

# **Atomic Energy for Military Purposes**

**The Official Report on the Development of the Atomic Bomb Under the Auspices of the United States Government**

## **(The Smyth Report)**

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**Published 1945**

## **CHAPTER XII: THE WORK ON THE ATOMIC BOMB**

### **THE OBJECTIVE**

12.1. The entire purpose of the work described in the preceding chapters was to explore the possibility of creating atomic bombs and to produce the concentrated fissionable materials which would be required in such bombs. In the present chapter, the last stage of the work will be described - the development at Los Alamos of the atomic bomb itself. As in other parts of the project, there are two phases to be considered: the organization, and the scientific and technical work itself. The organization will be described briefly; the remainder of the chapter will be devoted to the scientific and technical problems. Security considerations prevent a discussion of many of the most important phases of this work.

### **HISTORY AND ORGANIZATION**

12.2. The project reorganization that occurred at the beginning of 1942, and the subsequent gradual transfer of the work from OSRD auspices to the Manhattan District have been described in Chapter V. It will be recalled that the responsibilities of the Metallurgical Laboratory at Chicago originally included a preliminary study of the physics of the atomic bomb. Some such studies were made in 1941; and early in 1942 G. Breit got various laboratories (see Chapter VI, paragraph 6.38) started on the experimental study of problems that had to be solved before progress could be made on bomb design. As has been mentioned in Chapter VI, J. R. Oppenheimer of the University of California gathered a group together in the summer of 1942 for further theoretical investigation and also undertook to coordinate this experimental work. This group was officially under the Metallurgical Laboratory but the theoretical group did most of its work at the University of California. By the end of the summer of 1942, when General L. R. Groves took charge of the entire project, it was decided to expand the work considerably, and, at the earliest possible time, to set up a separate laboratory.

12.3. In the choice of a site for this atomic-bomb laboratory, the all-important considerations were secrecy and safety. It was therefore decided to establish the laboratory in an isolated location and to sever unnecessary connection with the outside world.

12.4. By November 1942 a site had been chosen - at Los Alamos, New Mexico. It was located on a mesa about 30 miles from Santa Fe. One asset of this site was the availability of considerable

area for proving grounds, but initially the only structures on the site consisted of a handful of buildings which once constituted a small boarding school. There was no laboratory, no library, no shop, no adequate power plant. The sole means of approach was a winding mountain road. That the handicaps of the site were overcome to a considerable degree is a tribute to the unstinting efforts of the scientific and military personnel.

12.5. J. R. Oppenheimer has been director of the laboratory from the start. He arrived at the site in March 1943, and was soon joined by groups and individuals from Princeton University, University of Chicago, University of California, University of Wisconsin, University of Minnesota, and elsewhere. With the vigorous support of General L. R. Groves, J. B. Conant, and others, Oppenheimer continued to gather around him scientists of recognized ability, so that the end of 1944 found an extraordinary galaxy of scientific stars gathered on this New Mexican mesa. The recruiting of junior scientific personnel and technicians was more difficult, since for such persons the disadvantages of the site were not always counterbalanced by an appreciation of the magnitude of the goal; the use of Special Engineer Detachment personnel improved the situation considerably.

12.6. Naturally, the task of assembling the necessary apparatus, machines, and equipment was an enormous one. Three carloads of apparatus from the Princeton project filled some of the most urgent requirements. A cyclotron from Harvard, two Van de Graaff generators from Wisconsin, and a Cockcroft-Walton high-voltage device from Illinois soon arrived. As an illustration of the speed with which the laboratory was set up, we may record that the bottom pole piece of the cyclotron magnet was not laid until April 14, 1943, yet the first experiment was performed in early July. Other apparatus was acquired in quantity, subsidiary laboratories were built. Today this is probably the best-equipped physics research laboratory in the world.

