17 April 1945

TO: Major General L. R. Groves

From: R. C. Tolman

Subject: Program for Trinity Test

1. Purpose of Test.

This brief description of the technical aspects of the program for the proposed Trinity Test is made in response to your recent request.

The purpose of the Trinity Test is to obtain as much information as possible from the proof firing of an implosion nuclear bomb, substantially identical with the first models which are being designed for combat use. In contrast to the case of the gun assembly type of bomb, such a proof firing is regarded as necessary in the case of an implosion bomb in view of the present unavoidable uncertainties as to the behaviour of the implosion process. If the nuclear reaction, set off by the implosion, does not result in a satisfactory high order nuclear explosion, the test will be important in diagnosing the cause of the trouble and in suggesting necessary modifications in design. If the nuclear explosion does take place high order, the test will be important in determining the extent of blast damage, the extent of the toxic radioactive effects, and the nature of behaviour of the upper air to be expected in military use of the weapon.

2. General Character of the Test.

The test is being carried out at an isolated location "Trinity", with sufficient area under military control and guard, to provide the distances necessary for making the desired measurements, for providing protection for the personnel conducting the tests, and for assuring the safety of inhabitants of the region. It is my opinion that proper attention is being given to these questions.

The results of the Trinity firing will of course be correlated with the studies of the implosion process being made at Los Alamos, and also with the existing body of information as to the effects produced both by the experimental and accidental detonation of various amounts of ordinary high explosives.

In addition various small scale tests of the effects of explosions are being made both at Los Alamos and Trinity to prove in experimental methods and to settle specific points. For example, tests on crater formation have already been made at Trinity to determine the effects of the particular soil structure at that location.

The first large scale test at Trinity, which is now scheduled for 5 May 1945, will consist in the firing of 100 tons of ordinary high explosive, stacked in the form of an octagonal cylinder, approximately 18 feet high, on the platform of a 20 foot tower. The charge will consist primarily of some 3590 boxes each containing 50 lbs. of TNT, supplemented at six points by boxes of composition B, among which will be special boxes prepared to receive the tetryl boosters which will initiate the explosion. Pipes of plastic tubing of appropriate composition will be inserted horizontally into the pile in a regular array, into which will be introduced a radioactive tracer mixture consisting of a dissolved "slug" from Hanford. This preliminary test will make it possible to make a realistic trial of all measurements to be employed in the final test except those having to do with the special character of a nuclear explosion.

The final principal test at Trinity is now scheduled for 4 July 1945. It will consist in the static firing of an implosion bomb substantially identical with those being designed for incorporation in the "fat man" and for combat use. The bomb will be of the so-called Christy type,

The present expectation is that the chances for successful high order detonation will be sufficiently great so that the bomb should be exploded in the open air without attempt to recover active material in case of a fizzle. This will be done on the platform of a steel tower 100 feet high, - this distance above ground scaling in accordance with the "cube root law" with the distance above ground of 29 feet to the center of the 100 ton charge.

All plans for measurements are being made on the basis of such an open air firing. If later estimates as to the probability of successful detonation make it necessary to fire inside "Jumbo", to allow for recovery in case of a fizzle, some of the proposed measurements will not be feasible at all, and most of them -- in case high order detonation is achieved -- will be much less immediately applicable for predicting the effects to be expected in actual combat use from explosion in open air.

3. Program of Measurement and Observation.

The primary measurements and observations, to be taken at the time of the explosion, may be grouped under four main headings in accordance with the sequence of events which occur and must be studied after the implosion of the high explosive is started. These headings may be taken as:-

1) Behaviour of the Implosion.

2) Nuclear Energy Released.

3) Damage Effects Produced.

4) Overall Behaviour of the Explosion and its After Effects.

The behaviour of the implosion will be studied by determining the time interval within which the detonators for the high explosive act, the time interval between the action of these detonators and the initiation of the nuclear reaction, and if possible by obtaining a complete time record of the rise of nuclear activity after initiation. The amount of nuclear energy released will be measured by various methods of determining the number of nuclear fissions which have taken place. The study of the damage effects produced will involve measurements of blast pressure in air, and of displacements and crater formation in earth. The overall behaviour and after effects will be mainly studied by photographic and spectrographic observations. The specific measurements and observations falling under the above headings will be described in more detail in later sections.

