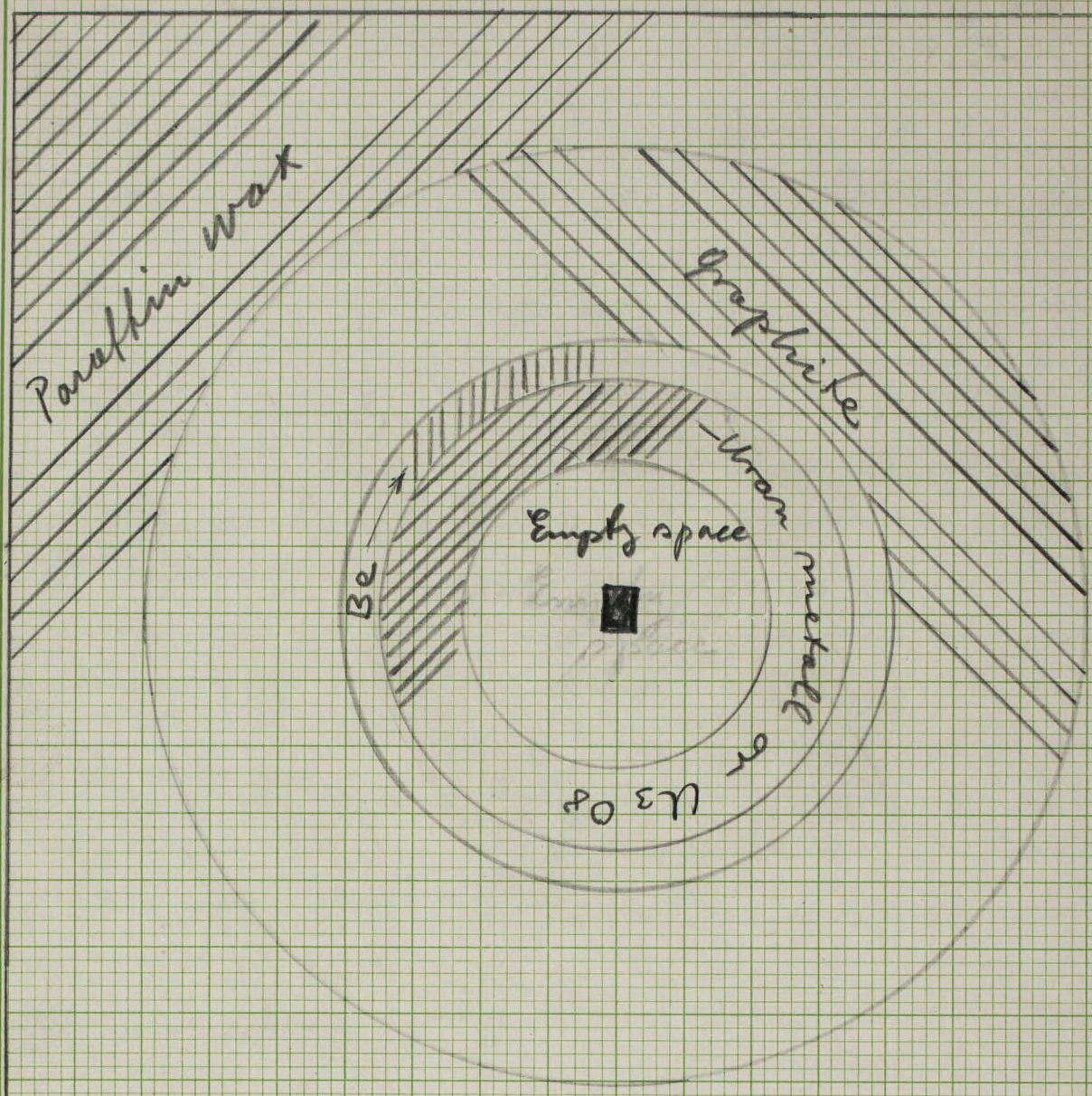
MEMORANDUM ON MATERIALS ACQUIRED UNDER THE FIRST CONTRACT - ~~January~~ February 5, 1941

Of the $~~8~~9,000 appropriation for materials of the first contract about $4,000 may be used for purchasing graphite to be used in measurements in physical constants. ~~Since these measurements may be carried on during the period of the second contract this graphite will not be available for the purpose of the intermediate scale experiment.~~ About $4,000 to $5,000 may be used for purchasing one ton of uranium oxide to be used in experiments under the first contract. Since according to our present plan 7 tons of uranium oxide will be used in the intermediate scale experiment from the 8 tons of uranium oxide which may be ~~prepared~~ purchased under the second contract one ton would be free to be converted into metal while the intermediate ~~experiment~~ rule with oxide is being performed. It is hoped that by the time the first ton of metal is delivered the one ton of uranium oxide purchased under the first contract will be available to be converted into metal for the purposes of the intermediate scale experiment. About $2,000 of the appropriation for materials under the first contract may be expended for obtaining uranium metal, approximately 200 pounds and this metal ~~will~~ may be used for physical measure ments which may be continued during the performance of the intermediate scale experiment. About $2,000 of the appropriation for materials under the first contract may be spent for the purchase of beryllium metal for the purpose of preliminary experiments.

5 tons of graphite to be insert if needed to give 40 tons of graphite for intermediate experiment.—

Experiment No 1 a.) without Be
6.) with Be



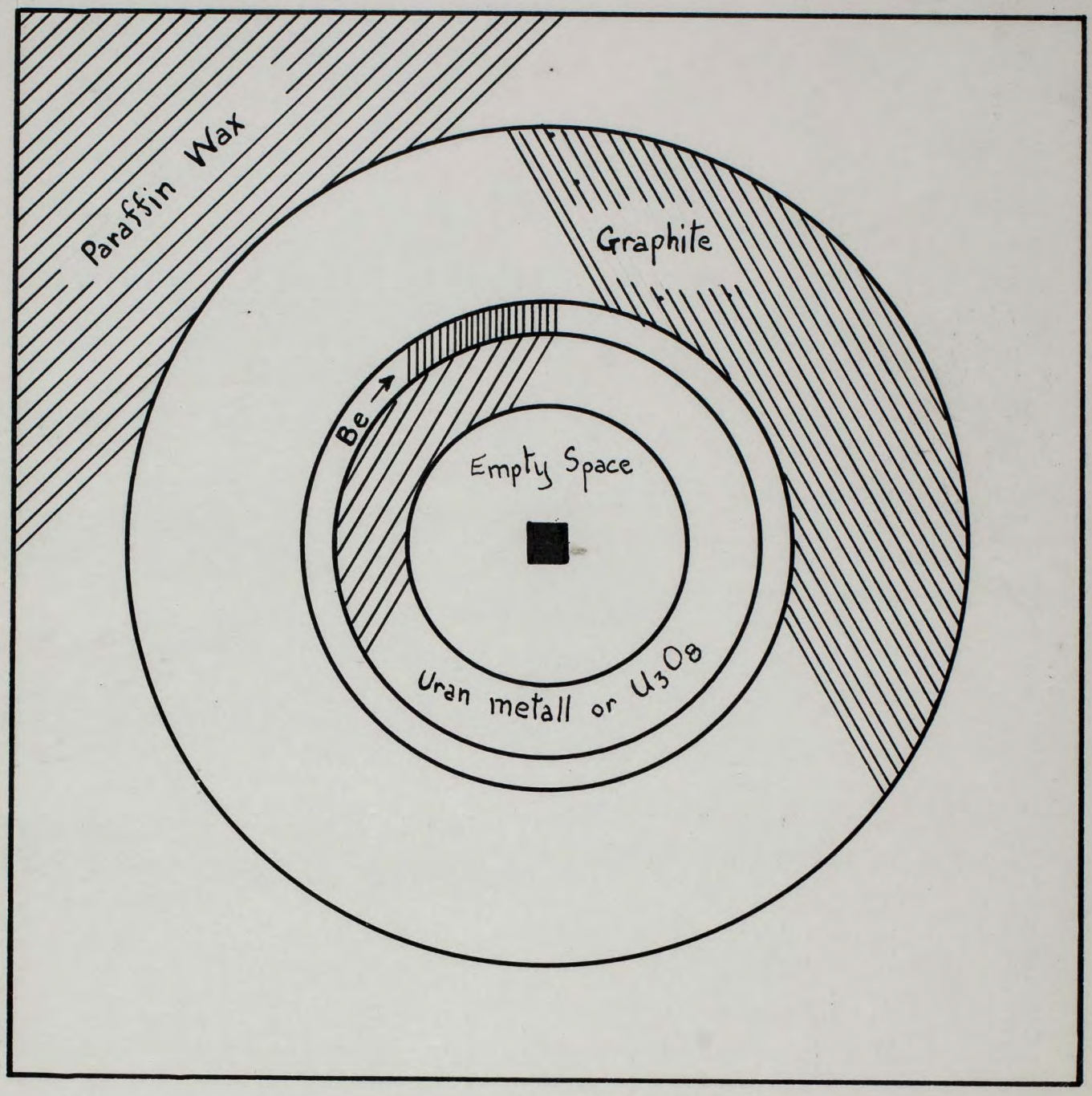
Neutron source in center
Graphite sphere 60 to 80 cm diameter
75 to 150 lbs Be
Paraffine cube 120 × 120 × 120 cc

