw any switches after the arming switches and timing sequence switches have been closed.

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APPENDIX

PHOTOGRAPHIC ACCOUNT OF TRINITY TEST

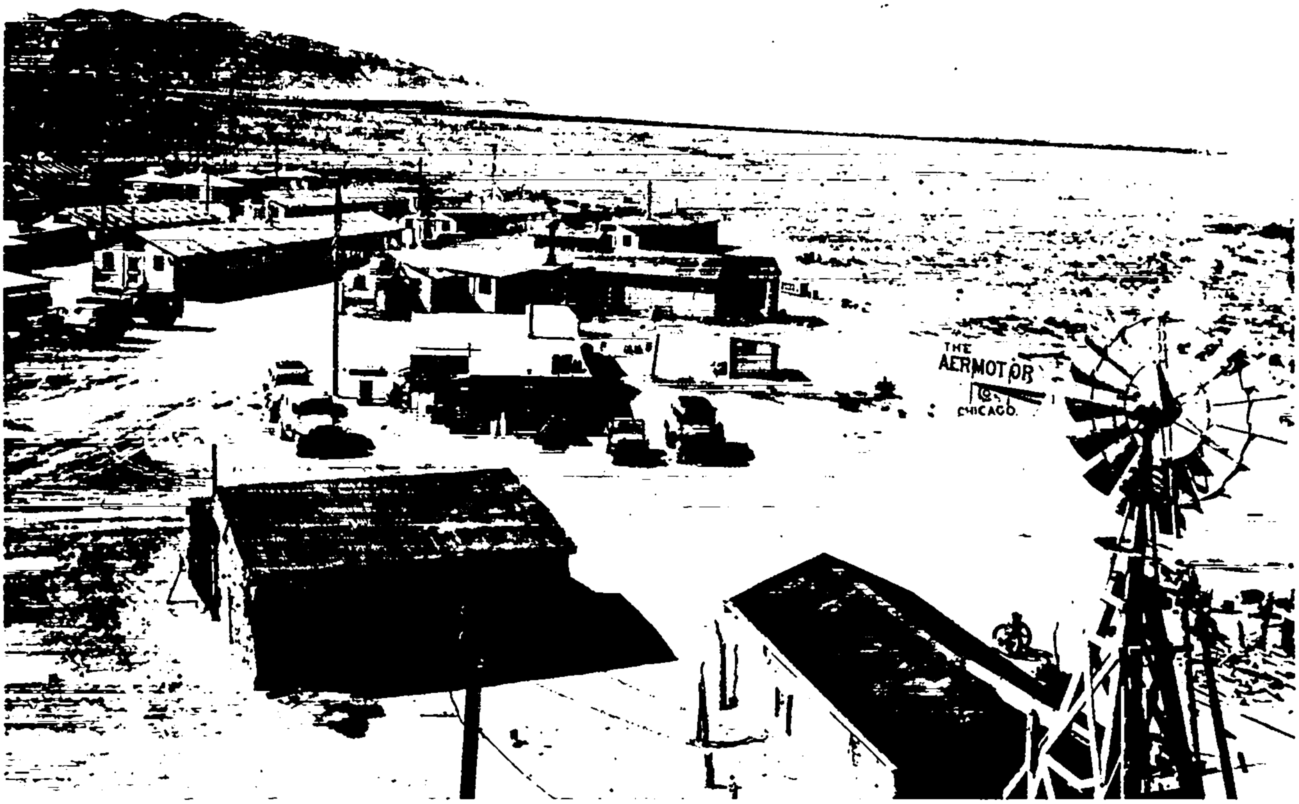

Fig. A-1.
Base camp.

Fig. A-2.
Oscuro Mountains on edge of firing site.

