April 23, 1939

Memorandum

By comparing the values for the fission cross section, the absorbing cross section and the balance of neutron production and absorption, as manifested in experiments in which neutrons emitted from uranium are slowed down and the total number of the slow neutrons present is measured, it appears at present almost certain that the number of neutrons emitted per fission from uranium is about two. I believe that experiments which are now being carried out will confirm this in the near future. It seems to me that it should then be possible to decide the question whether or not a chain reaction with fast neutrons is possible. The following simple experiments will decide this question, perhaps not with certainty, but with a high degree of probability.

An uranium compound is to be exposed to thermal neutrons, the radioactive uranium having a 25 minute period which is produced by radiative capture, and is separated from the other activities which are produced by fission. Both activities are measured by a beta ray counter or by a ionisation chamber, and the ratio A (A = activity due to capture / activity due to fission) of the two - in arbitrary units - is determined. The same uranium compound is then exposed to photo neutrons from a radon-beryllium source, and the ratio B (B = Activity due to capt. / Activity due to fiss.) of the two activities, observed in the same way as before and expressed in the same arbitrary units, is again determined.

The quotient $\frac{B}{A} = C$ is a measure of the shift in balance between neutron absorption and neutron production by changing over from thermal neutrons to photo neutrons. If C is small, for instance if it is smaller than 1/4 one could be almost certain that a chain reaction can be maintained in uranium in the absence of hydrogen containing substances.

It seems therefore reasonable to perform the above mentioned experiments, and, if the outcome is positive, to take at once steps in the direction of a large scale experiment in the absence of hydrogen containing substances. It is to be expected that neutrons emitted from uranium will be slowed down by inelastic collisions in uranium to velocities between 10.000 to 100.000 volt, and therefore behave in a way very similar to photo neutrons from a radon- beryllium source. ~~It~~

April 23, 1939

Memorandum

By comparing the values for the fission cross section, the absorbing cross section and the balance of neutron production and absorption, as manifested in experiments in which neutrons emitted from uranium are slowed down and the total number of the slow neutrons present is measured, it appears at present almost certain that the number of neutrons emitted per fission from uranium is about two. I believe that experiments which are now being carried out will confirm this in the near future. It seems to me that it should then be possible to decide the question whether or not a chain reaction with fast neutrons is possible. The following simple experiments will decide this question, perhaps not with certainty, but with a high degree of probability.

An uranium compound is to be exposed to thermal neutrons, the radioactive uranium having a 25 minute period which is produced by radiative capture, and is separated from the other activities which are produced by fission. Both activities are measured by a beta ray counter or by a ionisation chamber, and the ratio $\left(A = \frac{\text{activity due to capture}}{\text{activity due to fission}}\right)$ of the two - in arbitrary units - is determined. The same uranium compound is then exposed to photo neutrons from a radon-beryllium source, and the ratio (B = ——————) of the two activities, observed in the same way as before and expressed in the same arbitrary units, is again determined.

The quotient $\frac{B}{A} = C$ is a measure of the shift in balance between neutron absorption and neutron production by changing over from thermal neutrons to photo neutrons. If C is small, for instance if it is smaller than one could be almost certain that a chain reaction can be maintained in uranium in the absence of hydrogen containing substances.

It seems therefore reasonable to perform the above mentioned experiments, and, if the outcome is positive, to take at once steps in the direction of a large scale experiment in the absence of hydrogen containing substances. It is to be expected that neutrons emitted from uranium will be slowed down by inelastic collisions in uranium to velocities between 10.000 to 100.000 volt, and therefore behave in a way very similar to photo neutrons from a radon- beryllium source. It may be added that the number of neutrons emitted by fission with energies above 200.000 volt seems to be only about one per fission, and that we therefore suspect a large number of neutrons to be emitted with energies below 200.000 volt. We suspect therefore that the slow neutron density at the surface of a sample of uranium will be appreciably increased by these comparatively slow fission neutrons, and this point is now being checked by comparing the apparent absorption of a sample of uranium metal with a sample of boron, both in a narrow and in a wide paraffin cavity.

Memorandum.

May 21st, 1939

Zinn and I are at present engaged to obtain the energy distribution of the neutrons emitted in the fission of uranium. The results are so far not conclusive, but it ~~should~~ appears possible to measure this distribution, and having measured it, to obtain a value for the number of neutrons emitted per fission.

The experiment which is being carried out at present with 500 pounds of uranium oxide appears to be crucial for the further program. If this experiment is positive a large scale experiment using several tons of uranium oxide ought to be the next step and would absorb much of our time and attention.