letter to G.B.F. Dec. 5.

L. Szilard

Experiment *1

a.) Without Be
b.) With Be



Neutron Source in Center
Graphite Sphere 60 to 80 cm diameter
75 to 100 lbs Be
Paraffin Cube 120x120x120 cc
Letter to Dec 5.

Copy

January 21, 1942

Memorandum to Dr. Szilard:

In the matter of finding a laboratory for the egg-boiling experiment, the following has been found so far in the vicinity of New York City.

(1) The Pegassus Club polo field structure in Bergen County, New Jersey (advertisement in the NEW YORK TIMES).

(2) At Bendix Field, Bendix, New Jersey, the Fokker hangar of the Air Associates, Inc. is for sale. This hangar has a floor space of 125 ft. x 100 ft. and a ceiling height of about 25 ft. It has a second floor for offices and work rooms and is provided with heating. The agent is Mr. Hageman, Triangle 5-3434. The disadvantage of this building is that it is only about 1000 ft. from Air Associates, Inc. who are manufacturing airplane parts, and 3000 ft. from the Bendix Aviation Company. The air field will be used by the Army as a small base for pursuit and fighter planes.

(3) On the same field is the Goodyear blimp hanga r which has a ceiling height of about 50 ft. and about 80 ft. x 125 ft. floor area. This building is about a quarter of a mile from the Bendix plant. The same agent as for (2) should be referred to.

(4) The Curtiss Wright hangar at Valley Stream, Long Island. There are six hangars altogether of floor area 137 ft. x 133 ft. each, and a clearance of about 25 ft. under the beams and an additional 12 ft. between the beams which are spaced 20 ft. apart. These seem to be very desirable structures and are apparently quite isolated on this field. The rental for these hangars is at the rate of about 30¢ per square foot of floor area. The agent is Mr. Esterbrook of Brown, Wheelock, Harris, Stevens, Inc. The telephone number is Lexington 2-6100.

(5) In Clifton, New Jersey, there is a building of 100 ft. x 200 ft. with a ceiling clearance of 35 ft. made of reinforced concrete and steel, which had been used as a machine shop and has a 7 1/2 ton crane installed. This is near the N. P. Nelson Machine Company but otherwise isolated. The agent is Mr. Williams of Joseph J. Garibaldi Organization, Rector 2-7171.

(6) There is available in Yonkers, New York, a golf course which could be had very cheaply. However there is no building. Mr. Gleason is the agent. Telephone Fairbanks 4-2174.

(7) In Armong, New York, the Armonk air field has two fair sized hangars on a field which covers as area of about 65 acres. This is about 20 miles from Columbia University, however. Same agent as for No. 6.

Herbert L. A nderson (signed)

January 23, 1941

Conversation with Dr. P. P. Alexander

Dehydrogenated uranium metal is not pyroforic when made but becomes so in about a week if exposed to air and moisture. Eighteen pounds of this material are at present in a pyroforic state in a concrete pit. In future dehydrogenated material will be produced in the following way:

After reduction in a ni-chrome retort, the material is taken out and ground to a fine powder. This is replaced in the retort, heated to about 900°C for three or four hours at a pressure of 700 micron. After this the material is leeched and dried at 60°C. It must then be filled into airtight containers right away. Otherwise it will become pyroforic.

The present retort takes a charge up to about 50 lbs. of uranium. It is heated by gas and made out of ni-chrome. One pound of uranium takes about one pound of calcium. The first reduction takes place at 600 to 700°C and is due to water which is combined with uranium oxide. The temperature is then further raised to 1000°C. The calcium used at present is not very pure and is sold for $1.25 by the Union Carbide and Carbon Corporation. The Union Carbide and Carbon could probably be persuaded to furnish distilled calcium perhaps for $2 a pound. The calcium hydride is made from calcium by Dr. Alexander.

The advantage of calcium hydride over calcium is chiefly that it can be produced in powdered form. If we furnish special equipment to Dr. Alexander, he would at once be in the position of supplying the metal in 20 lb. lots for a cost of $20 per lb.

To prepare 20 to 50 lbs. of uranium metal would represent two days operation, one for reducing and one for leaching and drying.

The small sample of uranium metal which has been dehydrogenated and afterwards tested and found satisfactory by the B ureau of Standards, was treated the same way as the big lot of 18 lbs. of pyroforic uranium. It was crushed and heated to 900°C for one hour, but note that this was carried out at a pressure of 20 micron. It was leached after dehydrogenation. While some hydrogen was driven out of the 18 lb. sample, since it subsequently became pyroforic, we have no evidence as to the amount of hydrogen which was left in this sample that was dehydrogenated at 700 micron pressure.

The following elements could be used in principle for reducing uranium: K, Na, Mg, Be, Al, B, Si, CaBaSr. If only low pressure processes are considered in which the uranium does not fuse and if leaching is used for separating the uranium, then magnesium, aluminum, beryllium and silicon are not suitable because their oxides are more difficult to dissolve in dilute acids than calcium oxide. Potassium, sodium and calcium could be used in place of calcium hydride, but it is not easy to obtain them in powdered form and therefore the reduction would have to go through the vapor phase. To prevent a too violent reaction, calcium oxide could then be used for diluting these metals. Finely divided Ca could however be obtained by Dr. H. from Ca hydride

Question: Could one not use magnesium, beryllium, or silicon and separate by a method of flotation rather than leaching?

Question: Could one not prepare an alloy of uranium with tin, lead or bismuth by reducing with calcium and calcium oxide or magnesium and magnesium oxide?

Conditions would have to be chosen so that the molten lead, tin or bismuth should be held in position by capillarity until the temperature is so high that the uranium is reduced to metal and the heavy uranium alloy then brought to fuse by gravity over-compensating the capillary forces. Alternatively the tin, lead or bismuth would separate from the uranium (before it) is reduced and the alloying could take place through the vapor phase.

Dr. Alexander would undertake to prepare a few pounds of beryllium metal by reducing beryllium oxide with calcium hydride. For this purpose he would want beryllium oxide which contains no sulfur and which is fluffy, i.e. he wants the lowest possible firing temperature, and not beryllium oxide which has been sintered at a high temperature.

Note Dr. Alexander thinks that U_3O_8 does not lose its crystal water until about 1200°C. He warns that uranium oxide is very poisonous.

