17 MAY 1941 [redacted] ~~CONFIDENTIAL~~

5/17/41

[redacted] REPORT OF

NATIONAL ACADEMY OF SCIENCES COMMITTEE ON ATOMIC FISSION

Frank B. Jewett, President
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C.

Dear President Jewett:

The committee of the National Academy of Sciences to which you have referred the matter of possible military aspects of atomic fission, held a meeting in Washington, April 30, with Dr. Briggs' "Uranium Committee", and a second meeting in Cambridge, May 5. Further conferences were held by mail and wire.

We have been concerned primarily with question "b" of your letter of appointment, "as to whether, all things considered, larger funds and facilities and more pressure are indicated in the light of our present scientific knowledge and the probability of applications useful in connection with national defense problems."

Our primary recommendation is that during the next 6 months a strongly intensified effort should be spent on this problem. This is in accord with the view urged by Dr. Briggs on behalf of his committee, and with the unanimous opinion of the other qualified persons with whom we have consulted.

It now appears probable that the results obtained by that time will show the need for a large scale program with regard to atomic fission. It remains possible that on the contrary the results will then indicate that vigorous effort will no longer be justified in view of other urgent military demands on the attention of physicists. The possibilities associated with a successful outcome of the work are however of such importance and are so imminent that, in our opinion, we must not risk giving an enemy nation the advantage of first putting atomic fission to military use.

Intensive immediate effort will involve sharply increased appropriations in support of present work, and means for facilitating the efficient use of the men qualified to work in this field.

For accomplishing these objectives specific recommendations are presented in the final section of this report.

It would seem to us unlikely that the use of nuclear fission can become of military importance within less than two years, though it would appear that some of the British experts/anticipate applications more prompt than this. If, however, the chain reaction can be produced and controlled, it may rapidly become a determining factor in warfare. Looking, therefore, to a struggle which may continue for a decade or more, it is important that we gain the lead in this development. That nation which first produces and controls the process will have an advantage which will grow as its applications multiply.

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Possible Military Applications

Applications of military importance in connection with atomic fission are based upon the expectation of producing a nuclear chain reaction. In this reaction, when a U_{235} atom combines with a slow neutron, it divides with great energy (the process of "fission"), emitting rays among which are fast neutrons. When these neutrons are slowed down by collision with other atoms, such as deuterium, beryllium or carbon, they may be captured by other U_{235} atoms, which in turn divide. This is the chain reaction, continuing as long as a sufficient number of U_{235} atoms and atoms of the slowing agent are present. The energy thus liberated per atom of U_{235} is about 130,000,000 times that developed per atom from such a chemical reaction as combustion of carbon in oxygen or about 2,000,000 times as much per pound of U_{235} as per pound of carbon burning in oxygen. It is anticipated that under suitable conditions the reaction will be under control with respect to speed of development, but that under other conditions it may proceed with explosive violence.

Proposed military applications of a uranium fission reaction include:

(a) Production of violently radioactive materials to be used as missiles destructive to life in virtue of their ionizing radiations. For this purpose the function of the central installation for producing the chain fission reaction would be to produce the artifically active materials. These might then be carried by airplanes to be scattered as bombs over enemy territory. While this might be the most promptly applicable military use of the method, because of the hazards that will necessarily be involved, it could hardly be applied within less than twelve months from the first successful production of a chain reaction. This would mean not earlier than 1943.

(b) As a power source on submarines and other ships. This is perhaps the most straightforward use of atomic power, but because of the engineering difficulties involved, and the necessary protection against hazards, it can hardly have important application within less than three years from the time of production of the first chain reaction.

(c) Violently explosive bombs. It would now appear that a strong concentration of uranium 235, or of some other element which is subject to fission on capturing thermal neutrons, will be required in order to produce an explosive atomic reaction. The destructive power of such an explosion should be enormous as compared with that from chemical explosives. Optimistic estimates of the time required for separation of adequate amounts of uranium isotopes would be from three to five years. It is possible that element 94, usable for this purpose, may be produced abundantly by the chain fission reaction. If this is true, such atomic bombs might become available within twelve months from the time of the first fission chain reaction. Because of the hazard in its use, however, some years will be required for development. This means that atomic bombs can hardly be anticipated before 1945.

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In making these time estimates, we have been guided by normal, high pressure development of scientific and engineering processes. It is possible that with luck the times would in certain cases be appreciably reduced. It seems to us more likely, however, that the effectiveness of the methods concerned will become most evident at later dates than those here indicated.

On the other hand, it should be kept in mind that the outcome of a new process such as this will certainly open new possibilities now unthought of. Some of these may be of prompt application, but most of them will only gradually be realized.

Progress toward Securing a Chain Reaction

The calculations seem to make it clear that a chain reaction of atomic fission should easily be produced with a sufficiently large quantity of the 235 isotope of uranium. The separation of this isotope is possible, but according to present indications, can be achieved in quantity only by the installation of large, expensive plants whose suitable design has not yet been determined. In time, this may become a most important aspect of the problem, and work now under way in studying the methods of isotope separation must, therefore, be continued.