The personnel carrying out the above program will be working in shelters built at three stations, located 10,000 yards from the zero or firing point, to the south, west and north. The shelters are of strong enough construction to protect against fragment damage even if "Jumbo" is used, and the blast pressure at 10,000 yards is expected to have dropped to a safe figure of 0.3 lbs. per square inch. The prevailing winds to be expected are from a south-west direction, and the nearest town to the east is across a mountain range 28 miles in a southeasterly direction, so that protection from toxic radioactive effects should be good both for scientific personnel and local inhabitants.

Receiving instruments for different types of measurement will be located at various distances from the zero point and will transmit their signals electrically by wire to the south, west, and north 10,000 yard stations. In addition, signals from certain pressure gauges will be transmitted by radio. Firing will be controlled from the south 10,000 yard station which is nearest to the base camp. About twelve men will be needed at the south 10,000 yard station for measurements on implosion and nuclear behaviour; about twelve men at the west 10,000 yard station for controlling photographic and spectroscopic exposures, for making observations on cooperating airplanes and on meteorological phenomena, and in readiness for sample collection; and about fifteen men at the north 10,000 yard station for measurements on air blast, and for photographic observations.

In addition to the primary measurements and observations mentioned above, meteorlogical observations will be necessary to study beforehand the behaviour of winds over the mountains to the east, to forecast the weather as the proposed firing time approaches, and to study the meteorological phenomena produced by the explosion itself. Futhermore, after the explosion, measurements of radioactive contamination will be made in the neighborhood of the firing point and in the mountains and territory to the east. Such measurements will be needed for the protection of the scientists in the work to be undertaken after the explosion, and for the protection of local inhabitants. It is now expected that the best time for firing will be at about an hour before sunrise, at a time when wind velocities are low, and when photographic and spectrographic observations will not be disturbed by direct sunlight. Such an early firing hour will also provide a long daytime in which officials in charge of health protection can secure evacuation from contaminated areas if this proves necessary on the basis of their radioactive measurements.

4. <u>Organization for Carrying Out the Program.</u>

The scientific and technical aspects of the program outlined above are under the general direction of Dr. K. T. Bainbridge as Head of the Trinity Project. The work under him

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is organized into six divisions, TR-1 to TR-6, under six Group Leaders, and he is assisted in planning and carrying out the work by a number of consultants and by officers of the Post. The organization chart of the project as of the present date is approximately as follows:

Organization Chart for the Trinity Project

	K. T. Bainbridge	Head
	V. Weisskopf	Consultant on Theory
	W. J. Penney	Consultant on Damage
	Ens. G. T. Reynolds	Consultant on Damage
	J. Hirschfelder	Consultant on Expected Behavior
	R. W. Carlson	Consultant on Structures
	S. Kershaw	Safety Committee Representative
	Capt. S. P. Davalos	C. O. Engineer Det. at Trinity
	Lt. H. C. Bush	C. O. MP Det. at Trinity
	Lt. R. A. Taylor	Military Security
TR-1	J. H. Williams	Technical Services
	~~Lt. Comdr. T. Keiller~~	~~Deputy~~
	K. W. Marlowe	Timing, locking, telephone communication.
	Man from G-4	Radio Communications
	R. J. Van Gemert	Purchase and follow-up
TR-2	J. H. Manley	Air Blast and Earth Shock
	W. C. Bright	Condenser gauges
	R. L. Walker	Piezo gauges
	J. C. Hoogterp	Paper gauges
	T. Jorgensen	Blast impulse
	H. H. Barschall	Excess blast velocity
	J. H. Coon	Earth displacement and crater
		Geophones and seismographs
TR-3	R. R. Wilson	Physical Measurements
	P. B. Moon	Consultant
	R. R. Wilson	Intensity of prompt gamma rays
	J. H. Williams	Intensity of delayed neutrons
	E. H. Segre	Intensity of delayed gamma rays
	P. B. Moon	Intensity of delayed gamma rays
	H. L. Anderson	Assay of 49 conversion
	L. H. Hempelmann	Extent of contamination
TR-4	J. Hubbard	Meteorology
	Lt. C. D. Curtis	SCR-584 radar on corner reflectors
		Motion of ball of fire
TR-5	J. E. Mack	Photography and Spectroscopy
	With team from G-11	
TR-6	B. Waldman	Airborne Measurements
	With team from O-2	

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This organization chart gives only a partial picture of the responsibilities that will have to be assumed by the men listed and by others who will be associated. The picture will be supplemented by more detailed descriptions of the different measurements in later sections.

