

May 15, 1940

STATEMENT by E. Fermi and L. Szilard

The preliminary work on the possibility of producing a self perpetuating nuclear chain reaction in a mixture of ordinary uranium and carbon seems in our opinion to be encouraging and to warrant the organization of the work on a wider scale according to the following plans:

a) perform a number of measurements and preliminary researches for the purpose of improving the estimate of the chances of success and of enabling us to find the best possible conditions for the large scale experiment. While these measurements and researches are in progress to work out the constructional details for a large scale experiment and to prepare drawings for such an experiment.

b) on the assumption that this preparatory work under a) should give a satisfactory result, perform a large scale experiment for the actual production of the chain reaction.

We estimate the expense for part a) of our program to be about \$50,000. Part b) of the program will involve much greater cost since considerable amounts of material and labor will be involved. It is estimated that 100 to 200 tons of graphite and 10 to 20 tons of metallic uranium might have to be used. The total cost may perhaps amount to \$500,000.

The program that we suggest presents the advantage that the actual expenditure for the second stage of the work will be incurred only if the results of the first preparatory stage are encouraging.

signed:

In support and explanation of these proposals the following considerations are submitted:

A forecast whether or not a chain reaction would be self perpetuating under given circumstances can be made only with the knowledge of several

likely than not that the large scale experiment would be successful.

It is mainly due to these circumstances that it seems advisable, before embarking on the final experiment, which will certainly involve a very considerable expense, to carry out a preparatory program as outlined under a). The very nature of the measurements involved does not make us very hopeful of being able, after completion of this preparatory stage of the program, to predict with certainty the outcome of the experiment but we shall then be in a better position to estimate the chances and determine the most favorable geometrical conditions for the final experiment. *

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The program that we suggest presents however the advantage that the actual expenditure for the second stage of the work will be incurred only if the results of the first preparatory stage are encouraging.

signed:

2. Remarks by L. Szilard to the above joint statement

Carrying out a large scale experiment seems to be the only way in which the possibility of a chain reaction using ordinary uranium can be established beyond doubt. Clearly the survey of the nuclear constants which we propose to include in the first stage of the work as discussed under a) is a prerequisite for finding the best conditions for the large scale experiment. I personally have little doubt left that a chain reaction can be set up in ordinary uranium if the neutrons are slowed down in a suitable manner; **all** the more so since there is reason to think that the

progress towards finding conditions favorable for the maintainance of a chain reaction which started a year ago is still continuing. We wish, therefore, particularly to emphasize ~~the necessity of~~ ^{that it would be very desirable} designing during the first preparatory stage ~~discussed under a)~~ ^{constructional} the ~~conditional~~ details of the large scale experiment. This would make it possible to carry

out the large scale experiment in a very short time ~~after the decision~~ ^{at this time} is reached that this second stage of the work is to be entered upon. ~~and put at the disposal of some board of trustees~~ ^{needed to actually carry}

If the required funds were available I would be glad, jointly with Professor Fermi, to assume the responsibility for carrying out the proposed work. ~~It~~ ^{Perhaps} might be advisable ~~to~~ have a small committee of scientists supervise our work and cooperate in coordinating work on uranium which might be carried out in various universities.

Signed: L. Sz.

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May 15, 1940

Statements by E. Fermi and L. Szilard

1. Statement by E. Fermi and L Szilard

The preliminary work on the possibility of producing a self perpetuating nuclear chain reaction in a mixture of ordinary uranium and carbon seems in our opinion to be encouraging and to warrant the organization of experiments on a wider scale according to the following plans:

a) perform a number of measurements and preliminary researches for the purpose of improving the estimate of the chances of success and of enabling us to find the best possible conditions for the large scale experiment. *while this work is in progress we wish to work out the constructional details and prepare drawings* It might be advisable to prepare for the large scale experiment during this stage of the work also by designing the constructional details of all the apparatus which would have to be built later if the large scale experiment were actually to be performed. /

b) on the assumption that this preparatory work under a) should give a satisfactory result , perform a large scale experiment for the actual production of the chain reaction.