12.7. The laboratory was financed under a contract between the Manhattan District and the University of California.

## **STATE OF KNOWLEDGE IN APRIL 1943**

### **GENERAL DISCUSSION OF THE PROBLEM**

12.8. In Chapter II we stated the general conditions required to produce a self-sustaining chain reaction. It was pointed out that there are four processes competing for neutrons: (1) the capture of neutrons by uranium which results in fission; (2) non-fission capture by uranium; (3) non-fission capture by impurities; and (4) escape of neutrons from the system. Therefore the condition for obtaining such a chain reaction is that process (1) shall produce as many new neutrons as are consumed or lost in all four of the processes. It was pointed out that (2) may be reduced by removal of U-238 or by the use of a lattice and moderator, that (3) may be reduced by achieving a high degree of chemical purity, and that (4) may be reduced (relatively) by increasing the size of the system. In our earlier discussions of chain reactions it was always taken for granted that the chain reacting system must not blow up. Now we want to consider how to make it blow up.

12.9. By definition, an explosion is a sudden and violent release of a large amount of energy in a small region. To produce an efficient explosion in an atomic bomb, the parts of the bomb must not become appreciably separated before a substantial fraction of the available nuclear energy has been released, since expansion leads to increased escape of neutrons from the system and thus to premature termination of the chain reaction. Stated differently, the efficiency of the atomic bomb will depend on the ratio of (a) the speed with which neutrons generated by the first fissions get into other nuclei and produce further fission, and (b) the speed with which the bomb flies apart. Using known principles of energy generation, temperature and pressure rise, and expansion of solids and vapors, it was possible to estimate the order of magnitude of the time interval between the beginning and end of the nuclear chain reaction. Almost all the technical difficulties of the project come from the extraordinary brevity of this time interval.

12.10. In earlier chapters we stated that no self-sustaining chain reaction could be produced in a block of pure uranium metal, no matter how large, because of parasitic capture of the neutrons by U-238. This conclusion has been borne out by various theoretical calculations and also by direct experiment. For purposes of producing a non-explosive pile, the trick of using a lattice and a moderator suffices - by reducing parasitic capture sufficiently. For purposes of producing an explosive unit, however, it turns out that this process is unsatisfactory on two counts. First, the thermal neutrons take so long (so many micro-seconds) to act that only a feeble explosion would result. Second, a pile is ordinarily far too big to be transported. It is therefore necessary to cut down parasitic capture by removing the greater part of the U-238 - or to use plutonium.

12.11. Naturally, these general principles - and others - had been well established before the Los Alamos project was set up.

## **CRITICAL SIZE**

12.12. The calculation of the critical size of a chain-reacting unit is a problem that has already been discussed in connection with piles. Although the calculation is simpler for a homogeneous metal unit than for a lattice, inaccuracies remained in the course of the early work, both because of lack of accurate knowledge of constants and because of mathematical difficulties. For example, the scattering, fission, and absorption cross sections of the nuclei involved all vary with neutron velocity. The details of such variation were not known experimentally and were difficult to take into account in making calculations. By the spring of 1943 several estimates of critical size had been made using various methods of calculation and using the best available nuclear constants, but the limits of error remained large.

## **THE REFLECTOR OR TAMPER**

12.13. In a uranium-graphite chain-reacting pile the critical size may be considerably reduced by surrounding the pile with a layer of graphite, since such an envelope "reflects" many neutrons back into the pile. A similar envelope can be used to reduce the critical size of the bomb, but here the envelope has an additional role: its very inertia delays the expansion of the reacting material. For this reason such an envelope is often called a tamper. Use of a tamper clearly makes for a longer lasting, more energetic, and more efficient explosion. The most effective tamper is the one having the highest density; high tensile strength turns out to be unimportant. It

is a fortunate coincidence that materials of high density are also excellent as reflectors of neutrons.

## **EFFICIENCY**

12.14. As has already been remarked, the bomb tends to fly to bits as the reaction proceeds and this tends to stop the reaction. To calculate how much the bomb has to expand before the reaction stops is relatively simple. The calculation of how long this expansion takes and how far the reaction goes in that time is much more difficult.

12.15. While the effect of a tamper is to increase the efficiency - both by reflecting neutrons and by delaying the expansion of the bomb, the effect on the efficiency is not as great as on the critical mass. The reason for this is that the process of reflection is relatively time-consuming and may not occur extensively before the chain reaction is terminated.