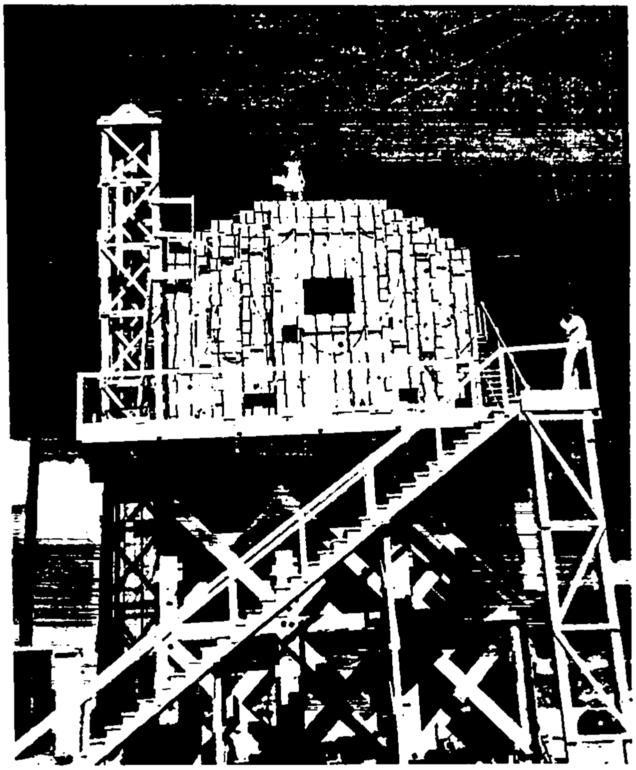

Fig. A-3.
Tower with 100 tons of explosive used as a blast calibration shot 10 wk before test.

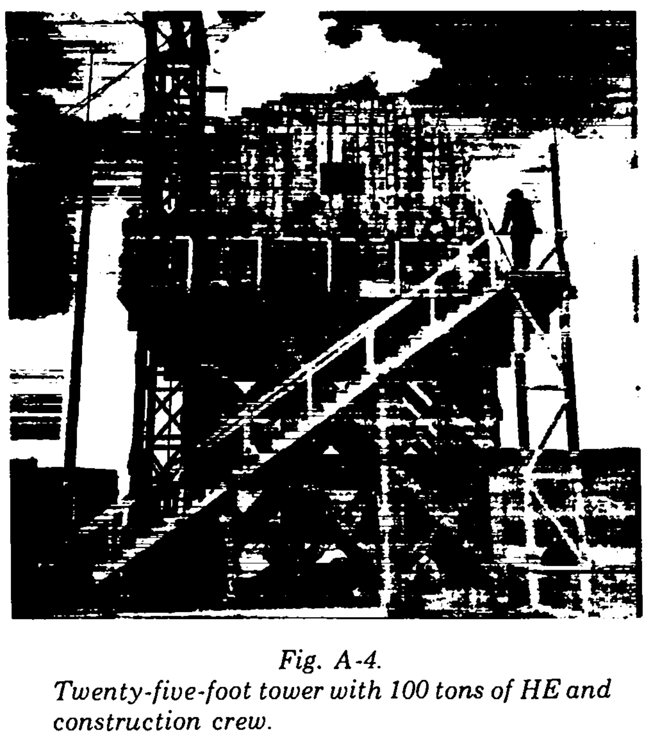

Fig. A-4.
Twenty-five-foot tower with 100 tons of HE and construction crew.