In support and explanation of these proposals we submit the following considerations.

A forecast whether or not a chain reaction would be self perpetuating under given circumstances can be made only with the knowledge of several nuclear constants related to uranium and to the process of slowing down of the neutrons in carbon. These constants could so far be measured only with a very low accuracy and therefore any forecast that can at present be made is affected by a very considerable probability of error. Taking for these constants what now appear to be the best values a large scale experiment ~~ought to be expected~~ to be successful; but, for the reasons mentioned above , this statement means only that at present it appears more

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It is mainly due to these circumstances that it seems advisable, before embarking on the final experiment, which will certainly involve a very considerable expense, to carry out a preparatory program as outlined under a). The very nature of the measurements involved does not make us very hopeful of being able, after completion of this preparatory stage of the program, to predict with certainty the outcome of the experiment but we shall then be in a better position to estimate the chances and determine the most favorable geometrical conditions for the final experiment.

signed:

I personally have very little doubt that a chain reaction can be set up in ordinary uranium if the neutrons are slowed down in a suitable manner. Our present values of the nuclear constants involved are known only within fairly wide limits of experimental error and therefore they would in themselves perhaps not be sufficient for making a reliable forecast. However, in making a forecast one has also to bear in mind the process of making progress towards finding conditions more and more favorable for the maintenance of a chain reaction. Considerable progress has been made during the past twelve months in that direction and there is no reason to believe that this process of improvement has already reached its limit in the circumstances, etc.

May 10, 1940

STATEMENT

by
E. Fermi and L. Szilard

At the meeting held on April 27 in Washington under the chairmanship of Dr. Briggs we reported on the progress of an experiment which was carried out on 4 tons of graphite put at our disposal by the Government. This experiment has now been concluded and the result is satisfactory. It was found that the absorption of carbon for slow neutrons is small, the value obtained being about one-third of the previously reported upper limit.

Our work concerning systems composed of carbon and uranium has now reached a stage at which it seems necessary to organize a large scale experiment. Only through actually carrying out such an experiment can it be demonstrated beyond doubt that a nuclear chain reaction can in fact be maintained in a system composed of carbon and uranium.

All nuclear constants involved have now been measured and the best experimental values obtained for these constants lead to the conclusion that such an experiment may be expected to be successful. It must be pointed out however, that the number of nuclear constants which are involved is large and that the value of each of them is known only within the limits of experimental accuracy. In the circumstances, a fore-cast based on the best available values of these constants can be made perhaps with a fair degree of assurance but not with absolute certainty.

Since it appears necessary and urgent to obtain certainty in this matter we desire to start organizing a large scale experiment. This experiment would require about 100 tons of graphite and

As the first step it is proposed to carry out a general survey of all nuclear constants involved with a view to confirming the values previously obtained and of narrowing down the limits of experimental error of the observed values of these constants. Concurrently, with this survey, certain ^{other} work would have to be done in order to prepare the ground for the large scale experiment. Such work would include the working out of constructional details in the form of drawings, the carrying out of technological tests on samples of material which will be used in large quantities in the ultimate experiment, and negotiating for bids for the manufacture of such material in the required quality and quantity. An expenditure of \$50,000. would probably be sufficient to bring this first stage in the organization of the large scale experiment to its conclusion and would bring us up to the next stage ~~which may require considerably greater expenditure.~~

*Survey will do
the expenditure would gradually
rise 200 - 500 M.*

*have done the first and separate part of
and may reach a total of 200 for
of 700 000 dollar*

of 700 000 dollar

During the second stage of the work the expenditure would gradually rise and may reach a total of \$500,000. by the time the large scale experiment is concluded.

The engineering development proper which would include the energising of a steam boiler by the heat liberated in the chain reaction and the adaptation of such an atomic engine for the purpose of driving naval vessels is not included in this estimate of cost. Such an engineering development would probably require a frame-work which is different from the frame-work which is best suited for carrying out the first large scale demonstration.