## **DETONATION AND ASSEMBLY**

12.16. As stated in Chapter II, it is impossible to prevent a chain reaction from occurring when the size exceeds the critical size. For there are always enough neutrons (from cosmic rays, from spontaneous fission reactions, or from alpha-particle-induced reactions in impurities) to initiate the chain. Thus until detonation is desired, the bomb must consist of a number of separate pieces each one of which is below the critical size either by reason of small size or unfavorable shape. To produce detonation, the parts of the bomb must be brought together rapidly. In the course of this assembly process the chain reaction is likely to start - because of the presence of stray neutrons - before the bomb has reached its most compact (most reactive) form. Thereupon the explosion tends to prevent the bomb from reaching that most compact form. Thus it may turn out that the explosion is so inefficient as to be relatively useless. The problem, therefore, is two-fold: (1) to reduce the time of assembly to a minimum; and (2) to reduce the number of stray (predetonation) neutrons to a minimum.

12.17. Some consideration was given to the danger of producing a "dud" or a detonation so inefficient that even the bomb itself would not be completely destroyed. This would, of course, present the enemy with a supply of highly valuable material.

## **EFFECTIVENESS**

12.18. In Chapters II and IV it was pointed out that the amount of energy released was not the sole criterion of the value of a bomb. There was no assurance that one uranium bomb releasing energy equal to the energy released by 20,000 tons of TNT would be as effective in producing military destruction as, say, 10,000 two-ton bombs. In fact, there were good reasons to believe that the destructive effect per calorie released decreases as the total amount of energy released increases. On the other hand, in atomic bombs the total amount of energy released per kilogram of fissionable material (i.e., the efficiency of energy release) increases with the size of the bomb. Thus the optimum size of the atomic bomb was not easily determined. A tactical aspect that complicates the matter further is the advantage of simultaneous destruction of a large area of enemy territory. In a complete appraisal of the effectiveness of an atomic bomb, attention must

also be given to effects on morale.<sup>1</sup> The bomb is detonated in combat at such a height above the ground as to give the maximum blast effect against structures, and to disseminate the radioactive products as a cloud. On account of the height of the explosion practically all the radioactive products are carried upward in the ascending column of hot air and dispersed harmlessly over a wide area. Even in the New Mexico test, where the height of explosion was necessarily low, only a very small fraction of the radioactivity was deposited immediately below the bomb.

## **METHOD OF ASSEMBLY**

12.19. Since estimates had been made of the speed that would bring together subcritical masses of U-235 rapidly enough to avoid predetonation, a good deal of thought had been given to practical methods of doing this. The obvious method of very rapidly assembling an atomic bomb was to shoot one part as a projectile in a gun against a second part as a target. The projectile mass, projectile speed, and gun caliber required were not far from the range of standard ordnance practice, but novel problems were introduced by the importance of achieving sudden and perfect contact between projectile and target, by the use of tampers, and by the requirement of portability. None of these technical problems had been studied to any appreciable extent prior to the establishment of the Los Alamos laboratory.

12.20. It had also been realized that schemes probably might be devised whereby neutron absorbers could be incorporated in the bomb in such a way that they would be rendered less effective by the initial stages of the chain reactions. Thus the tendency for the bomb to detonate prematurely and inefficiently would be minimized. Such devices for increasing the efficiency of the bomb are called auto-catalytic.

## **SUMMARY OF KNOWLEDGE AS OF APRIL 1943**

12.21. In April 1943 the available information of interest in connection with the design of atomic bombs was preliminary and inaccurate. Further and extensive theoretical work on critical size, efficiency, effect of tamper, method of detonation, and effectiveness was urgently needed. Measurements of the nuclear constants of U-235, plutonium, and tamper material had to be extended and improved. In the cases of U-235 and plutonium tentative measurements had to be made using only minute quantities until larger quantities became available.

12.22. Besides these problems in theoretical and experimental physics, there was a host of chemical, metallurgical, and technical problems that had hardly been touched. Examples were the purification and fabrication of U-235 and plutonium, and the fabrication of the tamper. Finally, there were problems of instantaneous assembly of the bomb that were staggering in their complexity.

## **THE WORK OF THE LABORATORY**

### **INTRODUCTION**

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<sup>1</sup> The rest of this paragraph is from a War Department release subsequent to the first use of atomic bombs against Japan.