If the present experiment on 500 pounds has a negative result I would like to fall back to an experiment which was devised at an earlier stage. About 200 pounds of uranium oxide would then be used in the arrangement shown in the accompanying drawing. If this experiment is also negative, then we ought to verify that the absorption of our oxide for slow neutrons is not larger than the absorption of another sample of uranium oxide which is now being prepared for us in the Department of Chemistry, and which is presumably free from absorbing impurities. Having verified this point we could then consider the question of the slow neutron chain reaction in natural uranium as settled.

The value for the absorption of uranium for slow neutrons is at present of interest as it would enable us to say whether or not radiative capture leading to the 24 minute period and fission accounts for all the absorption of slow neutrons in uranium.

Zinn and I have ~~prepared~~ started a simple experiment which, we hope, will make it possible to measure the true absorption cross section for slow neutrons directly rather than by measuring certain combinations of both the absorbing and scattering cross section. The method in which the irradiation has to be carried out in a large cavity inside of paraffin or water is represented in figure 2. It gives only relative values, and therefore samples of uranium will be compared with samples of boron which give equal reduction of intensity of the rodium indicator.

The reduction of slow neutron density brought about by uranium in some of our arrangements is only partly due to absorption of thermal neutrons by uranium and may partly be due to absorption of faster neutrons by uranium. By comparing the values obtained in the proposed experiment in the large cavity with the result of a similar experiment in a small cavity it might be possible to distinguish between these two different absorbing actions of uranium.

It seems to me that apart from the question whether the slow neutron chain reaction is possible, which is now being investigated, by far the most important question is whether a chain reaction is possible with uranium in the absence of hydrogen containing substances. A comparatively simple experiment might decide this question, and such an experiment is now being prepared.

In order to understand this experiment it must be pointed out that most of the fission neutrons of uranium will probably be slowed down to a few 100 000 volts or even a few 10 000 volts before causing further fission. In order to determine whether a chain reaction is possible in the absence of hydrogen containing substances one ought to know something about the ratio of the radiative capture cross section leading to a 24 minute period to the fission cross section leading to certain fission periods for neutrons of a few 100 000 volts of energy. It appears to be simplest to compare the ratio of intensities of the 24 minute period to a suitable fission period for photo neutrons from beryllium with the ratio of the intensity of these two periods for thermal neutrons. If one finds for instance, as it might well be the case, that this ratio shifts very much in favor of the 24 minute period in going over from thermal neutrons to photo neutrons, this will indicate that no chain reaction will take place in the absence of hydrogen containing substances. On the other hand, as it also may be, if a shift occurs in the opposite direction, the possiblity of a chain reaction will have to be seriously considered.

COPY OF MEMORANDUM OF LEO SZILARD, DATED AUGUST 15, 1939, SUBMITTED TO THE PRESIDENT OCTOBER 1939

MEMORANDUM

August 15, 1939

Much experimentation on atomic disintegration was done during the past five years, but up to this year the problem of liberating nuclear energy could not be attacked with any reasonable hope for success. Early this year it became known that the element uranium can be split by neutrons. It appeared conceivable that in this nuclear process uranium itself may emit neutrons, and a few of us envisaged the possibility of liberating nuclear energy by means of a chain reaction of neutrons in uranium.

Experiments were thereupon performed, which led to striking results. One has to conclude that a nuclear chain reaction could be maintained under certain well defined conditions in a large mass of uranium. It still remains to prove this conclusion by actually setting up such a chain reaction in a large-scale experiment.

This new development in physics means that a new source of power is now being created. Large amounts of energy would be liberated, and large quantities of new radioactive elements would be produced in such a chain reaction.

In medical applications of radium we have to deal with quantities of grams; the new radioactive elements could be produced in the chain reaction in quantities corresponding to tons of radium equivalents. While the practical application would include the medical field, it would not be limited to it.

A radioactive element gives a continuous release of energy for a certain period of time. The amount of energy which is released per unit weight of material may be very large, and therefore such elements might be used -- if available in large quantities -- as fuel for driving boats or airplanes. It should be pointed out, however, that the physiological action of the radiations emitted by these new radioactive elements makes it necessary to protect those who have to stay close to a large quantity of such an element, for instance the driver of the airplane. It may therefore be necessary to carry large quantities of lead, and this necessity might impede a development along this line, or at least limit the field of application.

Large quantities of energy would be liberated in a chain reaction, which might be utilized for purposes of power production in the form of a stationary power plant.

In view of this development it may be a question of national importance to secure an adequate supply of uranium. The United States has only very poor ores of uranium in moderate quantities; there is a good ore of uranium in Canada where the total deposit is estimated to be about 3000 tons; there may be about 1500 tons of uranium in Czechoslovakia, which is now controlled by Germany; there is an unknown amount of uranium in Russia, but the most important source of uranium, consisting of an unknown but probably very large amount of good ore, is Belgian Congo.