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- Dr. Briggs: Opening remarks,
- Dr. Sachs: Background of this meeting
- Dr. Fermi: State of experimental work
- Dr. Szilard: Possible implications concerning national defense
- Dr. Pegram: Outline of possible organization of future work
- Dr. Wigner: Remarks on the above

Statements concerning the large scale experiment.

The work of Fermi and Szilard has now reached the stage at which it is necessary to start organizing a large scale demonstration experiment. Before making any arrangements for the proposed large scale experiment, it will be necessary to devote some time to remeasure all nuclear constants which enter into the large scale experiment. The exact knowledge of the values of these constants will render it possible to determine the best conditions under which the large scale experiment can be efficiently carried out.

It is suggested that for the work carried out preparatory for the setting up of the large scale experiment a fund of \$ 100,000 be secured. One of the purposes for which such a fund would be used, would be to employ, say, four younger physicists for carrying out a survey. This survey would comprise the following:

1. an improved estimate of the number of fast neutrons emitted by uranium per absorbed thermal neutron ();
2. a study of the resonance absorption of uranium (p);
3. a study of metallurgical problems connected with the large scale manufacturing of uranium metal;
4. cross-sections of uranium for thermal neutrons;
5. slowing down process in carbon;
6. measuring of combinations of nuclear constants in experiments in which a uranium metal sphere is embedded in graphite;
7. constructional details for the large scale experiment.

It is further proposed that the greater part of the fund be used for the preparation of the large scale experiment in a system composed of uranium and graphite. Part of the fund ought

to be spent for another line of research which, if successful, would lead to another type of chain reaction based on fast neutrons instead of slow neutrons.

Part of the fund could also be used for separation research concerning the separation of two uranium isotopes, by means of grants to university laboratories that are currently pursuing this line of research.

Statement by Dr. Sachs.

Early in March I ~~was~~ received a letter by Dr. Einstein, in which he informed me that he had learned from reliable sources that work on uranium in Germany is being carried out in great secrecy and on a very large scale. I understand that this information is confirmed by Prof. Debye who recently came from Germany. Dr. Einstein wrote me that Dr. Szilard has written a detailed paper on the possibility of chain reactions in a system composed of uranium and graphite, and that this paper has been sent to the Physical Review, and Dr. Einstein raised the question of secrecy in connection with all this work. At the same time, Dr. Einstein asked Dr. Szilard to submit a memorandum on the possible bearing of Dr. Fermi's and Dr. Szilard's work on questions of national defense, which memorandum I have in the meantime received. Accordingly, I submitted his communication to the President, and upon the President's return from his trip in the Canal Zone I was advised by him that he had asked his Secretary, General Watson, to arrange another meeting in Washington, with Dr. Briggs and the representatives of the Army and Navy ~~and others~~ and others. General Watson, on the same date, asked for suggestions from Dr. Einstein and myself as to the supplementary names for attendance at this conference, and so, through the kind offices and direction of Dr. Briggs, this conference has resulted.

This week, having heard from Dr. Einstein that he could not attend, I had the pleasure of calling on him and hearing his views. He told me that he had discussed the scientific aspects with Dr. Wigner and emphasized his conviction as to the importance of creating conditions under which the work can be pursued on an adequate scale. He also discussed some aspects of organization and

sought my views on that, but this can be deferred for a later stage of this conference.

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b.) If the government is not able to provide funds it might approach public-minded private persons and suggest to them that they should put up the required funds.

Any help that the government may wish to give in the form of loaning material or men will be ~~welcome~~ ^{helpful} but the work will be necessarily greatly slowed down unless in addition to such help free funds are also available. Funds could be made payable direct to certain universities rather than ~~through~~ ^{to} the trustees of the proposed organization but the existence of the proposed organization appears nevertheless to be essential in order to give to those who will be engaged in this work a clearer ^{ly defined} status with respect to this work. Unless this work will be considered by a number of people as a full-time job and unless the responsibilities are clearly defined it will not be possible to carry out in a satisfactory manner ^a ~~the~~ task which is of ~~very~~ ^{such} great complexity.