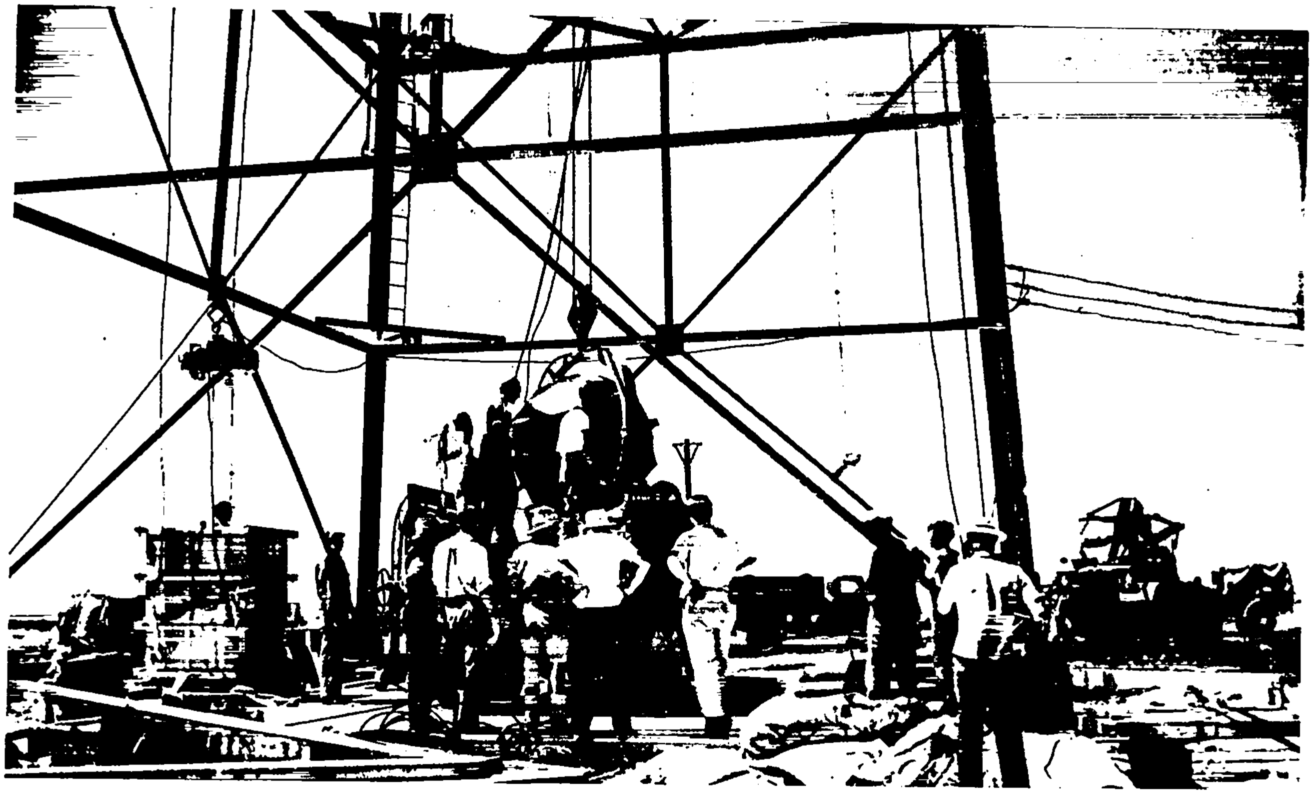

Fig. A-5.
Trinity bomb being hoisted to top of tower.

Fig. A-6.
Bomb tower with equipment ready to be raised.

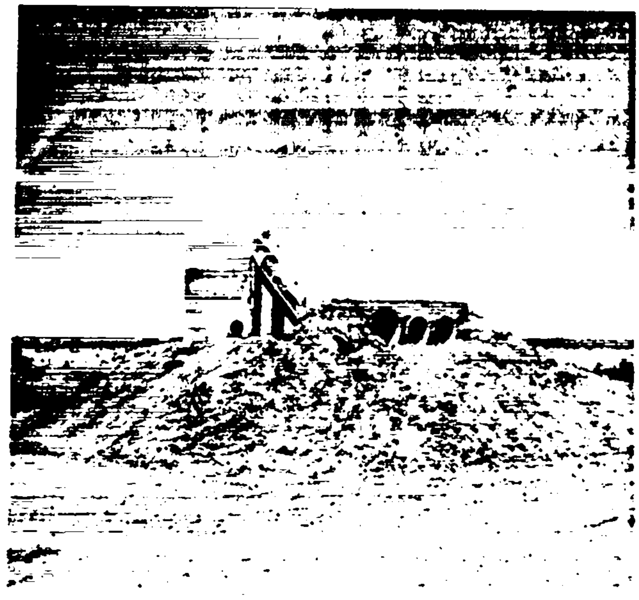

Fig. A-7.
Typical photographic bunker.