In addition to the operating organization as described in the above chart, appropriate committees have been set up for giving preliminary approval to new measurements of different kinds that may be proposed for inclusion in the program, and a master committee has been set for giving final approval with due consideration to the program as a whole, time schedule, space and wire available, priority, possible duplication, possible field interference, etc. The extent of the program is also limited by ceilings imposed by the Director on the number of man-shop-hours allowed, both in the machine and electronic shops, for the Trinity project.

We may now turn to a brief but more detailed description of the different measurements and observations that have been accepted for inclusion in the program as of the present date.

5. Behaviour of the Implosion.

Determination of the character of the implosion which leads to the nuclear explosion is of the greatest importance. The study of implosions has, however, turned out to be very difficult even at reduced scale and in the absence of nuclear material. In the Trinity test only the following measurements can be profitably made.

a. Detonator Simultaneity. The standard electronic apparatus developed for use in the Kingman drop tests to determine the timing of detonators, inserted into "dummy" blocks, will be adapted for the Trinity test. This apparatus will provide a record of the time interval between the firing of the first and last [redacted] used to detonate the high explosive. If successful this time interval should not be longer than [redacted] If a considerably longer time interval occurs, an assymetrical implosion and a nuclear explosion of reduced efficiency are to be expected. W. A. Higinbotham and K. Greisen will be responsible for the apparatus used, and the method of measurement is expected to be successful because of the standard character of the apparatus.

b. Time Interval Between Detonator and Nuclear Action. A measurement will be made of the time interval between the

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action of the detonators and the reception of the first gamma rays coming from the nuclear reaction. This time interval should be By comparing the actual value found with that which would be predicted, for a successful implosion combined with a successful initiation of the nuclear reaction at the right time, it may be possible to draw conclusions as to the actual behaviour of the implosion process and of the beryllium-polonium initiator which produces the burst of neutrons that starts the nuclear reaction. This measurement will be made by R. R. Wilson and has a high chance for successful performance, but may be difficult to calibrate.

c. Determination of α for the Nuclear Reaction. After the nuclear reaction is initiated, the intensity of the reaction, i.e. the rate at which neutrons are being formed or at which fissions are occurring, may be set proportional to a term of the form $e^{\alpha t}$, where α may be called the activity of the 49 core and t is the time after initiation. The activity α depends on the density of the 49 core and is a maximum when this is a maximum. Hence, if the reaction is initiated while the core is still being compressed by the implosion, α will be less than its maximum possible value and will increase with time until the effects of the nuclear reaction themselves start to force the core apart. If the reaction is initiated at the optimum instant of maximum density, α will have its maximum value and will remain substantially constant until mechanical effects from the nuclear reaction take hold. And if the reaction is initiated after the optimum instant, α will be less than its maximum possible value and will decrease with time. Furthermore, it is to be noted that α will be decreased from the value it otherwise would have, by assymetry of implosion which leads to poor compression, or by a mixing of active material with tamper. Hence a determination of α as a function of time would give a very powerful method of studying the implosion and its nuclear consequences.

Such a determination will be a very difficult matter but will be undertaken by R. R. Wilson. For this purpose he will set up to measure secondary gamma rays produced as a consequence of the absorption of neutrons in the outer layer of the tuballoy tamper, since it has been shown on theoretical grounds that their intensity will be proportional to the intensity of the nuclear reaction during the short period before mechanical effects from the nuclear explosion take hold. The great difficulty of the experiment is connected with the low intensity of the gamma rays and the very short time interval, during which the change in α must be followed. This makes it necessary to employ refined methods involving electron multipliers and time discriminating circuits.

Owing to the great difficulty of the complete experiment, a set-up will also be made by Wilson to determine only a single value for α during the course of the reaction. Also a set-up, proposed by Rossi, for determining a single value of α by measuring the effect of gamma ray ionization on the transmission of radar waves in the neighborhood of the bomb, may be made by Radiation Laboratory personnel if this can be arranged. The probability of complete success for the proposed experiments for determining α is not high, but their importance is very great.