Those working on the fission problem are, however, agreed that the probability of obtaining a chain reaction with the normal mixture of uranium isotopes is good. To make this process a success involves the use of an agent to slow down the fast neutrons liberated at the time of fission to a speed so low that they will not readily be captured by uranium 238. The best estimates indicate better than even chances that continued work along the lines now being followed will effect this reaction. If given sufficient support, adequate tests of these methods should be completed and the reaction perhaps obtained within 18 months.

The time and cost required to complete the tests needed to produce the chain reaction, if the method is practicable, is now estimated as follows:

a. Mixtures of uranium and carbon.

1. Intermediate experiment now in hand at Columbia University. Details are given in the attached report by George B. Pegram.

Cost - materials	$ 117,000	
Salaries	33,000	
Incidentals	24,000	$174,000

Time of completion: about July 1, 1942
Anticipated results: Definite evidence whether uranium-carbon mixture can give chain reaction, and reliable data from which to determine amount of material required to produce such reaction.
Present status: about $60,000 worth of material on order.

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2. Production of chain reaction with carbon and uranium. This cannot be intelligently planned until experiment (1) is complete. As now anticipated, it will require at least 120 tons of graphite and the erection of suitable housing. The cost of this stage will probably be between $500,000 and $1,000,000.

The uranium-carbon experiment is the most immediately applicable of the proposed methods. This is because the materials required are immediately available. It is estimated by Fermi to have an even chance of success. It does not appear as hopeful as methods b. and c. mentioned below. Because of its immediate applicability, however, and the importance of learning what the chain reaction will do, it is important to go ahead now with the intermediate stage (1) of this experiment.

b. Mixtures of uranium with beryllium or beryllium oxide.

Be and BeO seem to have advantages over C as slowing agents, because (1) the path required to bring the neutrons to rest is shorter, and (2) additional neutrons are released within the beryllium. BeO is available* in suitable quantity. Time will be required to produce metallic Be.†

1. Intermediate experiment on relative effectiveness of Be, BeO, and C as slowing agents. Experiments now in hand at University of Chicago. (See attached report by S. K. Allison)

Cost- materials, including 2 tons BeO and 250 pounds Be	$ 35,000	
Salaries, $15,000 + 50 percent	22,500+	
Incidentals	7,500	$65,000

Completion date of experiment: December 1, 1941
Result: Knowledge of comparative value of beryllium and carbon as slowing agent for neutrons, and an estimate of relative amount of beryllium, beryllium oxide, or carbon, required to produce a chain reaction.

(see p. 4a) → NOTE:

2. Determinative uranium-beryllium experiment. This will involve use of larger quantities of the materials. The design of the experiment will depend upon the state of the problem at the time. It should give definite information with regard to amount of materials required to produce the reaction. Its completion will probably be limited by the rate at which the materials can be supplied, but should not be later than July 1, 1942. Probable cost, about $130,000 additional.

3. Chain reaction with beryllium oxide and uranium. On the basis of present rough estimates comparable with those used for experiment a-2, above, this experiment will require some 20 tons of uranium oxide and 30 tons of beryllium oxide. Total cost should

* Present production rate of BeO 4 tons per month, all for essential industries. A high priority rating would be required for prompt delivery.

† Present production of Be is at the rate of [illegible]

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Allison suggests that plans should be made now for an experiment using about 1 cubic meter of BeO (3 to 4 tons), some 200 lbs. of Be metal, and 2 to 3 tons of uranium oxide or metal. Arranging the uranium in 2 concentric shells filled with beryllium, he believes a definite answer to the possibility of a chain reaction by this method can be given, and the amounts required definitely determined. There would be perhaps some chance of securing at once the chain reaction.

If the uranium and the metallic beryllium is borrowed from the carbon experiment, the material cost would be confined to that of the beryllium oxide, roughly $50,000. This would replace experiments b1 and b2 here indicated.

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be roughly somewhat less than that of the corresponding uranium carbon experiment. This, however, is based upon uncertain data.

By July 1942, it should be possible to choose reliably whether the carbon or the beryllium slowing agent is preferable and, thus, to select either experiment a-2 or b-3. It will probably not be desirable to carry through both at that time.

c. Using mixtures of uranium with pure, heavy water. (See attached report by H. C. Urey).

The use of heavy water as a slowing agent is the most promising method now on the horizon. Its effective use, however, awaits the separation of the necessary quantities of heavy hydrogen. Eventually it may be less expensive than the other methods, even though the other methods may be the first to give results and at lower initial cost. The most promising method of separating deuterium (heavy hydrogen) is, according to Urey, the chemical exchange reaction between water and hydrogen, in which the water is fed through a countercurrent system containing a catalyst, then converting this to hydrogen and feeding the hydrogen back through the catalyst system.