Dr. Alexander's assistant, Mr. Davis, may visit me in New York.

The following equipment would be desirable:

One pump	400
One retort	350
One large leaching tank	300
One iron container	50
Drying oven and shelves	300
One filter press	200
	1600

The prices are guesses which would have to be verified by obtaining bids.

Dr. Alexander intends to protect uranium from oxygen and nitrogen by using zirconium. Asks if a trace of zirconium would be harmful.

The equipment proposed could take care of a production of 100 kg. of uranium metal per week. End of memo

January 30, 1941

MEMORANDUM CONCERNING THE ESTIMATE OF COSTS
FOR THE INTERMEDIATE SCALE EXPERIMENT

It should be possible to determine whether or not a chain reaction can be made to work with thermal neutrons by performing experiments on 35 tons of graphite, 3 tons of uranium metal and 2 tons of beryllium metal. A variety of experiments may have to be performed in which the shape and form of the uranium and the ratio uranium to carbon may have to be varied in order to find in an empirical way the most favorable conditions which may have to be met in order to make the chain reaction work.

At present beryllium metal is not available at a reasonable price in the required purity. Experiments on the production of pure beryllium will have to be performed and other preliminary experiments on the nuclear properties of beryllium will have to be completed before the purchase of 2 tons of beryllium metal can be recommended. We propose to spend between two and five thousand dollars from our appropriation under our first constract for experimental orders on beryllium, in order to provide the facilities to manufacture pure beryllium, and also in order to secure the amount of beryllium required for the purpose of preliminary experiments. In the circumstances, and also because it may very well be that the chain reaction may be made to work without the use of beryllium, the enclosed estimate of cost for the intermediate experiment carries no item for the purchase of beryllium.

It is ~~suggested~~ that the proposed second contract should cover the expenses of a period of twelve months ending on the 30th of June, 1942, and that all work under this contract should be concluded by December 31, 1942 at which time a report would have to be rendered.

According to the present plans an intermediate experiment would be carried out with uranium oxide in order to make use of the time which will be necessary to complete arrangements for the supply of uranium metal in the desired purity and in the required form. We propose to spend about five thousand dollars under the appropriation of our first contract for experimental orders on uranium metal for the purpose of providing the facilities to manufacture pure uranium metal, and at the same time also in order to secure about 100 kg. of this metal for the purpose of preliminary experiments.

It is estimated that within three months after placing an order for three tons of uranium metal this metal could be obtained free from hydrogen in powdered form at the rate of 100 kg. per week. Thus if a sufficient amount of uranium oxide were available it would be possible to accumulate the required quantity of uranium metal while seven tons of uranium oxide are still tied up in the intermediate experiment. No item for an additional amount of three tons of uranium oxide as would be required for this purpose has been included in the enclosed estimate of cost.

In order to take care of this item and other expenditures which might become necessary, we have to envisage the possibility of a third contract which might cover a period from the first of August of this year to the end of 1941, and a tentative estimate of cost for this third contract has been drawn up and is being enclosed. It is not proposed to ask for any appropriation under the third contract at the present time, as the figures given are rather tentative and the final figures will not be available for another three or four months. The items included in this tentative estimate of cost for the third contract include the following.

An item called sintering and shaping of three tons of uranium metal in order to obtain the metal in a suitable form and at a density of 20 grams per c.c. Both the form and the density of the metal play an important part in the chain reaction.

An item for the processing of graphite in case such processing should be required in order to rid the graphite from boron after the graphitizing process has been completed.

An item for construction cost in order to take care of expenses in connection with varying the size and shape of the uranium bodies and the ratio of uranium to carbon, in order to determine empirically the conditions under which the chain reaction can be made to work.

An item for one ton of beryllium metal in case the use of beryllium metal should turn out to be necessary.

Additional items for experiments on sintering uranium and producing and possibly casting pure beryllium.

ESTIMATE OF COSTS

	MATERIALS		OTHER EXPENDITURES	
1.	6 tons of uranium oxide	30,000		
2.			Conversion of 3 tons of uranium oxide into dioxide and metal	60,000
3.			Experiments on the production of pure uranium metal	2,000
4.	35 tons of graphite	17,500		
5.			Experiments on the purity of graphite	2,000
6.			Experiments on the production of pure beryllium	2,000
7.			Salaries for a period of 12 months	19,000
8.			Construction work	5,000
9.			Running expenses for a period of 12 months	12,000
	TOTAL	47,500	TOTAL	102,000

GRAND TOTAL 149,500

ESTIMATE OF COSTS

MATERIALS		OTHER EXPENDITURES	
1. 3 tons of uranium oxide	13000 ~~15,000~~		
2.		Conversion of 3 tons of uranium oxide into dioxide and metal	60,000
3.		Experiments on the production of pure uranium metal	2,000
4. 35 tons of graphite (special brand)	~~12,500~~ 15000		
5. → 5 metal. tons	21,500	Experiments on the purity of graphite	2,000
6.		~~Purification of~~ Experiments on the ~~production of pure~~ beryllium	2,000
7.		~~Salaries~~ for a period of 12 months	19,000
8.		Construction work	5,000
9.		Running expenses for a period of 12 months	12,000
10 TOTAL	~~47,500~~	TOTAL	102,000

GRAND TOTAL 149,500

Rent of 14 flats for 12 months 2500

104,500

8 hours

4.5

For this reason an item for the purchase of 2 additional tons of uranium oxide has been included in ~~the~~ a supplementary estimate of cost which is inclosed ~~and~~ (one additional ton of uranium oxide might be purchased under the present contract and used for the purposes of intermediate experiment.)

Other items included in the supplementary estimate of costs are the following: An item of $15,000 for centering and shaping 3 tons of uranium metal; an item of $17,500 for processing graphite ~~if~~ such processing ~~should~~ be required in order to rid the graphite from its boron content; an item for construction costs which would give us a considerable larger scope in varying the geometric conditions in the intermediate experiments and finding ~~in a relatively short time~~ the most favorable conditions from the point of view of the chain reaction.

Jan 30th - 41

MEMORANDUM CONCERNING THE ESTIMATE OF COSTS FOR THE INTERMEDIATE SCALE EXPERIMENT

It should be possible to determine whether or not chain reaction can be made to work with thermal neutrons by performing experiments on 35 tons of graphite, 3 tons of uranium metal and 2 tons of beryllium metal. A variety of experiments may have to be performed in which the shape and form of the uranium inthe ratio uranium to carbon may have to be varied in order to find in an empirical way the most favorable conditions which may have to be met in order to make the chain reaction work.

At present beryllium metal is not available at a reasonable price in the required purity. Experiments on the production of pure beryllium would have to be performed in other preliminary experiments on whether nuclear properties of beryllium would have to be completed before the purchase of 2 tons of beryllium metal can be recommended. ~~Consequently, and also because~~ It may very well be, the chain reaction may be made to work without the use of beryllium. The inclosed estimate of costs ~~does not carry an item~~ for the purchase of beryllium.

It is suggested that the proposed contract should cover the expenses for a period ending on the 30th of June, 1942 and that all work under this contract should be concluded by December 31, 1942 at which time a report would have to be rendered. According to the present plans an intermediate experiment would be carried out with uranium oxide in order to make use of the time which will be necessary to complete arrangements for the supply of uranium metal in the desired purity and in the required form.** If a sufficient amount of uranium oxide could be obtained to carry out the transformation into metal on a 3 ton lot of uranium oxide while 7 tons of uranium oxide are still tied up in the intermediate experiment, a considerable saving of time would result. It is estimated that three months after the granting of the appropriation uranium metal could be obtained at a rate of 100 kilograms per week.