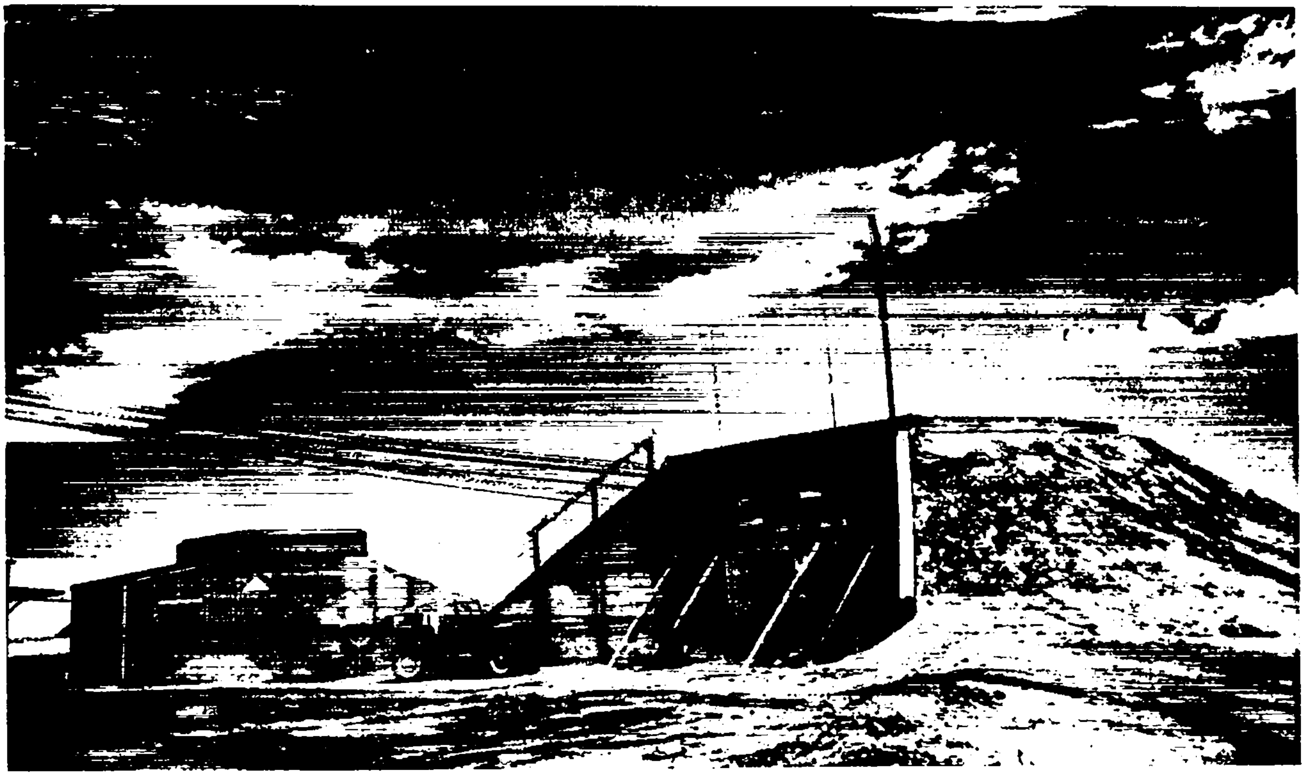

Fig. A-8.
Main instrumentation and firing bunker.