12.23. For administrative purposes the scientific staff at Los Alamos was arranged in seven divisions, which have been rearranged at various times. During the spring of 1945 the divisions were: Theoretical Physics Division under H. Bethe, Experimental Nuclear Physics Division under R. R. Wilson, Chemistry and Metallurgy Division under J. W. Kennedy and C. S. Smith, Ordnance Division under Capt. W. S. Parsons (USN), Explosives Division under G. B. Kistiakowsky, Bomb Physics Division under R. F. Bacher, and an Advanced Development Division under E. Fermi. All the divisions reported to J. R. Oppenheimer, Director of the Los Alamos Laboratory who has been assisted in coordinating the research by S. K. Allison since December 1944. J. Chadwick of England and N. Bohr of Denmark spent a great deal of time at Los Alamos and gave invaluable advice. Chadwick was the head of a British delegation which contributed materially to the success of the laboratory. For security reasons, most of the work of the laboratory can be described only in part.

## **THEORETICAL PHYSICS DIVISION**

12.24. There were two considerations that gave unusual importance to the work of the Theoretical Physics Division under H. Bethe. The first of these was the necessity for effecting simultaneous development of everything from the fundamental materials to the method of putting them to use - all despite the virtual unavailability of the principal materials (U-235 and plutonium) and the complete novelty of the processes. The second consideration was the impossibility of producing (as for experimental purposes) a "small-scale" atomic explosion by making use of only a small amount of fissionable material. (No explosion occurs at all unless the mass of the fissionable material exceeds the critical mass.) Thus it was necessary to proceed from data obtained in experiments on infinitesimal quantities of materials and to combine it with the available theories as accurately as possible in order to make estimates as to what would happen in the bomb. Only in this way was it possible to make sensible plans for the other parts of the project, and to make decisions on design and construction without waiting for elaborate experiments on large quantities of material. To take a few examples, theoretical work was required in making rough determinations of the dimensions of the gun, in guiding the metallurgists in the choice of tamper materials, and in determining the influence of the purity of the fissionable material on the efficiency of the bomb.

12.25. The determination of the critical size of the bomb was one of the main problems of the Theoretical Physics Division. In the course of time, several improvements were made in the theoretical approach whereby it was possible to take account of practically all the complex phenomena involved. It was at first considered that the diffusion of neutrons was similar to the diffusion of heat, but this naive analogy had to be forsaken. In the early theoretical work the assumptions were made that the neutrons all had the same velocity and all were scattered isotropically. A method was thus developed which permitted calculation of the critical size for various shapes of the fissionable material provided that the mean free path of the neutrons was the same in the tamper material as in the fissionable material. This method was later improved first by taking account of the angular dependence of the scattering and secondly by allowing for difference in mean free path in core and tamper materials. Still later, means were found of taking into account the effects of the distribution in velocity of the neutrons, the variations of cross sections with velocity, and inelastic scattering in the core and tamper materials. Thus it became possible to compute critical sizes assuming almost any kind of tamper material.

12.26. The rate at which the neutron density decreases in bomb models which are smaller than the critical size can be calculated, and all the variables mentioned above can be taken into account. The rate of approach to the critical condition as the projectile part of the bomb moves toward the target part of the bomb has been studied by theoretical methods. Furthermore, the best distribution of fissionable material in projectile and target was determined by theoretical studies.

12.27. Techniques were developed for dealing with set-ups in which the number of neutrons is so small that a careful statistical analysis must be made of the effects of the neutrons. The most important problem in this connection was the determination of the probability that, when a bomb is larger than critical size, a stray neutron will start a continuing chain reaction. A related problem was the determination of the magnitude of the fluctuations in neutron density in a bomb whose size is close to the critical size. By the summer of 1945 many such calculations had been checked by experiments.

12.28. A great deal of theoretical work was done on the equation of state of matter at the high temperatures and pressures to be expected in the exploding atomic bombs. The expansion of the various constituent parts of the bomb during and after the moment of chain reaction has been calculated. The effects of radiation have been investigated in considerable detail.