For this reason an item for the purchase of 2 additional tons of uranium oxide has been included in the supplementary estimate of cost wh which is inclosed and one additional ton of uranium oxide might be purchased under the present contract and used for the purposes of intermediate experiment.

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January 30, 1941

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According to the present plans an intermediate experiment would be carried out with uranium oxide in order to make use of the time which will be necessary to complete arrangements for the supply of uranium metal in the desired purity and in the required form. We propose to spend about five thousand dollars under the appropriation of our first contract for experimental orders on uranium metal for the purpose of providing the facilities to manufacture pure uranium metal, and at the same time also in order to secure about 100 kg. of this metal for the purpose of preliminary experiments.

It is estimated that within three months after placing an order for three tons of uranium metal this metal could be obtained free from hydrogen, in powdered form at the rate of 100 kg. per week. Thus if a sufficient amount of uranium oxide were available it would be possible to accumulate the required quantity of uranium metal while seven tons of uranium oxide are still tied up in the intermediate experiment. No item for an additional amount of three tons of uranium oxide as would be required for this purpose has been included in the enclosed estimate of cost.

In order to take care of this item and other expenditures which might become necessary, we have to envisage the possibility of a third contract which might cover a period from the first of August of this year to the end of 1941, and a tentative estimate of cost for this third contract has been drawn up and is being enclosed. It is not proposed to ask for any appropriation under the third contract at the present time, as the figures given are rather tentative and the final figures will not be available for another three or four months. The items ~~included~~ in this tentative estimate of cost for the third contract include the following:

An item ~~called~~ sintering and shaping of three tons of uranium metal in order to obtain the metal in a suitable form and at a density of 20 grams per c.c. Both the form and the density of the metal play an important part in the chain reaction.

An item for the processing of graphite in case such processing should be required in order to rid the graphite from boron after the graphitizing process has been completed.

An item for construction cost in order to take care of expenses in connection with varying the size and shape of the uranium bodies and the ratio of uranium to carbon, in order to determine empirically the conditions under which the chain reaction can be made to work.

An item ~~for~~ one ton of beryllium metal ~~in case the use of beryllium metal should turn out to be necessary~~.

Additional items for experiments on sintering uranium and producing and possibly casting pure beryllium.

Jan 30 42

MEMORANDUM CONCERNING THE ESTIMATE OF COSTS FOR THE INTERMEDIATE SCALE EXPERIMENT

It should be possible to determine whether or not a/ chain reaction can be made to work with thermal neutrons by performing experiments on 35 tons of graphite, 3 tons of uranium metal and 2 tons of beryllium metal. A variety of experiments may have to be performed in which the shape and form of the uranium ~~is~~ and the ratio uranium to carbon may have to be varied in order to find in an empirical way the most favorable conditions which may have to be met in order to make the chain reaction work.

At present beryllium metal is not available at a reasonable price in the required purity. Experiments on the production of pure beryllium ~~would~~ will have to be performed ~~in~~ and other preliminary experiments on ~~whether~~ nuclear properties of beryllium ~~would~~ will have to be completed before the purchase of 2 tons of beryllium metal can be recommended. ~~Consequently~~ Therefore, and also because it may very well be, the chain reaction may be made to work without the use of beryllium, The inclosed estimate of costs does not carry an item for the purchase of beryllium.

It is suggested that the proposed because contract should cover the expenses for a period (of 12 months) ending on the 30th of June, 1942 and that all work under this contract should be concluded by December 31, 1942 at which time a report would have to be rendered. According to the present plans an intermediate experiment would be carried out with uranium oxide in order to make use of the time which will be necessary to complete arrangements for the supply of uranium metal in the desired purity and in the required form. If ~~a sufficient~~ an additional amount of uranium oxide could be obtained to carry out the transformation into metal on a 3 ton lot of uranium oxide while 7 tons of uranium oxide are still tied up in the intermediate experiment, a considerable saving of time ~~would~~ may result. It is estimated that three months after the granting of the appropriation uranium metal could be obtained (from hydrogen bath in pressure bomb) at a rate of 100 kilograms per week.

C. Sups.

2 tons add. Ox.
1. to contin. ops while
3 tons is used for
ox. 8,200.

2. shaping 3 tons metals 15,000. x omits
Improving graph 15,000
3. ~~Be metal develop.~~ ~~3,000~~
interrupt. ops. 3,000 x omits.
~~Salaries~~ ~~4,000~~

conversion of another ton of oxide. 15,000 — 15,000

$. geometry variation 10,000.

58,200

D.

3 tons Be oxide to make 1 ton metal. 30,000 → 20,000. Σ = 50,000
50 ... 5 tons

A. 3 tons wrox. 13,000 ~~2000~~ 60,000

3,000

35 tons 15,000 3,000

19,000

Sal.

(2 Mech. 4,800 } Const 5,000

Rum exps. 12,000

~~2,900~~

Ra rent ins etc 2,200

38,000 ~~102,700~~

102,000

B. 1. 5 tons 21,500

2. Be methods 2,000

145,200

[14,000]

C. 58,200

188,400

D. 50,

15

62

15

12

5

19

12

130

2.

25.

27.

142

Beds
extra w/ ox

From Mitchell FEB - 1 1941

AN ESTIMATE OF THE COST FOR THE INTERMEDIATE SCALE EXPERIMENT

This experiment, the purpose of which is to determine whether or not a chain reaction can be made to work with thermal neutrons requires the use of thirty-five tons of graphite and three tons of Uranium metal.

This will necessitate expenditure for:-

The purchase of three tons of Uranium Oxide	$13,000	
The conversion of this oxide into metal		$60,000
Experiments to improve the method of converting oxide into metal		3,000
Thirty-five tons of graphite	15,000	
Experiments to improve the method of producing this graphite		3,000
Salaries of physicists and assistants		19,000
Construction		5,000
Running Expenses		12,000

It should be noted that the last two items include both the cost of materials and labor, especially that of instrument makers.

Total for non-expendable material	28,000	
Total for services and expendable material		102,000

THE PRELIMINARY EXPERIMENT now under contract requires the procurement of about 100 kgs. of Uranium metal. In order to be prepared to supply the larger quantity indicated above it is proposed to spend about five thousand dollars under the present contract for experiments in the production of Uranium metal in order to establish the best method of manufacturing metal of sufficient

purity and at the same time to procure the 100 kgs. now needed.

Supplementary Experiments With Uranium Oxide

It is probable that after the most suitable method of producing Uranium metal from its oxide has been developed about three months will be required to get the necessary equipment into production and that the production rate will be about 100 kgs. per week.

Since the possibility of producing the chain reaction with Uranium Oxide is not entirely excluded and since in performing the experiments with the oxide experience and valuable information is gained, it is advisable to carry out experiments with the oxide pending delivery of the metal.

For this purpose five more tons of oxide are required $21,500

Beryllium Metal

As is indicated in the supplementary report it may be necessary to obtain a large quantity of beryllium metal. At the present time beryllium metal is not available in the required purity and the price of even the quality now being produced seems unreasonable. For these reasons it is believed important that certain experiments in the production of pure beryllium should be carried out now and that about 150 lbs. of the pure metal should be obtained in order that experiments on the nuclear properties of beryllium may be begun in the near future. It is therefore proposed to spend between two and five thousand dollars out of the present contract for experimental orders on beryllium and that for the same purpose the following additional amount should be added to the contract for the intermediate

scale experiment.

Experimental production of pure beryllium	2,000

From Wigner

FEB - 1 1941

Supplement to the Estimate for the Intermediate Scale Experiment

It seems advisable at this time to envisage the possibility of a third contract for the extension of the intermediate experiment. Although it is not now proposed to ask for the immediate approval of such a contract the following tentative figures are presented for consideration.

Item 1. As the proposal for additional oxide for the oxide experiment assumes the temporary use of two out of the three tons purchased for the production of the metal it may be advisable to purchase an additional two tons in order to continue the oxide experiments while the three tons of metal are being produced.