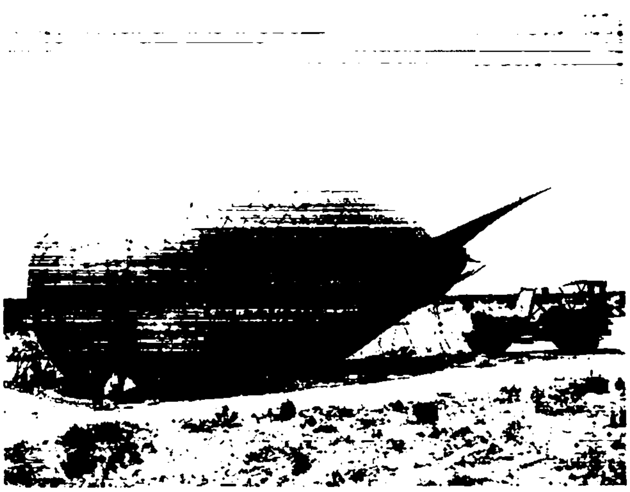

Fig. A-9.
One of two barrage balloons used to suspend airborne neutron flux vs time cameras.

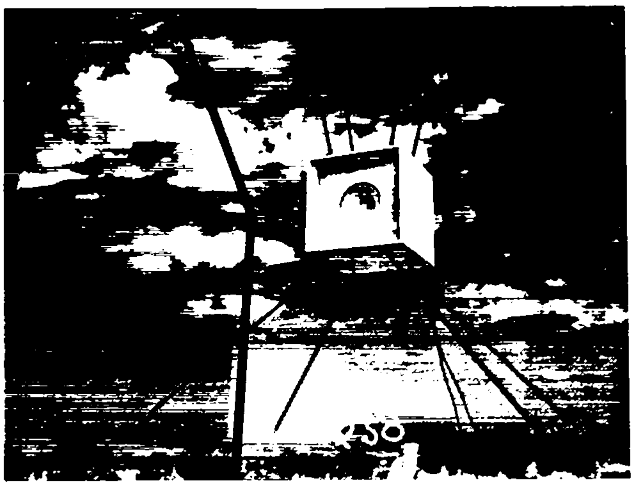

Fig. A-10.
Typical blast wave guage.

Fig. A-11
Jumbo being delivered.

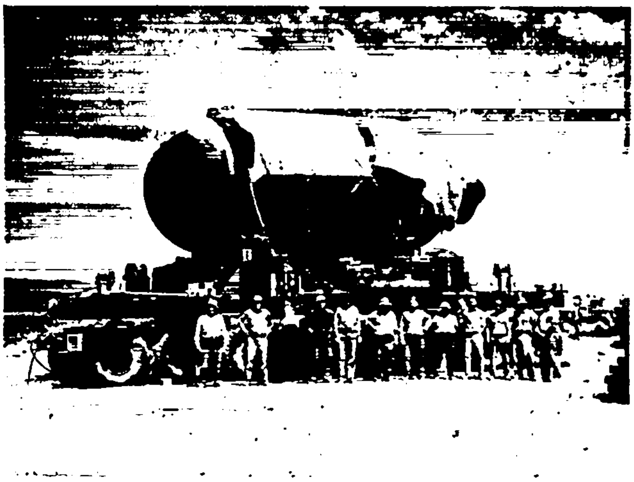

Fig. A-12
Jumbo on trailer.