12.29. Having calculated the energy that is released in the explosion of an atomic bomb, one naturally wants to estimate the military damage that will be produced. This involves analysis of the shock waves in air and in earth, the determination of the effectiveness of a detonation beneath the surface of the ocean, etc.

12.30. In addition to all the work mentioned above, a considerable amount of work was done in evaluating preliminary experiments. Thus an analysis was made of the back-scattering of neutrons by the various tamper materials proposed. An analysis was also made of the results of experiments on the multiplication of neutrons in subcritical amounts of fissionable material.

## **EXPERIMENTAL NUCLEAR PHYSICS DIVISION**

12.31. The experiments performed by the Experimental Nuclear Physics group at Los Alamos were of two kinds: "differential" experiments as for determining the cross section for fission of a specific isotope by neutrons of a specific velocity, and "integral" experiments as for determining the average scattering of fission neutrons from an actual tamper.

12.32. Many nuclear constants had already been determined at the University of Chicago Metallurgical Laboratory and elsewhere, but a number of important constants were still undetermined - especially those involving high neutron velocities. Some of the outstanding questions were the following:

1. What are the fission cross sections of U-234, U-235, U-238 Pu-239, etc.? How do they vary with neutron velocity?
2. What are the elastic scattering cross sections for the same nuclei (also for nuclei of tamper materials)? How do they vary with neutron velocity?

3. What are the inelastic cross sections for the nuclei referred to above?
4. What are the absorption cross sections for processes other than fission? 5. How many neutrons are emitted per fission in the case of each of the nuclei referred to above?
6. What is the full explanation of the fact that the number of neutrons emitted per fission is not a whole number?
7. What is the initial energy of the neutrons produced by fission?
8. Does the number or energy of such neutrons vary with the speed of the incident neutrons?
9. Are fission neutrons emitted immediately?
10. What is the probability of spontaneous fission of the various fissionable nuclei?

12.33. In addition to attempting to find the answers to these questions the Los Alamos Experimental Nuclear Physics Division investigated many problems of great scientific interest which were expected to play a role in their final device. Whether or not this turned out to be the case, the store of knowledge thus accumulated by the Division forms an integral and invaluable part of all thinking on nuclear problems.

12.34. *Experimental Methods.* The earlier chapters contain little or no discussion of experimental techniques except those for the observing of fast (charged) particles (See Appendix 1.). To obtain answers to the ten questions posed above, we should like to be able to:

- (1) determine the number of neutrons of any given energy;
- (2) produce neutrons of any desired energy;
- (3) determine the angles of deflection of scattered neutrons;
- (4) determine the number of fissions occurring;
- (5) detect other consequences of neutron absorption, e.g., artificial radioactivity.

We shall indicate briefly how such observations are made.

12.35. *Detection of Neutrons.* There are three ways in which neutrons can be detected: by the ionization produced by light atomic nuclei driven forward at high speeds by elastic collisions with neutrons, by the radioactive disintegration of unstable nuclei formed by the absorption of neutrons, and by fission resulting from neutron absorption. All three processes lead to the production of ions and the resulting ionization may be detected using electroscopes, ionization chambers, Geiger-Muller counters, Wilson cloud chambers, tracks in photographic emulsion, etc.

12.36. While the mere detection of neutrons is not difficult, the measurement of the neutron velocities is decidedly more so. The Wilson cloud chamber method and the photographic emulsion method give the most direct results but are tedious to apply. More often various combinations of selective absorbers are used. Thus, for example, if a foil known to absorb neutrons of only one particular range of energies is inserted in the path of the neutrons and is then removed, its degree of radioactivity is presumably proportional to the number of neutrons in the particular energy range concerned. Another scheme is to study the induced radioactivity known to be produced only by neutrons whose energy lies above a certain threshold.

12.37. One elegant scheme for studying the effects of neutrons of a single, arbitrarily-selected velocity is the "time of flight" method. In this method a neutron source is modulated, i.e., the source is made to emit neutrons in short "bursts" or "pulses." In each pulse there are a great many neutrons - of a very wide range of velocities. The target material and the detector are situated a considerable distance from the source (several feet or yards from it). The detector is "modulated" also, and with the same periodicity. The timing or phasing is made such that the detector is responsive only for a short interval beginning a certain time after the pulse of neutrons leaves the source. Thus any effects recorded by the detector (e.g., fissions in a layer of uranium deposited on an inner surface of an ionization chamber) are the result only of neutrons that arrive just at the moment of responsivity and therefore have travelled from the source in a certain time interval. In other words, the measured effects are due only to the neutrons having the appropriate velocity.