It is suggested therefore to explore the possibility of bringing over from Belgium or Belgian Congo a large stock of pitchblend, which is the ore of both radium and uranium, and to keep this stock here for possible future use. Perhaps a large quantity of this ore might be obtained as a token reparation payment from the Belgian Government. In taking action along this line it would not be necessary officially to disclose that the uranium content of the ore is the point of interest; action might be taken on the ground that it is of value to secure a stock of the ore on account of its radium content for possible future extraction of the radium for medical purposes.

Since it is unlikely that an earnest attempt to secure a supply of uranium will be made before the possibility of a chain reaction has been visibly demonstrated, it appears necessary to do this as quickly as possible by performing a large-scale experiment. The previous experiments have prepared the ground to the extent that it is now possible clearly to define the conditions under which such a large-scale experiment would have to be carried out. Still two or three different setups may have to be tried out, or alternatively preliminary experiments have to be carried out with several tons of material if we want to decide in advance in favor of one setup or another. These experiments cannot be carried out within the limited budget which was provided for laboratory experiments in the past, and it has now become necessary either to strengthen--financially and otherwise--the organizations which concerned themselves with this work up to now, or to create some new organization for the purpose. Public-spirited private persons who are likely to be interested in supporting this enterprise should be approached without delay, or alternatively the collaboration of the chemical or the electrical industry should be sought.

The investigations were hitherto limited to chain reactions based on the action of slow neutrons. The neutrons emitted from the splitting uranium are fast, but they are slowed down in a mixture of uranium and a light element. Fast neutrons lose their energy in colliding with atoms of a light element in much the same way as a billiard ball loses velocity in a collision with another ball. At present it is an open question whether such a chain reaction can also be made to work with fast neutrons which are not slowed down.

There is reason to believe that, if fast neutrons could be used, it would be easy to construct extremely dangerous bombs. The destructive power of these bombs can only be roughly estimated, but there is no doubt that it would go far beyond all military conceptions. It appears likely that such bombs would be too heavy to be transported by airplane, but still they could be transported by boat and exploded in port with disastrous results.

Although at present it is uncertain whether a fast neutron reaction can be made to work, from now on this possibility will have to be constantly kept in mind in view of its far-reaching military consequences. Experiments have been devised for settling this important point, and it is solely a question of organization to ensure that such experiments shall be actually carried out.

Should the experiments show that a chain reaction will work with fast neutrons, it would then be highly advisable to arrange among scientists for withholding publications on this subject. An attempt to arrange for withholding publications on this subject has already been made early in March but was abandoned in spite of favorable response in this country and in England on account of the negative attitude of certain French laboratories. The experience gained in March would make it possible to revive this attempt whenever it should be necessary.

Leo Szilard

MEMORANDUM

August 15th, 1939

Mučh experimentation on atomic desintegration was done during the past five years, but up to this year the problem of liberating nuclear energy could not be attacked with any reasonable hope for success. Early this year it became known that the element uranium can be split by neutrons. It appeared conceivable that in this nuclear process uranium itself may emit neutrons, and a few of us envisaged the possibility of liberating nuclear energy by means of a chain reaction of neutrons in uranium.

Experiments were thereupon performed, which led to striking results. One has to conclude that a nuclear chain reaction could be maintained under certain well defined conditions in a large mass of uranium. It still remains to prove this conclusion by actually setting up such a chain reaction in a large-scale experiment.

This new development in physics means that a new source of power is now being created. Large amounts of energy would be liberated, and large quantities of new radioactive elements would be produced in such a chain reaction.

In medical applications of radium we have to deal with quantities of grams; the new radioactive elements could be produced in the chain reaction in quantities corresponding to tons of radium equivalents. While the practical application would include the medical field, it would not be limited to it.

A radioactive element gives a continuous release of energy for a certain period of time. The amount of energy which is released per unit weight of material may be very large, and therefore such elements might be used - if available in large quantities - as a fuel for driving boats or airplanes. It should be pointed out however that the physiological action of the radiations emitted by these new radioactive elements makes it necessary to protect those who have to stay close to a large quantity of such an element, for instance the driver of the airplane. It may therefore be necessary to carry large quantities of lead, and this necessity might impede a development along this line, or at least limit the field of application.

Large quantities of energy would be liberated in a chain reaction, which might be utilized for purposes of power production in the form of a stationary power plant.

In view of this development it may be a question of national importance to secure an adequate supply of uranium. The United States has only very poor ores of uranium in moderate quantitées; there is a good ore of uranium in Canada where the total deposit is estimated to be about 3000 tons; there may be about 1500 tons of uranium in Czechoslovakia, which is now controlled by Germany; there is an unknown amount of uranium in Russia, but the most important source of uranium, consisting of an unknown but probably very large amount of good ore, is Belgian Congo.