For two tons of Uranium oxide 8,200

Item 2. In the conduct of the experiment with the Uranium metal it is quite probable that geometric variations will be indicated which are difficult although realizable. In order to carry out experiments with such variations it would then be necessary to reshape and increase the packing density of the three tons of Uranium metal because bothe the density and the form play an important part in the chain reaction.

For geometric variations $10,000

Item 3. There should also be provided

For the reduction of another ton of oxide 15,000

Item 4. The results of the intermediate experiment may show that much purer graphite than that available at the present time is important.

For required purification		15,000
Total of above for non-expendable material	8,200	
Total of above for services and expendable material		40,000

Item 5. The possible need for one ton of pure beryllium metal is not sufficiently remote to justify its omission from this supplementary estimate. If it is necessary there should be available

Three tons of Beryllium oxide	30,000	
To convert this oxide into one ton of metal		20,000

Total of items 1 to 5 inclusive		
Non-expendable materials	38,200	
Services and expendable materials		60,000
Combined total	$98,200	

Korr.

February 3, 1941

AN ESTIMATE OF THE COST FOR THE INTERMEDIATE SCALE EXPERIMENT

This experiment, the purpose of which is to determine whether or not a chain reaction can be made to work with ~~thermal neutrons~~ unsep. ur in system composed of carbon and uranium requires the use of thirty-five tons of graphite and three tons of Uranium metal. to begin with

This will necessitate expenditure for:-

1.	The purchase of three tons of Uranium Oxide	$13,000	
2.	The conversion of this oxide into metal		$60,000
3.	Experiments to improve the method of converting oxide into metal		3,000
4.	Thirty-five tons of graphite	15,000	
5.	Experiments to improve the method of producing this graphite		3,000
6.	Salaries of physicists and assistants		19,000
7.	Construction		5,000
8.	Running expenses		12,000
9.	The purchase of 5 tons of Uranium Oxide for the purpose of carrying out an experiment with oxide pending the delivery of the Uranium metal	21,500	
10.	Improvements in tests and production of pure Beryllium		2,000
11.	Measurements of individual nuclear constants		2,000
	Total for non expendable materials	$49,500	
	Total for services and expendable materials		$106,000
	GRAND TOTAL		$155,500.

New page 2, with alterations by Fermi included

Remark on item 9. In order to be in a position to obtain quick delivery of uranium metal of the required purity, we may ~~are going to~~ spend about $5,000 under our first contract for experiments, tests and equipment which can be used in manufacturing this metal. Even so we shall be able to obtain only delivery at the rate of 100 kg. per week, starting about three months after placing an order. In the circumstances, we propose to carry out the intermediate scale experiment with uranium oxide pending the delivery of three tons of uranium metal. This experiment with uranium oxide will give us very valuable information to be used for the detailed planning of the experiment with metal. This will put us in a position of speedily carrying out the experiment on metal. Moreover, there is a chance, though not a large one, that a chain reaction might be carried out with uranium oxide, in which case a very considerably saving of time would result. For all these reasons it is desirable to make use of the time while waiting for the delivery of the uranium metal by carrying out an experiment on oxide.

Remark on item 10. Since it might be necessary to improve the conditions for a chain reaction by using beryllium metal in conjunction with uranium metal, it is proposed to prepare the ground for the manufacture of one ton of pure beryllium metal in order to be in a position to be able to obtain delivery of this material at a later date if required. We ~~are going to~~ may

Remark on item 9. In order to be in a position to obtain quick delivery of uranium metal of the required purity, we are going to spend about $5,000 under our first contract for experiments, tests and equipment which can be used in manufacturing this metal. Even so we shall be able to obtain only delivery at the rate of 100 kg. per week, starting about three months after placing an order. In the circumstances, we propose to carry out the intermediate scale experiment with uranium oxide pending the delivery of three tons of uranium metal. This experiment with uranium oxide will give us the necessary experience and much useful information which is desirable to have in order to be in the position of speedily carrying out the experiment on metal after its delivery. Moreover, there is a slight chance that we may be able to demonstrate the possibility of a chain reaction by experiments carried out on uranium oxide. For all these reasons it is desirable to make use of the time while waiting for the delivery of the uranium metal by carrying out an experiment on oxide.

Remark on item 10. Since it might be necessary to improve the conditions for a chain reaction by using beryllium metal in conjunction with uranium metal, it is proposed to prepare the ground for the manufacture of one ton of pure beryllium metal in order to be in a position to be able to obtain delivery of this material at a later date if required. We are going to

spend about $3,000. under our first contract fot this purpose, and hope to obtain 150 lbs. of this material to be used in preliminary experiments under our first contract.

Remark on item 11. While the intermediate experiment is being performed, it is proposed to measure certain nuclear constants during the period of the second contract. A number of such measurements are being carried out under the first contract, and it may be desirable to re-measure some of these constants during the second contract in order to increase the accuracy of the values so far obtained.

Remark on items 7 and 8. These items include both the cost of materials and labor, especially that of instrument makers.

Leo Szilard

May 19, 1941

Memo

Up to date we have spent altogether $15,332.

Of this amount we have definitely used at least 5,200.

for materials, leaving from the original materials

account of $13,000 7,800.

on the materials account and no more.

From the original 40,000.

we have thus left 24,668.

and subtracting from this amount the 7,800.

which may still be on the materials account, we find that 16,868.

are left to spend for matters other than materials

during our present contract.

In making this calculation the salaries have been mortgaged up to the first of July.

March 11, 1941

Memo concerning U. S. Graphite Company

(Yesterday's conversation with Mr. Bolton)

1. Graphite should be transported in steel barrels to keep out moisture.

2. Graphitizing furnace has a maximum charge of 8 tons. Graphitizing process takes 4 weeks. Our present blocks are extruded 37" long and graphitized. They are cut after the graphitizing process. Graphite blocks previously supplied were extruded 8" x 8" and sawed after the graphitizing process.

3. The U. S. Graphite Company buys calcined coke from the Great Lakes Coke Company.

4. 37" long carbon blocks stand vertically in the furnace on a layer of refractory brick.

5. The engineer's name of U. S. Graphite is Mitchel. Chemist's name is Cay.

MEMORANDUM ON THE SUPPLY OF MATERIALS - February 5, 1941

The impurity of available grades of graphite have been studied and the arrangements were made with the National Carbon Company for working out matters to determine the amount of these impurities. It was found that the graphite which has been used in previous experiments contains about one part in 500,000 of boron. This amount of boron appears to be present in the ash and the amount actually contained in the graphite may be more as some of the process is lost in ashing. This particular question is now being investigated since it is not certain that it will be possible to make arrangements for the supply of boron free graphite. The question of processing graphite is now under investigation.

The question of obtaining uranium metal free from hydrogen, fussed or sintered, has been investigated. It was found that dehydrogenated uranium metal can not be conveniently used for our purposes since it becomes pyroforic after long exposure to air and moisture. It was not found possible to sinter this dehydrogenated metal but it is hoped that it will be possible to free from hydrogen sintered blocks which are prepared from hydrogen containing uranium powder. The equipment which will be required to obtain a supply of 100 milligrams per week of uranium could be obtained at a cost between $2,000 and $5,000. Other methods of preparing uranium metal are under investigation.

The question of using uranium dioxide instead of uranium oxide in our experiments has been studied. It appears that it should be possible to obtain by reduction of U_3O_8 in hydrogen a production which has a density of about 10 to 11 milligrams per c.c. as compared with the density of the unreduced oxide which is about 7 grams per c.c. Arrangements have been made for a supply of a few pounds of this material preliminary to obtaining particulars for the supply of

this material in one ton lots.