12.38. Production of Neutrons. All neutrons are produced as the result of nuclear reactions, and their initial speed depends on the energy balance of the particular reaction. If the reaction is endothermic, that is, if the total mass of the resultant particles is greater than that of the initial particles, the reaction does not occur unless the bombarding particle has more than the "threshold" kinetic energy. At higher bombarding energies the kinetic energy of the resulting particles, specifically of the neutrons, goes up with the increase of kinetic energy of the bombarding particle above the threshold value. Thus the  $\text{Li}^7(\text{p}, \text{n})\text{Be}^7$  reaction absorbs 1.6 Mev energy since the product particles are heavier than the initial particles. Any further energy of the incident protons goes into kinetic energy of the products so that the maximum speed of the neutrons produced goes up with the speed of the incident protons. However, to get neutrons of a narrow range of speed, a thin target must be used, the neutrons must all come off at the same angle, and the protons must all strike the target with the same speed.

12.39. Although the same energy and momentum conservation laws apply to exothermic nuclear reactions, the energy release is usually large compared to the kinetic energy of the bombarding particles and therefore essentially determines the neutron speed. Often there are several ranges of speed from the same reaction. There are some reactions that produce very high energy neutrons (nearly 15 Mev).

12.40. Since there is a limited number of nuclear reactions usable for neutron sources, there are only certain ranges of neutron speeds that can be produced originally. There is no difficulty about slowing down neutrons, but it is impossible to slow them down uniformly, that is, without spreading out the velocity distribution. The most effective slowing-down scheme is the use of a moderator, as in the graphite pile; in fact, the pile itself is an excellent source of thermal (i.e., very low speed) or nearly thermal neutrons.

12.41. *Determination of Angles of Deflection.* The difficulties in measuring the angles of deflection of neutrons are largely of intensity and interpretation. The number of neutrons scattered in a particular direction may be relatively small, and the "scattered" neutrons nearly always include many strays not coming from the intended target.

12.42. *Determination of Number of Fissions.* The determination of the number of fissions which are produced by neutrons or occur spontaneously is relatively simple. Ionization chambers, counter tubes, and many other types of detectors can be used.

12.43. *Detection of Products of Capture of Neutrons.* Often it is desirable to find in detail what has happened to neutrons that are absorbed but have not produced fission, e.g., resonance or "radiative" capture of neutrons by U-238 to form U-239 which leads to the production of plutonium. Such studies usually involve a combination of microchemical separations and radioactivity analyses.

12.44. *Some Experiments on Nuclear Constants.* By the time that the Los Alamos laboratory had been established, a large amount of work had been done on the effects of slow neutrons on the materials then available. For example, the thermal-neutron fission cross section of natural uranium had been evaluated, and similarly for the separated isotopes of uranium and for plutonium. Some data on high-speed-neutron fission cross sections had been published, and additional information was available in project laboratories. To extend and improve such data, Los Alamos perfected the use of the Van de Graaff generator for the  $\text{Li}^7(\text{p}, \text{n})\text{Be}^7$  reaction, so as to produce neutrons of any desired energy lying in the range from 3,000 electron volts to two million electron volts. Success was also achieved in modulating the cyclotron beam and developing the neutron time-of-flight method to produce effects of many speed intervals at once. Special methods were devised for filling in the gaps in neutron energy range. Particularly important was the refinement of measurement made possible as greater quantities of U-235, U-238 and plutonium began to be received. On the whole, the value of the cross section for fission as a function of neutron energy from practically zero electron volts to three million electron volts is now fairly well known for these materials.

12.45. *Some Integral Experiments.* Two "integral experiments" (experiments on assembled or integrated systems comprising fissionable material, reflector, and perhaps moderator also) may be described. In the first of these integral experiments a chain reacting system was constructed which included a relatively large amount of U-235 in liquid solution. It was designed to operate at a very low power level, and it had no cooling system. Its purpose was to provide verification of the effects predicted for reacting systems containing enriched U-235. The results were very nearly as expected.