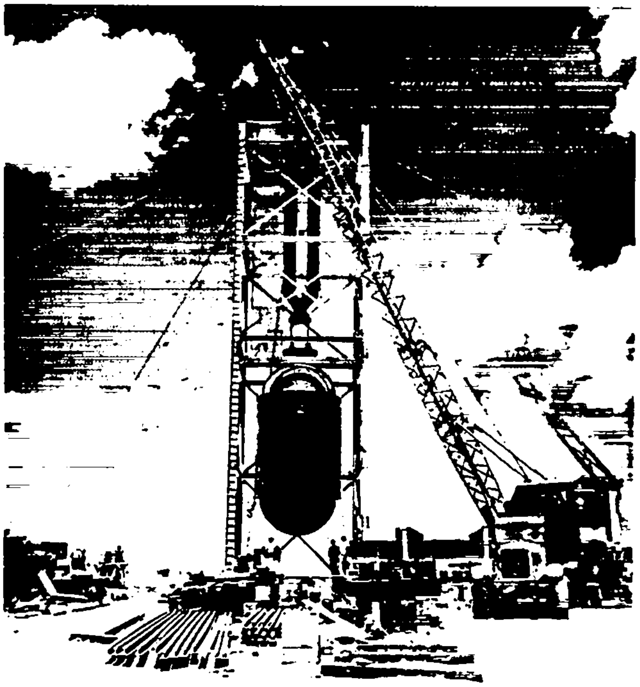

Fig. A-13.
Jumbo set up on 50-ft tower.

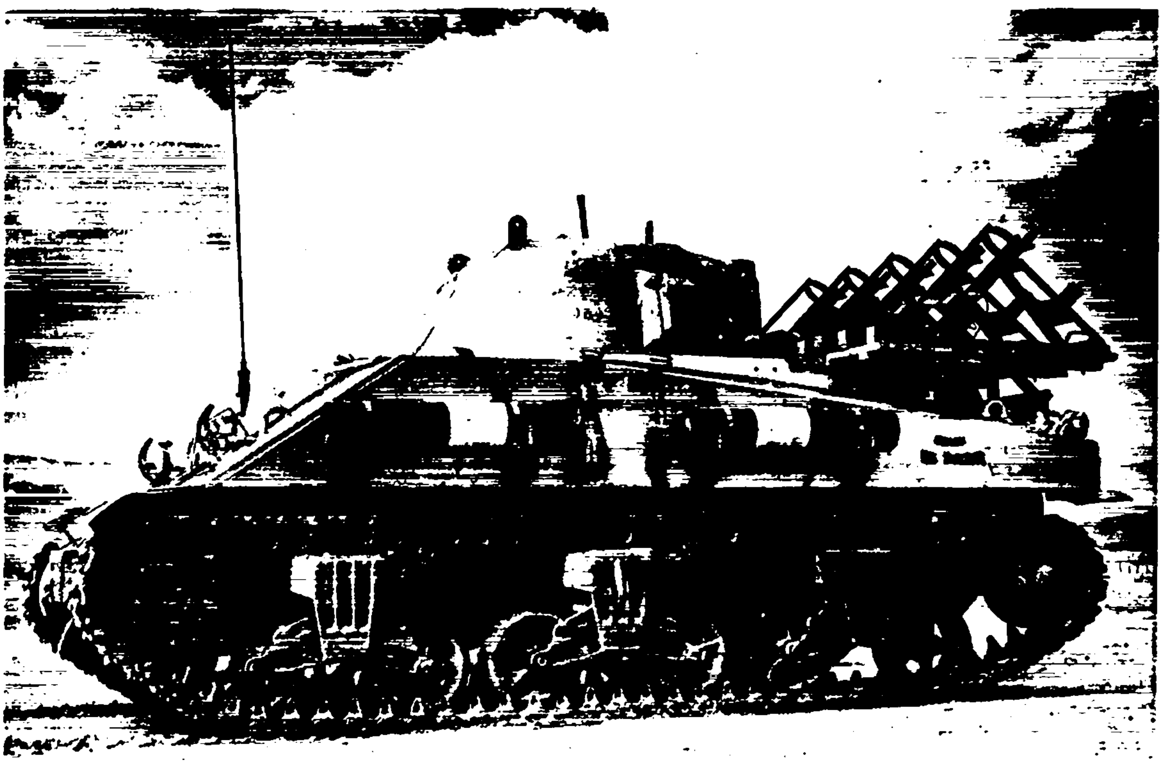

Fig. A-14.
Special tank with lead lining and air bottles mounted on side for air supply for crew. Trap door underneath permitted earth samples to be scooped up while tank was in crater.