The possibility of obtaining pure beryllium metal has been studied. Uranium oxide is available from two different sources, the production being obtained by two different processes, and consequently differing from each other by the nature of their impurities. Beryllium metal is at present supplied by the Beryllium Corporation of America. The origin of the impurities of this metal has been studied and it was found that these are partly due to the impurities of the oxide to minor degree to other chemical ingredients which are used and to a large degree to the particular equipment of the electrolytic cell. The purity of the production could be improved by making minor changes in the present method of production.

May 11,1941

Memorandum; Concerning conversation with Goldhaber in Washington, May 1941.

Scattering cross-section for thermal neutrons in heavy hydrogen 5.6.

Scattering cross-section for D resonance neutrons 3.3.

Capture cross-section according Halban Koch, and Frisch: smaller than 3/100; according to Wakakuki: smaller than 2/100.

Harkins published smaller than 1/10,000, based on radio-activity of triton for which he assumed a half life of 150 days. Actually, the half life is 30 years, factor of 10 uncertain.

May 28, 1941

Memorandum concerning the intermediate scale experiment:

Since several months may pass before we can obtain a contract for next year's work based on the appropriation to be voted by Congress, it would perhaps be advisable to bridge over the intermediate period by a sort of an interim contract.

Since we have all the materials for the intermediate scale experiment, it should perhaps be possible to obtain right now a contract for a small sum, say, $12,000 to cover the expenditure for construction cost which we will have to make within the next few months.

Unless this construction cost is secured, we shall be too hesitant in using our present appropriation for the purpose of securing within the next few months the collaborators which we will need during the period of the next larger contract.

L. S.

Leo Szilard

June 6, 1941

Memo

Mitchell reports over the telephone the following:

Dr. Rodden finds on a sample of uranium oxide that:

(1) water is driven off in the amount of .16% by heating the sample up to 200°C within a half-hour period and by keeping it at that temperature for a further half hour;

(2) the same sample heated up to 400°C gave off an additional amount of .04% of water;

(3) between 800 and 1000°C the same sample gave off .02% of a condensable liquid, not necessarily water.

L. S.

Next sample gave off 0.15% up to 200 and 0.02 up to 400

Fast neutrons

[Hist-K]

MEMORANDUM June 8, 1941

It is proposed to carry out the following experiments with a D+D neutron source in the center of a uranium sphere.

1.) A spherical fission chamber is being swung into the different positions around the neutron source and the number of fissions determined for various positions with and without the uranium sphere.

The first question which arises is whether the presence of the uranium increases or decreases the number of fissions produced. For the purpose of interpreting the results we might for the sake of argument make the following assumptions:

A.) That the cross-section for fission is 0 up to a certain energy, say, 1,000,000 volts, and constant between 1,000,000 and 4,000,000 volts.

B.) That uranium slows down a certain fraction of the D + D neutrons which pass through the spheres and that those neutrons which suffer an inelastic collision in uranium ~~for~~ have a practically uniform energy distribution between 0 and the energy of the primary (D+D) neutrons

C.) That the energy distribution of the fission neutrons produced D + D neutrons is the same as the energy distribution of the fission neutrons which are produced by thermal neutrons.

~~What~~ If we find that the uranium sphere causes an increase in the number of fissions it is then not possible directly to conclude that a fast neutron chain could be made divergent, That this conclusion can not be directly ~~wrong~~ made is connected with the fact that according to the assumptions made above, the ~~fissxionx~~ average energy of the D+D neutrons which leave the uranium sphere with sufficient energy to cause fission might be considerably lower than the initial energy. Consequently by increasing the size of the uranium sphere the number of fissions observed by the spherecal fission chamber might decrease after an initial increase with

MEMORANDUM

increasing radius of the uranium sphere.

Nevertheless, the result of this proposed experiment should give some sort of indication as to the chance of producing divergent chain with fast neutrons.

In order to determine the cross-section of uranium for the production of one additional fission neutron the following experiment is envisaged:

A spherical, gas-filled ionization chamber is swung around the neutron source and the number of recoil pulses is determined with such a high bias that the recoil pulses from the D + D neutrons are not recorded. No recorded pulses should then be recorded without the uranium sphere and a certain number of pulses will be recorded if the uranium sphere surrounds the target of the D + D source. By using a photo-neutron source for the production of thermal neutrons and the same high bias as before and by comparing the number of pulses obtained with this high bias and with a very low bias we put ourselves into the position to calculate for fission neutrons the low bias count from the high bias count. (This is based on the assumptions that the energy distribution of the fission neutrons is the same for thermal neutrons and for D + D neutrons.)

In order to find now the cross-section of uranium for the production of an additional fission neutron we have to make a low bias count with and without uranium around the target of a D + D source and make use of a previously made high bias count to calculate the contribution of the fission neutrons to the low bias count made with uranium surrounding the target. By comparing the contribution of the fission neutrons to the low bias count with the remainder of the low bias count in the

in the presence of the uranium sphere or with the total low bias in the absence of the uranium sphere we obtain an indication of the cross-section for uranium for the production of an additional fission neutron (D + D) neutrons. This indication is somewhat ~~spoiled~~ affected by the fact that the cross section of the gas used in the ion chamber is the function of the neutron energy. It is this fact which compels us to adopt the above described complicated proceedure. If it were not for this fact we could simply compare the low bias count obtained in the presence of uranium with the low bias count obtained in the absence of uranium and the difference of the two divided by the latter would give an indication of the cross-secti section which we want to attain.

Perhaps it would be worth while to determine for lead the low bias count with and without that using hydrogen or heavy hydrogen in the ion chamber.

MEMORANDUM CONCERNING BISMUTH

June 23, 1941

Walter C. Smith, Cerro de Pasco, Whitehall 4-7030, can supply bismuth at $1.25 per pound which contains less than 0.001 % Ag. If we order a thousand pounds or more, they could make us, without much extra charge, material which is even freer from Ag.

They have in stock ten pounds of spectroscopically pure bismuth which sells for $4.50 per pound.

The Belmont Smelting Co., telephone Dickens 2-4900, Mr. George Henning, says that they buy Cerro de Pasco bismuth for which he quotes a price of $1.30 per pound. He says that it very often runs 99.999 pure, and a typical analysis shows less than 0.070 ounces per ton of Ag.

To Mitchell

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L. L.

MEMORANDUM June 26, 1941

If fast neutrons interact with uranium 238 they may cause fission of this element and it is known that neutrons are emitted in this process. Thus a chain reaction is potentially possible and we are interested here in the question whether or not such a chain reaction is possible in reality.

While uranium 238 appears to have a considerable fission cross-section for fast neutrons, neutrons which have been slowed down below a certain energy are no longer efficient in causing fission of this element. A certain fraction of the neutrons emitted in the fission of uranium 238 is fast enough to be efficient in causing fission in other uranium atoms but a certain fraction of these neutrons may be slowed down by inelastic collisions to an energy below which they are not efficient in causing further fission. We thus have perhaps two processes which partly counter balance each other, namely: an increase in the number of "efficient" neutrons arising out of fission processes and a decrease in the number of efficient neutrons due to inelastic collisions. In order to obtain an indication of the balance of these two processes we have performed a simple experiment of the following type:

A target coated with heavy ice is bombarded by 0.1 M E V deuterons and serves as a source of neutrons with energies between and M E V. A spherical ionization chamber coated with a uranium oxide layer is placed at a certain distance from the neutron source and serves to register fission which are induced in uranium by D D neutrons. A fission count is first taken in this way and then a second fission count is taken when two half spheres of uranium are placed around the target so that the target is in the center of a complete uranium sphere. By comparing these two fission counts taken with and without uranium around the neutron source we obtain information on the interaction of the D D neutrons with uranium.