It is suggested therefore to explore the possibility of bringing over from Belgium or Belgian Congo a large stock of pitchblend, which is the ore of both radium and uranium, and to keep this stock here for possible future use. Perhaps a large quantity of this ore might be obtained as a token reparation payment from the Belgian Government. In taking action along this line it would not be necessary officially to disclose that the uranium content of the ore is the point of interest; action might be taken on the ground that it is of value to secure a stock of the ore on account of its radium content for possible future extraction of the radium for medical purposes.

Since it is unlikely that an earnest attempt to secure a supply of uranium will be made before the possibility of a chain reaction has been visibly demonstrated, it appears necessary to do this as quickly as possible by performing a large-scale experiment. The previous experiments have prepared the ground to the extent that it is now possible clearly to define the conditions under which such a large-scale experiment would have to be carried out. Still two or three different set-ups may have to be tried out, or alternatively preliminary experiments have to be carried out with several tons of material if we want to decide in advance in favor of one set-up or another. These experiments cannot be carried out within the limited budget which was provided for laboratory experiments in the past, and it has now become necessary either to strengthen - financially and otherwise - the organizations which concerned themselves with this work up to now, or to create some new organization for the purpose. Public-spirited private persons who are likely to be interested in supporting this enéerprise should be approached without delay, or alternatively the collaboration of the chemical or the electrical industry should be sought.

The investigations were hitherto limited to chain reactions based on the action of <u>slow</u> neütrons. The neutrons emitted from the splitting uranium are fast, but they are slowed down in a mixture of uranium and a light element. Fast neutrons lose their energy in colliding with atoms of a light element in much the same way as a billard ball loses velocity in a collision with another ball. At present it is an open question whether such a chain reaction can also be made to work with <u>fast</u> neutrons which are not slowed down.

There is reason to believe that, if fast neutrons could be used, it would be easy to construct extremely dangerous bombs. The destructive power of these bombs can only be roughly estimated, but there is no doubt that it would go far beyond all military conceptions. It appears likely that such bombs would be too heavy to be transported by airplane, but still they could be transported by boat and exploded in port with disastrous results.

Although at present it is uncertain whether a fast neutron reaction can be made to work, from now on this possibility will have to be constantly kept in mind in view of its far-reaching military consequences. Experiments have been devised for settling this important point, and it is solely a question of organization to ensure that such experiments shall be actually carried out.

Should the experiments show that a chain reaction will work with <u>fast</u> neutrons, it would then be highly advisable to arrange among scientists for withholding publications on this subject. An attempt to arrange for withholding publications on thiánswbgections has already been made early in March but was abandoned in spite of favorable response in this country and in England on account of the negative attitude of certain French laboratories. The experience gained in March would make it possible to revive this attempt whenever it should be necessary.

(Leo Szilard)

October 13th, 1939

MEMORANDUM

Early this year experiments have been started independently by Fermi, by Joliot and by myself on the neutron emission of uranium. The results made it appear conceivable that a nuclear chain reaction could be maintained in a large mass of uranium. Such a chain reaction might have important industrial applications, and far reaching military applications cannot entirely be ruled out.

At first Fermi and I withheld publication of our results for reasons which can be seen from the enclosed correspondence which covers the period from February 2nd to April 8th. At present all experiments are published in due course of time.

Both Fermi and I performed our experiments at Columbia University; at first we worked independently of each other, using different methods but obtaining identical results. Lately however we have jointly carried out a number of experiments.

In a certain sense these experiments have now reached their conclusion. We found that it is likely that a nuclear chain reaction could be maintained in a moderate amount of uranium oxide under certain well specified conditions. So far we have been working with a few kilograms of uranium oxide; in order to find out whether or not the setting up of such a chain reaction is an immediate practical possibility we have now to perform experiments involving several tons of material (other than uranium). If the outcome of these experiments is favorable an attempt should at once be made to set up a chain reaction in a mass of material containing perhaps 20 tons of uranium oxide.

It appears that for our further work assistance which we might receive from the Union Minière would be of great value. Some form of co-operation with the Union Minière is undoubtedly desirable, and the question how close this co-operation ought to be and what form it might take seems to deserve careful consideration at the stage of development which has now been reached.

(Leo Szilard)

(Memorandum of Leo Szilard submitted to Dr. Briggs, October 26, 1939).

5

THE POSSIBILITY OF A LARGE-SCALE EXPERIMENT IN THE IMMEDIATE FUTURE

At present it appears quite possible that a nuclear chain reaction could be set up in a system composed of uranium oxide (or uranium metal) and graphite. The graphite would have to be piled up in a space of perhaps 4 x 4 x 4 metres and might weigh about 100 metric tons. Perhaps 10 to 20 tons of uranium oxide would have to be used, embedded in some such pile of graphite.

