Chapter XV

WEAPON PHYSICS DIVISION

Introduction

15.1 At the time of its organization in August 1944, the Weapon Physics or G Division (G for gadget, code for weapon) was given a directive to carry out experiments on the critical assembly of active materials, to devise methods for the study of the implosion, and to exploit these methods to gain information about the implosion. In April 1945, the G Division directive was extended to include the responsibility for the design and procurement of the implosion tamper, as well as the active core. In addition to its primary work with critical assemblies and implosion studies, G Division undertook the design and testing of an implosion initiator and of electric detonators for the high explosive. The Electronics Group was transferred from the Experimental Physics Division to G Division, and the Photographic Section of the Ordnance Division became G Division's Photographic Group.

15.2 The initial organization of the division, unchanged during the year which this account covers, was as follows:

G-1	Critical Assemblies	O. R. Frisch
G-2	The X-Ray Method	L. W. Parratt
G-3	The Magnetic Method	E. W. McMillan
G-4	Electronics	W. A. Higginbotham
G-5	The Betatron Method	S. H. Neddermeyer
G-6	The RaLa Method	B. Rossi
G-7	Electric Detonators	L. W. Alvarez
G-8	The Electric Method	D. K. Froman
G-9	(Absorbed in Group G-1)	
G-10	Initiator Group	C. L. Critchfield
G-11	Optics	J. E. Mack

15.3 For the work of G Division a large new laboratory building was constructed, Gamma Building. New firing sites were established, with small laboratory buildings associated with them (see map Appendix No. 3). Most of the work of G Division occupied new office, laboratory, and field facilities; despite this, its work was well under way by the beginning of October 1944.

Critical Assemblies

15.4 The work of the Critical Assemblies Group was carried out at Omega Site, (6.64 ff) where it shared space with the Water Boiler Group. Its main work was to carry out experiments with critical amounts of active materials, including both hydrides and metals. It was given the further responsibility of investigating the necessary precautions to be observed in the handling and fabrication of active materials at Los Alamos, to be certain that in these operations no uncontrolled nuclear reactions could occur. When G Division acquired the definite responsibility of designing and preparing the core and tamper - the "pit assembly" - of the Trinity and subsequent implosion bombs, members of the Critical Assemblies Group were given this responsibility.

15.5 During the early period of this group's existence, a large number of critical assemblies were made with various uranium hydride mixtures. A relatively large amount of effort was spent in investigating these assemblies for two reasons. The first was that there was not yet enough material for a metal critical assembly without hydrogen. The second was that by successively lowering the hydrogen content of the material as more U^{235} became available, experience was gained with faster and faster reactions. It was also still not ruled out, at this time, that hydride bombs using small amounts of material might be built.

15.6 By November 1944 enough hydride-plastic cubes of composition UH_{10} had been accumulated to make a cubical reacting assembly in the beryllia tamper, if the effective composition was reduced to UH_{80} by stacking seven polythene cubes for each cube of UH_{10} plastic. Further experiments were made with less hydrogen and other tampers. In February 1944 this hydride was sent back to the chemists and metallurgists for recovery and conversion to metal, and the program of hydride critical assemblies was ended.

15.7 The most spectacular experiments performed with the hydride were those in which a slug of UH_{30} was dropped through the center of an almost critical assembly of UH_{30}, so that for a short time the assembly was supercritical for prompt neutrons alone. This experiment was called "tickling the dragon's tail," or simply the "dragon." The velocity of the falling slug was measured electrically. Before the experiment was actually performed a number of tests were made to prove that it was safe, for example that the plastic would not expand under strong neutron irradiation, thus causing the slug to stick and cause an explosion. On January 18, 1945, strong neutron bursts were obtained, of the order of 10^{12} neutrons.

15.8 These experiments gave direct evidence of an explosive chain reaction. They gave an energy production up to twenty million watts, with a temperature rise in the hydride up to 2°C per millisecond. The strongest burst obtained produced 10^{15} neutrons. The dragon is of historical importance. It was the first controlled nuclear reaction which was supercritical with prompt neutrons alone.

15.9 Because of the intensity and short duration of the bursts obtained, better measurements of delayed neutrons were possible than had been made previously. Several short periods of delayed emission were found, down to about 10 milliseconds, that had not been reported before. These experiments suggested a promising future method for producing modulated bursts of fast neutrons.

15.10 The Critical Assemblies Group made large numbers of safety tests for other groups. Most of these involved placing various amounts of enriched uranium with various geometries in water, in order to determine the conditions under which the accidental flooding of active material might be dangerous. During the course of these tests the first accident with critical materials occurred. A large amount of enriched uranium, surrounded by polythene, had been placed in a container to which water was being slowly admitted. The critical condition was reached sooner than expected, and before the water level could be sufficiently lowered the reaction became quite intense. No ill effects were felt by the men involved, although one lost a little of the hair on his head. The material was so radioactive for several days that experiments planned for those days had to be postponed.

15.11 Similar safety tests were made on models of the gun assembly. These tests were made because water immersion of the bomb might occur accidentally in transporting the bomb or in jettisoning it from aircraft. Immersion could also be thought of as the limiting case of wetting from other possible sources.

15.12 The number of tests made with U^{235} metal assemblies was much larger than those with Pu^{239}, since sufficient plutonium was available only rather late. The first critical assembly of the latter material, which was of a water solution of Pu^{239} with a beryllia tamper, was made in April 1945. By fabricating larger and larger spheres of plutonium and inserting these in a bomb mock-up, the critical mass in a bomb was determined.

15.13 In April 1945 when G Division was given the definite responsibility of designing the pit assembly of the bomb, the "G Engineers," Morrison and Holloway, were taken for this work from the Critical Assemblies Group. The G Engineers worked with the design staffs of X and O Divisions in the final detailed design of the implosion bomb.

Implosion Studies

THE X-RAY METHOD

15.14 The X-raying of small spherical charges was developed in the Ordnance Division and was in successful use in August 1944 (7.57). At this time the small scale work was placed in X Division, and the G Division X-ray Group was formed to extend this method of implosion study to larger scale. In addition to this development work the G Group continued a number of service activities, such as the servicing and improvement of the X-ray tubes for the X Division work. Other demands made upon them included the radiography of explosive charges for the RaLa Group. Radiographic examination of the final weapon tamper was also a problem for this group near the end of this period, but the work was done with radioactive sources of gamma rays rather than with X-rays.

15.15 In the early part of the new program the chief objective in the development work was to adapt X-ray techniques to large scale implosions (up to 200 pounds of high explosives). It was proposed actually to follow the course of the implosion by detecting the incidence of the X-rays as a function of time, using a grid of small Geiger counters. These counters were to be either of 1 or 3 millimeters in diameter, and disposed in the form of a cross in the X-ray shadow of the object. The principal aims of the projected program were (1) reliable action of the counters, and (2) reduction of the amount of scattered radiation that would be recorded. These objectives were pursued relentlessly, but because of the great technical difficulties involved, with little real success. The program was dropped in March 1945. It had become clear that, although the difficulties might not be insurmountable, there was not sufficient justification for retaining the highly trained personnel required for this work. At this time also it had become clear that essentially the same type of information was obtainable by repeated exposures with the betatron (15.23 ff).

15.16 Although the development of the counters and their electronic circuits and the reduction of the scattered radiation were uncertain of success in the new X-ray program, preparation of a field site where the technique could be tested was completed by early fall 1944. This site was called P Site. The protection required for X-ray equipment near exploding charges was designed so that it would be useful in other X-ray experiments as well. As a preparation for the final use of the X-ray and counter technique, the problems of using the magnetic method (15.18) in conjunction with the X-ray method were solved at P Site. The first combined X-ray and magnetic record was obtained in late January 1945. The technique was directly applicable to the combination of betatron and magnetic records (15.26).

15.17 As emphasis on lens design increased, flash X-ray photography was used to study the detonation waves. These studies paralleled those of the X-ray section of the Implosion Studies Group X-1. In April 1945 a second X-ray team was placed on the initiator problem. Altogether, a large amount of important experimental work on initiators was accomplished. The use of P Site for the initiator program branched out into various recovery experiments carried out there, and finally to the installation of the alpha counting experiment (15.38).

THE MAGNETIC METHOD

15.18 By August 1944 the magnetic method had been established as a practical way of determining the velocity of the external metal surface of an imploding sphere (7.57). By integration the average compression could also be obtained. The development of the method was directed along three main lines: (1) the improvement of the instrumentation and adaption of the method to large charges with electric detonation; (2) cooperation with RaLa, X-ray and betatron experiments to get coordinated records; and (3) the development of new methods.

15.19 The first part of the program started with the construction of a separate proving ground in the Pajarito Canyon (see Site Map). This was completed in December 1944. Meanwhile a great deal of work was done in the laboratory in improving the circuits and developing shielding techniques. When the field work got under way it was found that the main problem was to protect the magnetic record against spurious signals caused by the electric detonators and by the static charges developed in the explosion. New results were obtained when it became possible to "purify" the magnetic records and interpret their details. It was found that several reflected shock waves from the metal core could be recognized. The intersection of detonation waves also produced reliable signals.

15.20 The magnetic techniques were adapted to larger charges, more detonation points, and finally to the electric detonation of lenses. The increase of surface velocity with number of detonation points was demonstrated in this way.

15.21 A unique property of the magnetic method was the fact that it was the only experimental method that could be applied to a full scale implosion assembly. The electric method (15.31ff) could be applied at full scale, but not to complete spheres. One of the chief objectives of the magnetic program was to prepare for the investigation of full scale shots. Unfortunately the method could not be used at Trinity because it was desirable to fire that shot with the same type of metal case as used with the bomb assembly, and this case made it impossible to obtain magnetic records.

15.22 As technical difficulties were surmounted the method was applied successfully at various tamper diameters. At these scales the method was used alone as well as in coordination with the RaLa and betatron methods. The timing results were particularly useful in these cooperative tests. As a method by itself its main value lay in following the dynamic sequence in the implosion and giving data as to the way this changes with increasing size of the implosion.

THE BETATRON

15.23 The use of the betatron as an instrument to study the implosion had been proposed earlier, but was not decided upon until the time of the discussions which led to the formation of G Division. For this work the 15 million volt betatron of the University of Illinois was obtained, after expert analysis of its capabilities for this work by its inventor, D. W. Kerst, and of the possible use of a vertical cloud chamber for recording by Neddermeyer. These analyses gave sufficient promise of success to justify undertaking the development of the method. Experimental work was begun in the early fall of 1944, on the performance (rise and burst times) of the betatron at Illinois, and also on the refinement of shadow recording by means of flash photography of the cloud chamber.

15.24 Construction of the betatron site (K Site) was begun concurrently. As at the X-ray site, the test implosion was detonated between two closely spaced bomb-proof buildings, one containing the high voltage gamma ray source, the other containing the cloud chamber and recording equipment. Equipment was protected from the blast by aluminum nose pieces over the exit and entry ports through which the radiation passed, and by shock-mounting all equipment which could be damaged by the shock wave. Construction and installation required until the first of 1945 for completion.

15.25 In the meantime the cloud chamber technique was improved by finding means for trapping the low energy tracks to obtain better definition of the image in the cloud chamber, and by an intricate and ingenious sequence circuit developed in the laboratory. This circuit had to correlate the firing of the explosive charge, the gamma ray burst, and the expansion and photographing of the cloud chamber.

15.26 By the time the first test shots had been fired, the importance of results from the betatron had become crucial because of the likely abandonment of the counter X-ray method. The adaptation of the field installations, the electronic circuits, and the cloud chamber to their special purposes proceeded so rapidly that by April 1945 a systematic study of compression under scaled lens shots was started. The results of the early work showed an unexpected irregularity, but nonetheless gave evidence of definite compression of the uranium core by an amount not very different from that predicted theoretically. By June, the spread of data had been reduced enough to provide valuable experimental information for the correction of the constants used in the theory of the bomb. Cooperative data provided by the magnetic method (15.18 ff) indicated that the spread in experimental results was possibly caused by variation in the behavior of the high explosive.

15.27 The betatron program was one of the few that maintained a single purpose and function from its inception to the production of final results. If for this reason its history can be written briefly, the technical achievements and ultimate importance of this work are among the most impressive of the several such achievements at Los Alamos.

THE RaLa METHOD

15.28 The RaLa program (7.61) resembles the betatron effort in that it was a single-purpose, more or less direct, adaptation of a known radiographic technique to the study of implosions. Both methods had to be adapted to microsecond time resolutions. For RaLa this meant the development of unprecedented performance with ionization chambers as well as unheard of sources of gamma radiation. As has been said elsewhere (17.42), the source of radioactivity was the radiobarium from fission products of the chain reacting pile. By the fall of 1944, the extraction of radiolanthanum had been put on a working basis. The production of sufficiently fast ionization chambers had also been achieved.

15.29 The RaLa firing program itself got under way in Bayo Canyon (see Site Map) October 14, 1944. Because of the lack of knowledge as to how serious the contamination would be after imploding a source which was the equivalent of many hundred grams of radium, the permanent installations were kept at a minimum for these first trials. Sealed army tanks were used as observation stations. The contamination danger appeared so conveniently small, however, that permanent bomb proofs were subsequently installed (November 1944).

15.30 The early shots were fired by multipoint, primacord systems and the results were correspondingly erratic.

THE ELECTRIC METHOD

15.31 The principal technique of the electric method of investigating the implosion was that of recording electronically the electrical contacts formed between the imploding sphere and prearranged wires. This is a well-established method of investigation but, as always in adapting old methods to implosion work, it was necessary to sharpen the time resolution and meet rather more serious interference with the circuits on the part of the explosive than had previously been encountered.

15.32 The development of the electric method was undertaken in August 1944. Although many possible applications of electronic circuits suggested themselves, the first effort was to make oscillographic recordings of the position of a plate as a function of time, when the plate was accelerated by a high explosive charge. This was done by merely spacing small pins at intervals differing by about a millimeter from the surface to be accelerated. The first successful results were obtained in early October 1944. The technique was then rapidly developed and refined, so that by the early part of 1945 quantitative data on the acceleration of plates was being obtained. The method was then adapted to the more severe implosions of partial spheres, and finally used on lens systems in which only one lens was omitted. Information was obtained on velocities of material at various depths in the core, and on shock-wave velocities. This information was particularly valuable in supplying the Theoretical Division with direct, quantitative data on which to test its conclusions and base its predictions for the implosion bomb.

15.33 Variations of the technique described above were studied but not developed as fully as the contact method. These included the condenser microphone and resistance wire methods. The use of tourmaline crystals for timing signals, as well as for possible pressure recording, was pursued by the Initiator Group. In addition to the information of general theoretical interest on the properties of metals under compression, these methods were useful in many particular studies. Thus the Initiator Group was able to determine the pressure distribution in a detonation wave, and the Electric Method Group measured transit times relative to detonation times, uniformity of lens operation, and the location and velocities of spalls and jets. They also measured many velocities of interest in connection with initiator design, and the velocity of shock-operated jets formed in the thin crack between tamper halves.

15.34 Aside from its general usefulness for many research purposes of G Division, the Electric Method was--apart from the magnetic method--the only one which could be applied at very large scale. By June 1945, the technique was being applied regularly at large scale and to almost complete spheres of lens charges.

Initiators

15.35 The Initiator Group differed from those discussed above in that it was primarily concerned with the development of a component of the bomb rather than with a particular research method.

15.36 A proving ground was built in Sandia Canyon (see map) for initiator work. The nature of proof was not predetermined, however, and in any case could not be complete, because the performance requirements could be measured only by operation in the bomb itself. Many leads were followed, accordingly, in the attempt to simulate actual conditions as closely as possible and to learn as much as possible about the mechanisms that were supposed to make the various designs work.

15.37 The initiator program involved a great deal more than the attention of the Initiator Group. A large part of the problem was the procurement and radiochemical preparation of polonium. (17.32 ff) There was considerable theoretical investigation of proposed initiator mechanisms, and a large amount of experimental corroboration was produced by the X-ray, flash photography, and electric methods. The function of the Initiator Group was to coordinate these researches with its own and with trends in design.

15.38 By February 1945 it was pretty well decided that the initiator should be of an (α, n) type. Many designs were invented, and the work of selecting promising ones and testing them was started. All designs worked by some mechanism for mixing the α-n material, previously kept separated by some α-absorbing material under the impact of the incoming shock-wave. At this time the possibility of complete recovery of imploded spheres was discovered. The recovery of units with and without α-n materials in them formed an important part of the early work. Although the results thus obtained built up confidence in the feasibility of initiators, this work superseded by studies of specific mechanisms.

15.39 The deadline for a decision on the feasibility of an initiator was met, with a favorable report, on May 1, 1945.

15.40 In the course of the month after May 1 the acceptance specifications and fabrication procedures were established, and the first service unit was finished by the radiochemists early in June.

15.41 The Initiator Group set up handling procedures in cooperation with the G Engineers and the Radiochemists for production, surveillance, and recording the history of each unit. This plan had just been put in operation by the end of the war.

Electric Detonators

15.42 The need for a high degree of simultaneity in the multipoint detonation of the implosion had been realized from the beginning, as had the potential usefulness for this purpose of electric detonators. The early development of primacord branching systems, the investigation of timing errors associated with them, and the experimental and theoretical work on the importance of such errors were undertaken (7.63). Electric detonators were already under development and during August 1944 this work was transferred to the new G Division.

15.43 The degree of perfection desired was, of course, not built into the commercial electric detonators, and the problem of simultaneously firing many such units had not been faced. This required the development of an adequate high voltage power supply and of a simultaneous switching device. The high voltage supply could be made from commercial units, and was simply a bank of high voltage condensers. The switch problem, acute at first, was met by straightforward developments which led to several designs adequate for experimental purposes.

15.44 The switch finally developed for weapon use and the particular detonators used were proved in X Division (16.37). But with a firing circuit adequate for experimental purposes it soon became apparent that there was a serious lack of simultaneity and source of failure in the detonators themselves.

15.45 Facilities for rapid loading of experimental detonators were developed at Los Alamos, and this local supply became the primary one.

15.46 The criterion for acceptance was, of course, a small maximum time spread and percentage of failures. Tests were made by oscillographic methods and later by photographic observation, using the rotating mirror camera.

15.47 In the spring of 1945 the Detonator Group was burdened with the supervision of the preparation of thousands of detonators for field work in the implosion program. By the end of May the specifications for the combat service units had been completed, and responsibility for putting the units into service was taken by Group X-7 (16.37-16.38).

Photography

15.48 The Photographic and Optics Group, which before August 1944 had been a part of the Instrumentation Group of the Ordnance Division, was responsible in G Division for the development of optical instruments and for the operation of technical photographic facilities. As such it was partly a service group and partly an experimental group. It prepared photographic and spectrographic equipment for the Trinity test. Before that it had played a substantial part in the Wendover drop tests.

15.49 Besides procurement of photographic equipment and maintenance of a photographic stockroom, the Photographic Group designed and built cathode ray oscilloscope cameras, armored still cameras for various high explosives test sites, an armored stereoscopic camera for the flash photography of imploding hemispheres, (16.9) and a cloud chamber stereoscopic system for the betatron cloud chamber (15.25). The group built boresights and a photo velocity system for the 20 millimeter gun. It designed and developed the rotating prism and rotating mirror cameras (15.46). As with electronic, so with photographic recording of data, the Laboratory was able to reach a high level of perfection in accurate high speed work. Much of this work stands to the credit of the Photographic Group.