In general such a fission count is determined by the number of neutrons which pass through the fission chamber, by the average fission cross-section of these neutrons and by their angular distribution of these neutrons. If D D neutrons pass through a thick layer of uranium their number is changed because they cause fission in which neutrons are emitted and perhaps also because of radiative capture which they may suffer; their energy distribution is changed on account of inelastic scattering and also on account of the ad-

mixture of a certain fraction of fission neutrons and finally their angular distribution is changed on account of both elastic and inelastic scattering by uranium. This last factor has however no influence on the fission count if a spherical fission chamber is used which has a small radius compared to the distance between the center of the ionization chamber and the surface of the uranium sphere which surrounds the source. In this particular case the fission count is a direct measure of F, the product of the number of neutrons which pass through the chamber and their average fission cross- section.

If the neutrons emitted by our neutron source had an isotropic distribution we would have simply to compare the fission count of the spherical ionization chamber taken with and without uranium at some fixed position of the fission chamber, in order to obtain the change in the product F which is caused by the passage of D D neutrons through the uranium sphere. Since the distribution of the D D neutrons is an isotropic both with respect to their number and with respect to their energy we have to determine the fission count with and without uranium for a number of positions with respect to the deuteron beam and perform an intergration.

In the experiment which we actually performed we used a complete uranium sphere of a radius of about 7 cm. and a uranium density of gms. per c.c. We found that by placing this uranium spherearound the neutron source the the product F was decreased by a factor of about . This has to be considered as a strong indication in favor of the view that no chain reaction could be maintained in uranium 238 by means of fast neutrons. It should be emphasized, however, that this result can not be considered at present as an absolute proof.

In order to discuss to what extent our result indicates the impossibility of a chain reaction in uranium 238 we might argue as follows:

Let us assume that a chain reaction were possible in uranium 238. In such a chain reaction we would then have a certain characteristic energy distribution of the fission neutrons. If we had at our disposal a point source of neutrons which have just this energy distribution , we could be certain that by surrounding this point source with a uranium sphere we would get an increase rather than a decrease in the product F.

It is, however, not possible simply to reverse this conclusion and to say without additional qualifications that the chain reaction is impossible if the uranium sphere reduces rather than increases the product F for D D neutrons.

These neutrons have energies between and M E V whereas the fission neutrons may have energies between 0 and perhaps 3.5 M E V. For all we know at present uranium might for instance have an energy level close to 2 M E V which might be responsible for practically all the slowing down by inelastic collisions below 3 M E V. Such an assumption does not appear very likely but it would be consistent with the decrease in the product F observed in our experiment. If this assumption were correct fission neutrons which have energies below 2 M E V would not appreciably be affected by inelastic collisions in uranium and the possibility of a chain reaction in uranium 238 would consequently not be excluded by our observation.

However, barring such " accidents" our result can be considered as prima facie evidence for the impossibility of a chain reaction in uranium 238 and a somewhat closer study of the manner in which uranium is slowing down neutrons might very well enable us to make this conclusion water-tight.

July 29, 1941

Memorandum on conversation with Alexander and Davis
Monday, July 21, 1941

(1) Look into question how Rodden analyzes for hydrogen.

(2) Does uranium burn in nitrogen?

(3) Make analysis for rare earths in uranium metal and in calcium, also for lithium.

(4) Look into question of using beryllium in co-reduction as an alloying element.

(5) Look into question of organizing heat treating of pressed uranium powder slabs in vacuum in order to get rid of paraffin.

(6) Note that 25 lbs. of uranium which was satisfactory was produced by adding calcium hydride to the unleeched reduced uranium and treating this mixture in the furnace for a second time.

There is a suspicion that the 70 pound lot of uranium which was not satisfactory got oxidized already in the furnace, because it was kept two hours at 900°C after driving off the hydrogen. It is possible that not the fact of dehydrogenization in itself, but this oxidation in the furnace is the cause of pyroforic behavior. The 25 lb. lot which was twice reduced but only once leeched is probably coarser than material which is only once reduced and once leeched.

Material which is twice leeched and twice reduced, i.e. which is put back into the furnace after being leeched with calcium hydride added seems to become very much coarser which is of advantage. However, it may not be possible to leech this material properly and calcium oxide inclusions may be unavoidable. For this reason it is considered to use zirconium in the second heat treatment for protection against oxidation, rather than calcium.

(7) Note that recast calcium is very much better for Alexander to handle in making calcium hydride than ordinary calcium, and Alexander thinks it would be well

worth 50¢ more to use recast material.

(8) Make definite statement about use of lead, tin and bismuth as binders. Also bismuth, tin alloys. Also consider possibility of having uranium entirely set into molten bismuth which could be pushed into unpressed uranium metal powder by carbon dioxide or argon admitted into the vacuum furnace.

(9) Note that to work out copper, tin or lead coating of uranium powder would require another chemist.

(10) Note that the J. I. Baker Co., Phillipsburgh, New Jersey, Mr. H. H. Garis, might be helpful in purifying calcium chloride.

LS Memo

L. Szilard September 26, 1941

MEMORANDUM

In order to obtain uranium oxide free from rare earths for the purpose of our experiments, it seems that it will be necessary to make a fluoride precipitation at some stage of the processes leading from the ore to the black oxide. Since we may need ten tons of oxide in New York and ten further tons of oxide for the production of the metal, the purification will have to be carried out on about twenty tons of material. This affords a unique opportunity for making an attempt to find out if the pitchblende contains a quantity of element 94. Though the chemical properties of this element are not known, it appears likely that it would be precipitated with the rare earth fluorides provided that the precipitation is carried out under certain conditions of acidity and in the presence of a reducing agent. We may expect a certain amount of element 94 to be present in the uranium ore which originates indirectly through spontaneous fission of uranium. This quantity, however, should be too small to be of significance. The real question is rather whether, apart from this small quantity of the element 94, there is a considerably larger quantity of this element present in the ore. A quantity of one part in ten thousand parts of uranium would be of great importance, since by concentrating it ten times it might increase the efficiency of uranium for our purposes

by ten per cent. It seems quite important to investigate this point for an additional reason. Unless we are sure about this point, we might risk obtaining by purification a uranium oxide which might be less efficient for our purposes than other samples of oxide which are chemically less pure and contain more of element 94. It is, therefore, proposed to attempt a fluoride precipitation under suitable conditions, so that, while we remove the rare earths, we collect in the precipitate such quantities of element 94 which may be present.

The present constellation seems to offer a unique opportunity which should not be missed.

LS:MEB

L. Szilard September 30, 1941

P.S. TO MEMORANDUM OF SEPTEMBER 26, 1941

While the quantity of element 94 accumulated in the pitchblende through the action of neutrons emitted by spontaneous fission should be too small to be of any practical significance, this quantity might be sufficient to be important in other respects. If the age of the deposit is about one billion years, then twenty tons of uranium might yield in the process of purification perhaps one hundred milligrams of element 94. This amount would enable us to make an accurate determination of those properties of this element which have a bearing on the main line of our research.

LS:MEB

Depot Szilard Memos

bbs-39C

MEMORANDUM ON THE POSSIBILITIES OF A FAST CHAIN REACTION IN UNSEPARATED URANIUM

October 27, 1941

The possibility that very powerful nuclear explosions can be engineered if a fast nuclear chain reaction is feasible in unseparated uranium, has been brought to the attention of the Government in a memorandum submitted in August, 1939. The question whether a fast nuclear chain reaction is possible in unseparated uranium was discussed in detail at a meeting under the chairmanship of Dr. Briggs on October 21, 1939. Dr. E. P. Wigner of Princeton, Dr. E. Teller of George Washington University and Dr. Roberts of the Carnegie Institute of Terrestrial Magnetism took an active part in the discussion. The following view which was presented was supported by Dr. Wigner and Dr. Teller.