The probable success or failure of such a large-scale experiment cannot be forecast at present with any degree of assurance. The properties of a system composed of uranium and graphite have been calculated independently, for a homogeneous mixture, by Fermi, and, for a lattice of spheres of uranium oxide, or uranium metal, embedded in graphite, by myself. The results of these two independent calculations are in reasonable agreement and show that the two arrangements have different properties. For instance, in the case of using a lattice of spheres a great advantage could be obtained by using uranium metal instead of uranium oxide, whereas in the case of the homogeneous mixture the use of uranium metal would be of no great advantage. In spite of these calculations, we cannot foretell with certainty whether or not a nuclear chain reaction can be maintained in such a system because the absorption cross section of carbon for slow neutrons is not sufficiently known.

In order to remove this uncertainty, Fermi and I have devised two different experiments by means of which the absorption cross section of carbon, which is very small, could be measured. It is assumed that one of these experiments, or both of them, will be started at Columbia University as soon as the facilities required can be obtained.

If the absorption of carbon should turn out to be comparatively large, we could conclude that the large-scale experiment is bound to fail, and in this case it need not be started. If the absorption of carbon should prove to be exceedingly small, the large-scale experiment would appear to be very promising, and it can be assumed that everybody will then be in favor of starting it without delay.

Unfortunately, we must be also prepared to find an intermediate value for the carbon absorption. In this case a large-scale experiment will have to be performed in order to find out whether or not a nuclear reaction can be achieved with a combination of uranium and graphite, we may have to make the experiment and risk its possible failure.

It should be borne in mind that a negative result of the large-scale experiment could also be of value by showing with certainty that a chain reaction cannot be achieved with simple means in the near future. Otherwise there remains an ever-present potential threat arising out of experiments on uranium, which are carried out in certain other countries. Therefore, in my personal opinion, a large-scale experiment ought to be performed unless the possibility of its success can be excluded with reasonable assurance on the basis of experiments which are designed to determine the absorption of carbon, or other similar experiments which can be carried out on a moderately small scale.

RECOMMENDATIONS CONCERNING LARGE-SCALE EXPERIMENTS

No expenses need be incurred in connection with large-scale experiments until the absorption of carbon has been measured. On the other hand, steps ought to be taken now in order to prepare the ground for a large-scale experiment, so that this can be started without delay at the proper time. For instance, the possibility of converting uranium oxide into uranium metal ought to be explored. An attempt ought to be made to obtain a promise on the part of certain industrial corporations to supply at the proper time the quantities of the materials, which are required. If possible, these materials ought to be loaned without any financial consideration. Barring an accident in the case of a successful large-scale experiment, most of the materials used would remain unaffected and could be returned after the experiment is completed.

100 metric tons of graphite represent a value of about $33.00 -- at the rate of 15¢ per pound. If a purer brand of graphite has to be used, which rates at 24¢ per lb. the value involved would be $53.00.

20 metric tons of uranium oxide represent a value of $100,000. -- at the rate of $2.50 per lb. If it need not be converted into uranium metal but can be used in the form of oxide in the large-scale experiment, this material could be kept pure and could be returned undamaged. It would be desirable to have up to 50 tons of uranium oxide readily available for experiments in the United States.

STATEMENT CONCERNING THE POTENTIAL ASSISTANCE OF THE UNION MINIERE DU HAUT KATANGA

It would be of particular value to enlist the assistance of this Belgian corporation which is to some extent controlled by the Belgian Government. It appears to be the only corporation which could supply at short notice 20 metric tons of uranium oxide, and probably even 50 tons. I understand that the Managing Director, Mr. E. Sengier, is on a short visit in America.

From conversations which Professor G. B. Pegram of Columbia University had with a representative of the Eldorado Gold Mines, Ltd., it appears that this Canadian corporation might be able to supply uranium oxide for our purposes at the rate of 1 ton per week. If the uranium oxide were to be bought rather than obtained as a gift or a loan, it might be secured from Canada probably just as easily as from Belgium. On the other hand, the Canadian corporation is rather small and can hardly be asked to give away large quantities of material without financial compensation.

So far, radium up to about 2.5 gms. was used in our experiments, and we had to pay a high rent to a subsidiary of the Union Miniere, the only corporation from which large quantities of radium can be readily rented in this country. An attempt ought to be made to obtain radium for the purposes of such experiments rent-free from the Union Miniere in the future.

Carnotites containing uranium are mined in the U.S.A. by the U. S. Vanadium Corporation which is owned by the Union Carbon and Carbide Corporation. A conversation which I recently had with William F. Barrett, Vice-President of this corporation, did not encourage the hope of obtaining large quantities of uranium oxide from this firm, but the issue could perhaps be reopened.