6. Nuclear Energy Released.

The release of nuclear energy is the main function of the bomb, and the efficiency with which this occurs is of primary importance. Several methods for determining the amount of nuclear energy released will be used. No one of these is certain to provide accurate results, but the interpretation of their combined results can be important.

a. Delayed Neutrons. It has been shown, on theoretical grounds, that the intensity of the delayed neutrons, emitted from the fission products, after the expansion of the explosive gases permits relatively free transmission, will give a measure of the number of fissions that have taken place and hence of the nuclear energy that was released. Measurements of this intensity will be made by J. H. Williams by using the neutron counter which he has developed, and also by allowing the neutrons to produce activation in strips of gold foil. These important measurements have a considerable chance of successful performance.

b. Delayed Gamma Rays. The intensity of the delayed gamma rays from the fission products should also give a measure of the extent of the nuclear reaction. The high speed of gamma rays as compared with neutrons is advantageous in avoiding disturbances due to dust, but evaluation of the attenuation of the gamma rays by their passage through air will be difficult. Moon and Segre will both make measurements of gamma-ray intensity using ion chambers and differently designed circuits, and Mack will make photographic measurements using pinhole gamma ray cameras. It is hoped that some of these measurements will provide useful information.

c. Conversion of 49 to Fission Products. A relatively direct determination of the extent of the nuclear reaction could be made by a successful assay of the amounts of unconverted 49 and converted 49 - i.e. fission products - in the products of the explosion. This will be undertaken by H. L. Anderson by radio-chemical analysis of soil in the neighborhood

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of the explosion. The work is made difficult by the highly toxic contamination of the soil from which samples must be collected. It is also made difficult by uncertainties as to distribution, but preliminary studies on the distribution of tracer material in the 100 ton shot will help in this connection. It is probable that useful results will be obtained by this method.

7. Damage Effects Produced.

A considerable number of measurements for determining the damage to be expected from the explosion are possible. Some of these are of a sufficiently standardized character so that useful results are to be expected. The measurements are concenred with the effects of air blast and of earth shock. The former will be determined at various distances to get radii for different classes of damage. The latter will be important in checking the energy of the explosion, but will not be of much military importance.

a. Blast Pressure at Ground Level from Piezo Gauges. The pressure in the air blast will be measured, as a function of time, at various distances from the explosion, using standard piezo gauge technique. The piezo gauges will probably have to be constructed of quartz rather than of tourmaline, as is more common in American practice, since the tourmaline guages have been found to be highly sensitive to temperature changes, a property which does not interfere with their underwater use or use for air blast waves of short duration, but would be troublesome for the blast wave of long duration from an enormous explosion. Quartz gauges may have to be obtained from England. Piezo gauge measurements are the responsibility of R. L. Walker.

b. Blast Pressure at Ground Level from Condenser Gauges. Similar measurements of blast pressure will be obtained from condenser gauges that have been developed at CIT by Dumond and Panofsky. These gauges are arranged to transmit their information by frequency modulation of a radio signal. This work is the responsibility of W. C. Bright.

c. Blast Pressures at Ground Level from Excess Velocity. The velocity of a blast wave through air is greater than that of ordinary sound by an excess amount which increases with the pressure difference across the blast front. Hence sufficiently accurate measurements of velocity can be used to measure pressure. Such measurements will be made by H. H. Barschall using ordinary microphones. The velocity of ordinary sound will be determined just before the main explosion by shooting a small charge of high explosive. Measurements of excess velocity will also be made under the direction of J. E. Mack by the photography on a moving film of flash bombs placed at different distances from the explosion and set off by blast operated switches.

d. Peak Pressure at Ground Level from Paper Gauges. The peak pressure in the blast wave will be estimated at different distances by the use of the Aberdeen type of paper gauge in which paper, covering holes of various sizes, is exposed to rupture by the blast. Aluminum foil will be used instead of paper since this has been found to give much more reproducible results. The work is the responsibility of J. C. Hoogterp.

e. Blast Impulse at Ground Level from Piston Acting on Fluid. Measurements of the integrated pressure-time action of the blast will be determined by the movement of a piston which forces fluid through a small hole. This work is the responsibility of T. Jorgenson.

f. Blast Pressure at Higher Levels from Condenser Gauges. The CIT condenser gauges, mentioned under (b), which transmit their information by radio, will also be dropped on parachutes from a plane to give measurements of pressure at higher levels above ground. This measurement is of importance on account of the effect of the Mach wave on pressure as a function of height of explosive and height of receiving point. These measurements which are being developed for use in combat delivery are under the direction of B. Waldman.

g. Earth Shock. The velocity of earth movements produced by the explosion will be measured with the help of converted geophones; permanent earth displacements will be measured with the help of suitable stakes driven in the ground; and crater dimensions will be measured directly. These measurements are the responsibility of H. M. Houghton and J. H. Coon. It is estimated by Ensign Reynolds that at a height of 100 feet only about one per cent of the energy of the explosion may be expected to go into crater formation. Even so, the main shot should produce a crater 275 feet across and 80 feet deep. Determination of earth movements in the case of the preliminary 100 ton shot will be very important in designing apparatus and apparatus shelters for the main shot.

