MEMORANDUM ON THE HISTORY OF THERMONUCLEAR PROGRAM

Hans A. Bethe

May 28, 1952

(Assembled by C. Hansen on 5/12/90 from 3 different versions.)

It seems appropriate at this time to review the history of our thermonuclear program, in order to correct two apparently widespread impressions which I consider erroneous. These are (1) that the progress of this program, since the Presidential directive of January 1950, has been slower than was technically feasible, and (2) that the Russians may have been able to arrive at a usable thermonuclear weapon by straightforward development from the information they received from Fuchs in 1946.

This historical sketch might perhaps be better written by a member of the Los Alamos Scientific Laboratory who would have more direct knowledge than I have. However, I may have the advantage that I have been equally exposed to the views of the management of the Los Alamos Laboratory and to those of Dr. Edward Teller who has been my personal friend for twenty-five years. Moreover, I have kept in continuous close touch with the work here and have participated in it part of the time.

In the summer of 1946, the following facts on thermonuclear reactions appeared to have been established by the work of Dr. Teller's group during and after the war:

(a) In a sufficiently rich mixture of T and D, a reaction could take place and could propagate, given sufficient initial temperature [deleted]

(b) A self-sustaining and propagating reaction in pure liquid deuterium seemed a likely possibility.

(c) If successful, such a reaction could deliver energies equivalent to 1000 fission bombs and more, from a device weighing not much more than an ordinary fission bomb and containing mainly cheap materials. This device is now known as the [deleted]

(d) To initiate a reaction in deuterium, mixtures of deuterium and tritium were useful, and it was believed that amounts of [deleted] might be sufficient for the purpose.

(e) The initial heating of the T-D mixture to the required temperature appeared perhaps as the most difficult task because (1) it was questionable whether fission bombs of sufficient yield could be constructed and [deleted]

This was approximately the state of affairs when Fuchs left Los Alamos on June 15,1 946. From then until the end of 1947, rather intensive theoretical work on thermonuclear reactions was done, especially by Teller, Richtmyer and Nordheim. In particular, the Alarm Clock, a device consisting of [deleted] was invented and investigated.

After the summer of 1947, work on large-scale thermonuclear reactions was curtailed, first because no idea for a thermonuclear weapon seemed to exist that offered great and immediate promise, and second because it was felt that the Los Alamos Laboratory, with its limited scientific personnel, could not carry this work in addition to its more immediate responsibilities of improving fission weapons. However, by the middle of 1948, Teller had invented the booster, in which a fission bomb initiates a thermonuclear reaction in a moderate volume of a mixture of T and D, and this reaction in turn serves to enhance the yield of the fission bomb. Substantial theoretical work on the booster was done in 1948, and on the basis of this work it was proposed in the Fall of 1948 to include the booster in the next weapons test. In the first part of 1949, a more thorough theoretical investigation of the booster was carried out. A recent test in Nevada [deleted] demonstrated the practical usefulness of the booster for small-diameter implosion weapons. Calculations have shown that the yield [deleted] Most significant, perhaps, is that the booster, working with T-D at high density [deleted] is more directly related to our present designs of thermonuclear weapons [deleted]

In September 1949, the first Russian bomb created a changed situation. As an answer, Dr. Teller recommended the acceleration of the thermonuclear program. The Los Alamos Laboratory which had in the meantime been greatly strengthened by the addition of new personnel, accepted Teller's suggestion immediately and enthusiastically. The joint recommendation by Teller and the Laboratory led, after considerable discussion, to the Presidential directive of January 1950, which in turn put the effort at Los Alamos on full scale.

The main progress which Dr. Teller had made prior to his recommendation concerned the initiation of the reaction (point e). [deleted]

Apart from this, the program was resumed in 1949 on the basis of the theoretical assumptions of 1946. In particular, even as late as Spring 1950, Dr. Teller, in a memorandum to the G.A.C., estimated the amount of tritium required to initiate a reaction in deuterium, [deleted] Entirely separate from the main theoretical effort which was inspired by Dr. Teller, and with only one assistant and one computer to help him, Dr. S. Ulam undertook the important task of determining more accurately the amount of T required. His results were spectacular: the amount was calculated to be at least [deleted] or the equivalent of the [deleted] of present design. More detailed and thorough calculations by other members of the Theoretical Division of Los Alamos confirmed Ulam's estimates. These results were entirely opposite to the 1946 assumption (d), and made the economic soundness of the H-bomb program highly questionable.

In the summer of 1950, Fermi and Ulam showed by an approximate calculation that there can probably be [deleted] reaction in pure D. This conclusion, which was contrary to thesis (b) of 1946, has since been strengthened by the drop in experimental cross sections resulting from the accurate measurements of Tuck and his group in 1951. The calculations of Fermi and Ulam, however, were not definitive, and the final decision about the feasibility of a thermonuclear reaction in liquid deuterium will only come when a full-scale machine calculation on this problem is carried out which takes into account all important physical processes. Such a calculation has now been prepared. Even if the reaction should turn out to be feasible, it will remain impractical and uneconomical.