STATEMENT ABOUT URANIUM ORE

As far as I was able to find out, pitchblend, which is an ore rich in uranium, is mined in Czechoslovakia, Canada and Belgian Congo. The total content of uranium in the deposit in Czechoslavakia is estimated to be between 1000 and 1500 tons. The canadian deposit visibly contains a total of 3000 tons. Theamount of pitchblend in the Belgian Congo is not known, but it is believed to be very much larger. In the United States uranium occurs chiefly in the form of carnotites, which is an ore poor in uranium, and is mined for the sake of its vanadium content. The total deposit is estimated to contain 3000 tons of uranium oxide. (Perhaps there are in the United States larger quantities of ore containing a very small amount of uranium which are not included in the above estimate.)

RECOMMENDATION CONCERNING URANIUM ORE

Steps to secure a stock of uranium ores for the government can hardly be recommended at the present time if such steps would involve financial commitments on the part of the government. It might, however, be advisable to begin to study the question in what manner the government could secure such a stock at a later date if required.

For instance, the question has been raised whether it might not be possible to obtain for the government a large quantity of pitchblend from Belgium as a token reparation payment. Such a transaction would not cause alarm abroad if it were arranged before the world learns of the results of some successful large-scale experiment. The transaction could be justified without reference to the uranium content of the ore. Pitchblend is also the ore of radium, and action could be taken on the ground of securing the ore for the sake of its radium content, with a view of extracting the radium at some future date for medical purposes. Action taken on this ground alone might in fact be entirely justified.

October 26th, 1939

Memorandum

Part I.

Meeting of October 21st, 1939, Washington, D.C.

by Leo Szilard.

SUMMARY

Recent experimental work and calculations based on its results make it appear possible that in the immediate future a nuclear chain reaction might be set up under certain well specified conditions in a system composed of uranium and graphite. In view of this and other possibilities it seems desirable

1. that it should be made the responsability of some person or persons to watch on behalf of the government the further development of this branch of research, so that the government should be at any time in the position of taking such action as it deems appropriate;

2. that some person or persons, who have the confidence of the government, should take upon themselves the task of furthering this branch of research, of insuring that it should not suffer from lack of facilities, and of preparing the grounds for experiments on a large scale, which might become necessary.

Observation to the above.

The fairly large quantities of material, which might be required for performing large-scale experiments, might perhaps be secured, without drawing on existing funds, by enlisting the assistance of certain industrial firms in the U.S.A. and of the Union Minière du Haut Katanga. Most of the materials required are produced by large corporations who own uranium mines and would therefore directly benefit if the present development created a market for uranium. Some of these firms could be approached now with a view of obtaining the promise of their assistance.

THE POSSIBILITY OF A LARGE-SCALE EXPERIMENT IN THE IMMEDIATE FUTURE.

At present it appears quite possible that a nuclear chain reaction could be set up in a system composed of uranium oxide (or uranium metal) and graphite. The graphite would have to be piled up in a space of perhaps 4 x 4 x 4 metres and might weigh about 100 metric tons. Perhaps 10 to 20 tons of uranium oxide would have to be used, embedded in some such pile of graphite.

The probable success or failure of such large-scale experiment cannot be forecast at present with any degree of assurance. The properties of a system composed of uranium and graphite have been calculated independently, for a homogeneous mixture by Fermi, for a lattice of spheres of uranium oxide, or uranium metal, embedded in graphite, by myself. The results of these two independent calculations are in reasonable agreement and show that the two arrangements have different propoerties. For instance, in the case of using a lattice of spheres a great advantage could be obtained by using uranium metal instead of uranium oxide, whereas in the case of the homogeneous mixture the use of uranium metal would be of no great advantage. In spite of these calculations, we cannot foretell with certainty whether or not a nuclear chain reaction can be maintained in such a system, because the absorption cross-section of carbon for slow neutrons is not sufficiently known.

In order to remove this uncertainty Fermi and I have devised two different experiments by means of which the absorption cross-section of carbon, which is very small, could be masured. It is assumed that one of these experiments, or both of them, will be started at Columbia University as soon as the facilities required can be obtained.

If the absorption of carbon should turn out to be comparatively large we could conclude that the large-scale experiment is bound to fail, and in this case it need not be started. If the absorption of carbon should prove to be exceedingly small the large-scale experiment would appear to be very promising, and it can be assumed that everybody will then be in favor of starting it without delay.

Unfortunately, we must also be prepared to find an intermediate value for the carbon absorption. In this case a large-scale experiment will have to be performed in order to find out whether or not a nuclear chain reaction can be achieved with a combination of uranium and graphite. So we may have to make the experiment and risk its possible failure.

It should be borne in mind that a negative result of the large-scale experiment could also be of value by showing with certainty that a chain reaction <u>cannot</u> be achieved with simple means in the near future. Otherwise there remains an ever present potential threat arising out of experiments on uranium, which are carried out in certain other countries. Therefore, in my personal opinion, a large-scale experiment ought to be performed unless the possiblity of its success can be excluded with reasonable assurance on the basis of experiments which are designed to determine the absorption of carbon, or other similar experiments which can be carried out on a moderately small scale.