Electronics

15.50 Early in September 1944, the Electronics Group was greatly expanded because of the very heavy demands placed on it by the Laboratory. At this time many types of equipment were in production. Among the standard items made were scalers, power supplies, discriminators, and two types of amplifiers with rise times of 0.1 and 0.5 microseconds. Many new pieces of equipment were designed and built. A scaler with a resolving time of 0.5 microsecond per stage, amplifiers with less than 0.05 microsecond rise time, a ten-channel pulse height analyzer, and a ten-channel time analyzer were constructed. The group built most of the electronic equipment used on the betatron and much auxiliary equipment for the cyclotron, van de Graaffs and D-D sources. It designed and built new sweep circuits, delay circuits, calibrating circuits, and a host of other circuits needed by a laboratory as large and diversified as Los Alamos had become. If the above gives some indication of the variety of work carried out by the Electronics Group, its magnitude is indicated by the fact that the membership of the group averaged in the neighborhood of fifty. These ranged from wire men to designers of new equipment. The number of major construction items ranges over a thousand, and the number of service and repair items far beyond this figure, for the period covered.

15.51 The services of this group are not reflected directly in a single part of the weapons finally developed at Los Alamos and for this reason are likely to be slighted. But it is safe to say that without its services many of the experiments of G Division and the Laboratory would not have been done as well, they would have required more time, and the completion of the bomb itself would have been delayed.

Chapter XVI

EXPLOSIVES DIVISION

Organization and Liaison

16.1 The Explosives Division, organized in August 1944, consisted originally of the Explosives Experimentation, High Explosives, and S Site Groups of the old Ordnance Division. Its rapid growth from that time (see Graph No. 5) was accomplished by subdivision of groups into sections and by addition of new groups. Two organization lists are given below, for September 1944 and for August 1945:

September 1944

X-1	Implosion Research	Cmdr. N. E. Bradbury
1A	Photography with Flash X-Rays	K. Greisen
1B	Terminal Observations	H. Linschitz
1C	Flash Photography	W. Koski
1D	Rotating Prism Camera	J. Hoffman
1E	Charge Inspection	T/3 G. H. Tenney
X-2	Development, Engineering, Tests	K. T. Bainbridge
2A	Engineering	R. W. Henderson
2B	High Explosives	Lt. W. F. Schaffer
2C	Test Measurements	L. Fussell, Jr.
X-3	Explosives Development and Production	Capt. J. O. Ackerman
3A	Experimental Section	Lt. J. D. Hopper
3B	Production Section	J. B. Price

August 1945

X-1	Implosion Research	Cmdr. N. E. Bradbury
1B	Terminal Observations	H. Linschitz

1C	Flash Photography	W. Koski
1D	Rotating Prism Camera	J. Hoffman
1E	Charge Inspection	M/S G. H. Tenney
X-2	Engineering	R. W. Henderson
X-3	Explosives Development and Production	Maj. J. O. Ackerman
3A	Experimental Section	Lt. J. D. Hopper
3B	Special Research Problems	D. H. Gurinsky
3C	Production Section	R. A. Popham
3D	Engineering	B. Weidenbaum
3E	Maintenance and Service	Lt. G. C. Chappell
X-4	Mold Design, Engineering Service and Consulting	E. A. Long
X-5	Detonating Circuit	L. Fussell, Jr.
X-6	Assembly and Assembly Tests	Cmdr. N. E. Bradbury
X-7	Detonator Developments	K. Greisen

16.2 The following are the principal developments in the administrative history of X Division. The new division was headed by G. B. Kistiakowsky, whose previous status had been Deputy Division Leader of the old Ordnance Division, in charge of the Implosion Project. Kistiakowsky was assisted by Major W. A. Stevens for administration and construction. Group X-4 was created early in October under E. A. Long and J. W. Stout. It was charged with the engineering of molds for S Site, research on sintered and plastic bonded explosives, and miscellaneous services for the division. A section was added to this group in December 1944 under W. G. Marley, responsible for some aspects of lens research. In November 1944 a second research section under D. H. Gurinsky was added to Group X-3.

16.3 A major organizational change occurred in March 1945 when Group X-2 under Bainbridge was dissolved. Bainbridge was put in charge of the new Trinity Project, preparing for the Trinity test. Three new groups were formed to continue the work of X-2: an Engineering Group under R. W. Henderson, X-2; a Detonator Firing Circuit Group, X-5, under L. Fussell, Jr., whose section of X-2 had already acquired the responsibility for the design and development of a firing unit for the electric detonators; and an Assembly and Assembly Test Group, X-6, under N. E. Bradbury. In March 1945, M. F. Roy joined the Laboratory staff as Assistant to the Division Leader of X Division. In May 1945, Section X-1A was discontinued and a new group formed under K. Greisen, X-7, to carry through the final development of detonators.

16.4 The directive of the new division was, in essence, to develop the explosive components of the implosion bomb. In the same sense it was the directive of G Division to develop the active components. These directives did not mark out separate areas of work so much as they did specify the directions from which the two divisions should attack the central problem, which was to produce the optimum assembly of active material. X Division was specifically:

(a) To investigate methods of detonating the high explosive components.

(b) To develop methods for improving the quality of high explosive castings.

(c) To develop lens systems and the methods for fabricating and testing them.

(d) To develop engineering design for the explosive and detonating components of the actual weapon.

(e) To provide explosive charges for implosion studies in G and X Divisions.

(f) To specify and initiate the design of those parts of the final weapon for whose development it was responsible.

16.5 Since it was the joint responsibility of X and G Divisions to carry out the fundamental implosion development work, these two divisions worked in close cooperation. Both, for example, carried out studies of implosion dynamics. In these studies G Division was primarily concerned with the measurement of the assembly velocity and compression of the bomb pit while X Division was primarily concerned with the explosive techniques for achieving high assembly velocity and compression. But no real separation along these lines is possible. In practice the methods of implosion study which were already developed and known to be reliable remained in X Division, while G Division concentrated on the development of new methods.

16.6 The division of labor between X and O Divisions in relation to the implosion bomb can be described roughly by saying that the former was responsible for the explosive components, the latter for the case, including under the latter mainly what was necessary to convert such a bomb as was set off at the Trinity Test into a combat weapon.

16.7 The important outside connections of the Explosives Division were with the Explosives Research Laboratory at Bruceton, and later with the Camel Project of the California Institute of Technology. Work was done also at the Yorktown Naval Mine Depot and by the Hercules Powder Company. The Yorktown Naval Mine Depot supplied explosives and when a new type of explosive was under investigation supplied information on its physical and explosive properties. Hercules produced spark-gap detonators to Los Alamos specifications. The general liaison with the Camel Project is discussed in 9.15ff. Special items related to the work of X Division are discussed in the appropriate sections below.

16.8 The history of X Division, like that of the whole implosion project, is one of gradual development, usually in the direction of greater complexity of the operating mechanism. From the situation in the summer of 1944, described at the end of Chapter VII, it was a long time before there was any real assurance of success. Programs were complex. Alternatives had still to be worked on with fair priority. The pursuit of these various developments would, morever, have been useless without constantly improving techniques of experiment and observation, attention to which was therefore a large part of the division program. A good deal of theoretical effort went into the interpretation of implosion jets.

16.9 Three principal techniques were used in the implosion studies; rotating pyramid and rotating mirror photography; high explosive flash photography; and flash X-ray photography. Measurement at maximum compression was possible by careful timing of the X-ray flash and the explosive detonation. The rotating prism or mirror techniques and the high explosive flash technique gave shadow photography of imploding cylinders. By a device which gave a succession of high explosive flashes it was possible to obtain images on the same negative at different stages of collapse. Hemispherical implosions were observed by reflected high explosive flash light, and photographed stereoscopically. These observations made it possible to verify predictions about jetting based on two-dimensional cylinder results, and served to remove the last possible doubt that the cylinder jets might be optical illusions. Early in 1945, this hemisphere technique became standard, and the cylinder work was dropped.

6.10 Apart from timing studies and lens development work, discussed in the next sections, the remaining work of the Implosion Research Group also centered on the investigation of jet phenomena. Experimental data needed to test the theory that jets were caused by shock-wave interaction were obtained by so-called slab shots. Slabs of explosive were placed on top of metal slabs and detonated at two or more points. The effects of interaction between the shock waves were observed by flash photography and terminal observation. It was thus possible to study jetting as a function of the angle between detonation waves.

16.11 The need for special means of initiating the high explosive at several points "simultaneously" was recognized from the beginning. What was not recognized was the degree of simultaneity required.

Explosives Development and Production

16.12 In Chapter VII the early development of production facilities has been reviewed. After August 1944, the story is one of continual expansion, constant training of new personnel, and research on better and more reliable production methods. The size of the undertaking is indicated by the records of X Division, which show that in a period of eighteen months some twenty thousand castings of adequate experimental quality were produced, and a much larger number rejected through quality control tests. At its peak, S Site used something over 100,000 pounds of high explosives per month. Seven or eight different explosive materials were used in castings, in an enormous variety of shapes and sizes. The principal explosive used was Composition B. Others used in smaller quantity were Torpex, Pentolite, Baronal, and Baratol. Casting methods were used wherever possible. Some development was carried out at the Explosives Research Laboratory of precision pressing techniques, but without encouraging results.

16.13 It may perhaps be thought that in such a field as high explosives casting there was an existing art which could be made use of at Los Alamos. This unfortunately was not so. Military techniques for loading explosives are crude when measured by such standards as were needed in the implosion. Very little scientific work had ever been done in the field, and there had been very little incentive to regard high explosives as possible precision means for producing phenomena outside the ordinary range of experimental physical techniques. But just such an incentive was created by the requirements of the implosion program at Los Alamos. Hence many of the problems faced were new. Their solution was undertaken primarily by the Explosives Development and Production Group.

16.14 The machining of explosives, entailed by the use of risers and of overcasting techniques, became a well-developed art at S Site and was the greatest innovation introduced in the manufacture of explosive charges. By removing the top section of the casting (in which its imperfections had been concentrated), a charge meeting the necessary standards of quality was obtained. This machining program required close cooperation between the explosives groups concerned and the Shop Group (9.49). Holding jigs and cutters finally used represented several months of development and experimentation. The earliest molds were designed so as to minimize machining by the use of small risers. This kind of machining is normally considered very dangerous, and its development is considered as a revolutionary development in explosives manufacturing. By careful design and control of operating conditions all hazards were virtually eliminated, as is shown by the fact that more than

50,000 major machining operations had been conducted by the end of the war, without detonation of the explosive

16.15 During all its history, S Site was forced by the growing demands for explosives production to grow at a rate faster than the completion of facilities and arrival of personnel would easily allow. That S Site successfully fulfilled its objective is largely the result of faithful and efficient work by the soldiers who constituted more than 90 per cent of its staff.

16.16 S Site, or Sawmill Site as it was originally called, was placed in limited operation in May 1944 after a winter of construction and difficult equipment procurement. It was subsequently enlarged, and its equipment completely modified.

16.17 All early castings made in the large casting buildings at S Site were cylinders of Composition B, ranging in weight from 30 to 500 pounds. Small castings of Pentolite at that time were being cast at the Anchor Ranch casting room which had been placed in operation in October 1943. This small casting room was equipped with four kettles of two gallon size. It continued to furnish very small cylinders and special castings of Pentolite throughout the war.

16.18 Experience gained from an examination of the cylinder castings, made by the Standard methods of ordnance practice, showed that extensive research would be necessary to produce large castings with the required quality.

16.19 As a result, a Research and Development Section was set up in June 1944. It started with four men but was enlarged throughout the war as qualified men could be assigned to the work. Initially a building suitable for experimental casting research was not available. Building S-28, the trimming building, was used temporarily until the laboratory buildings were completed in September 1945.

16.20 Early research was confined to the determination of the nature of the explosives and to the problems of securing in castings a quality adequate for the testing program. Little time was available for the longer range program of making large castings of uniform quality.

16.21 Beginning in November 1944 the experimental work was divided into two fundamentally different parts; the first was the solving of problems encountered in making high quality large castings with slurries, and the second was the development of methods to manufacture explosive lenses.

16.22 The adoption of lenses imposed upon S Site a tremendous development program not only in the research for, but in the production of, many forms of lenses. No little part of the research work conducted in late 1944 and early 1945 was directed toward the production line manufacture of small-scale lens charges.

16.23 Incidental items of research included the development casting of special explosives such as Torpex and Baronal.

16.24 When the use of lenses became a certainty late in 1944, the designs for a series of lens molds were frozen. These molds covered the range of predictable explosives rates and lens sizes, from small to full scale. This freezing of design was a wise decision, as it permitted meeting schedules later. On the other hand, it greatly increased the burden on research, to make available molds work in spite of their known deficiencies.

16.25 Throughout most of 1944, production of charges in large quantity was not required. Late in 1944 the demand for various sizes and shapes of casting increased greatly as a result of the introduction of new methods of studying implosion and the general growth of the Laboratory staff. The new testing methods included the betatron, X-ray equipment, new mirror camera installations, RaLa, flash X-rays, the magnetic method, and the "pin" method. These tests stimulated requirements for lenses as well as solid charges.

16.26 As a result of these increased requirements a new small casting line, consisting of five buildings, was constructed between December 1944 and March 1945. This line was designed to meet the then predictable requirements for small castings. It later was called upon to meet more varied requirements in the lens program. It was in this line of buildings that the quantity production of small lenses used in the testing program was conducted.

16.27 The adoption of lenses and full machining of charges for the full scale unit called attention to the inadequacy of facilities for full scale work. Buildings S-25 and S-26 were, therefore, built for this purpose between March 1945 and June 1945.

16.28 Because of increased demands for full scale, high quality castings not only for Trinity but for combat use, manufacturing, research and control were intermingled during June and July 1945. New problems arose continuously, involving major changes in process and control. The requirements for inspection, both by physical measurement and by gamma and X-ray examination, increased so greatly as to make the success of this phase of engineering one of the primary accomplishments of the period.

16.29 Throughout the work at S Site, it was common to speak of "production casting." This was really a misnomer, as all castings were of tailored quality and were produced in reasonably small quantity in a large variety of molds. Such production differed from ordnance production not only in that its maximum monthly output of 100,000 pounds of castings would be one day's run of a standard ordnance line, but more significantly in that it consisted of thousands of high quality charges 1 pound to 120 pounds in size compared with a small number of large units weighing thousands of pounds each.

16.30 Because of the requirement of the site for men with scientific or explosives experience and willingness to work with explosives, each new request for assignment of enlisted men or civilians was followed by a long delay. The site was always hampered in its work by a shortage of manpower. On the other hand, the growth in manpower which did occur made the training of new men a continuous problem.

16.31 Similarly, the general shortage of personnel available to the construction contractor delayed construction at S Site. It was necessary always to reduce building requirements to the minimum in order to meet time schedules.

Recovery Program

16.32 The early work of the recovery program has been discussed in Chapter VII (7.61 ff). This was one of the branches of the Laboratory's activity which was dropped, after extensive research and development, for reasons extraneous to the program itself. It was argued, orginally, that the chances for a nuclear explosion at the first test might not be great, and that in this case it would be necessary to recover the active material. As the time approached for the test, however, two arguments were sufficient to justify the abandonment of recovery plans. One was that with the weapon finally designed the chances for no nuclear explosion became very small; the other was that the use of a containing sphere or "water baffle" would make it quite difficult to obtain information that would explain a partially successful nuclear explosion, by this time a more realistic worry than complete failure. Hence when the first test was made, Jumbo, which was such a magnificent piece of engineering, stood idly by, half a mile from the test tower. After the test Jumbo was unscathed; but its crumpled rigging tower was a preview of the damage to steel structures in Japan.

16.33 The specifications for Jumbo had been that it must, without rupture, contain the explosion of the implosion bomb's full complement of high explosive, and permit subsequent mechanical and chemical recovery of the active material.

16.34 The final design of Jumbo was the elongated elastic design described in Chapter VII. An order was placed for this container early in August 1944, with the Babcock and Wilcox Corporation. It was delivered to the test site in May 1945 and erected on its foundation. Because of its size (about 25' by 12') and weight (214 tons) Jumbo had to be transported to the nearest rail siding on a special car over an indirect route to provide adequate clearance. From the siding it was transported overland to the test site on a special 64-wheel trailer.

16.35 Jumbo was constructed from the design of R. W. Carlson. Numerous tests were made with scale model "Jumbinos" to determine their ability to contain charges without rupture.

16.36 The other recovery method investigated in this period was the "water baffle," in which fragments were stopped by a 50:1 ratio of water to high explosive mass. This work was dropped before conclusive results were obtained, but showed that high-percentage recovery would be difficult to achieve. For use in recovery experiments, a shallow concrete catch basin, 200 feet in diameter, was constructed at Los Alamos.

The Detonating System

16.37 The main development work on electric detonators was carried out in the Electric Detonator Group of G Division. But the detonators designed there were primarily intended for experimental work, either on detonators themselves or for firing experimental charges. Detonators for the weapon had to satisfy further requirements, such as durability, ruggedness, and reliability. Reliability was a particularly important consideration.

16.38 The firing of the electric detonators was accomplished by discharging a bank of high voltage condensers through a suitable low inductance switch. This problem was assigned to Section X-2C, later to become Group X-5, the Detonating Circuit Group. Mechanical switches were incapable of doing this. One type of switch extensively developed, and used in experimental work when accurate timing was required, was the so-called explosive switch. In this switch electrical contact was made by the detonation of an explosive charge which broke through a thin dielectric layer between two metal discs, between which the high voltage then passed. This switch was made double by the use of four semicircular discs. Its disadvantage was that it could not be tested before use. Because of this an alternative switch was finally adopted, an electronic device resembling the thyratron. This switch operated between two electrodes, the discharge being triggered by charging a third, "probe" electrode to a suitable high voltage. These switches were able to pass very high currents in the order of a microsecond. The firing units incorporating them were built by the Raytheon Company. Delays in their production made it possible to test only a few of them before the Nagasaki drop.

Engineering, Testing, Assembly

16.39 The division of labor between the Explosives Division and the Ordnance Division has been described above by saying that the former was responsible for that part of the completed weapon which would be tested in the Trinity test, the latter for its use as an airborne weapon. But those components for which X Division was responsible had to be developed to the point of adequacy in combat use. In addition to developing these elements, the engineers of X Division worked with the engineers of O Division in designing their assembly within the Fat Man case. Once this design was completed, it had to be given assembly tests, and tests for reliability and ruggedness under conditions of combat use. Assembly design was the work of the Engineering Group. Assembly tests were the work of the same group, until the formation for this purpose of a special group, X-6, in March 1945. The latter group also collaborated with other interested groups in the drop tests at Wendover Field (19.3).

16.40 Aside from miscellaneous engineering work for the division, the Engineering Group was at first responsible for the design of high explosives molds, particularly lens molds of various types and sizes. Mold development and procurement became such a serious bottleneck by October 1944 that the engineering of molds was made one of the main responsibilities of the new Engineering Service Group established at that time. A system was developed by which experimental molds were built in the Los Alamos shops, while the same designs were sent out for outside procurement. These outside orders were closely followed, with local shop experience as a guide. When the Camel Project came into existence, its engineering group gave valuable assistance in expediting procurement in the Los Angeles area. Even so, the bottleneck remained and it was only by a matter of days that enough final full scale lens molds were obtained for the Trinity test.