Barring surprises from such a calculation, the theoretical work of 1950 has shown that every important point of the 1946 thermonuclear program had been wrong. If the Russians started a thermonuclear program on the basis of the information received from Fuchs, it must have led to the same failure.

In spite of the apparent failure of the program, it was decided in the Fall of 1950 to proceed with the planned thermonuclear experiment at Eniwetok in the Spring of 1951. This experiment which proved fully successful was designed primarily to confirm proposition (a) of 1946, the burning of D-T, about which there had never been serious doubt. In addition the experiment was to try out one of several possible mechanisms which might be used to provide initial ignition [deleted] if the latter should turn out to be feasible. In this particular mechanism, the energy was conducted by radiation from a fission bomb to [deleted] T-D, and the radiation was used not only to heat but also to compress the T-D.

It was largely accidental that just this mechanism was chosen. In one of the alternatives, [deleted] Another alternative was the [deleted] proposed by Teller in Fall, 1949, which by many members of the laboratory was considered a more promising scheme. The accidental choice of the radiation scheme, however, proved fortunate because it led to a theoretical consideration of thermonuclear reactions at high densities, as well as of the propagation of radiation.

The former line of work demonstrated that high densities lower the "ignition temperature" of a T-D mixture and thus make the reaction more efficient. Since the T-D reaction occurs easily anyway, this was perhaps not very remarkable. However, after several months, it occurred to Teller to make the bold extrapolation to the [deleted]. He was able to show by an appropriate calculation that at a [deleted] This would be the case even in [deleted]

If this idea of [deleted] it was necessary to [deleted] Here again a fortunate accident intervened: in December 1950, Ulam had suggested to use the energy from a fission bomb to compress [deleted] This idea was conceived entirely independently of the thermonuclear program, and its aim was to use fissionable materials more economically. Ulam's idea was to utilize [deleted] Several months later, when Teller recognized the importance of [deleted] he suggested that [deleted] might be capable of achieving the required [deleted] This led to our present concept of thermonuclear reactions.

This concept, then, came about by a number of accidents, the accidental choice of one particular device for the Eniwetok test rather than two others, the ingenious extrapolation by Teller [deleted] and the invention of radiation implosion just at the right time. None of these three steps was at all an obvious, logical development which would occur in every thorough scientific investigation of the problem. On the contrary, the results of the calculations of Ulam and Fermi in 1950 (which were logical steps in the program) would have led nearly every scientist to give up the thermonuclear program altogether. Only Teller's persistent belief in the practicality of thermonuclear reactions led to our present, completely novel concepts in this field. It would be a most remarkable coincidence if the Russian project had taken a similar course.

The new design for a thermonuclear reaction is known as [deleted] to initiate the thermonuclear reaction.

It was immediately clear to all the scientists concerned that Teller's new suggestion provided for the first time a firm basis for a thermonuclear program. Without hesitation, Los Alamos adopted the new program. The G.A.C. held a meeting on this subject in Princeton in the middle of June 1951. This meeting was also attended by the members and the manager of the AEC and by a considerable number of Staff Members and consultants of the Los Alamos Laboratory. The meeting was unanimously in favor of active and rapid pursuit of work on the [deleted] with a test to be prepared as soon as it was clear what exactly was to be tested.

However, in September 1951, when the initial calculations had shown promise, disagreement arose between Teller and the rest of the Los Alamos Laboratory as to the date for a full-scale test. Los Alamos proposed November 1952, whereas Teller demanded a date four to six months earlier. It will be shown in the following that Teller's date could not have been met.

The theoretical work started immediately, in June 1951. Four major problems had to be solved, concerning

(1) [deleted]

(2) [deleted]

(3) [deleted]

(4) [deleted]

The second of these problems was clearly the crucial one and received first attention from Los Alamos. Beginning already in the Summer of 1951, results were obtained from machine calculations and were very encouraging. Concerning (4), results on the efficiency of [deleted] were obtained at Los Alamos in the Fall of 1951, and reasonably definitive calculations on [deleted] were made by the Matterhorn Project in Spring 1952. By combining the results of problems (2) and (4), it now appears probable that the combination of radiation implosion and thermonuclear reaction will work.

Problem (3) turned out to be much simpler than had been anticipated. It should be noted that this is a complete reversal of the position in 1946 when [deleted] But equally important in making the problem "easy" is the much better understanding of fission weapons which the Los Alamos project had acquired in the meantime.

Problem (1) was initially considered to be the easiest of all. In March 1952 unforeseen difficulties appeared, connected with the [deleted] These difficulties could only be minimized by a very major redesign of [deleted] This redesign came at the latest moment compatible with meeting the test date of November 1952; had Teller's test date been accepted, redesign would have been impossible and the test would very probably have failed.