12.46. The second integral experiment was carried out on a pile containing a mixture of uranium and a hydrogenous moderator. In this first form, the pile was thus a slow-neutron chain reacting pile. The pile was then rebuilt using less hydrogen. In this version of the pile, fast-neutron fission became important. The pile was rebuilt several more times, less hydrogen being used each time. By such a series of reconstructions, the reaction character was successively altered, so that thermal neutron fission became less and less important while fast neutron fission became more and more important - approaching the conditions to be found in the bomb.

12.47. *Summary of Results on Nuclear Physics.* The nuclear constants of U-235, U-238, and plutonium have been measured with a reasonable degree of accuracy over the range of neutron energies from thermal to three million electron volts. In other words, questions 1, 2, 3, 4, and 5 of the ten questions posed at the beginning of this section have been answered. The fission spectrum (question 7) for U-235 and Pu-239 is reasonably well known. Spontaneous fission (question 10) has been studied for several types of nuclei. Preliminary results on questions 6, 8, and 9, involving details of the fission process, have been obtained.

## **CHEMISTRY AND METALLURGY DIVISION**

12.48. The Chemistry and Metallurgy Division of the Los Alamos Laboratory was under the joint direction of J. W. Kennedy and C. S. Smith. It was responsible for final purification of the enriched fissionable materials, for fabrication of the bomb core, tamper, etc., and for various other matters. In all this division's work on enriched fissionable materials especial care had to be taken not to lose any appreciable amounts of the materials which are worth much more than gold. Thus the procedures already well-established at Chicago and elsewhere for purifying and fabricating natural uranium were often not satisfactory for handling highly-enriched samples of U-235.

## **ORDNANCE, EXPLOSIVES, AND BOMB PHYSICS DIVISIONS**

12.49. The above account of the work of the Theoretical Physics, Experimental Nuclear Physics, and Chemistry and Metallurgy Divisions is very incomplete because important aspects of this work cannot be discussed for reasons of security. For the same reasons none of the work of the Ordnance, Explosives, and Bomb Physics Divisions can be discussed at all.

## **SUMMARY**

12.50. In the spring of 1943 an entirely new laboratory was established at Los Alamos, New Mexico, under J. R. Oppenheimer for the purpose of investigating the design and construction of the atomic bomb, from the stage of receipt of U-235 or plutonium to the stage of use of the bomb. The new laboratory improved the theoretical treatment of design and performance problems, refined and extended the measurements of the nuclear constants involved, developed methods of purifying the materials to be used, and, finally, designed and constructed operable atomic bombs.

## **CHAPTER XIII: GENERAL SUMMARY**

### **PRESENT OVERALL STATUS**

13.1. As the result of the labors of the Manhattan District organization in Washington and in Tennessee, of the scientific groups at Berkeley, Chicago, Columbia, Los Alamos, and elsewhere, of the industrial groups at Clinton, Hanford, and many other places, the end of June 1945 finds us expecting from day to day to hear of the explosion of the first atomic bomb devised by man. All the problems are believed to have been solved at least well enough to make a bomb practicable. A sustained neutron chain reaction resulting from nuclear fission has been demonstrated; the conditions necessary to cause such a reaction to occur explosively have been established and can be achieved; production plants of several different types are in operation, building up a stock pile of the explosive material. Although we do not know when the first explosion will occur nor how effective it will be, announcement of its occurrence will precede the publication of this report. Even if the first attempt is relatively ineffective, there is little doubt that later efforts will be highly effective; the devastation from a single bomb is expected to be comparable to that of a major air raid by usual methods.

13.2. A weapon has been developed that is potentially destructive beyond the wildest nightmares of the imagination; a weapon so ideally suited to sudden unannounced attack that a country's major cities might be destroyed overnight by an ostensibly friendly power. This weapon has been created not by the devilish inspiration of some warped genius but by the arduous labor of thousands of normal men and women working for the safety of their country. Many of the principles that have been used were well known to the international scientific world in 1940. To develop the necessary industrial processes from these principles has been costly in time, effort, and money, but the processes which we selected for serious effort have worked and several that we have not chosen could probably be made to work. We have an initial advantage in time because, so far as we know, other countries have not been able to carry out parallel developments during the war period. We also have a general advantage in scientific and particularly in industrial strength, but such an advantage can easily be thrown away.