8. Overall Behaviour of the Explosion and its After Effects.

In accordance with the latest version coming from the difficult theoretical studies which have to be made, the overall

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behaviour of the explosion and its after effects are now expected to have the following character. The energy emitted by the fission process produces mechanical expansions which start after initiation. These expansions bring the energy emission substantially to an end (90% of neutrons emitted) The shock wave which accompanies the expansions passes outward from the surface of the sphere of 49 and heats up the sorroundings to a very high temperature. At about 50 microseconds this gives a sphere of about 10 meters radius at a temperature of 250,000°. This hot sphere (ball of fire) expands rapidly and at about 40 milliseconds has reached a radius of 130 meters, a density of 10^{-6}, and a temperature of about 20,000°. The ball of fire will keep its shape and position for several seconds. Because of its low density it moves slowly upward, and starts disintegrating by turbulent mixing. After about a minute it will have completed disintegration at a height of 1 to 2 kilometers. The material that was in the sphere will, however, continue to rise and finally mushroom out at a height of about 5 kilometers. During the first one-tenth second the ball of fire is expected to give an average illumination equal to that of the sun, and at the end of two seconds to have fallen to one tenth this intensity.

The behaviour of the ball of fire and after effects will be followed by photographic and spectrographic observations carried out by J. E. Mack and his group. Many of these observations should be successful.

a. Size, Shape, Behaviour and Path of the Ball of Fire. Fastax cameras, a Mitchell camera, and a home movie camera will be used for following the behaviour of the ball of fire.

b. Radiation and Temperature of Ball of Fire. Hilger spectrographs, a Bausch and Lomb spectrograph, a 35 mm. movie camera with filters, a drum camera with photo cells, and thermopiles with galvanometers, will be used for analyzing the radiation from the ball of fire and determining its temperature.

c. Behaviour of Hot Column. Aero mapping cameras will be used for obtaining a space-time plot of the behaviour of the hot column and its final mushrooming out.

d. Mach Wave and Air Velocity. Observations on the Mach wave, which is expected in the neighborhood of the explosion, will be made by photographing the appearance of a

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detonating primacord hung from a suitably placed balloon. When the branches of the Mach wave pass over the primacord its intensity should increase. Furthermore, the motion of the primacord should give information as to the velocity of air in its neighborhood.

9. Meteorological Observations.

As already mentioned, in addition to the primary observations, meteorological observations and studies will be needed for determining the behaviour of winds over the mountains to the east, and for forecasting a suitable time for the shot to avoid bad after effects, and for following meteorological effects of the explosion. For this work Mr. Hubbard and Lt. Curtis will be provided with a field balloon set for theodolite observations, radio sondes, and a SCR-584 radar set with corner reflectors for attachment to balloons.

10. Health Control.

Dr. Hempelmann will be provided with apparatus, needed in connection with health control both in local and remote areas. For this purpose, he will have (a) portable alpha particle air samplers, (b) portable alpha particle air filters, (c) portable gamma ray meters determining doses in the range 0.001 to 0.02 Roentgens per 8 hours, (d) portable meters for doses in the neighborhood of 10 Roentgens per 8 hours, and (e) radio-equipped cars for communicating the extent of contamination found.

11. Justification and Prognosis for the Program.

The program of experimentation described above may seem at first sight unduly elaborate. I share, however, the opinion of those associated with the program that this is not the case.

If the bomb fails to detonate high order, it will be necessary to have extremely good information as to its actual behaviour in order to introduce modifications which will lead to a successful design. The need for a successful implosion design is a real one, since we can no longer regard the implosion type of bomb as merely an alternate to the gun type, since we now know that the latter cannot be used with 49 as actually manufactured at Hanford. To assure the necessary information, a very considerable number of measurements of implosive and nuclear behaviour must be made, since none of the possible experiments is certain to be successful or to provide accurate results, and the combined information they provide will certainly be needed.

If the bomb does detonate high order, we shall still be interested in its implosive and nuclear behaviour, but will now also be concerned for military reasons with its damage and upper air effects. Here too duplication of experimental methods is needed to assure successful collection of the needed data.

As a prognosis, I agree with those associated with the program that the proposed tests will come off approximately on schedule, and that a sufficient number of the different kinds of measurements will be successful to provide a good fraction of the necessary information.

Richard C. Tolman,
Vice-chairman, N.D.R.C.

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