Chapter XVII

CHEMISTRY AND METALLURGY

Introduction

17.1 In August 1945 the Chemistry and Metallurgy Division had evolved to the following group organization:

CM-1	Service Group	R. H. Dunlap
CM-2	Heat Treatment and Metallography	G. L. Kehl
CM-4	Radiochemistry	L. Helmholtz
CM-5	Plutonium Purification	C. S. Garner
CM-6	High Vacuum Research	S. I. Weissman
CM-7	Miscellaneous Metallurgy	A. U. Seybolt
CM-8	Plutonium Metallurgy	E. R. Jette
CM-9	Analysis	H. A. Potratz
CM-11	Uranium Metallurgy	S. Marshall
CM-12	Health	W. H. Hinch
CM-13	DP Site	J. E. Burke
CM-14	RaLa Chemistry	G. Friedlander
CM-15	Polonium	I. B. Johns
CM-16	Uranium Chemistry	E. Wichers

This organization evolved by the following steps:

(a) In September 1944 Group CM-3, Gas Tamper and Gas Liquefaction, was transferred to the new Explosives Division.

(b) In April 1945 the following changes occurred: Uranium and plutonium chemistry, formerly concentrated in CM-5, was divided between CM-5 and a new group, CM-16. CM-1 was divided into a Service Group (CM-1) and a Health Group (CM-12). The old Radiochemistry Group (CM-4) was split into three groups, with CM-14 and CM-15 taking charge of RaLa and polonium work, respectively. R. W. Dodson, former group leader, became Associate Division Leader in charge of radiochemistry. C. C. Balke, former group leader of CM-7, left the Laboratory. Miscellaneous metallurgical services were transferred to this group with its new group leader, A. U. Seybolt. CM-11 remained as the Uranium Metallurgy Group. CM-10, the Recovery Group, was absorbed into the new DP Site Group, CM-13.

17.2 These changes were motivated primarily by the expansion of radiochemical work associated with the expanding RaLa implosion studies and the preparation of polonium for the implosion initiator program, and by the need to streamline the processing of uranium and plutonium, arriving in ever increasing quantities.

17.3 The transition to large scale operation involved a constant growth of personnel in the division, and a constant expansion of laboratory, shop and plant facilities. The main steps in this physical expansion were the completion in August 1944 of a large annex to D Building; the completion of the metallurgy building, Sigma Building, in October 1944; the construction of the RaLa Chemistry Building in Bayo Canyon in November 1944. The last and and greatest addition was the chemical and metallurgical production plant, DP Site. The first buildings of this site were completed and being occupied in the summer of 1945.

Uranium Purification and Recovery

17.4 The flow of beta stage enriched uranium received from the Y-12 plant was generally as follows: The material was received as a purified fluoride and reduced directly to metal. For hydride experiments the metal was converted to hydride and formed by plastic bonding. When hydride or metal experiments were completed, the material was returned for recovery, as in the meantime were crucibles, liners, and other containers that had been used in fabrication. Recovered solutions were converted to hexanitrate, extracted with ether, and precipitated as reduced oxalate. The oxalate was ignited to oxide and converted back to the original tetrafluoride.

17.5 The essential step of purification was the ether extraction method that had been developed at the end of the first period (8.18). This method was also applied by the radiochemists to the decontamination of Water Boiler solutions, and by the Recovery Group in experiments on test-shot recovery methods. In April 1945 uranium recovery and purification was concentrated in a new group, CM-16. Before that time extensive investigations had been made to determine the best reagents and ion concentrations for the extraction.

17.6 The dry purification step--reduction of UO_2 to UF_4--was developed to a point where fluoride yields were as high as 99.9%. Fluorination of the trioxide and oxalate were also investigated.

17.7 The studies of recovery from liners and slag revealed the necessity for complete dissolution of these materials prior to recovery. Ether extraction was then employed. Continuous extraction apparatus was designed and built by the Recovery Group, capable of extracting a large volume of solution per hour, and giving recovery yields averaging better than 99.9%. The average amount of uranium remaining in stripped solutions was not more than 60 micrograms per liter.

17.8 A very difficult research problem, undertaken by the Recovery Group, was that of recovering active material in case of a test shot failure. Recovery of uranium dissipated through a large volume of sand, sawdust, and similar materials was attempted. This was in imitation of the conditions that would obtain if the bomb material were scattered over a large area by high explosives. Recovery by this method was found to be very poor. Recovery from sealed containing spheres was entirely successful. A 3/4 inch sphere of uranium, scattered explosively inside of a 12 inch "Jumbino" containing sphere, was recovered about 99%.

Uranium Metallurgy

17.9 By August 1944 it was possible to obtain metallic uranium with a neutron count below tolerance. A number of developments after that date were essential, however, to the final U^{235} weapon. The principal topics are the stationary bomb reduction, uranium remelting, uranium forming, cladding and protection of surfaces, use of uranium sponges, and production of final weapon parts.

17.10 After the adoption of the stationary bomb reduction technique a large number of minor improvements were made. A better product was obtained by increasing the bulk density of the tetrafluoride to be reduced. A wide survey of liners was made, resulting in the final choice of two: (1) a magnesia liner developed by the Miscellaneous Metallurgy Group; (2) a magnesia plus silica liner developed at the Massachusetts Institute of Technology. Other investigations included the effect of impurities in the reductant, grain size, firing technique, and the use of inert gases in the bomb. The net result of this research was a very high yield of high purity, well-consolidated metal.

17.11 Work on uranium remelting was begun in June 1944. This process served the double purpose of driving off volatile impurities and preparing the metal for shaping. A great deal of trouble was encountered in obtaining crucibles that would not crack on cooling. Magnesia and beryllia were finally used, with special heating methods.

17.12 Techniques for forming uranium were intensively investigated after August 1944. Three main techniques used were casting, hot pressing, and rolling. Both magnesia and graphite molds were used successfully for casting. A serious difficulty was that of melting large amounts of uranium, but the trouble was overcome by resistance heating. Investment and centrifugal casting were tried, and the latter adopted as by far the best. Hot pressing was not used in preparing parts for the full-sized gun assembly; it gave no greater accuracy than casting. It was used, however, for smaller pieces, including hemispheres for sphere multiplication experiments and the preparation of slugs for rolling.

17.13 A variety of cladding techniques were investigated, including electroplates of gold, zinc, silver, and later nickel and chromium. Chromium gave the best, but still inadequate, protection. Evaporated metal techniques proved better.

17.14 Low density compacts of uranium were prepared by sintering metal powder obtained from decomposition of the hydride. These had densities ranging from 1 to 6. Protection against spontaneous combustion and corrosion was obtained by treatment with nitrogen, which formed a nitride coating on the metal.

17.15 The culminating work of the Uranium Metallurgy Group was the casting of the final parts for the Hiroshima bomb. This work had been scheduled more than a year before for completion on July 26, 1945. It was in fact completed July 24.

Plutonium Purification

17.16 The plutonium purification program was of course the most directly affected by the abandonment of the plutonium gun program in August 1944.

17.17 Concentration of effort in plutonium purification after this time was upon simplification, production routine, efficiency, and the plutonium health hazard.

WET PURIFICATION

17.18 Shortly after the beginning of this period the first completely enclosed full scale apparatus was completed. The full run of 160 grams required 24 hours, with about 60 liters of supernatant remaining for recovery. Aside from minor difficulties and improvements, this represented the completed form of the "A" process of wet purification, described in Chapter VIII (8.30).

17.19 Early in 1945 investigation and testing of a "B" and "C" wet process began. The "B" process, the one finally adopted for routine plutonium purification, was simpler than the "A" process, and gave higher yields and a smaller volume of supernatants. It involved only two steps: an ether extraction with calcium nitrate, and an oxalate precipitation. The process met purity requirements and gave a product satisfactory for further processing. In July 1945 the "A" process was dropped completely.

17.20 For a time some thought was given to an even simpler "C" process involving only an oxalate precipitation. Purification, however, was not sufficient. The chart on the following page gives the essential information on the "A" and "B" processes.

DRY CONVERSION

17.21 After it was decided to employ only fluoride metal reduction (8.43), effort was concentrated on the production of the fluoride. Three methods were investigated, involving nitrate, oxalate, and oxide hydrofluorination. The method finally chosen was the oxide method, which involved the conversion of the oxalate from wet purification to oxide by heating in oxygen, and introducing hydrogen fluoride at 325°C in the presence of oxygen. The process involved a 24 hour cycle, and gave yields of 92 to 99%.

RECOVERY

17.22 Aside from recovery methods developed earlier (8.34 ff), the principal development of this period was that of peroxide precipitation. Of the four steps first employed--oxalate precipitation, ether extraction, sodium plutonyl acetate precipitation, and a final oxalate precipitation--the ether step was eliminated, and the sodium plutonyl acetate step used only for rather heavily contaminated material.

17.23 The danger of plutonium to the health of operators was greatest

"A" Process

Nitrates from X or W

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓ $H_2C_2O_4$

$Pu_2(C_2O_4)_3$, $9H_2O$

↓ oxidation with $NaBrO_3$ and HNO_3

PuO_2^{++}

↓

$NaPuO_2Ac_3$

↓ HNO_3

PuO_2^{++}

↓ ether extraction with NH_4NO_3 and HNO_3

PuO_2^{++}

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓

$Pu_2(C_2O_4)_3$, $9H_2O$

Yield 95 per cent
supernatant 60 liters
16 - 24 hours run

"B" Process

Nitrates from X or W

↓ oxidation

PuO_2^{++}

↓ ether extraction $Ca(NO_3)_2$ and HNO_3

PuO_2^{++}

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓ $H_2C_2O_4$

$Pu_2(C_2O_4)_3$, $9H_2O$

Yield near 100 per cent
supernatants 30 - 40 liters
10 - 11 hours run

in the recovery operations. The need to vary procedures to fit the type of contamination involved made the development of enclosed apparatus difficult. Such apparatus was, in fact, not developed until after the period covered by this history (November 1945 at DP Site). The main safety effort was perforce the careful monitoring of personnel; those who showed exposure in excess of body tolerances were taken away from further exposure until counts returned to normal (9.30).

Plutonium Metallurgy

17.24 When the new purity tolerances were established, all metal reduction methods were eliminated except the stationary bomb reduction of the tetrafluoride. Work continued as before in the field of crucible research for remelting. It became possible, however, to use magnesia since with increased tolerances the danger of magnesium impurities was less serious. A good deal of research was done on the physical properties of plutonium metal, since more than two allotropic phases were suspected, and this was of primary importance in forming operations. Work began on alloys, with the purpose of finding one that would keep a high temperature phase stable at room temperature. The stable room temperature phase, called the alpha phase, is brittle and difficult to work with. Fabrication operations were investigated, as were methods of surface cleaning and protection. Because plutonium is highly susceptible to corrosion, these were far more important topics than in the case of uranium.

17.25 The techniques of metal reduction and remelting were well established by August 1944. This work, of course, was on a very small scale, and the techniques had to be adapted to large scale operation as more plutonium became available.

17.26 Within the limited time available to them, the metallurgists made rather extensive studies of the physical properties of plutonium. The first transuranic element manufactured in kilogram amounts proved to have a remarkable physical structure. It exists in five distinct allotropic forms between room temperature and the melting point, labeled in the order of temperatures at which they are stable α, β, γ, δ, ϵ. It is very electropositive, but had the highest electrical resistivity of any metal. It is very corrosive in water and air.

17.27 Of all the phases the α, or room temperature phase, is the densest. Because this phase is brittle, and the δ and ϵ phases malleable, the material was pressed at δ phase temperatures. When a series of hemispheres were cast by this method for multiplication studies, warpage and cracks appeared after the metal stood a day or so at room temperature. Evidently higher temperature phases were being retained for a time at room temperature, the warping and cracks being caused by a delayed transition to the denser phase.

17.28 While cleaning and etching plutonium surfaces caused no serious problems, that of protective coating did. A large number of electroplated and evaporated metal coatings were tried, and electrodeposited silver was decided upon for the Trinity hemispheres. At the last minute, however, small pinholes were discovered in the coat as well as blistering caused by the retention of small amounts of plating solution under the coat. Since the scheduled test was only a few days away, it was decided to use the material in this condition, with the blisters polished down to restore the fit of the hemispheres.

Miscellaneous Metallurgy

17.29 The principal metallurgical work of this period, other than uranium and plutonium metallurgy, was that of the Miscellaneous Metallurgy Group in fabricating the gun tamper, beryllium crucibles and refractories, and some boron compacts.

17.30 In crucible research cerium sulfide continued in use for some time after the lowering of purity standards. The material finally adopted for all plutonium and uranium crucibles and liners was a vitrified magnesia developed by the Miscellaneous Metallurgy Group and manufactured at Los Alamos, at the Massachusetts Institute of Technology, and at Ames.

Radiochemistry

17.31 The principal developments in radiochemistry after August 1944 were the following: The implosion initiator program was gotten under way, and the staff of men in this program engaged in polonium research was increased. Radiolanthanum work, in colloaboration with the RaLa Group, was carried out at the Bayo Canyon Laboratory. These two groups were formally separated from the Radiochemistry Group in April 1945. Work began with the high-power Water Boiler, with its consequent problem of decontaminating highly irradiated uranium. Foil chemistry was continued. A new sensitive neutron detector was developed. A calorimeter was built for polonium work. A microtorsion balance was constructed for use in the determination of the mass purity of samples.

POLONIUM

17.32 The use of polonium for the implosion initiator represented a major technical achievement which, moreover, involved a good deal of basic research into the chemical and "metallurgical" properties of this element. Investigation of this element might be said to be as novel as that of plutonium.

17.33 The main problems were these: first, to prepare polonium of sufficient purity to meet the neutron background tolerance; second, to prepare high-density uniform foils; third, to coat these foils against polonium and alpha particle escape. It must also be said that this work is hazardous, both because of the high alpha activity of polonium, and because of its extreme mobility. It is virtually impossible to work with polonium and avoid entrance of the material into the human system. It is eliminated rapidly, however, and does not settle in dangerous concentrations in the bone, as do radium and plutonium. The full extent of the polonium hazard can only be determined with time. Pragmatic safety rules were intended to minimize and detect polonium absorption. Persons with more than a tolerance dose were removed from possible contact with the material until urine counts dropped below tolerance.

17.34 After the first half curie, which was recovered from residues from radon capsules, the polonium used at Los Alamos was obtained from bismuth irradiated in the Clinton pile. Polonium was separated from the bismuth at two plants of the Monsanto Chemical Company in Dayton, Ohio. This material was deposited on platinum foils and shipped to Los Alamos in sealed containers. Much trouble was encountered throughout by migration of the polonium off these foils, on to the walls of the container.

17.35 Polonium purification was primarily the responsibility of Monsanto, although some research on chemical purification and purification by distillation was done at Los Alamos.

17.36 Other work of the polonium chemists was chiefly the preparation of (α, n) neutron sources for the experimental physicists. Of these the most complicated were the mock-fission sources referred to in 12.11.

WATER BOILER CHEMISTRY

17.37 Work on the low power boiler ended in August 1944, and operation of the high power boiler was begun in December 1944. It was decided to use the nitrate in the second boiler, so the first job of the radiochemists was the repurification and conversion of the old material from sulfate to nitrate. The main reason for choice of the nitrate was that the nitrate had to be used in decontamination (ether extraction); the nitrate also was found to be slightly less corrosive than the sulfate.

17.38 It became necessary to build a "hot" chemistry laboratory and remote control decontamination apparatus. Research was carried out in collaboration with the Recovery Group on the use of the ether extraction method.

17.39 The remote control apparatus was placed behind a thick concrete wall. The irradiated material was run directly from the boiler into an underground tank. From there it was pumped up into the extraction column by means of air pressure. After extraction of the solution it could be run back into an underground vault, or let out into the "hot" laboratory if concentration was desired. Concentration was carried out behind a shield of lead bricks.

17.40 The heavy irradiation of the nitrate in the boiler caused decomposition and loss of nitrogen. This caused precipitation of the basic nitrate. To avoid this, frequent analyses of the boiler solution were made, and nitric acid was added to make up the deficit.

RADIOLANTHANUM

17.41 The first remote control apparatus mentioned in 8.70 was developed largely before August 1944, but its first use falls in the period after that date, and the entire subject is discussed in this place. The determining feature of the RaLa chemistry, essential to the RaLa method, was the enormous radioactivity involved. A single batch of material could represent up to 2300 curies of activity.

17.42 The isolation of radiobarium from the fission products of the Clinton pile was arranged in April 1944. The material received from Clinton consisted of a mixture of Ba^{140} and La^{140}. After arrival, the short-lived lanthanum had to be separated from its parent barium.

17.43 The first control apparatus and associated means for separating lanthanum from barium was designed as protection against about 200 curies of activity, and operated by the so-called phosphate method. In small scale tests, the separation of the lanthanum from about 100 times its mass of barium was found to be nearly quantitative when the phosphate was precipitated from an acid phosphate solution. But in full scale practice the method did not turn out well. Difficulties were encountered because of long filtration times and strong hydrogen ion dependence.

17.44 As the RaLa method was developed, moreover, the requirements on source strength and dimensions became more stringent. It became necessary to develop a new and better method. This method would have to provide shorter filtration time and precipitation on a smaller filter area, and would have to give good separation with higher yield. And the operators would have to be given protection against higher activities.

17.45 In March 1945 work began on a new method, with collaboration between the radiochemists and the Plutonium Chemistry Group and Recovery Group. For greater radiation protection the controls were removed to a distance of 90 feet. The separation method developed was a hydroxide-oxalate process. Lanthanum hydroxide was precipitated with sodium hydroxide, filtered on a platinum sponge filter, dissolved in nitric acid, and reprecipitated with oxalic acid; the oxalate was allowed to stand approximately 25 minutes, and then a small quantity of hydrogen fluoride was added. The resulting precipitate was crystalline, which could be filtered rapidly on a small area and was not affected by intense radiation.

17.46 Half-life measurements of carefully purified La^{140} gave a value of 40.4 hours.

INSTRUMENTS AND SERVICES

17.47 Mention has been made of boron trifluoride investigations for filling proportional neutron counters. The preparation of very pure trifluoride was investigated, as were methods of recovery of the costly isotope 10 from counters no longer needed. In addition to filling counters in large numbers as a service to the experimental physicists, the radiochemists developed a very sensitive counter, the "quadruple proportional counter," for quick measurement of weak neutron sources.

17.48 Among other important services a large number of foils were prepared for the experimental physicists. The essential problems and accomplishments of this work have already been described.

17.49 A calorimeter was built for use in connection with the measurement of the half-life of polonium. A microtorsion balance was constructed for weighing polonium samples. The comparison of weight and activity of samples was found to be a reliable method of purity analysis.

Analysis

17.50 In the early work of the Analysis Group, the main emphasis had been upon the determination of very small amounts of light element impurities. After the discovery of Pu^{240}, however, the need for strict contamination control was eliminated, as was that for further research on methods for determining these elements. Tolerance limits were easily determined by existing methods, and it became possible to turn attention to investigations which had previously been secondary, particularly in heavy element analysis. The Analysis Group devoted increasing effort to the problems of the metallurgists, to improvement of instrumental techniques and development of routing methods. The following is an outline of the principal analytical methods investigated after August 1944.

Spectrochemical methods
- a. Plutonium
  - (1) The cupferron method for heavy elements
  - (2) The gallium oxide pyroelectric method
- b. Uranium
  - (1) The determination of zirconium in uranium
  - (2) The determination of uranium in urine
- c. Miscellaneous
  - (1) Impurities in calcium and magnesium oxides

Volumetric methods
- a. Determination of acid soluble sulfide in U and Pu
- b. Determination of sulfate in Pu

Assay methods
- a. Radioassay
- b. Photometric assay
- c. Gravimetric assay
- d. Microvolumetric assay

SPECTROCHEMICAL METHODS

17.51 The cupferron procedure as applied to heavy element determination was essentially the same as that developed earlier for light element trace analysis. It eventually proved applicable to 39 element impurities. In addition to its use for plutonium analysis, it was applied in analyses of other elements, including uranium. The procedure consists in forming the acid-insoluble cupferride of plutonium, and extracting the compound from the impurities with chloroform. The aqueous impurity solution is then evaporated on copper electrodes, sparking of which gives the impurity spectrum. It may also be noted that this method was used by the Health Medical Group to determine plutonium in urine samples.