Dr. Fermi and Dr. Szilard emphasize ^{the importance of this} ~~work~~ ^{if this work is to be} for obtaining substitutes of radium for medical purposes in large quantities. They ^{are} ~~would be~~ ^{able} glad to carry out these experiments under the indirect supervision of the Government, i.e. within the framework of ^{some} ~~the~~ organization which would be controlled by the Government by virtue of the fact that its trustees are nominated by the Government committee. ^{as proposed by us} ~~Dr. Fermi and Dr. Szilard~~ and those whom they would ask to collaborate ^{they have agreed} ~~would be~~ glad to delay the publication of ^{their} ~~the~~ results obtained in the first instance for two years; after that period the question of publishing results would be ^{re-} considered in the light of the further development. Any patents taken out by those who collaborate ^{might be} ~~would be~~ given ^{without financial consideration} ~~free of charge~~ to the corporation or ^{direct} to one of the Government Departments. A committee of scientists ^{could} ~~serveng~~ in advisory capacity to this organization, and it is assumed that Drs. Pegram and Uryi of New York, Drs. Wigner and Wheeler of Princeton, and Drs. Tuve and Teller of Washington would consent to serve ^{in this} ~~in this~~ capacity. ^{on this} ~~Dr. Fermi and Dr. Szilard~~ would be glad to ^{submit} ~~keep this~~ committee ^{informed} ~~of the progress of the work,~~ and ^{the} ~~this~~ committee could advise the trustees as ~~to~~ to the justification of any proposed expenditure. ^{at frequent intervals} ~~500,000 would be required~~ for the start to organize the work and might ^{cover a period of} ~~1 month to 1 year.~~ —

in the enclosed copy of Dr. E. letter.

Statement.

The first question which the Government has decided ^{to} can be put in a hypothetical form, as follows: Assuming that it is possible to maintain a chain reaction in a system composed of 100 tons of graphite and 10 tons of uranium, does this fact appear to have a bearing on questions of national defense which are sufficiently important to make it advisable for the Government to support this ~~line~~ line of research? The answer to this question ought to envisage the necessity of an expenditure either by the Government or by private sources, which would start with about \$ 50.000 and ^{may} ~~would~~ gradually rise to a total of perhaps \$ 500.000.

Backs on Briggs

Statement.

Our work concerning systems composed of carbon and uranium has now reached a stage at which it appears desirable to organize a large scale experiment. All nuclear constants involved have now been measured, and the most probable values for these constants point to the conclusion that the large scale experiment may be expected to be successful. Since, however, these nuclear constants are subject to large experimental errors, obviously it cannot be stated with certainty that the large scale experiment will in fact be successful.

In these circumstances, and since the large scale experiment will involve great expenditures both for material and for labor, we propose to proceed step by step in carrying out this experiment. If the results obtained in the first step are satisfactory, then the expenditure necessary for the second step will be considered as justified, and the work will proceed according to schedule. In this way, the expenditure would rise parallel to the increase of our assurance of ultimate success.

As a the first step it is proposed to carry out a general survey of all nuclear constants involved with a view of reducing the experimental errors affecting the values of these constants.

~~The result of this survey may considerably increase our assurance of ultimate success, but it cannot decide the question with certainty. The number of nuclear constants involved is considerable, and in the circumstances it will be necessary, in order to obtain certainty, actually to carry out the large scale experiment.~~

Dr. Fermi and Dr. Szilard have expressed their willingness to postpone the publication of the method which they invented for a period of two years, after which time the question of publication would have to be considered. The same restraint concerning publication would be expected of all others who would collaborate with the proposed organization.

Dr. Fermi and Dr. Szilard have expressed their willingness to give to the proposed organization or directly to ^{some} ~~the~~ Govern-
ment department any patents which they may take out without asking for financial compensation *and the same would apply to all others who would collab. within the framework of the proposed organization.*

STATEMENT

May 10, 1940

by
E. Fermi and L. Szilard

Our work concerning systems composed of carbon and uranium has now reached a stage where it seems desirable to organize a large scale experiment using about 100 tons of graphite and perhaps 10^{to 20} tons of uranium metal. The only way in which it can be shown with certainty that a nuclear chain reaction can be maintained in such a system consists of actually carrying out such a large scale experiment. All nuclear constants involved have now been measured and the best probable experimental values obtained for these constants point to the conclusion that such an experiment may be expected to be successful. It must be pointed out however that the number of nuclear constants which are involved is large and that the value of each of them is known only within certain limits of experimental error. Accordingly, a fore-cast based on the best available values of these constants can be made perhaps with a fair degree of assurance but not with certainty.