I believe it is obvious from this outline that the theoretical program on [deleted] has proceeded at maximum speed from the moment this device was conceived. This rate of progress was only possible by the extensive use of high-speed computing machines which did not exist a year earlier. The conception of [deleted] itself was a matter of inspiration, and it was, therefore, unpredictable when it would occur; in my opinion, it is remarkable that it occurred so soon after full-scale theoretical work on the hydrogen bomb was resumed.

At present, roughly 75 percent of the work of the Staff Members of the Los Alamos Theoretical Division is devoted to thermonuclear reactions, and in addition the entire work of the Matterhorn Project. It should be noted that in this field the theoretical work determines the overall progress to a much greater extent than anywhere else.

Engineering of [deleted] for test was started in October 1951. This early start duplicated war-time procedure, and, just as during war time, put a considerable strain on both the theoretical and engineering work because theoretical progress necessitated frequent changes of design. Preparation of observations for the test was an equally difficult problem and was begun as soon as [deleted] was conceived.

It is impossible to predict whether the test of [deleted] will be successful. On purely theoretical grounds, success may be expected, but the action of the device is so complicated that failure at one point or another would not be surprising. In case of success, the yield may be anywhere from [deleted]

Even in case of success, [deleted] as now designed is too heavy (80 tons) to be practical. Reduction in weight to about 20 tons, and in diameter to about 65 inches may be possible by:

(a) engineering with smaller safety factors,

(b) reducing the volume of the thermonuclear reaction vessel with a sacrifice of yield, and

(c) using Li^6D instead of liquid deuterium.

[deleted]

Perhaps more promising than the [deleted] is the "Alarm Clock." This device was invented on August 31, 1946, two and a half months after Fuchs left Los Alamos. In its original form, it consisted [deleted] Intensive calculations on this device were carried out by Nordheim, Richtmyer and others from the time of its invention to the end of 1947.

[deleted]

About the late summer of 1950, Teller suggested that Li^6D might be used instead of pure D in the "Alarm Clock." This [deleted] showed up very well in theoretical calculations. When combined with the radiation implosion, it gives promise for a practical thermonuclear weapon. Relatively small amounts of [deleted] may suffice to give a yield of about [deleted] and the weight and size specifications could be met with more assurance than in the case of the [deleted] However, the theoretical probability of satisfactory working of the "Alarm Clock" is far smaller than for [deleted] because of the likely occurrence of Taylor instability.

For the further development of thermonuclear weapons, tests of components rather than full-scale weapons appear fruitful. Thus it has been suggested to test the [deleted] cannot be calculated reliably. One or more tests of Taylor instability have been proposed in connection with the "Alarm Clock." Finally, for the purpose of reducing weight, it has been suggested to test the [deleted] In this work, the collaboration of another competent laboratory with Los Alamos would be desirable.

The yields now expected for devices which might be carried by a plane are of the order of [deleted] as compared with perhaps [deleted] in 1946. The yield of a fission bomb in 1946 was 20 kilotons; at present, a 500-kiloton bomb is in the design stage and 1 megaton seems entirely feasible at the expense of more fissionable material. The yields expected from feasible fission and fusion bombs have, therefore, come rather close to each other, and while fusion bombs now appear feasible, they have remained extremely complicated in comparison with fission bombs. In addition, the weight of fusion bombs of substantial yield is likely to remain substantially higher than that of a Mark-6 fission bomb. All these points will tend to reduce their practical usefulness as weapons.

It should also be noted that there will still be a long way from the test of [deleted] late this year to a weapon. Even if the "Alarm Clock" should be successful, this time can hardly be less than one and a half to two years. It is more likely that theoretical work, component tests and full-scale test will show the "Alarm Clock" to be less efficient than is now expected, and that changes of design and, therefore, time delays will be necessary.

I would summarize the history of thermonuclear development as follows:

(1) The "runaway super" as conceived in 1946 is probably not feasible, certainly impractical.

(2) There at present only two promising ways to obtain large-scale thermonuclear reactions, namely [deleted]

(3) Development of a possibly practicable device could begin in earnest only after the invention of the radiation implosion which originated outside the thermonuclear program.

(4) The invention of [deleted] in 1951 was largely accidental. It is unpredictable whether and when a similar invention was made or will be made by the Russian project. The invention in our project could probably not have been accelerated by harder work. Since the time the invention was made, work has progressed at maximum speed.

(5) The "Alarm Clock" was invented after Fuchs left, and it became practical only by the inclusion of Li^6 (in 1950)

and its combination with the radiation implosion.

(6) The thermonuclear work at Los Alamos was never really interrupted. Between Fall 1947 and Fall 1949, the booster was developed which proved very important in its own right and proved closer to present design than the 1946 version of a full-scale thermonuclear reaction.

Distribution:

1A - Gordon Dean
2A - David Griggs
3A - Robert Oppenheimer
4A - N. E. Bradbury
5A - H. A. Bethe