17.52 The pyroelectric gallium oxide method was developed in the first period for uranium analysis, but became one of the important methods for plutonium analysis as soon as such analysis became necessary. In this case the material was arced in a dry-box to reduce health hazards.

17.53 For certain elements, notably titanium, zirconium, thorium, columbium, and tantalum, no satisfactory spectrochemical method was discovered by the end of the period considered in this history. None of these elements, fortunately, was of crucial importance.

17.54 Some further investigation of uranium analysis was made in this period. At the end a method was being studied for the determination of zirconium in uranium. A process was being investigated for determining uranium in amounts of 0.1 to 1 microgram in urine samples. This method was being sought for use in health control work.

17.55 The analysis of impurities in calcium oxide and magnesium oxide became important with the adoption of these materials as crucibles and liners in plutonium metallurgy. The investigation was begun early in 1944, but was pursued more intensively after they were adopted for that purpose. The method was one of direct arc spectrography. Difficulties were encountered in obtaining consistent results, most of which were found to be caused by variation in the state of subdivision of the oxides. This was overcome by very fine grinding of the samples.

17.56 Several useful developments of spectrochemical techniques were made during this period. These included the double spectrograph, the double slit spectrograph and the dry box arc. The double spectrograph consists of two spectrographs aligned in opposition, and passes light emitted from the source through the slits of both instruments. The double slit spectrograph produces juxtaposed spectra of two wave length ranges on the same film. The advantages of these methods lay in halving the sample size in one case, and the time for a complete analysis in the other. They were important because of economy of valuable material, reduction of analysis time, and reduction of exposure to plutonium on the part of the operator. The dry box arc with outside controls was developed because of the extreme danger from arcing plutonium. Laboratory contamination is serious with ordinary arcing, and the danger to operators very great.

VOLUMETRIC METHODS

17.57 Acid soluble sulfide was determined by distillation of hydrogen sulfide, which was absorbed and determined volumetrically. The method was used for plutonium and uranium metals. Sulfate in plutonium was determined by reduction to sulfide, followed by volumetric measurement of absorbed hydrogen sulfide.

ASSAY METHODS

17.58 Photometric, volumetric, and gravimetric methods were investigated to establish a procedure for routine plutonium assay. Results from the photometric method were untrustworthy. The gravimetric was good but too slow. The volumetric method was the one finally adopted. After its development in early 1945, all Hanford material was assayed by this method.

DP Site

17.59 At the beginning of 1945 all plutonium production work had been planned for and was being carried out in the Chemistry Building, Building D. Three things contributed to the alteration of this plan. The first was the increasing realization of the seriousness of the plutonium health hazard. As has been pointed out before, Building D was originally planned with the idea in mind of preventing the contamination of plutonium by light element impurities. In fact, the most serious contamination problem was to prevent the contamination of personnel with plutonium. The building was not ideal from this point of view, and as larger amounts of plutonium began to arrive, adequate decontamination became increasingly difficult. The second factor was an increase in the expected rate of flow of the Hanford material, which would, at maximum production, tend to overstrain the resources of D Building. The third factor of importance in changing the plutonium production plan was a bad fire which occurred in C Shop on January 15, 1945 (9.40). This fire demonstrated vividly the possibility of fire in D Building. The consequences of such a fire, including the spread of contamination over a wide area of the Laboratory, indicated that it was imperative to build a new production plant, designed so that fire was unlikely, and so located that accidents would not retard the work of the Technical Area.

17.60 In February, consequently, a committee was appointed to design and expedite the construction of a new plant. The plans for this plant were enlarged so as to accommodate the processing of polonium, which in the meantime had shown itself to be a serious hazard, and which was inadequately housed in the Technical Area.

17.61 The new plant, the so-called DP Site, located on South Point, was divided into two areas. The first of these, the East Area, was designed for the processing of polonium and the production of initiators, under the supervision of Group CM-15, the Polonium Group. The second area, the so-called West Area, was designed for the processing of plutonium and the production of bomb cores. This area was under the control of Group CM-13.

BUILDING DESIGN

17.62 When building design work started, the final processes were not worked out. However, it was necessary to design buildings which would house any finally accepted process. The buildings consist of four identical working buildings, plus an office, in the West Area, and one working building plus an office in the East Area. The buildings are of entirely noncombustible construction, steel walls and roof, rock wool insulation, metal lathe and plaster lining. All rooms have smooth walls and rounded corners for easy cleaning. Each of the West Area operating buildings is 40 x 200 feet and contains two 30 x 30 feet operating rooms and two 40 x 50 feet operating rooms. The East Area operating building is 40 x 240 feet and is broken up into small rooms.

17.63 The chief feature of the buildings is the ventilating system. The air is withdrawn from the rooms through hoods at a rate of about 2 cubic feet per second. Where the hood capacity of the rooms is too small, additional exhaust ducts are furnished so that the air in every room is changed once every 2 minutes. The exhaust ducts assemble into a common duct. The exhaust air from each Area (East and West) is then passed through a bank of electrostatic filters to remove contamination, through a bank of paper emergency filters, and finally through a series of 50 foot stacks. The air is exhausted by four 50 horsepower blowers in the West Area, and by two 40 horsepower blowers in the East Area.

17.64 A few preliminary building drawings were made early in February and serious design work started about the first of March. About March 15 work was started on the East Area buildings. The latter set of buildings was essentially complete June 1. Installation of equipment was complete by July 15, and operations started shortly after that date. The West Area buildings were complete by July 15. The much more extensive process installation was essentially complete by October 1, but minor difficulties prevented plant operation until November 1, after the end of the period described in this history.

PROCESS DESIGN

17.65 When work started on design of a new plant, the operating procedures were not fully worked out. Subsequently, these processes were worked out by various groups in the CM Division. While these procedures were being used in D Building, a new plant committee supervised the redesign of the equipment for use at DP Site.

17.66 For safe operation with plutonium and polonium, all operations are carried out in closed systems. For easy plant operation, all operations are designed to be carried out in a routine fashion. Finally, to prevent chain reactions with plutonium, all equipment is designed so that no more than a safe amount can be charged into any piece of apparatus.

17.67 Improved protective furniture (hoods, and dry boxes--sealed boxes containing an inert atmosphere with inserted gloves) was designed for every operation. This equipment was all made out of stainless steel for corrosion and fire resistance and ease of decontamination. A total of about 20 carloads of this furniture was fabricated by the Kewaunee Manufacturing Company in about 100 days.

Chapter XVIII

PROJECT TRINITY

Pre-Trinity

18.1 Preparations for an experimental nuclear explosion were begun in March 1944 when it was decided by the Director and most of the group and division leaders of the Laboratory that such a test was essential. It was extremely difficult to plan integral experiments which would duplicate in any satisfactorily complete way the conditions of a bomb. The many questions about a practical bomb left unanswered by theory and differential and integral experiments could only be answered by an actual experiment with full instrumentation. Kistiakowsky, then Deputy Division Leader for the implosion program in the Engineering Division, formed E-9, the High Explosives Development Group, under Bainbridge, to investigate and design full scale HE assemblies and prepare for a full scale test with active material. Group E-9 became Group X-2 (Development, Engineering, Tests) during the general Laboratory reorganization.

18.2 The first systematic account of the test plan was made in a memorandum early in September 1944 by Fussell and Bainbridge, in which it was considered that the energy release might be from 200 tons to 10,000 tons TNT equivalent. These early plans were based on the assumption that Jumbo, a large steel vessel, would enclose the bomb so that the active material could be recovered in case of a complete failure. Among the tests planned at this time were the following:

Blast measurements - piezo electric gauges
paper diaphragm gauges
condenser blast gauges
Barnes' Boxes (not used)
condenser gauge blast measurement from plane

Ground shock measurements - geophones
seismographs

Neutron measurements - gold foil
fast ion chamber (not used in this form)

Gamma Rays - recording in plane, dropped "gauges" - (not used)
gamma ray sentinels

Nuclear efficiency

Photographic studies - fastax cameras at 800 yards
spectrographic studies, radiation characteristics
photometric
ball of fire studies

SCR-584 Radar

Meteorology

Additional nuclear measurements were considered in three reports by Moon, who anticipated some of the experiments later adopted.

18.3 One of the early problems of the test group was that of selecting a site. At one time eight different sites were considered - the Tularosa Basin; Jornada del Muerto; the Desert training area near Rice, California; San Nicolas Island off the coast of southern California; the lava region south of Grants, New Mexico; southwest of Cuba, New Mexico, and north of Thoreau; sand bars off the coast of south Texas; and the San Luis Valley region near the Great Sand Dunes National Monument in Colorado. There were a number of factors to be considered in making the selection. Scientific considerations required that the site be flat to minimize extraneous effects on blast and that the weather be good on the average because of the large amount of optical information desired. Safety precautions required that ranches and settlements be distant to avoid possible danger from the products of the bomb. Tight time scheduling required a minimum loss of time in travel of personnel and transportation of equipment between Project Y and the test site, while security required complete separation of the activities at the test site from the activities at Y. The choice 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, California. The final choice of the Jornada del Muerto was made, with General Groves' approval, after consultation with General Ent of the Second Air Force early in September 1944. The project secured the use of an area approximately 18 x 24 miles within the base, with the nearest habitation 12 miles away and the nearest town about 27 miles away.

18.4 Once a site had been selected it became extremely important to secure good maps of the region. Arrangements were made with the Second

Air Force for a 6 inch to the mile mosaic to be made of a strip 6 x 20 miles including point zero (the point of detonation) at the center. These aerial mosaics were extremely useful both for the early exploratory work and for final precise planning. A great deal of delay was occasioned because of an inadequate supply of maps, which had to be obtained through the Security Office in order not to reveal the Laboratory's interest in the regions in question. The maps finally used were obtained by devious channels and included all of the geodetic survey maps for New Mexico and southern California, all of the costal charts of the United States, and most of the grazing service and county maps for the state of New Mexico.

18.5 The original plans for construction of the base camp at the test site were drawn up by Capt. S. P. Davalos (Assistant Post Engineer), Bainbridge, and Fussell in October 1944, and provided for a maximum of 160 men. This was supported by a memorandum from Kistiakowsky outlining the plan and scope of the proposed operations and justifying construction requirements. These two documents were approved by Gen. Groves and contracts were let for the initial construction early in November. The camp was completed late in December, and a small detachment of Military Police under Lt. H. C. Bush took up residence. Laboratory personnel concerned with the Trinity tests agreed that the wise and efficient running of the Base Camp by Lt. Bush under extremely primitive conditions contributed greatly to the success of the tests.

18.6 With the concentration of the Laboratory on the implosion program beginning in August 1944, the test program lost in priority. The shortage of manpower for research and development work resulted in the members of the Development, Engineering, Tests Group devoting most of their time and effort to engineering problems and abandoning to a large extent their work on the test. Among the few accomplishments during this period were the layout of the test site, the design and construction of shelters, the collection of earth samples, the procurement of meteorological and blast gauge equipment, and a certain amount of planning for the measurement of nuclear radiations.

Trinity Organization

18.7 By March 1945 almost all the essential physics research for the bomb had been completed and Oppenheimer proposed the establishment of Project TR, an organization with division status, composed of personnel chiefly from the Research Division, which was to have full responsibility for a complete test. As originally organized, Project TR included the following:

Head	K. T. Bainbridge
Safety Committee	S. Kershaw
TR U.S.E.D.	Capt. S. P. Davalos
Security	Lt. R. A. Taylor
CO MP Detachment	Lt. H. C. Bush
Consultants	W. G. Penney
	V. F. Weisskopf
	P. B. Moon
TR-1 Services	J. H. Williams
TR-2 Shock and Blast	J. H. Manley
TR-3 Measurements	R. R. Wilson
TR-4 Meteorology	J. M. Hubbard
TR-5 Spectrographic and Photographic	J. E. Mack
TR-6 Airborne Measurements	B. Waldman

This organization expanded rapidly and by the time of the test involved about 250 technical men. Groups R-1, R-2, R-3, R-4, F-4, G-11, O-4, T-3, and T-7 worked full time on the Trinity Project, and various other groups gave a great deal of time to this work. Group G-4 manufactured the greater part of the electronic equipment.

18.8 In June 1945 Project TR included the following:

Head		K. T. Bainbridge
Aide		F. Oppenheimer
TR U.S.E.D.		Capt. S. P. Davalos
Security		Lt. R. A. Taylor
CO MP Detachment		Lt. H. C. Bush
Consultants	Structures	R. W. Carlson
	Meteorology	P. E. Church
	Physics	E. Fermi
	Damage	J. O. Hirschfelder
	Safety	S. Kershaw
	Earth Shock	L. D. Leet
	Blast and Shock	W. G. Penney
	Physics	V. F. Weisskopf
TR Assembly		Cmdr. N. E. Bradbury
		G. B. Kistiakowsky, Alternate
TR-1 Services		J. H. Williams
TR-2 Air Blast and Earth Shock		J. H. Manley

TR-3	Physics	R. R. Wilson
TR-4	Meteorology	J. M. Hubbard
TR-5	Spectrographic and Photographic Measurements	J. E. Mack
TR-6	Air Blast	B. Waldman
TR-7	Medical Group	Dr. L. H. Hempelmann

18.9 By the time Project TR was set up, all of the elaborate schemes for recovery of active material were virtually abandoned, including the use of Jumbo (16.53) and the use of large quantities of sand or of water. At the time recovery methods were considered seriously the supply of active material was extremely limited and there was a very strong feeling that the bomb might fail completely to explode. As confidence in the ultimate success of the bomb increased and adequate production of active materials seemed assured, the recovery program no longer seemed essential. Perhaps the most important deciding factor, however, was the fact that any effective recovery program would interfere seriously with securing information on the nature of the explosion, which was, after all, the principal reason for the test. Jumbo was taken to the site and erected at a point 800 yards from its originally planned location, since it was not to be used for this test.

Rehearsal Test

18.10 The first task of the new group was that of preparing a rehearsal shot known as the 100 ton shot. This had been proposed in the summer of 1944 both as a full dress administrative rehearsal and as a way of providing calibration of blast and earth shock equipment for the nuclear bomb test. It was finally scheduled to take place on May 5, 1945. The date was extended to May 7 to allow the installation of additional equipment, but several requests for an additional time extension had to be refused because any further delay would have delayed the final test, which was already very tightly scheduled.

18.11 The test was carried out early in the morning of May 7 with 100 tons of HE stacked on the platform of a 20 foot tower. Very little experimental work had ever been done on blast effects above a few tons of HE, and it was important to obtain blast and earth shock results in order to determine the proper structures to use to withstand these effects for the final shot. By using appropriate scale factors, the center of gravity of the 100 ton stack of HE was made 28 feet above the ground in scale with the 100 foot height for the 4000 to 5000 tons expected in the final test. The stack of HE was provided with tubes containing 1000 curies of fission products derived from a Hanford slug 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 apparatus shelters were made at distances in scale with the distances proposed for the final shot. Measurements to determine "cross-talk" between circuits and photographic observations were in general carried out at the full distances proposed for the final shot.

18.12 The test was successful as a trial run, and was useful chiefly for suggesting methods for improving procedures for the final test. The most critical administrative needs emphasized by the test were better transportation and communication facilities and more help on procurement. The chief purposes of the test were accomplished. Men who had worked in well-equipped laboratories became familiar with the difficulties of field work. Blast measurement and earth shock data were valuable in calibrating instruments and providing standards for the safe design of shock-proof instrument shelters. Measurement of the effects from the radioactive material inserted in the stack of HE was especially valuable in giving information on the probable amount and distribution of material which would be deposited on the ground. This information secured by the Fission Studies Group of F Division was essential for planning the recovery of equipment, the measurement of bomb efficiency, and protection of personnel for the final test. The high percentage of successful measurements in the final test may be attributed in large measure to the experience gained from the rehearsal shot practice.

Preparations for the Trinity Test

18.13 When Project Trinity was established, July 4 was set as the target date for the test, although it was doubtful that this date could be met. Preparations for the test continued at an increasingly rapid pace after the completion of the rehearsal shot. The breadth and intensity of the preparations which were necessary for the Trinity test cannot be overemphasized. The task was one of establishing under conditions of extreme secrecy and great pressure a complex scientific laboratory on a barren desert. The number of people available was very small in comparison with the amount of work to be done. Over 20 miles of black top road were laid, plus a paved area in the vicinity of the tower. All personnel and equipment had to be transported from Los Alamos, and after considerable effort the Trinity staff succeeded in securing about 75 vehicles. About 30 more were added during the last week by the monitoring and intelligence groups. A complete communications system had to be installed, including telephone lines, public address systems in all of the buildings, and FM radios in 18 of the cars. Miles of wires were used both for the communications system and in conjunction with the various experiments. A complete technical stockroom had to be established, and all of its varied contents transported from Los Alamos. The stockroom was officially known as "Fubar." Sanitary conditions were difficult to maintain, especially in the mess hall, because of the hardness of the water. Because of the extremely tight schedule for the test, any delay in the procurement or delivery of needed material meant that the group affected would have to redouble its efforts when the things finally did arrive. The combination of tight schedule and shortage of personnel meant that most of the people at Trinity, from mess attendants to group leaders, worked at fever pitch, especially during the last month. A 10 hour working day was considered normal, and often it stretched to 18 hours.

18.14 Among the most complex administrative problems associated with the test were those solved by the Services Group. This group undertook the very difficult task of providing the wiring, power, transportation, communication facilities, and construction needed. The construction schedule was especially tight and required a great deal of careful planning and hard work to complete successfully. For a month before the test there were nightly meetings to hear reports on field construction progress and to plan the assignment of men for the following day. Construction help was assigned on the basis of the priority of the experiments for which it was needed.

18.15 Considerable attention was paid to security and to the legal and safety aspects of the test. A great effort was made to dissociate the work at Trinity from that at Los Alamos. There was a great deal of discussion about what should be done about people in surrounding towns. This was finally settled by having a group of 160 enlisted men under the command of Major T. O. Palmer stationed north of the test area with enough vehicles to be able to evacuate ranches and towns if this was found necessary at the last moment. At least 20 men associated with Military Intelligence were stationed in neighboring towns and cities up to 100 miles away, and most of these men served a dual function by carrying recording barographs in order to get permanent records of blast and earth shock at remote points.

18.16 One minor source of excitement was the accidental bombing, with two dummy bombs, of the Trinity base camp by a plane from the Alamogordo Air Base early in May. The incidents were reported to the base commander through the Security officer and precautions were taken to prevent their recurrence.

18.17 Early in April Project TR secured the services of J. M. Hubbard, meteorology supervisor for the Manhattan District. He requested information from the various experimental groups on the particular weather conditions or surveys which they would find useful in their operations, and made an effort to find a time that would meet nearly every specification of the various groups. He secured the cooperation of the Weather Division of the Army Air Forces and was able to draw on information of a world-wide nature in making his surveys. The period which he selected as first choice for the final test was July 18 to 19, 20 to 21, with 12 to 14 as second choice, and July 16 only a possible date.