Studies of the appropriate catalyst and of the construction of a pilot fractionation system are now in progress.

2. Large scale production of heavy water. "The plant may cost a half million or a million dollars". The heavy water should cost between \$10,000 and \$25,000 per ton. As a rough estimate, several tons will be required for effecting the fission chain reaction.

3. Tests of uranium and heavy water mixtures. Preliminary tests of this type have been performed by Halban in England, using 120 kilograms of heavy water. The result was very encouraging, and has apparently convinced ~~the~~ British physicists that the chain reaction can be produced by this method. The experiment is not however clear cut, and needs repitition with perhaps a ton of heavy water before the conditions for the chain reaction experiment itself can be definitely formulated. Materials available for making this test may be available by July 1942.

4. Chain reaction with uranium and heavy water. This experiment should be possible not later than 1943 at a cost, in addition to that for the building of the deuterium separation plant, of from \$200,000 to \$400,000.

Recommendations

Budget

We understand that the intermediate experiment on uranium and graphite is already partially financed, as is also a pilot plant for the production of pure heavy water. In addition to giving

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these two projects full support, we would urge emphasis on the beryllium project to the extent of approximately the $65,000 for the next six months indicated above. The other work on the separation of uranium isotopes should also be kept active, although it does not need the urgent emphasis that should be placed upon the use of normal uranium. There should thus be made available for the next six months a total of about $350,000. This is as far as the committee believes that present information justifies definite plans.

Toward the end of this 6 month period, i. e. about November, 1941, the results should however be reconsidered by a committee similar to the present one. If the indications are favorable, one or both of the following projects should then be carried through: (a) The next stage of the beryllium experiment, at a cost of about $130,000, and (b) the construction of the separation plant for producing heavy water, at a cost of perhaps $800,000.

It would now seem that a comparable expenditure during the following year may be required in order actually to produce the atomic chain reaction in usable form. It is doubtful whether the cost can be reduced much below a total of two million dollars[x] without so prolonging the experiments that we should be trailing the work done in other countries.

We recognize that this is a heavy demand on the funds available for national defense research. We believe, however, that the military possibilities of atomic fission are so vast, and the dangers of its neglect until some other nation has outdistanced us are so serious, that if necessary a request should be made for a special appropriation to cover this work. Within a half dozen years the consequences of such investigations may be crucial in determining the nation's military position.

It is noteworthy that our emphasis on its high importance reflects the seemingly unanimous judgment of those in this country and England who have studied intimately the possibilities of atomic fission. This includes all of the individual members of the Uranium Committee, as well as the investigators with whom we have conferred. (See especially the minutes of the May 5 meeting of our committee)

Personnel

The question of employing on this problem scientific men who might be more useful at other national defense problems has been considered. This difficulty is not as serious as would at first appear, for two reasons: (1) The greater part of the expense does not go into the employment of physicists, but rather into the supplying of the expensive materials required. (2) The physicists

[x]It may be noted that the market value of the material purchased will be a considerable fraction of this cost.

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to be used on this project are, and will continue to be, for the most part, those whose qualifications do not fit them for important positions in other national defense projects. This applies to most of the physicists and chemists now employed at Columbia and Chicago, with the exception of Mr. Pegram and Mr. Allison.

In order to insure the rapid and efficient progress of these studies we would recommend:

1. The formation of a sub-committee, called perhaps the Research Committee of the Uranium Committee, consisting of S. K. Allison, G. Breit, E. Fermi, G. Pegram, and H. C. Urey. As its chairman, Coolidge, Slater and Compton favor Allison; Van Vleck favors Urey, and Lawrence favors either Urey or Allison. It would be the function of this sub-committee (1) to plan and carry through the research program, (2) to confer continuously on the developments as they occur, (3) to see that newly obtained information is promptly available to those investigators that need it, and (4) to report as may be desired to the central uranium committee.

2. We consider it vital that every effort be made to insure that those working on the uranium problem at the request of the uranium committee be kept acquainted with the advances made by other investigators and be encouraged to confer upon their mutual problems. Experience indicates that only thus can rapid progress be made; and rapid progress is in the present instance of first importance.

3. In order to progress most rapidly, it will be of value to bring immediately by air to the United States Mr. Halban, now at work on this problem in Cambridge, England.[x] He has information that will greatly aid our investigations, and can take back to England such information as we may have obtained that may be of value in their study of the same problem.

We wish to congratulate the Uranium Committee on the excellent progress that has thus far been made. We would encourage the National Defense Research Committee to give even more complete support to the capable men now engaged upon this research. This we believe can best be done by giving prompt and adequate financial support along the lines indicated above.

Respectfully submitted,

Arthur H. Compton

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With the expressed approval of the following members of the committee: W. D. Coolidge, E. O. Lawrence, J. C. Slater, J. H. Van Vleck. Because of illness, Mr. Bancroft Gherardi has taken no part in the committee's discussions.

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[x] It is suggested that such an invitation be routed through Mr. Cockcroft.

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