Since it appears urgent and important to have certainty in this matter it is now proposed to start organizing the large scale experiment. Realizing that this is an enterprise which requires large expenditure it is suggested to proceed by steps in carrying out this experiment. If the results obtained in the first step appear to be encouraging then the expenditure necessary for the second step will be considered as justified and the second step will be carried out according to schedule, etc. By proceeding in this way the expenditure would rise parallel to the increase in assurance for ultimate success.

As the first step it is proposed to carry out a general survey of all nuclear constants involved with a view to confirming the values previously obtained and of narrowing down the limits of experimental error of the observed values of these constants. Concurrently, with this survey, certain work would have to be done in order to prepare the ground for the large scale experiment. Such work would include the working out of constructional details in the form of drawings, the carrying out of technological tests on samples of material which will be used in large quantities in the ultimate experiment, and negotiating for bids for the manufacture of such material in the required quality and quantity. An expenditure of \$50,000. would probably be sufficient to bring this first stage in the organization of the large scale experiment to its conclusion and would bring us up to the next stage which may require considerably greater expenditure.

Statement concerning Secrecy.

One of the ~~chief~~ reasons for keeping the work of Fermi and Szilard secret is to give the Government an opportunity to secure a supply of uranium ore from abroad before other governments take action. A particularly serious situation might arise if Germany joined by Italy should emerge victorious out of the war and thus would gain control of Belgian Congo.

The necessity of keeping results secret would bring the physicists who are employed by university laboratories into a conflict of loyalties. Moreover, it would not be fair to ask young physicists to refrain from publishing without being offered some financial compensation. Insofar as salaries could be paid from a fund controlled by trustees who are nominated by the Government Committee, the physicists engaged in this work could be given a clear status and a financial compensation, and in this way secrecy could be assured.

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Statement on procedural aspects and secrecy.

If we take it for granted that it will be possible to maintain a chain reaction in a system composed of uranium and carbon, the first question which arises is the following:

1. Does the Government consider this fact to have an important bearing on questions of national defense? If the answer to this question is positive, then it is obviously important that the Government should be in a position to secure, if required, an adequate supply of uranium from abroad. This will only be possible if

a) the Government finds ahead of foreign governments that uranium can in fact be used for certain specific purposes in connection with national defense;

b) if this fact is kept secret at least long enough to enable the Government to secure an adequate supply of uranium from abroad, for otherwise foreign governments will contract the uranium coming from Canadian or Belgian sources. In view of the progress of the war and the danger of its assuming a totalitarian form, we cannot exclude the possibility of reverses to the Allies, leading to a domination of South Africa, including Belgian Congo, by the Axis Powers. Hence, the urgency for decision and for assuring the conditions conducive to speedy and secret work.

Statements concerning the large scale experiment.

The work of Fermi and Szilard has now reached the stage at which it is necessary to start organizing a large scale demonstration experiment. It is not contemplated actually to place any orders for this large scale experiment within the next six months or one year. This time interval ought to be used to remeasure all nuclear constants which enter into the large scale experiment, since the exact knowledge of the value of these constants will ^{render} ~~make~~ it possible to ^{determine} ~~find~~ the best conditions under which the large scale experiment can be ^{effected} ~~carried out~~.

If a fund of \$ 50,000 were available, four younger physicists could be employed for carrying out this survey which would include:

1. an improved estimate of the number of fast neutrons emitted by uranium per absorbed thermal neutron ();
2. a study of the resonance absorption of uranium (p);
3. study of metallurgical problems connected with the large scale manufacturing of uranium metal;
4. cross-sections of uranium for thermal neutrons;
5. slowing down process in carbon;
6. measuring of combinations of nuclear constants in experiments in which a uranium metal sphere is embedded in graphite;
7. constructional details for the large scale experiment.