18.18 One of the most difficult problems faced by Project TR was that of scheduling. Weekly meetings were held, with consultants and responsible group and section leaders attending to consider new experiments and discuss detailed scheduling and progress reports. It was important to get as much information from the test as possible, but it was not possible because of the limitations of time and personnel to schedule every experiment proposed. In order to have a new experiment considered by the weekly scheduling meeting, the person making the proposal would have to prepare a detailed account of the objectives of the experiment, the accuracy expected, and the requirements for equipment, personnel, and machine shop and electronics shop time. On the basis of such information the Trinity scheduling group could decide whether a particular experiment was suitable and whether it had any possibility of being successfully completed.

18.19 The July 4 date accepted in March was soon found to be unrealistic. Delays in the delivery of full scale lens molds and the consequent delay in the development and production of full scale lenses, as well as the tight schedule in the production of active material, made it necessary to reconsider the date. The Cowpuncher Committee made an effort to schedule the pacing components in order to determine the time at which other components or other developments would have to be completed in order not to delay the test. By the middle of June, the Cowpuncher Committee agreed that July 13 was the earliest possible date, and the 23rd was a probable date. Because of the great pressure to have the test as early as possible, it would undoubtedly have to take place before all reasonable experiments, tests, and improvements could be made, but the July 13 date was fixed so that essential components would be ready at that time. On June 30 a review was made of all schedules by the Cowpuncher Committee, and the earliest date for Trinity was changed to July 16 in order to include some important experiments. Commitments had been made in Washington to have the test as soon after July 15 as possible, and these commitments were met by firing the shot early on the morning of July 16, as soon as weather conditions were at all suitable.

18.20 Four rehearsals were held on the 11th, 12th, 13th and 14th with all personnel cooperating. A "dry run" of the assembly of the HE component of the bomb was held early in July following a number of tests to study methods of loading and effects of transportation. Final assembly of the HE began on July 13, and of the active core on the same day. Nuclear tests and the assembly of the active component were carried out in McDonald's ranch house - a four room frame house about 3400 yards from the detonation point. The various pieces of apparatus employed were identical with those already shipped to Tinian, and the operation took on the character of a field test for the overseas expedition. On July 11 the active material was brought down by convoyed sedan from Los Alamos in a field carrying case designed for use overseas. The HE components were assembled at one of the outlying sites at Los Alamos and brought down by convoyed truck, arriving at Trinity on Friday, July 13.

18.21 Before the assembly started, a receipt for the active material was signed by Brig. Gen. T. F. Farrell, deputy for Gen. Groves, and handed to L. Slotin who was in charge of the nuclear assembly. The acceptance of this receipt signalized the formal transfer of the precious Pu^{239} from the scientists of Los Alamos to the Army to be expended in a test explosion. The final assembly took place on a canvas-enclosed flooring which had been built for the purpose within the base of the tower. Active material in large quantity was put within HE for the first time on this occasion. Although the people performing the operation and those watching it were outwardly calm, there was a great feeling of tension apparent. Only one difficulty was encountered which made the actual carrying out of the assembly anything more than a routine repetition of rehearsals. The heat of the desert together with the heat generated by the active material caused an interference between some of the parts, because a portion of the assembly had been completed the night before on the high mesa of Los Alamos and was cold to the touch. Differential expansion between these two parts was enough to cause interference. A delay of a minute or two occurred while the hot material was placed in contact with the cold material and cooled sufficiently to permit its entry as planned.

18.22 After the HE and nuclear components were completely assembled, the bomb was still without detonators. It was hauled to the top of its 100 foot tower where it rested in a specially constructed sheet steel house. On the 14th the Detonator Group installed the detonators and informers, and the Prompt Measurements Group and other test groups checked and completed the installation of apparatus for their experiments. Visits were made to the top of the tower every 6 hours by members of the Pit Assembly Group to withdraw the manganese wire whose induced radioactivity was a measure of the neutron background.

18.23 Elaborate plans were made for the evacuation of personnel in the event of any serious difficulty, with the Medical Officer to be in charge. The Arming Party, a small group responsible for final operations, also assumed responsibility for guarding the bomb against possible sabotage, and remained at the tower until the last possible moment. The weather seemed unfavorable early in the morning of the 16th, and not until shortly before 5:00 a.m. did the weather reports received from Hubbard begin to look satisfactory. As originally planned, the decision whether or not to run the test was to be made by Oppenheimer, Gen. Farrell, Hubbard, and Bainbridge, with one dissenting vote sufficient to call it off. The final decision was made and announced at 5:10 a.m. and the shot was scheduled to be fired at 5:30 a.m.

18.24 Nearest observation points were set up 10,000 yards from the tower with Base Camp located 17,000 yards from the tower. A number of distinguished visitors came for the test including Tolman, Bush, Conant, Gen. Groves, C. Lauritsen, Rabi, E. O. Lawrence, A. Compton, Taylor, Chadwick, Thomas, and von Neumann. All were instructed to lie on the ground, face downward, heads away from the direction of the blast. The control station, which was located at 10,000 yards, was connected to the various observation points by radio. From here periodic time announcements were made beginning at minus 20 minutes until minus 45 seconds. At that time automatic controls were switched on, setting off the explosion at 5:29 a.m. on Monday, July 16, 1945, just before dawn.

Trinity

18.25 There have been a great many descriptions of the explosion; one of the most graphic is that of Gen. Farrell who saw it from one of the 10,000 yard observation points. He said, in part: "The effects could well be called unprecedented, magnificent, beautiful, stupendous and terrifying. No man-made phenomenon of such tremendous power had ever occurred before. The lighting effects beggared description. The whole country was lighted by a searing light with the intensity many times that of the midday sun. It was golden, purple, violet, gray and blue. It lighted every peak, crevasse and ridge of the nearby mountain range with a clarity and beauty that cannot be described but must be seen to be imagined...." Several of the men stationed at Base Camp and members of the Coordinating Council of the Laboratory who watched the explosion from the hills about 20 miles away prepared eyewitness accounts of their experiences. All were deeply impressed by the intensity of the light, and also by the heat and the visible blue glow. Of the heat, one man said, "I felt a strong sensation of heat on the exposed skin of face and arms, lasting for several seconds and at least as intense as the direct noon sun." Of the blue glow, another reported, "Then I saw a reddish glowing smoke ball rising with a thick stem of dark brown color. This smoke ball was surrounded by a blue glow which clearly indicated a strong radioactivity and was certainly due to the gamma rays emitted by the cloud into the surrounding air. At that moment the cloud had about 1000 billions of curies of radioactivity whose radiation must have produced the blue glow." There were also many detailed accounts of the appearance of the now familiar mushroom-shaped cloud. It was several minutes before people noticed that Jumbo's steel tower had disappeared from view (16.32). At Los Alamos, over 200 miles away, a number of people who were not directly involved in the test and were not members of the Coordinating Council watched for a flash in the southern sky. As the shot had originally been scheduled for 4:00 a.m., many watchers grew impatient and gave up. A few did see it, however, and they reported a brief blinding flash of considerable intensity.

18.26 For many of the men who watched the test at Trinity, the immediate reaction was one of elation and relief, for the successful explosion of the first nuclear bomb represented years of difficult concentrated work. With this elation and relief came a feeling of awe and even of fear at the magnitude of what had been accomplished. For many the successful completion of the Trinity test marked the successful completion of the major part of their work for the Los Alamos Laboratory, and there was a general letdown and relaxation after the intensive efforts of the past months. For those men who were going overseas, however, there was no rest, and their preparations for Trinity were simply a rehearsal of their duties at Tinian.

18.27 Security, which always pervaded the work of the Laboratory, was not forgotten even in the hectic hours after Trinity. As the first cars of weary excited men stopped for food in the little town of Belen on their way back to Los Alamos, they spoke only of inconsequential things, and the occupants of one car did not recognize the occupants of another. In fact, the members of the coordinating council were required to return directly to Los Alamos in buses, avoiding any stops in New Mexico communities. Not until they reached the guarded gates of Los Alamos did the flood of talk burst loose. There was a great sale of Albuquerque newspapers the following day because in them was an account of an "explosives blast" at the Alamogordo Air Base. The story was credited to the Associated Press, but appeared in very few papers outside of New Mexico, and then only as a brief note about an unimportant accident.

Results of Trinity Experiments

18.28 To give some notion of the number and scope of the experiments done in connection with the Trinity test, the following summary is included. (See chart of location of Trinity experiments in Appendix 4). There were six chief groups of experiments: (1) Implosion; (2) Energy release by nuclear measurements; (3) Damage, blast and shock; (4) General phenomena; (5) Radiation measurements, and (6) Meteorology.

Implosion experiments included:

(a) Detonator asimultaneity measured with detonation wave-operated switches and fast scopes. These records were fogged by gamma rays.
(b) Shock wave transmission time measured by recording on a fast scope the interval from the firing of the detonators to the nuclear explosion.
(c) The multiplication factor (α) measurement was done by three methods - with electron multiplier chambers and a time expander; by the two chamber method; and with a single coaxial chamber, coaxial transformers, and a direct deflection high speed oscillograph.

The calculation of energy release by nuclear measurements included:

(a) Delayed gamma rays measured by ionization chambers, multiple amplifiers, and Heiland recorders from both ground and balloon sites.
(b) Delayed neutron measurements done in three ways - by the use of a cellophane catcher and U^{235} plates both on the ground and airborne, by the use of gold foil detectors to give an integrated flux, and by the use of sulphur threshold detectors. For the cellophane catcher method a record was obtained from the 600 meter station. With the gold foil method the number of neutrons per square centimeter per unit logarithmic energy interval was measured at 7 stations ranging from 300 to 1000 meters from the explosion. Of the sulphur threshold detectors only 2 of the 8 units used were recovered, and these gave the neutron flux for energies

of 3 Mev at 200 meters.

(c) The conversion of plutonium to fission products, measured by determining the ratio of fission products to Pu, gave a result equivalent to 18,600 tons of TNT. An attempt to collect fission products and plutonium on filters from planes at high altitude from the dust of the shot after it circled the world gave no results, although later some indications were obtained after the Hiroshima explosion by this method.

Damage, blast and shock experiments were divided into three groups: (a) blast, (b) earth shock, and (c) ignition of structural materials.

(a) Blast measurements included:

(1) Quartz piezo gauges - these gave no records since the traces were thrown off scale by radiation effects.

(2) Condenser gauges of the California Institute of Technology type were dropped from B-29 planes but no records were obtained because the shot had to be fired when the planes were out of position.

(3) The excess velocity of the shock wave in relation to sound velocity was measured with a moving coil loudspeaker pick-up, by the optical method with blast-operated switches and torpex flash bombs, and by the Schlieren method. By the moving coil loudspeaker method the velocity of sound was obtained for a small charge and then the excess velocity for the bomb; this measurement gave a yield of 10,000 tons and proved to be one of the most successful blast measuring methods.

(4) Peak pressure measurements were done with spring-loaded piston gauges at an intermediate pressure range of from 2.5 pounds to 10 pounds per square inch, with the same kind of gauges above ground and in slit trenches at a pressure range of from 20 to 150 pounds per square inch, with crusher type gauges, and with aluminum diaphragm "box" gauges at a range of from 1 to 6 pounds. The first of these methods gave blast pressure values which were low compared to all other methods, the crusher type gauges gave the highest pressure range, and the box gauges gave a TNT equivalent to 9900 ± 1000 tons. This last method was found to be inexpensive and reliable.

(5) Remote pressure barograph recorders gave results consistent with 10,000 tons. These were necessary for legal reasons.

(6) Impulse gauges - mechanically recording piston liquid and

orifice gauges - also gave results consistent with 10,000 tons.

(7) Mass velocity measurements were made by viewing with Fastax cameras suspended primacord and magnesium flash powder.

(8) Shock wave expansion measurements were made with Fastax cameras at 800 yard stations and gave a total yield of 19,000 tons.

(b) Earth shock measurements included:

(1) Geophone measurements with velocity-type moving coil strong motion geophones gave 7000 tons after extrapolation from a small charge and 100 ton data.

(2) Seismograph measurements done with Leet 3-component strong motion displacement seismographs gave results of approximately 15,000 tons. These were necessary for legal reasons.

(3) Permanent earth displacement measurements using steel stakes for level and vertical displacements gave results of 10,000 ± 5000 tons.

(4) Remote seismographic observations at Tucson, El Paso, and Denver showed no effect at these distances.

(c) The ignition of structural materials was observed using roofing materials, wood, and excelsior on stakes. Observations showed that the risk of fire produced by radiant energy is small for distances greater than 3200 feet. The risk of fire from direct radiation was likely to be much less than the risk of fire from stoves, etc., at the time of the explosion. These conclusions were confirmed at Hiroshima and Nagasaki.

The study of general phenomena consisted chiefly of photographic studies of the ball of fire and the column of blast cloud effects. This group of studies did include a radar study with 2 SCR-584 radars in which two plots of the cloud were obtained; radar reflection, however, was not found to be favorable. Photographic equipment used for these studies included Fastax cameras ranging from 800 to 8000 frames per second, standard 16 millimeter color cameras, a 24 frame per second Cine-Special, 100 frames per second Mitchell cameras, pinhole cameras, gamma ray cameras, Fairchild 9 x 9 inch aero view cameras at 10,000 yards and at 20 miles for stereo-photos. These photographic records were extremely valuable.

The rise of the column was followed with searchlight equipment and the first 18 miles of the main cloud path was obtained by triangulation. A part of this group of experiments was a number of spectrographic and photometric measurements and measurement of total radiation. Spectrographic measurements were done with Hilger and Bausch and Lomb high-time-resolution spectrographs, photometric measurements with moving film and filters and with photocells and filters recording on drum oscillographs, and total radiation measurements with thermocouples and recording equipment.

Post-shot radiation measurements included:

(a) Gamma-ray sentinels - these ionization chambers which recorded at 10,000 yard shelters were extremely valuable in giving the distribution of radioactive products immediately after the shot until safe stable conditions were assured.
(b) Portable chamber observations in the high gamma flux region were made from heavily shielded army tanks using portable ionization chambers of standard design about 4 hours after the shot, and ionization data from these chambers were radioed back to the control shelter.
(c) A dust-borne product survey was made by the Health Group with portable alpha and gamma ionization chambers and Geiger counters, both at the site of the explosion and at remote points up to 200 miles in order to measure dust-deposited fission products.
(d) Measurement of airborne products from B-29 planes equipped with special air filters was unsuccessful as noted above under blast measurements (2).
(e) A detailed crater survey was made with ionization chambers and amplifiers after 4 weeks and showed approximately 15 roentgens per hour at the edge of the crater and 0.02 roentgen per hour at 500 yards.

Weather information was obtained up to 45 minutes before the shot from the point of detonation to 20,000 feet and 25 minutes after the shot. Low level smoke studies were made to determine the spread of active material in case the nuclear explosion failed to occur. This information was vitally important for the success of the test.

Chapter XIX

PROJECT ALBERTA

Delivery Group

19.1 Although Project Alberta was not organized formally until March 1945, its work had been done by the Delivery Group of the Ordnance Division since June 1943 (7.67 ff) The group was responsible for the delivery of the bomb as a practical airborne military weapon, and during the first part of the Project's history participated in design of the final bomb, and undertook to act as liaison with the Air Force on such matters as the selection of aircraft and the supervision of field tests with mock bombs.

19.2 After the general reorganization of the Laboratory, when it was clear that the plutonium gun assembly method would not be used, three models remained - the Little Boy for the U^{235} gun assembly (7.71), the 1222 Fat Man model of the implosion assembly, and the model which became the finally adopted 1561 Fat Man. By September 1, 1944, it was decided to freeze the external shapes and aircraft requirements of the three models so that the Air Force could begin immediately to train a combat unit for the delivery of the bomb. A production lot of fifteen B-29's was modified at the Martin Nebraska plant under the guidance of S. Dike and M. Bolstad of Los Alamos. The first aircraft became available in October. Wendover Army Air Base in Utah, sometimes called by the code name Kingman, or the symbol W-47, was designated as the training and test center for the new Atomic Bomb Group, and Col. P. W. Tibbets was appointed commanding officer of the combat group known as the 509th Composite Group.

19.3 The first tests began at Wendover in October 1944, and continued up to the time of the first combat drop. A number of groups from O, X, and G Divisions, in addition to the Delivery Group, participated in the Wendover tests, including the Fusing Group, the Gun Group, the HE Assembly Group, the Electric Detonator Group, and the Ballistic Group. In November

1944, Cmdr. F. L. Ashworth, USN, assumed the responsibility of supervising these field operations. The long series of tests which had been begun with three tentative and later with the two final models included tests for ballistics information, for electrical fusing information, for flight performance of electrical detonators, for operation of the aircraft release mechanism, for vibration information, for assembly experience, and for temperature effects. Because the first lot of B-29's proved to have poor flying qualities and the special project modifications to have a number of weaknesses, a new lot of fifteen planes was obtained in the spring of 1945. These aircraft, which proved extremely satisfactory, had fuel injector engines, electrically controlled propellers, very rugged provisions for carrying the bomb, and all armament removed except the tail turret. In addition to the tests based at Wendover, a number of test drops were made at the Camel Project's field at Inyokern during 1945 (9.16). In connection with the Wendover tests, the Ballistics Group of O Division did some research on the problem of aircraft safety in delivery. They were concerned with such problems as the shock pressure that a B-29 could safely withstand, the maneuver that would carry the plane a maximum distance away from the target in a minimum time, and the use of special shock bracing for personnel.

19.4 During the fall of 1944 and winter of 1945, the Delivery Group at Los Alamos continued a program of design and production of mock bombs in an effort to achieve a final model. During this period the 1561 Fat Man was adopted in place of the 1222 model. In addition to the Wendover tests, numerous physics and engineering tests on complete units were made at one of the outlying sites at Los Alamos. The Delivery Group also began formulating plans for the establishment of an overseas operating base, known by the code word "Alberta."

Organization and Tests

19.5 In March 1945, Project Alberta or Project A was established to provide a more effective means of integrating the activities of the various Los Alamos groups working on problems of preparation and delivery of a combat bomb than the Delivery Group by itself had been able to offer. The new Project A was independent of any existing division and was organized as a loose coordinating body, with all specific work being done by groups of other divisions, and with Project A providing direction only insofar as preparations for combat delivery were concerned. Captain Parsons was the officer in charge of Project Alberta, with Ramsey and later Bradbury as deputies for scientific and technical matters. The organization included three groups - an administrative group known as the Headquarters Staff, a technical policy committee called the Weapons Committee (9.10) and a working group of representatives from other divisions. Cmdr. Ashworth was operations officer and military alternate for Capt. Parsons and served as chief of the Headquarters staff which eventually included Alvarez, Bolstad, S. Dike, G. Fowler, and S. J. Simmons. Simmons came to the Project in June from Massachusetts Institute of Technology Radiation Laboratory, where he had engaged in similar liaison activities with the Air Force. The Weapons Committee, of which Ramsey was Chairman until he went overseas and was succeeded by Bradbury, included Birch, Brode, G. Fowler, Fussell, Morrison, and Warner. Group representatives included:

Tests at Wendover	Cmdr. Ashworth
Tests at Wendover after June, 1945	Simmons
Measurements, airborne observations	Waldman and Alvarez
General Theory	Bethe
Gun Assembly	Birch
Aircraft	Bolstad and Dike
HE Assembly for implosion	Bradbury and Warner
Fusing	Brode
Electrical detonator system	Fussell
Engineering	Galloway
Supply	Lt. Col. Lockridge
Pit (active material and tamper of Fat Man)	Morrison and Holloway
Radiology	Capt. Nolan
Damage	Penney
Ballistics	Shapiro

19.6 Project Alberta was concerned chiefly with three problems: (1) the completion of design, procurement, and preliminary assembly of bomb units which would be complete in every way for use with active material; (2) continuation of the Wendover test program; and (3) preparation for overseas operations against the enemy.