RECOMMENDATIONS CONCERNING LARGE-SCALE EXPERIMENTS

No expenses need be incurred in connection with large-scale experiments until the absorption of carbon has been measured. On the other hand, steps ought to be taken now in order to prepare the ground for a large-scale experiment, so that this can be started without delay at the proper time. For instance, the possibility of converting uranium oxide into uranium metal ought to be explored. An attempt ought to be made to obtain a promise on the part of certain industrial corporations to supply at the proper time the quantities of the materials which are required. If possible, these materials ought to be loaned without any financial consideration. Barring an accident, in the case of a successful large-scale experiment, most of the materials used would remain unaffected and could be returned after the experiment is completed.

100 metric tons of graphite represent a value of about $ 33.000 at the rate of $ .15 per lb. If a purer brand of graphite has to be used, which rates at $ .24 per lb., the value involved would be $ 53.000.-

20 metric tons of uranium oxide represent a value of $ 100.000 at the rate of $ 2.50 per lb. If it need not be converted into uranium metal but can be used in the form of oxide in the large-scale experiment this material could be kept pure and could be returned undamaged. It would be desirable to have up to 50 tons of uranium oxide readily available for experiments in the United States.

STATEMENT CONCERNING THE POTENTIAL ASSISTANCE OF THE UNION MINIERE DU HAUT KATANGA.

It would be of particular value to enlist the assitance of this Belgian corporation which is to some extent controlled by the Belgian government. It appears to be the only corporation which could supply at short notice 20 metric tons of uranium oxide, and probably even 50 tons. I understand that the Managing Director, Mr. E. Sengier, is on a short visit in America.

From conversations which Professor G.B. Pegram of Columbia University had with a representative of the Eldorado Gold Mines, Ltd., it appears that this Canadian corporation might be able to supply uranium oxide for our purposes at the rate of 1 ton per week. If the uranium oxide were to be bought rather than obtained as a gift or a loan, it might be secured from Canada probably just as easily as from Belgium. On the other hand, the Canadian corporation is rather small and can hardly be asked to give away large quantities of material without financial compensation.

So far, radium up to 2.5 grams was used in our experiments, and we had to pay high rent to a subsidiary of the Union Minière, the only corporation from which large quantities of radium can be readily rented in this country. An attempt ought to be made to obtain radium for the purposes of experiments - like the proposed measurement of the carbon absorption and other similar small-scale experiments - rent-free from the Union Minière in the future.

Carnotites containing uranium are mined in the U.S.A. among others by the U.S. Vanadium Corporation which is owned by the Union Carbon and Carbide Corporation. A conversation, which I recently had with William F. Barrett, Vice-President of the corporation, did not encourage the hope of obtaining large quantities of uranium oxide from this firm, but the issue could perhaps be reopened.

STATEMENT ABOUT URANIUM ORE.

As far as I was able to find out, pitchblend, which is an ore rich in uranium, is mined in Czechoslovakia, Canada and Belgian Congo. The total content of uranium in the deposit in Czechoslovakia is estimated to be between 1000 and 1500 tons. The Canadian deposit visibly contains a total of 3000 tons. The amount of pitchblend in the Belgian Congo is not known, but it is believed to be very much larger. In the United States uranium occurs chiefly in the form of carnotites, which is an ore poor in uranium, and is mined for the sake of its vanadium content. The total deposit is estimated to contain 3000 tons of uranium oxide. (Perhaps there are in the United States larger quantities of ore containing a very small amount of uranium, which are not included in the above estimate).

RECOMMENDATIONS CONCERNING URANIUM ORE.

Steps to secure a stock of uranium ores for the government can hardly be recommended at the present time if such steps would involve financial commitments on the part of the government. It might, however, be advisable to begin to study the question in what manner the government could secure such a stock at a later date, if required.

For instance, the question has been raised whether it might not be possible to obtain for the government a large quantity of pitchblend from Belgium as a token reparation payment. Such a transaction would not cause alarm abroad if it were arranged before the world learns of the results of some successful large-scale experiment. The transaction could be justified without reference to the uranium content of the ore. Pitchblend is also the ore of radium, and action could be taken on the ground of securing the ore for the sake of its radium content, with a view of extracting the radium at some future date for medical purposes. Action taken on this ground alone might in fact be entirely justified.