13.3. Before the surrender of Germany there was always a chance that German scientists and engineers might be developing atomic bombs which would be sufficiently effective to alter the course of the war. There was therefore no choice but to work on them in this country. Initially many scientists could and did hope that some principle would emerge which would prove that atomic bombs were inherently impossible. This hope has faded gradually; fortunately in the same period the magnitude of the necessary industrial effort has been demonstrated so that the fear of German success weakened even before the end came. By the same token, most of us are certain that the Japanese cannot develop and use this weapon effectively.

### **PROGNOSTICATION**

13.4. As to the future, one may guess that technical developments will take place along two lines. From the military point of view it is reasonably certain that there will be improvements both in the processes of producing fissionable material and in its use. It is conceivable that totally different methods may be discovered for converting matter into energy since it is to be remembered that the energy released in uranium fission corresponds to the utilization of only about one-tenth of one per cent of its mass. Should a scheme be devised for converting to energy even as much as a few percent of the matter of some common material, civilization would have the means to commit suicide at will.

13.5. The possible uses of nuclear energy are not all destructive, and the second direction in which technical development can be expected is along the paths of peace. In the fall of 1944 General Groves appointed a committee to look into these possibilities as well as those of military significance. This committee (Dr. R. C. Tolman, chairman; Rear Admiral E. W. Mills (USN) with Captain T. A. Solberg (USN) as deputy, Dr. W. K. Lewis, and Dr. H. D. Smyth) received a multitude of suggestions from men on the various projects, principally along the lines of the use of nuclear energy for power and the use of radioactive by-products for scientific, medical, and industrial purposes. While there was general agreement that a great industry might eventually arise, comparable, perhaps, with the electronics industry, there was disagreement as to how rapidly such an industry would grow; the consensus was that the growth would be slow over a period of many years. At least there is no immediate prospect of running cars with nuclear power or lighting houses with radioactive lamps although there is a good probability that nuclear power for special purposes could be developed within ten years and that plentiful supplies of radioactive materials can have a profound effect on scientific research and perhaps on the treatment of certain diseases in a similar period.

## **PLANNING FOR THE FUTURE**

13.6. During the war the effort has been to achieve the maximum military results. It has been apparent for some time that some sort of government control and support in the field of nuclear energy must continue after the war. Many of the men associated with the project have recognized this fact and have come forward with various proposals, some of which were considered by the Tolman Committee, although it was only a temporary advisory committee reporting to General Groves. An interim committee at a high level is now engaged in formulating plans for a continuing organization. This committee is also discussing matters of general policy about which many of the more thoughtful men on the project have been deeply concerned since the work was begun and especially since success became more and more probable.

## **THE QUESTIONS BEFORE THE PEOPLE**

13.7. We find ourselves with an explosive which is far from completely perfected. Yet the future possibilities of such explosives are appalling, and their effects on future wars and international affairs are of fundamental importance. Here is a new tool for mankind, a tool of unimaginable destructive power. Its development raises many questions that must be answered in the near future.

13.8. Because of the restrictions of military security there has been no chance for the Congress or the people to debate such questions. They have been seriously considered by all concerned and vigorously debated among the scientists, and the conclusions reached have been passed along to the highest authorities. These questions are not technical questions; they are political and social questions, and the answers given to them may affect all mankind for generations. In thinking about them the men on the project have been thinking as citizens of the United States vitally interested in the welfare of the human race. It has been their duty and that of the responsible high government officials who were informed to look beyond the limits of the present war and its weapons to the ultimate implications of these discoveries. This was a heavy responsibility. In a free country like ours, such questions should be debated by the people and decisions must be made by the people through their representatives. This is one reason for the release of this report. It is a semi-technical report which it is hoped men of science in this country can use to help their fellow citizens in reaching wise decisions. The people of the country must be informed if they are to discharge their responsibilities wisely.

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STS.003 The Rise of Modern Science  
Fall 2010

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