19.7 Since the time schedule was becoming tighter, the major designs were of necessity continued with as few alterations as possible, although they were in many cases the result of a number of compromises and guesses made at a time when the problem was not well understood. The emphasis during this period was on supplying the many details necessary for successful operation and correcting faults which became apparent in tests. Examples of problems solved are such matters as the exact design of the tamper sphere, inclusion of a hypodermic tube between the HE blocks for monitoring purposes, and strengthening the Little Boy tail. Actually the Little Boy was far ahead of the Fat Man from the point of view of design and development, since the Gun Assembly group had a relatively long time to devote to such improvements. Members of the Weapons Committee were concerned with the need for starting work on an integrated design for the Fat Man based on current knowledge with no commitments to past production, but realized that such a program could not interfere with the primary job of patching up the existing model as quickly as possible. The job of redesigning the Fat Man from a sound engineering point of view eventually became the task of Z Division which was barely organized by the end of the war (9.13). Liaison problems in connection with the development of bombs were of great importance during this period and were handled primarily by Capt. Parsons and Cmdr. Ashworth. Among the military and semimilitary organizations and individuals involved in addition to the United States Engineers were the 20th Air Force, the Bureau of Ordnance, the Assistant Chief of Naval Operations for Material, Commander Western Sea Frontier, Commandant 12th Naval District, Commandant Navy Yard Mare Island, Bureau of Yards and Docks Navy Department, NOTS Inyokern, NMD Yorktown, and NAD McAlester. After Parsons and Ashworth went overseas much of this work was handled by Capt. R. R. Larkin, USN, who arrived at Los Alamos in June.

19.8 The Wendover test program under the supervision of Project Alberta continued at an increasing rate. The principal difficulty encountered in carrying out this program was the unfortunate failure of the company manufacturing Fat Man firing units, known as X-units, to meet its delivery schedule. In addition to reducing the number of tests possible on the X-Units, this failure prevented efficient over-all testing since many tests had to be repeated twice - once at an early date with all components except an X-unit, and once at a critically late date with an X-Unit. The tightness of schedule resulting can best be illustrated by the fact that it was not until the end of July that sufficient X-Units had been tested to confirm their safety with HE. The first live tests with the X-unit were not made until August 4 (Wendover) and August 8 (Tinian). Despite these difficulties a total of 155 test units were dropped at Wendover or Inyokern between October 1944 and the middle of August 1945. Much information was obtained from these tests and the corresponding changes incorporated into the design of the bombs.

Destination

19.9 Perhaps the most important function of Project Alberta was planning and preparing for overseas operations. As early as December 1944 the initial planning and procurement of some kits of tools and materials had begun, and these activities continued at an accelerated rate through July. In February Comdr. Ashworth was sent to Tinian to make a preliminary survey of the location and select a site for project activities. By March the construction needs for the Tinian Base, known as Destination, were frozen, and construction began in April. The buildings which were used by Project Alberta had all been especially constructed by the Seabees. Most of the buildings were located in the area assigned to the 1st Ordnance Squadron (Special) of the 509th Group, near the beach. These buildings included four airconditioned Quonset huts of the type normally used for bombsight repair, in which all the laboratory and instrument work was performed. These buildings were enclosed in a specially guarded area within the guarded working area of the group. In addition five warehouse buildings, a shop building, and an administration building were located here. About a mile away were three widely-spaced, barricaded and guarded, airconditioned assembly buildings. Ten magazines and two special loading pits equipped with hydraulic lifts for loading bombs into the aircraft were also constructed. A third such pit was constructed at Iwo Jima for possible emergency use. Materials for equipping the buildings and for handling heavy equipment in assembly, tools, scientific instruments, and general supplies were all included in special kits prepared by the various groups concerned. A kit for a central stockroom was also started, but the materials for the latter had not been shipped by the time the war ended. Beginning in May five batches of kit materials and of components for test and combat units were shipped by boat to Tinian, and a number of air shipments for critically needed items were made in five C-54 aircraft attached to the 509th Group. Project Alberta was able to beat its schedules largely because of the availability of these C-54's for emergency shipments.

19.10 As early as June 1944, the need had been considered for selecting personnel for field crews required in final delivery of the bomb and in the later stages of experimentation and testing prior to delivery. At that time it was agreed, however, that since the type of work might change and since there were many people anxious to volunteer, it would be wise to delay recruiting. Actually the personnel for the project teams at Tinian were selected early in May 1945, and were organized as follows;

Officer-in-Charge	Captain Parsons
Scientific and Technical Deputy	Ramsey
Operations Officer and Military Alternate	Comdr. Ashworth
Fat Man Assembly Team	Warner
Little Boy Assembly Team	Birch
Fusing Team	Doll
Electrical Detonator Team	Lt. Comdr. E. Stevenson
Pit Team	Morrison and Baker

Observation Team	Alvarez and Waldman
Aircraft Ordnance Team	S. Dike
Special Consultants	Serber, Penney, and Capt. J. F. Nolan

Team members included: H. Agnew, Ens. D. L. Anderson, T/5 B. Bederson, M. Bolstad, T/Sgt. R. Brin, T/Sgt. V. Caleca, M. Camac, T/Sgt. E. Carlson, T/4 A. Collins, T/Sgt. R. Dawson, T/Sgt F. Fortine, T/3 W. Goodman, T/3 D. Harms, Lt. J. D. Hopper, T/Sgt. J. Kupferberg, L. Johnston, L. Langer, T/Sgt. W. Larkin, H. Linschitz, A. Machen, Ens. D. Mastick, T/3 R. Matthews, Lt. (jg) V. Miller, T/3 L. Motichko, T/Sgt. W. Murphy, T/Sgt. E. Nooker, T. Olmstead, Ens. B. O'Keefe, T. Perlman, Ens. W. Prohs, Ens. G. Reynolds, H. Russ, R. Schreiber, T/Sgt. G. Thornton, Ens. Tucker, and T/4 F. Zimmerli.

19.11 The Los Alamos group formed part of what was known as the First Technical Service Detachment, and this army administrative organization provided housing and various services and established security regulations at Tinian. Also closely associated with the work of Project Alberta at Tinian were the members of the 509th Composite Group, whose duty it was to deliver the bombs to the enemy.

19.12 It was decided that Laboratory employees would remain on the Contractor's payroll. They were provided with per diem and uniform allowances in addition to their regular salaries and also with insurance policies. Each civilian was required to wear a uniform and received an assimilated army rank in accordance with his civilian salary classification.

19.13 Team leaders formed a Project Technical Committee under the chairmanship of Ramsey to coordinate technical matters and to recommend technical actions. Project personnel were responsible for providing and testing certain of the bomb components; for supervision and inspection during the assembly of bombs; for inspection prior to takeoff; for testing completed units; for over-all coordination of project activities, including the certification of the satisfactoriness of the unit; and finally for providing advice and recommendations about the use of the weapon.

19.14 Although preliminary construction at Tinian began in April, technical work did not begin to any great extent until July. The first half of July was occupied in establishing and installing all of the technical facilities needed for assembly and test work at Tinian. After completion of these technical preparations a series of four Little Boy tests was carried out with uniformly excellent results. The last of these included as part of the test a check of facilities at Iwo Jima for emergency reloading of the bomb into another aircraft. The first of three Fat Man tests was made on August 1 and showed essential components operating satisfactorily; the last of these tests on August 8 was conducted as a final rehearsal for delivery and used a unit that was complete except for active material.

19.15 The U^{235} projectile for the Little Boy was delivered at Tinian by the cruiser Indianapolis on July 26, only a few days before its tragic sinking off Peleliu. The Indianapolis had been especially held at San Francisco to wait for this cargo, and had then made a record run across the Pacific. The rest of the U^{235} components arrived on the 28th and 29th of July, as the only cargo of three Air Transport Command C-54's. Since the earliest date previously discussed for combat delivery was August 5 (at one time the official date was August 15). Parsons and Ramsey cabled Gen. Groves for permission to drop the first active unit as early as August 1. Although the active unit was completely ready, the weather was not, and the first four days of August were spent in impatient waiting. Finally on the morning of August 5 a report came that weather would be good the following day, and shortly afterwards official confirmation came from Maj. Gen. LeMay, Commanding General of the 20th Air Force, that the mission would take place on August 6. The Little Boy was loaded onto its transporting trailer the moment the official confirmation came through and was taken to the loading pit and loaded into the B-29. Final testing of the unit was completed and all was ready early in the evening. Between then and takeoff the aircraft was under continuous watch both from a military guard and from representatives of the key technical groups. Final briefing was at midnight, and shortly afterward the crews assembled at their aircraft under brilliant floodlights with swarms of photographers taking still and motion pictures. For this mission Col. P. W. Tibbets was pilot of the Enola Gay, the B-29 which carried the bomb. Maj. Thomas Ferebee was bombardier, Capt. Parsons was bomb commander, and Lt. Morris Jepson was electronics test officer for the bomb.

19.16 Only a few days before the scheduled drop it was decided by the technical group that it was not safe to take off with the bomb completely assembled, since a crash might mean tremendous destruction to men and materials on Tinian. Full safing could not be secured, but it was finally agreed that a partial safeguard would come if the cartridge which contained the propellant charge were inserted through the opening in the breech block during flight rather than on the ground. This scheme had been considered before (14.14) but was not finally adopted until this time. Capt. Parsons, who was already assigned to the crew as weaponeer, was given the job. This decision meant that Capt. Parsons had to be trained in a short time to perform the operation, and also that the bomb bay of the B-29 had to be modified to provide him with a convenient place to stand while completing the assembly. These things were done and the bomb was not completely assembled until the plane was safely in the air.

19.17 The progress of the mission is described in the log which Capt. Parsons kept during the flight:

6 August 1945

0245 Take Off
0300 Started final loading of gun
0315 Finished loading
0605 Headed for Empire from Iwo
0730 Red plugs in (these plugs armed the bomb so it would detonate if released)
0741 Started climb

Weather report received that weather over primary and tertiary targets was good but not over secondary target

0838 Leveled off at 32,700 feet
0847 All Archies (electronic fuses) tested to be OK
0904 Course west
0909 Target (Hiroshima) in sight
0915-1/2 Dropped bomb (Originally scheduled time was 0915)

Flash followed by two slaps on plane. Huge cloud

1000 Still in sight of cloud which must be over 40,000 feet high
1003 Fighter reported
1041 Lost sight of cloud 363 miles from Hiroshima with the aircraft being 26,000 feet high

The crews of the strike and observation aircraft reported that 5 minutes after release a low 3 mile diameter dark grey cloud hung over the center of Hiroshima, out of the center of this a white column of smoke rose to a height of 35,000 feet with the top of the cloud being considerably enlarged. Four hours after the strike, photo-reconnaissance planes found that most of the city of Hiroshima was still obscured by the cloud created by the explosion, although fires could be seen around the edges. Pictures were obtained the following day and showed 60 per cent of the city destroyed.

19.18 The active component of the Fat Man came by special C-54 transport. The HE components of two Fat Men arrived in two B-29's attached to the 509th Group, which had been retained at Albuquerque especially for this purpose. In all cases the active components were accompanied by special personnel to guard against accident and loss.

19.19 The first Fat Man was scheduled for dropping on August 11 (at one time the schedule called for August 20, but by August 7 it was apparent that the schedule could be advanced to August 10. When Parsons and Ramsey proposed this change to Tibbets he expressed regret that the schedule could not be advanced two days instead of only one, since good weather was forecast for August 9 and bad weather for the five succeeding days. It was finally agreed that Project Alberta would try to be ready for August 9, provided it was understood by all concerned that the advancement of the date by two full days introduced a large measure of uncertainty. All went well with the assembly, however, and the unit was loaded and fully checked late in the evening of August 8. The strike plane and two observing planes took off shortly before dawn on August 9. Maj. C. W. Sweeney was pilot of the strike ship Great Artiste, Capt. K. K. Beahan was bombardier, Comdr. Ashworth was bomb commander, and Lt. Philip Barnes was electronics test officer.

19.20 It was not possible to "safe" the Fat Man by leaving the assembly incomplete during takeoff in the same manner as the Little Boy. The technical staff realized that a crash during takeoff would mean a serious risk of contaminating a wide area on Tinian with plutonium scattered by an explosion of the HE, and even some risk of a high-order nuclear explosion which would do heavy damage to the island. These risks were pointed out to the military with the request that special guarding and evacuation precautions be taken during the takeoff. The Air Force officer in command decided that such special precautions were not necessary, and as it turned out the takeoff was made without incident. This mission was as eventful as the Hiroshima mission was operationally routine. Comdr. Ashworth's log for the trip is as follows:

0347 Take off
0400 Changed green plugs to red prior to pressurizing
0500 Charged detonator condensers to test leakage. Satisfactory.
0900 Arrived rendezvous point at Yakashima and circled awaiting accompanying aircraft.
0920 One B-29 sighted and joined in formation.
0950 Departed from Yakashima proceeding to primary target Kokura having failed to rendezvous with second B-29. The weather reports received by radio indicated good weather at Kokura (3/10 low clouds, no intermediate or high clouds, and forecast of improving conditions). The weather reports for Nagasaki were good but increasing cloudiness was forecast. For this reason the primary target was selected.
1044 Arrived initial point and started bombing runs on target. Target was obscured by heavy ground haze and smoke. Two additional

runs were made hoping that the target might be picked up after closer observations. However, at no time was the aiming point seen. It was then decided to proceed to Nagasaki after approximately 45 minutes spent in the target area.

1150 Arrived in Nagasaki target area. Approach to target was entirely by radar. At 1150 the bomb was dropped after a 20 second visual bombing run. The bomb functioned normally in all respects.

1205 Departed for Okinawa after having circled smoke column. Lack of available gasoline caused by an inoperative bomb bay tank booster pump forced decision to land at Okinawa before returning to Tinian.

1351 Landed at Yontan Field, Okinawa

1706 Departed Okinawa for Tinian

2245 Landed at Tinian

Because of bad weather good photo reconnaissance pictures were not obtained until almost a week after the Nagasaki mission. They showed 44 per cent of the city destroyed; the discrepancy in results between this mission and the first was explained by the unfavorable contours of the city.

19.21 Exchange of information between Tinian and Los Alamos was extremely unsatisfactory and caused considerable difficulty at each end. Necessarily tight security rules made direct communications impossible, and teletype messages were relayed from one place to the other through the Washington Liaison Office, using an elaborate table of codes prepared by Project Alberta. Late in July, the Laboratory sent Manley to the Washington Liaison Office in an attempt to make sure that there would be no friction in the regular channels of information, and that no information was being held up in Washington which would conceivably be of interest. The first news of the Hiroshima drop came to Los Alamos in a dramatic teletype prepared by Manley summarizing the messages sent by Parsons from the plane after the drop (see Appendix No. 2).

19.22 On the day following the Nagasaki mission, the Japanese initiated surrender negotiations and further activity in preparing active units was suspended. The entire project was maintained in a state of complete readiness for further assemblies in the event of a failure in the peace negotiations. It was planned to return all Project Alberta technical personnel to the United States on August 20, except for those assigned to the Farrell mission for investigating the results of the bombing in Japan. Because of the delays in surrender procedures, Gen. Groves requested all key personnel to remain at Tinian until the success of the occupation of Japan was assured. The scientific and technical personnel finally received authorization and left Tinian on September 7, except for Col. Kirkpatrick and Cmdr. Ashworth who remained to make final disposition of project property. With this departure the activities of Project Alberta were terminated.

19.23 The objective of Project Alberta was to assure the successful combat use of an atomic bomb at the earliest possible date after a field test of an atomic explosion and after the availability of the necessary nuclear material. This objective was accomplished. The first combat bomb was ready for use against the enemy within 17 days after the Trinity test, and almost all of the intervening time was spent in accumulating additional active material for making another bomb. The first atomic bomb was prepared for combat use against the enemy on August 2, within four days of the time of the delivery of all of the active material needed for that bomb. Actual combat use was delayed until August 6 only by bad weather over Japan. The second bomb was used in combat only three days after the first, although it was a completely different model and one much more difficult to assemble.

Chapter XX

CONCLUSION

20.1 After the end of the war the Laboratory experienced a sudden relaxation of activities. Everything had been aimed at a goal, and the goal had been reached. It was a time for evaluation and stock-taking. Plans for the future of Los Alamos and of nuclear research in general were widely discussed. Members of the Scientific Panel of the President's Interim Committee on Atomic Energy met at Los Alamos and prepared for the Committee an account of the technical possibilities then apparent in the atomic energy field. A series of lecture courses was organized, called the "Los Alamos University," to give the younger staff members the opportunity to make up for some of the studies they had missed during the war years.

20.2 While research projects that had been under way at the end of the war were being completed, plans for the period to follow were being formulated. Although their discussion leads beyond the period of the present report, one that may be mentioned was the outlining and writing of a Los Alamos Technical Series, under the editorship of H. A. Bethe, to set down a more systematic and polished record of the Laboratory's work than had been possible during the war. There was some concentration of effort to complete the theoretical investigations of the Super described in Chapter 13. Weapon production had to continue, and plans were made to finish the development work on the implosion bomb (11.2).

20.3 This history has been an account of problems and their solution, of work done. The other side of the history of Los Alamos, the reactions of these accomplishments upon the people who made them, is present only by implication. This account ends at a time, however, when these reactions assumed a sudden importance, and it is appropriate that it should end with some description of them.

20.4 For many members of the Laboratory the Trinity test marked the successful climax of years of intensive and uncertain effort. A new kind of weapon had been made, and the magnitude and qualitative features of its operation had been successfully predicted. Despite the fact, perhaps in part because of the fact, that the explosion occurred as expected, the sight of it was a stunning experience to its creators, an experience of satisfaction and of fear. A new force had been created, and would henceforth lead a life of its own, independent of the will of those who made it. Only at Trinity, perhaps, were its magnitude and unpredictable potentialities fully grasped and appreciated.

20.5 Four days after the first bomb was dropped over Hiroshima, the Japanese began surrender negotiations. The feelings that had marked the success of the Trinity test were evident once more. But now the Laboratory, experiencing the sudden slackening of effort that followed the end of the war, began to speak seriously of the bomb and its consequences for the future. The thoughts that were expressed were not new, but there had been no time before to express them. Since 1939, when the decision had been made to seek Government support for the new development, a uniformity of insight had grown up among the working scientists of the Manhattan District. They had come to realize that atomic warfare would prove unendurable. This was learned by the Japanese in the days of Hiroshima and Nagasaki, and soon all the world was saying it.