B-17

Die in Peconic aufgesetzte Formulierung:

Es sind in der letzten Zeit Arbeiten bekanntgeworden, die es wahrscheinlich machen, dass Uran zu einer wichtigen, neuartigen Energiequelle wird. Eine neue Arbeit von E.Fermi und L.Szilard, die noch nicht veroeffentlicht ist, mir aber im Manuskript zugeschickt worden ist, lässt es als wahrscheinlich erscheinen, dass in der unmittelbaren Zukunft die Energiebefreiung aus dem Uran mit Hilfe einer Kettenreaktion gelingen wird. Nichtso sicher aber doch nicht zu vernachlässigen ist die Moeglichkeit, dass dadurch Bomben moeglich werden, die zwar zu schwer sein koennten um durch Flügzeuge transportiert zu werden, aber nicht zu schwer für Boote, und eine einzige solche Bombe im Hafen explodiert, koennte sehr wohl den Hafen zusammen mit der Umgebung zerstoeren.

In dieser Lage wäre es von Vorteil, wenn die Administration einen dauernden Kontakt mit der Gruppe von Physikern hätte, die in diesem Lande über die Kettenreaktion arbeiten. Vielleicht wäre ein moeglicher Weg dazu, dass ein privater Mann, der Ihr Vertrauen geniesst, damit beauftragt wird, einen solchen Kontakt herzustellen und aufrecht zu halten. Soweit ich verstehe, hat Deutschland die Ausfuhr von Uranerz bereits eingestellt und dies ist damit vielleicht erklärlich, dass der Sohn des Staatssekretärs von Weszäcker als Physiker im Kaiser Wilhelm Institut in Berlin tätig ist, wo jetzt die amerikanischen Arbeiten über Uran wiederholt werden.

Die Vereinigten Staaten haben nur sehr minderwertige Uranerze, das Hauptvorkommen des Urans ist in Belgisch-Congo.

Ihr sehr ergebener.....

I felt ~~that~~ it is my duty to inform you of these facts.

If you consider it advisable a person who has your confidence ~~were entrusted to~~ with contacting these physicists who work ~~out~~ in this field & he could serve perhaps in ~~an~~ ~~cabin~~ an unofficial capacity as a link between the lab and your admin.

In view of the consequences which might be grave the existence of ~~such~~ a permanent contact between the lab and your admin would seem desirable.

German ~~Administration~~ might perhaps be the explanation for the early action which seems to have been taken by the German Government.

The United States has only very poor ores of uranium in rather moderate quantities; by far the most important source of uranium is Belgian Congo.

I wonder whether some private person who has your confidence might not be entrusted by you to establish contact with those who work on this problem in this country and might not serve perhaps entirely informally as a link between them and the Administration.

Very truly yours,

May I ask you whether you would consider in this situation ~~think advisable to~~ entrust some person who has your confidence to establish contact with those who work on this problem in America. ~~and that such a person~~ serve, perhaps in an ~~entirely~~ unofficial capacity, as a link between the laboratories and the Administration.

~~Would you~~ In these circumstances would you

I believe it ~~to~~ is my duty to call to your attention the results of certain recent unpublished developments in nuclear physics which make it increasingly probable that uranium may become a ~~not~~ potent source of energy. ~~of large~~

~~The most significant aspect of these developments lies in the possibility of constructing transportable bombs which ~~would not be~~ could ~~be~~ destroy a port and its surrounding countryside.~~

The distribution and ownership of the available stocks of uranium ores therefore ~~has~~ acquires ~~a new~~ a new economic significance. Of even greater significance is the possibility, which no longer appears remote, that uranium may become the exothermic ingredient in ~~#~~ ~~boats of~~ ship transportable ~~by ship and capable~~ bombs of such power that a single one could destroy ~~and~~ a port and its surrounding countryside.

The ~~uranium~~ ores of the United States are poor. Better ores in moderate quantities are mined in Canada and ~~China~~ Czechoslovakia. The most important supply of uranium is in the Belgian Congo. Germany, I understand, has stopped the sale of the ore mined in ~~the~~ Czechoslovakia. This ~~last mentioned~~ fact may be connected with the fact that the son of the German under-secretary of State, von Weizsäcker, is a physicist attached to the Kaiser Wilhelm ~~institute~~ in Berlin where intensive research on this subject is being conducted.

I am calling these matters to your attention with the idea that you may wish to appoint a person of suitable qualifications to maintain contact with the group of physicists working ~~on these developments~~ in this field & to keep ~~the~~ pertinent departments of the Administration informed of ~~about~~ ~~th~~ the developments.

Kallir
601 West 113th Street
New York, N.Y.

October 28, 1939.

Mr. Leo Szilard
Kings Crown Hotel
Wets 116th Street
New York, N.Y.

Oct. 25	2 hours typing	$ 1.00
Oct. 26	2 hours typing	$ 1.00
Oct. 27	2 hours typing	$ 1.00
	Paper	$ .40
		$ 3.40

sailing June 13th
New Amsterdam

Maurice A. Biot
141 Boulevard du Jubilé
Bruxelles

Fontenais

M. Fontainas, Union Minière

M. Galopin Société Générale

Dr. Alexander Sachs
Lehman Corporation

Robert Lehman