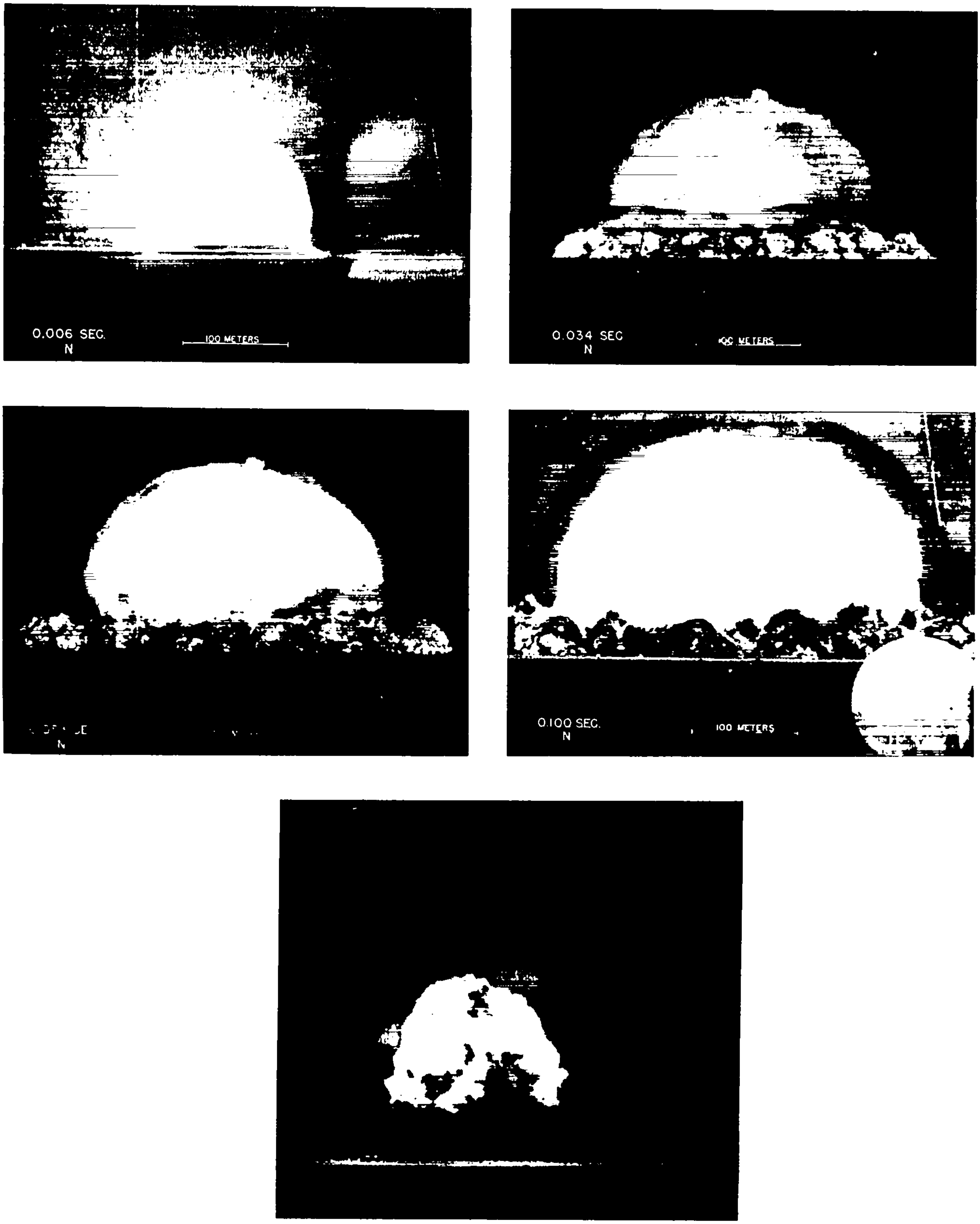

Fig. A-15.
Sequential shots of burst.

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