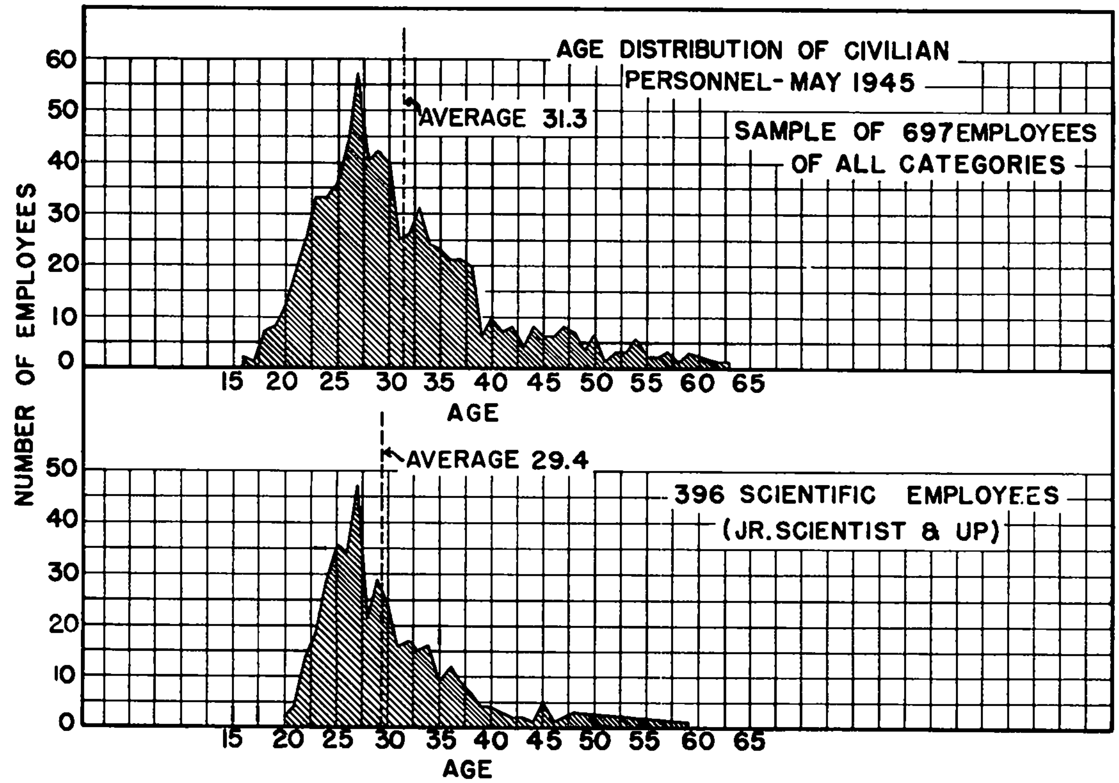
20.6 What the members of the Laboratory saw who joined in these discussions was more incisive than this. Atomic bombs were offensive or retaliatory weapons, their existence was a threat to the security of every nation which it could not venture, without the gravest risk, to meet on the military plane alone. The law of counterdevelopment, which has so uniformly in military affairs operated to produce new defenses against new weapons, could in this case operate to open channels of collaboration that have not previously existed among nations. The wartime scientific collaboration that had produced this weapon could, by its worldwide extension, be made uniquely the means for eliminating it from national armaments. Men of science, who had as a group never been concerned with the problems of society and of nations, felt responsible to tell the American public of the nature and implications of the new weapon, and to make clear the alternatives for the future that had arisen. This concern received perhaps its best and simplest expression in a speech by Oppenheimer, given on October 16, 1945, when the Laboratory was presented by General Groves with a certificate of Appreciation from the Secretary of War:

20.7 "It is with appreciation and gratitude that I accept from you this scroll for the Los Alamos Laboratory, for the men and women whose work and whose hearts have made it. It is our hope that in years to come we may look at this scroll, and all that it signifies, with pride.

"Today that pride must be tempered with a profound concern. If atomic bombs are to be added as new weapons to the arsenals of a warring world, or to the arsenals of nations preparing for war, then the time will come when mankind will curse the names of Los Alamos and Hiroshima.

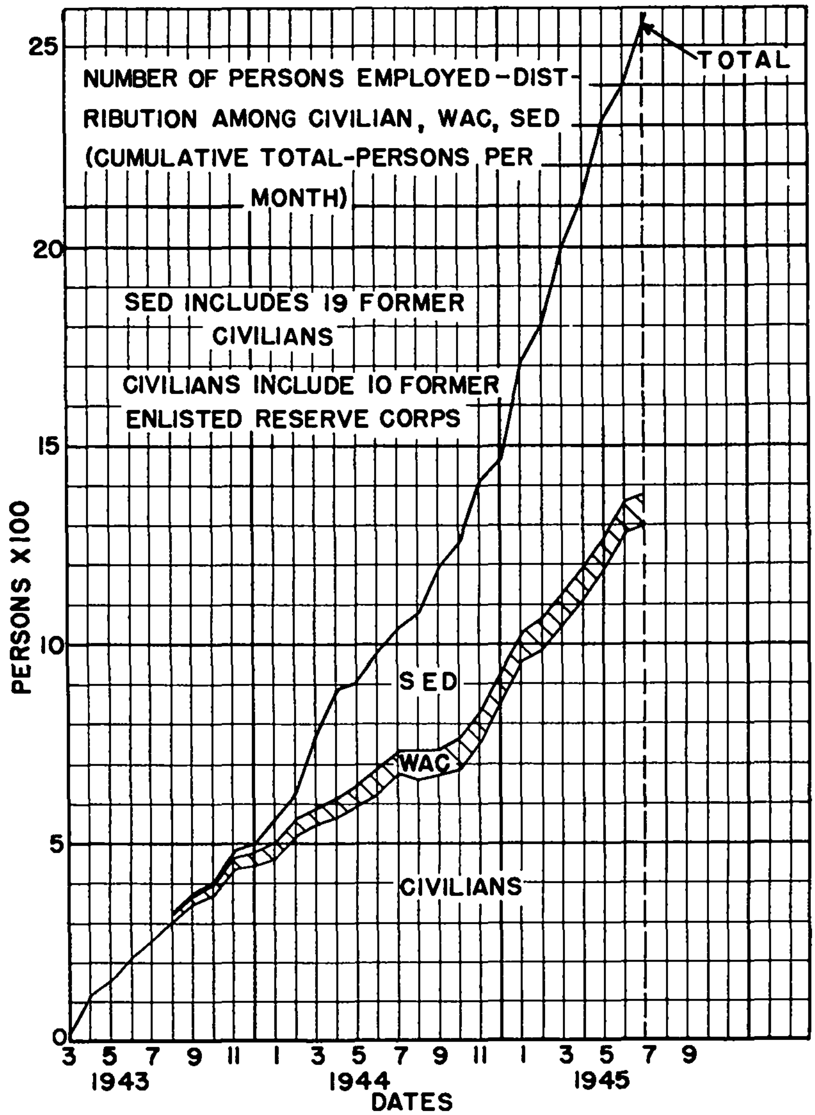
"The peoples of this world must unite, or they will perish. This war, that has ravaged so much of the earth, has written these words. The atomic bomb has spelled them out for all men to understand. Other men have spoken them, in other times, of other wars, of other weapons. They have not prevailed. There are some, misled by a false sense of human history, who hold that they will not prevail today. It is not for us to believe that. By our works we are committed, committed to a world united, before this common peril, in law, and in humanity."

GRAPHS



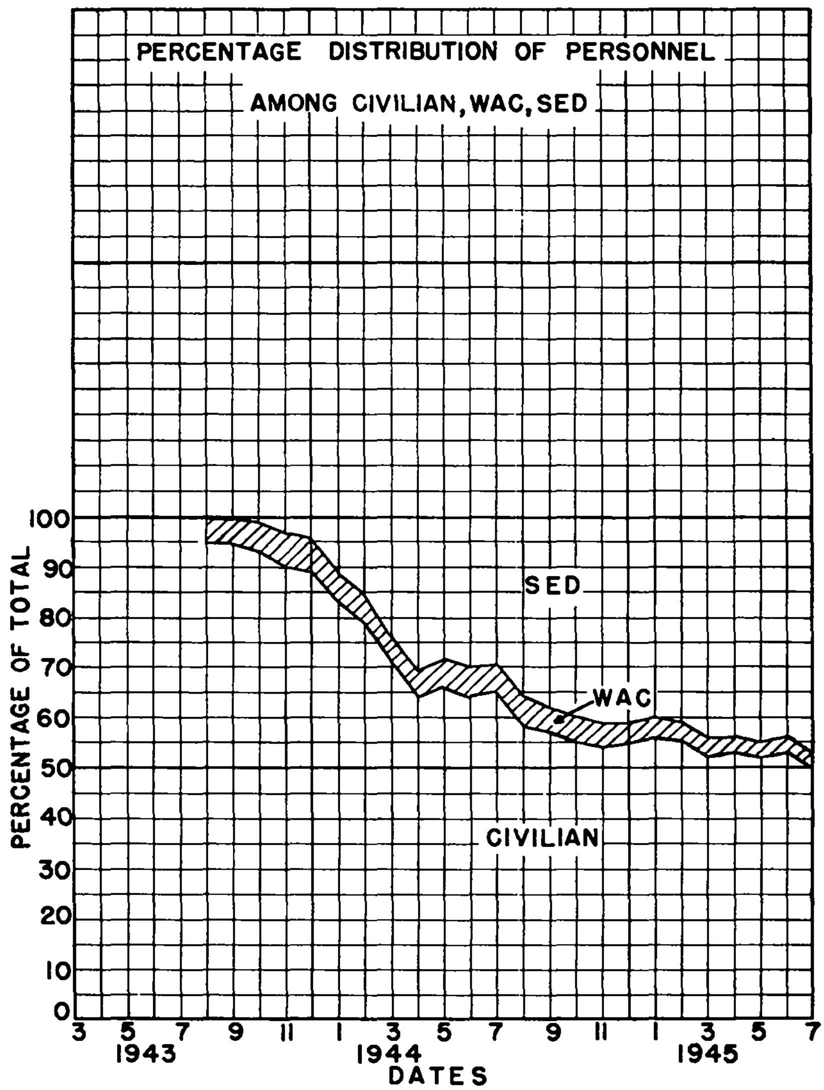
Graph Number 1. Age Distribution of Civilian Personnel - May 1945

Two curves are shown, one a sample of all employees, the other of scientific employees only. The averages for both are low - 29.4 for the scientists and 31.3 for the others - with 27 the most probable age for both. Actually there is only one man over 58 among the scientific employees. These figures emphasize the importance of the draft deferment problem. Information was obtained from the active card file of the Personnel Division in June 1945.



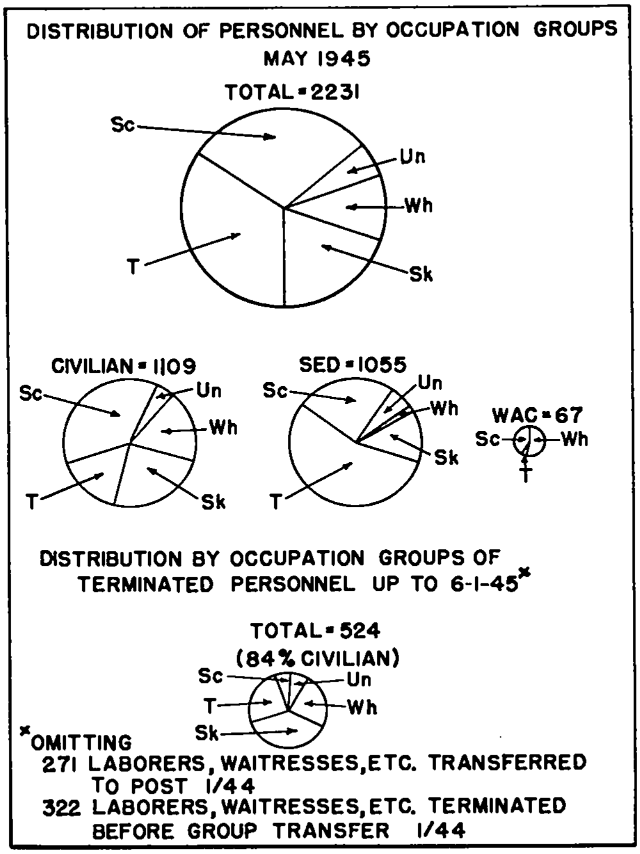
Graph Number 2. Number of Persons Employed - Distribution among Civilians, WAC, SED

Shows sharp and continuous increase of personnel from beginning of project. Civilians increase at a steady rate, WAC contingent remains about the same, and SED contingent increases very rapidly. Information was obtained from records of Technical Area and SED personnel offices.



Graph Number 3. Percentage Distribution of Personnel among Civilians, WAC, SED

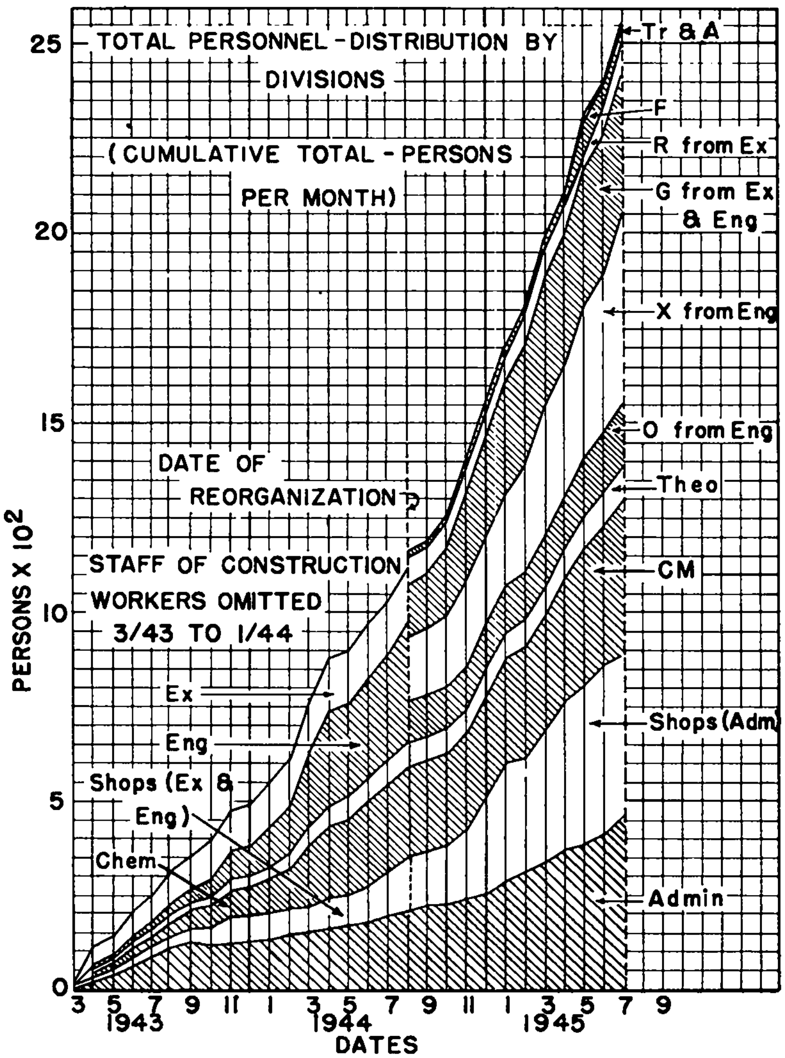
Data of previous graph replotted on percentage basis. Project changed from being 100% civilian during first five months to 50% civilian in July 1945.



Graph Number 4. Distribution of Personnel by Occupation Groups

Classification of personnel into five large categories, according to occupation, as of May 1945. Pie charts are proportional in diameter to number represented. In the chart for the total number one sees the preponderance of scientific and technical personnel; in the civilian chart the preponderance of scientific personnel; in the SED chart the preponderance of technical personnel. The chart of terminations shows the very small proportion of scientific personnel terminating and the relatively large proportion of skilled labor terminating. The latter fact reflects some of the difficulties encountered by the shops in retaining personnel, as well as a difference in motivation. Information was obtained from card files in Tech area and SED personnel offices

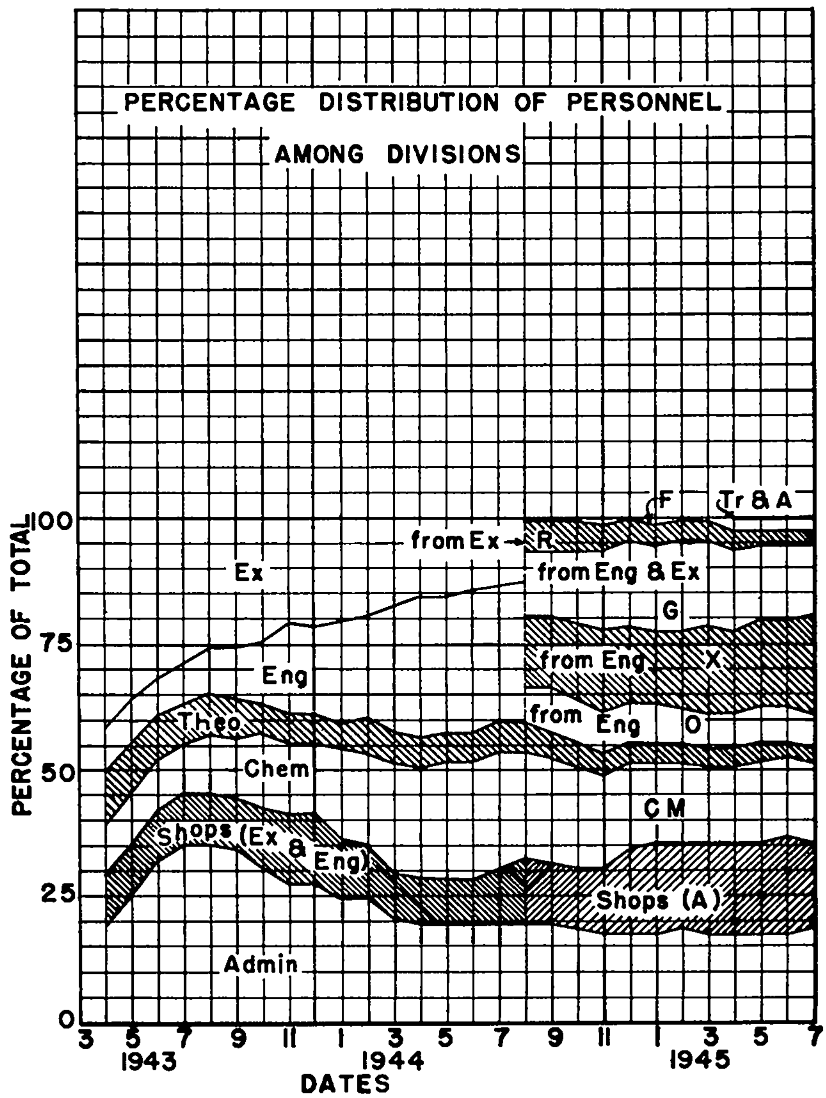
Un - Unskilled (Laborer, Messenger, Warehouse Ass't.)
Wh - White Collar (Clerk, Secretary, Nurse, Teacher)
Sk - Skilled (Machinist, Toolmaker, Glassblower)
T - Technical (Technician, Draftsman, Scientific Ass't.)
Sc - Scientific & Administrative (Jr. Scientist and up)



Graph Number 5. Total Personnel - Distribution by Divisions

Shows growth of various divisions, reflects change in emphasis from research to engineering, especially after reorganization in August 1944. Engineering divisions G, X, and O assume large proportions while research divisions R and T remain small. Information was obtained from group assignment records of Tech Area and SED personnel offices. Abbreviations and letters refer to various divisions:

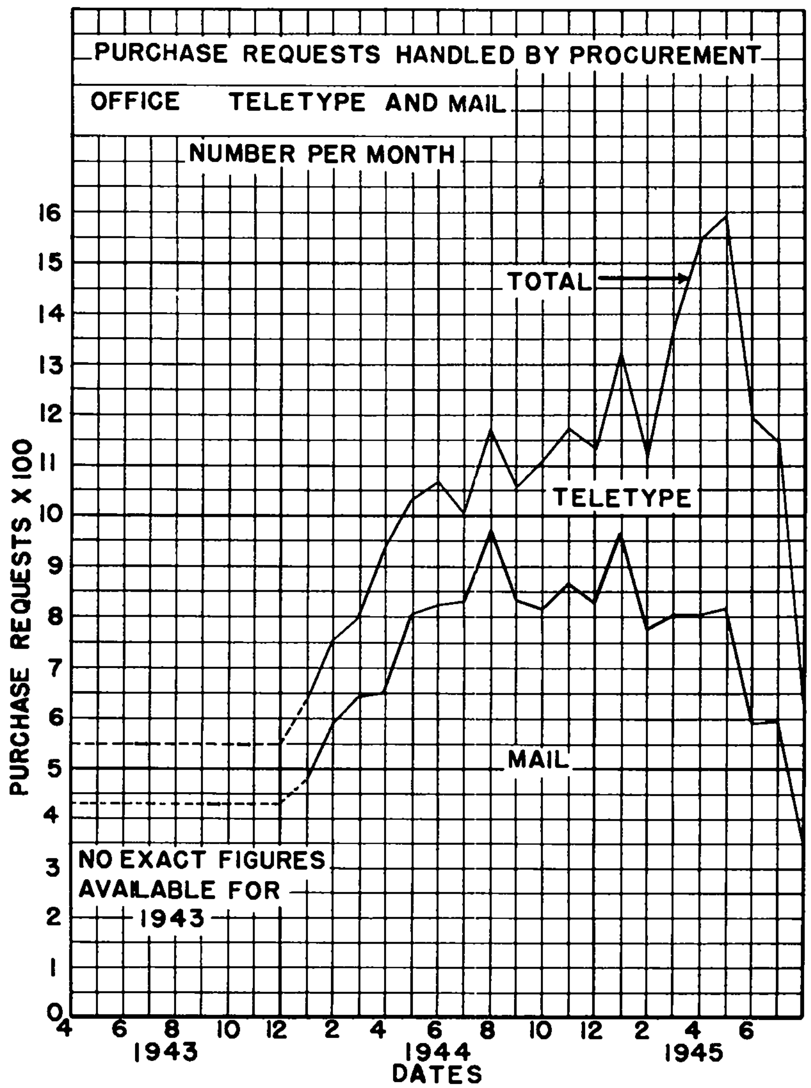
Exp.	Shops	R	O
Eng.	Admin.	G	T
Theo.	Tr & A	X	CM
Chem.	F		



Graph Number 6. Percentage Distribution of Personnel among Divisions

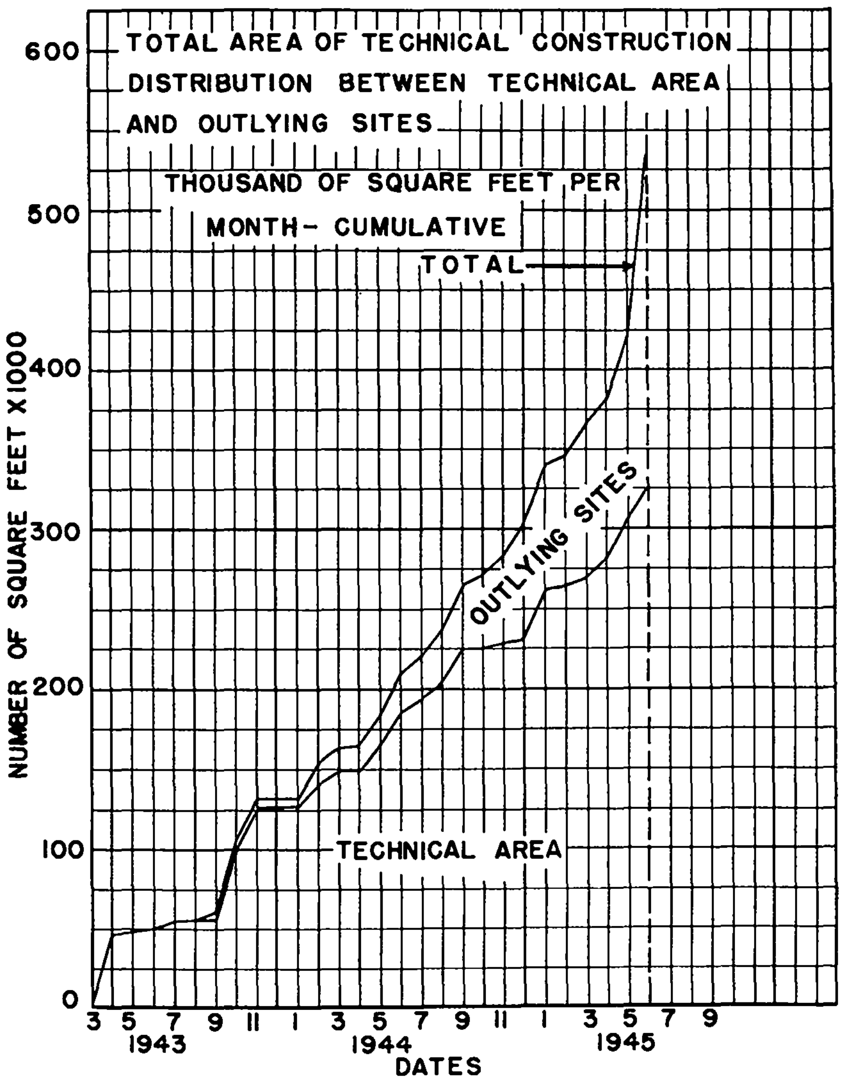
Data of previous graph replotted on percentage basis. Shops, G, X and O account for more than half of total personnel. Abbreviations and letters refer to various divisions:

Exp.	Shops	R	O
Eng.	Admin.	G	T
Theo.	Tr & A	X	CM
Chem.	F		



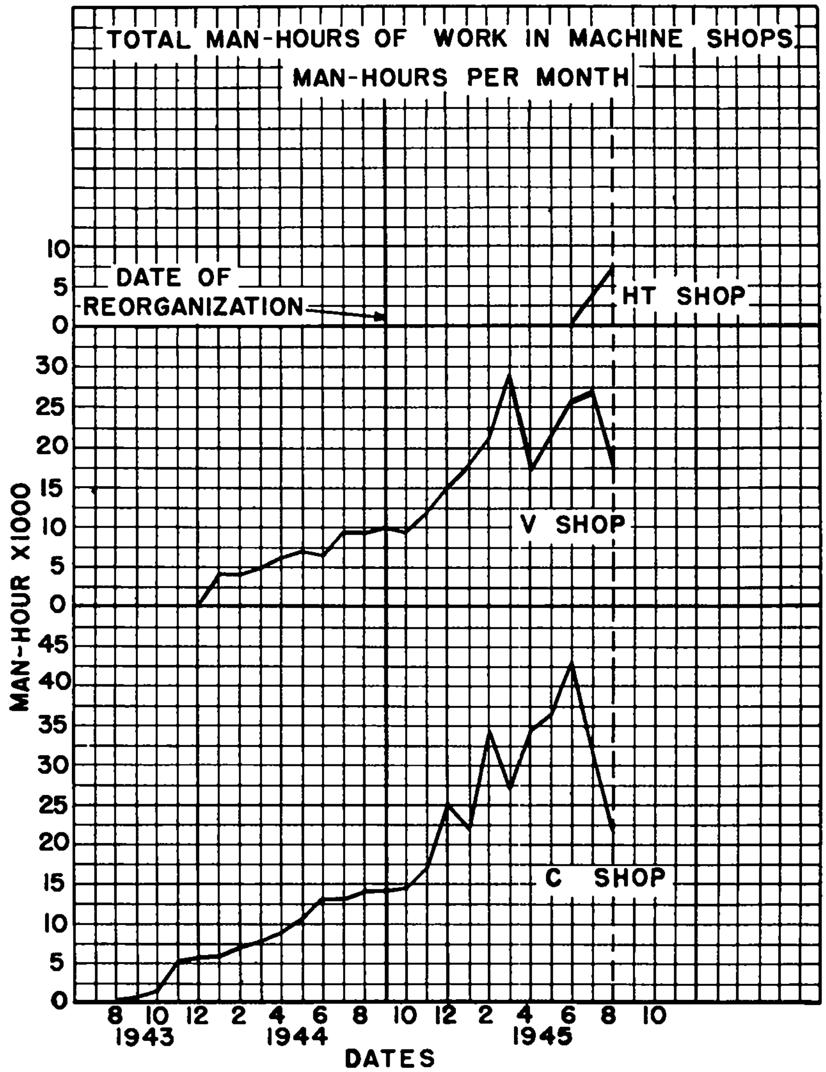
Graph Number 7. Purchase Requests Handled by Procurement Office - Teletype and Mail

Total number of requests handled each month by Procurement during 1944 and part of 1945. Mail requests represent bulk of routine business; teletype requests those items needed with special urgency. Peak month, especially for teletype requests, was May 1945, in preparation for Trinity. Note the sharp slump which follows. Each request involves at least 60 pieces of paper, according to Procurement records. Information was obtained from a monthly record of purchase requests kept in the request file section.



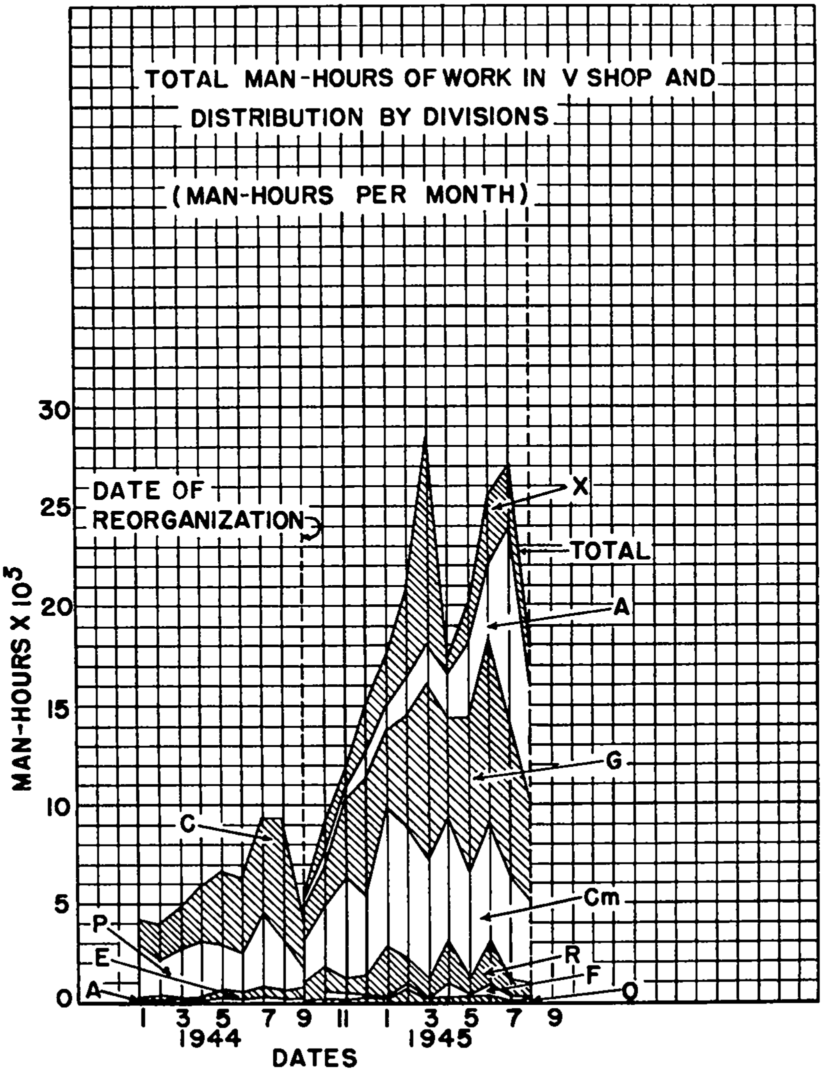
Graph Number 8. Total Area of Technical Construction - Technical Area and Outlying Sites

Shows steady growth of construction both in Technical Area and outlying sites. Sharp rate of increase in outlying site construction in June 1945 represents completion of first buildings at DP site. For more information see map of sites, Appendix 3. Information was obtained from files of D. Dow in Director's Office, files of Post Construction Officer, and files of W. C. Kruger, Project Architect.



Graph Number 9. Total Man-Hours of Work in Machine Shops

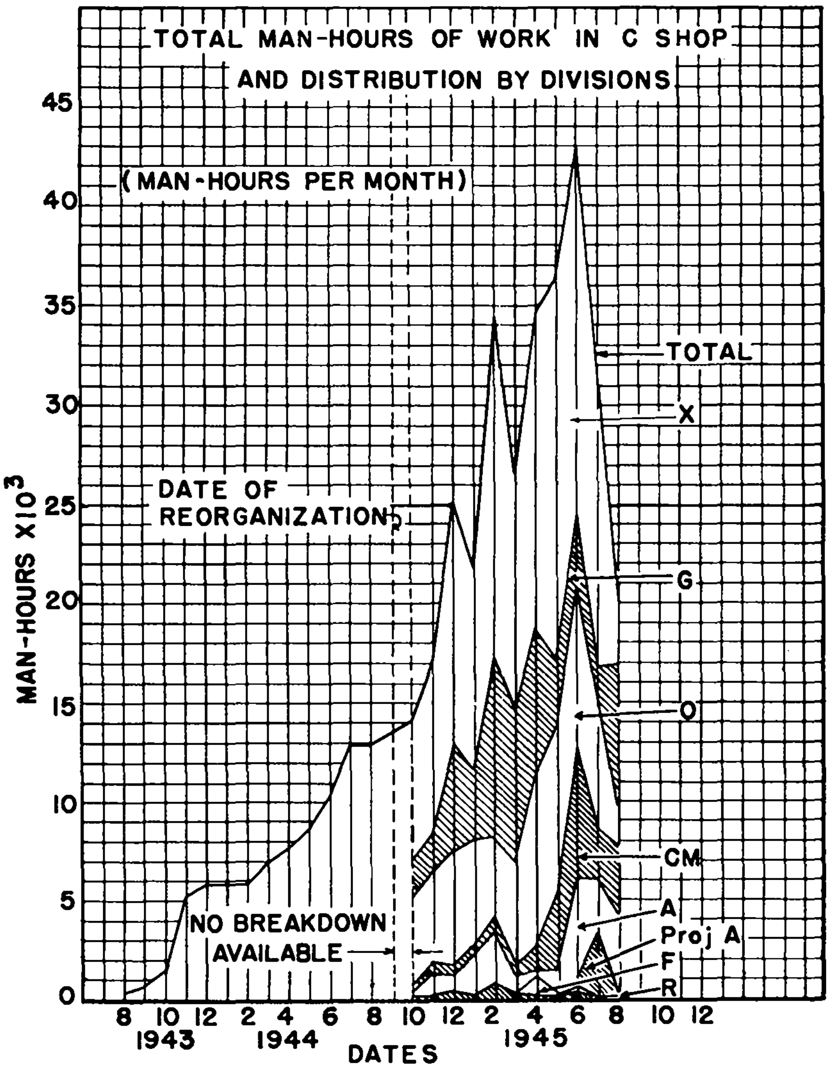
Shows rapid expansion of shops after reorganization. Slump in C Shop in January and sharp rise in February indicate results of fire. Peak of activity in C Shop in June preparatory to Trinity, followed by sharp decrease in activity; one month lag in peak for V Shop, but same sharp decrease follows. Information was obtained from weekly records kept in office of machine shops.



Graph Number 10. Total Man-Hours of Work in V Shop and Distribution by Divisions

Shows largest proportion of work done in V Shop for G and CM Divisions. Work done for A Division represents work done for shops themselves. Decrease in activity for all divisions except A after June 1945. Information was obtained from weekly records kept in machine shop office. Letters refer to various divisions:

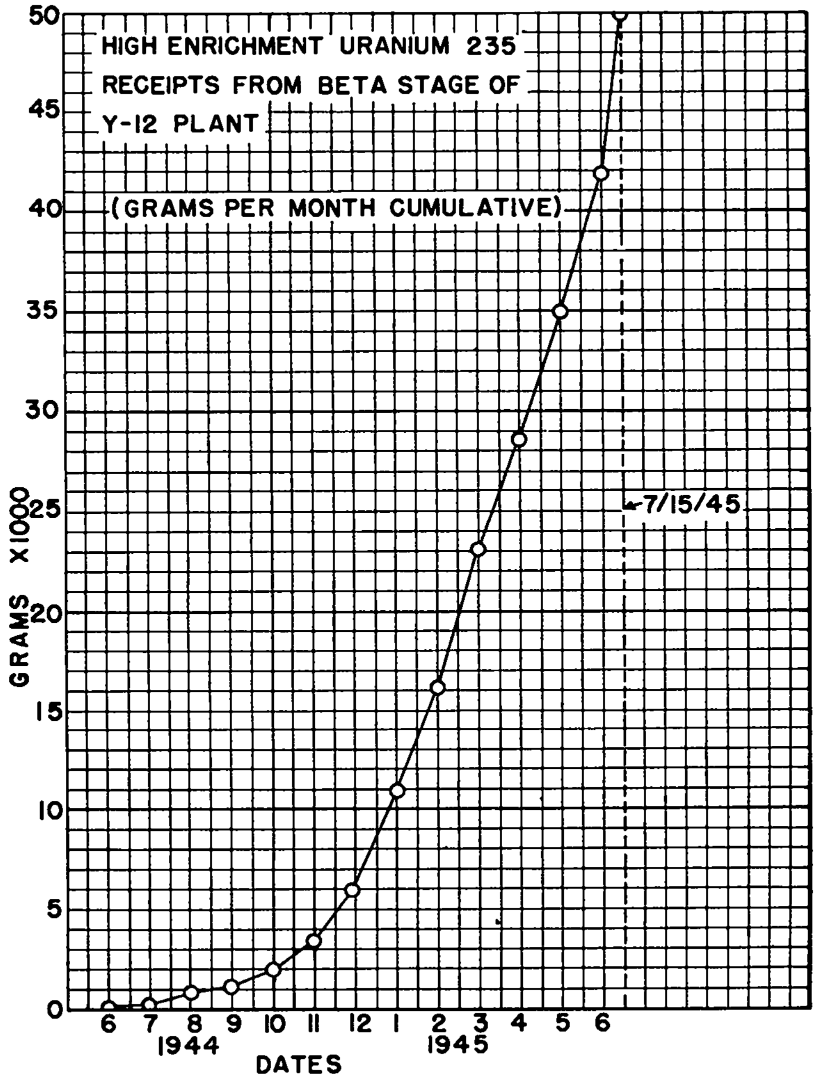
C	A	G	F
P	X	CM	O
E	A	R	



Graph Number 11. Total Man-Hours of Work in C Shop and Distribution by Divisions

Shows largest proportion of work done in C Shop for X Division. Fire accounts for slump in activity in January; no apparent reason for subsequent slump in March. Information was obtained from weekly records kept in machine shop office. Letters refer to various divisions:

X	CM	F
G	A	R
O	Project A	



Graph Number 12. High Enrichment U^{235} Receipts from Beta Stage of Y-12 Plant

Cumulative total of U^{235} received up to date of Trinity test. This represents all highly enriched U^{235} produced by the District. Such material was shipped after the final processing done in the beta stage of the Y-12 plant at Oak Ridge. Enrichment of U^{235} in tuballoy increased from 63% to 89%. Information was obtained from records of receipts in Director's Office, now filed with the Quantity Control Section of the Chemistry and Metallurgy Division.