It is proposed that three fourths of the fund be used for the preparation of the large scale experiment in a system composed of uranium and graphite, and one fourth of the fund be used for another line of research which, if successful, would lead to another type of chain reaction.

Statement for Dr. Sachs.

In order to put the Government in the position of securing the adequate supply of uranium for purposes of national defense, it is necessary for the Government to know with certainty that uranium can in fact be used for certain specific purposes. According to the enclosed statement by Dr. Fermi and Dr. Szilard such certainty can not be obtained by any other means but by carrying out a rather expensive experiment, and the question arises whether the Government is willing to spend or to ~~request~~ ^{encourage} public spirited private citizens to spend, if necessary, up to half a million dollar for the purpose of finding out whether a chain reaction can be maintained in ^{u + c.} ~~circumstances~~ which would ~~be useful for certain naval purposes and purposes connected with national defense. An expenditure of \$ 50-100,000 is envisaged preliminary to the carrying out of the large scale experiment and would cover a period of perhaps one year.~~

In order to be in a position to take the necessary action concerning the acquisition of uranium ore, it will be necessary for the Government to know with certainty that a chain reaction can in fact be maintained in a system composed of uranium and graphite. In order to obtain this certainty it is necessary that a large scale experiment be carried out, which would involve the use of about 100 tons of graphite and perhaps 20 tons of uranium. Drs. Fermi and Szilard have expressed their willingness to carry out such an experiment, and in doing so to proceed step by step, so that the expenditure would gradually rise with increasing assurance of success.

In my view, the responsibility for carrying out such an experiment should lie with some organization created for the purpose, and I have discussed this point with Dr. Einstein, Dr. Fermi and Dr. Szilard. I am enclosing a copy of Dr. Einstein's letter ~~xxx~~ which is addressed to Dr. Briggs, and which deals with the subject. Dr. Fermi and Dr. Szilard have also associated themselves with my suggestion and have expressed their willingness to carry out their experiments within such a framework. A committee of scientists serving in advisory capacity to this organization would be constantly informed on the progress of the experiments and would advise the trustees of this organization as to the justification of ^{any} ~~the~~ proposed expenditure.

\$ 50,000 would be required for the start to organize this work, and this sum might cover the expenditure for a period of 6 months to one year. The total expenditure might finally amount to about \$ 500,000. It is assumed that Drs. Pegram and ~~Urg~~ of New York and Drs. Wigner and Wheeler of Princeton would consent to serve on this committee. (True & Keller)

STATEMENT

May 10, 1940

by
E. Fermi and L. Szilard

Our work concerning systems composed of carbon and uranium has now reached a stage where it seems desirable to organize a large scale experiment using about 100 tons of graphite and perhaps 10 ^{to 20} tons of uranium metal. ~~The only way in which it can be shown with certainty that a nuclear chain reaction can be maintained in such a system consists of~~ ^{is through} actually carrying out such a large scale experiment. All nuclear constants involved have now been measured and the best ~~probable~~ ^{lead} experimental values obtained for these constants ~~point~~ ^{lead} to the conclusion that such an experiment may be expected to be successful. It must be pointed out however that the number of nuclear constants which are involved is large and that the value of each of them is known only within certain limits of experimental error. Accordingly, a fore-cast based on the best available values of these constants can be made perhaps with a fair degree of assurance but not with ~~absolute~~ ^{absolute} certainty.

Since it appears urgent and important to have certainty in this matter it is now proposed to start organizing the large scale experiment. ^{For this purpose (actual)} Realizing that this is an enterprise which requires large expenditure it is suggested to proceed by steps in carrying out this experiment. If the results obtained in the first step appear to be encouraging then the expenditure necessary for the second step will be considered as justified and the second step will be carried out according to schedule, etc. By proceeding in this way the expenditure would rise parallel to the increase in assurance for ultimate success.