Experiments have shown[x] that a considerable fraction of the neutrons emitted in the fission of uranium have energies above 1 MEV. One has, therefore, to consider the possibility that these fission neutrons can cause fission with a cross-section of about .5 x 10^{-25} cm.^{2} in uranium, and that a chain reaction is possible in unseparated uranium in which neutrons of more than 1 MEV of energy form the links of the chain. This would lead to a very dangerous fast chain reaction in a comparatively small amount of unseparated uranium. Such a chain reaction, however, is not possible if uranium has a large cross-section for inelastic collisions with neutrons of one to three MEV, and, if accordingly, the neutrons are efficiently

---

[x] Zinn and Szilard, Physical Review, 1939.

slowed down by uranium below the 1 MEV fission threshold of uranium 238. Since there was no experimental evidence at the time concerning such inelastic collisions in uranium, it was proposed that this question should be investigated. Experiments along this line were started in collaboration with Dr. Zinn in February, 1940, and these experiments will be discussed below.

Assuming a large cross-section for inelastic collisions in uranium, it appears reasonable to conclude that the fission neutrons of uranium would fairly quickly be slowed down by such inelastic collisions to energies of perhaps 100,000 volts and from then on slowed down rather slowly by elastic collisions in uranium. Whether or not a fast chain reaction is possible in which neutrons of 10 to 100,000 volt energy form the link of the chain depends on the balance of fission by 235 which is contained in ordinary uranium and radiative capture in 238 which forms the bulk of ordinary uranium.

At the meeting of October 21, 1939, it was submitted that it would be very important to measure this balance since there was an appreciable chance that it might be in favor of fission in 235, particularly since unpublished experiments of Zinn and Szilard performed in April, 1939, have shown that ordinary uranium has an appreciable cross-section for photo-neutrons from a radium-beryllium source. It appeared, therefore, possible that considerable but still practicable amounts of unseparated uranium might allow the setting up of fast nuclear chain reactions.

An experimental program based on these general views was devised in 1939 but had to be postponed when the photo-neutron source

used in previous experiments ceased to be available. A memorandum dated May 21, 1939, which was submitted to G. B. Pegram of Columbia University, describes one possible line of attack. The following lines are taken from that memorandum:

"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 possibility of a chain reaction will have to be seriously considered."

At the time when these lines were written it was intended to work out a Szilard-Chalmers separation for uranium in order to be able chemically to separate the 24-minute activity from the bulk of the irradiated uranium. In the meantime Abelson and MacMillan discovered that the 24-minute period is followed by a period of 2.3 days which is due element 93, and Dr. Goldhaber of Urbana, to whom I communicated in 1939 the above outline of the proposed experiment, suggested to use the 2.3-day period rather than the 24-minute period for obtaining a measure of the radiative capture.

In October of this year a photo-neutron source again became available, and it is proposed to take up this line of research at the point where it had been left in 1939.

Note Added November 6, 1941

Whether the 24-minute period of uranium 239 is sufficiently strongly excited by our photo-neutron source to perform the proposed experiment without any chemical separation other than that which is necessary to remove the natural beta activity of uranium and the fission products, is an open question which will be decided by the experiments. The situation is more favorable in this respect if a cyclotron is used. By using the cyclotron for the production of neutrons and a carbon column for slowing down the neutrons, one could perform the proposed experiment in the following form.

A sample of uranium oxide is placed in the graphite column so far away from the neutron source that most of the radiative capture, and most of the fission which takes place in the center of the sample should be due to thermal neutrons. The activity due to fission is then measured in some arbitrary units: for instance, by measuring the activity of a cellophane layer imbedded in the uranium oxide (a technique which has been lately successfully used in Princeton). Similarly, the radiative capture is measured in some other arbitrary units: for instance, by determining the activity of the uranium 239 which is formed. The ratio of these two activities, K_0, is then noted and is considered as a characteristic measure of the balance between radiative capture and fission. Since we know that about $\nu = 1.5$ fast neutrons are emitted per thermal neutron, we can calculate for any other category of neutrons -- for instance, 10,000-volt neutrons --, ν the number of fast neutrons emitted for one 10,000-volt neutron which is absorbed, if the characteristic ratio K of fission to radiative capture is measured

in the same arbitrary units which were used for thermal neutrons. The proposed experiment consists therefore in surrounding the uranium sample in the graphite column with increasing thick layers of boron up to about a one-inch boron layer and determining for each thickness of boron the characteristic ratio, K, of fission to radiative capture in the above-mentioned arbitrary units. We have:

$$\eta = \eta_0 \frac{K\nu + \beta_0 \nu}{K_0 + \beta_0 K}$$

where $\beta_0 = \frac{\sigma_f}{\sigma_r}$ which, according to Anderson and Fermi's measurements (1939), has a value of $\frac{\sigma_f}{\sigma_r} = 1.18$

In this way we obtain the number of fast neutrons emitted per neutron absorbed for various energy categories, the thickest boron layer corresponding to energies between 5 and 50,000 volts.

Experiments of this type may show whether or not a fast neutron chain reaction can be maintained in a large quantity of uranium metal if the neutrons are slowed down by inelastic collisions below the fission threshold of uranium 238, and are further slowed down by elastic collisions to perhaps 5,000 volts or even further to perhaps a couple of hundred of volts.

As to the quantity of uranium metal which might be required for a fast neutron chain reaction, we may say the following:

By re-calculating the experiments which Dr. Zinn and I performed in 1939 using for the number of neutrons emitted per millicurie radon-beryllium the value of 12,000 which was obtained by Fermi who re-measured this value ih 1940, we find for the fission cross-section of photo-neutrons from radium-beryllium the value of 1.3×10^{-26} cm.^{2} While this is only a

preliminary result to which not much weight should be given, it seems to be in agreement with the value which has been obtained by Frisch. This value is also in agreement with a preliminary experiment which was recently performed by Fermi and his collaborators.

This cross-section might require between 50 to 100 tons of uranium metal to make a chain reaction possible, provided that the radiative capture is sufficiently small. Perhaps a ten times smaller amount of uranium might be sufficient for producing a fast neutron chain reaction if the radiative capture is sufficiently small in the region between a couple of hundred of volts and 5,000 volts, i.e., in the region where the fission cross-section can be expected to obey the 1/v law. It is conceivable that, by adding to the uranium a small amount of a lighter element to obtain a more rapid slowing down of neutrons, we may have conditions in which the neutrons will cause fission before they are slowed down in the region below 200 volts where they would be captured at resonance without causing fission. This possibility has been particularly emphasized by G. Placzek in 1939.

A comparatively small amount of uranium metal would be required for maintaining a fast neutron chain reaction if uranium did not slow down fission neutrons below the fission threshold of U238 with a cross-section larger than the fission cross-section of U238 for fission neutrons. In order to obtain information about this point Dr. Zinn and I started experiments along this line in February, 1941. These experiments show that certain

heavy elements, such as lead and bismuth, have a very small cross-section indeed for slowing down D + D neutrons below the fission threshold of U238.

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Leo Szilard

Report not sent

MEMORANDUM ON THE POSSIBILITIES OF A FAST CHAIN REACTION IN UNSEPARATED URANIUM

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At the meeting of October 21, 1939, it was submitted that it would be very important to measure this balance since there was an appreciable chance that it might be in favor of fission in 235, particularly since unpublished experiments of Zinn and Szilard performed in April, 1939, have shown that ordinary uranium has an appreciable cross-section for photo-neutrons from a radium-beryllium source. It appeared, therefore, possible that considerable but still practicable amounts of unseparated uranium might allow the setting up of fast nuclear chain reactions.

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At the time when these lines were written it was intended to work out a Szilard-Chalmers separation for uranium in order to be able chemically to separate the 24-minute activity from the bulk of the irradiated uranium. In the meantime Abelson and MacMillan discovered that the 24-minute period is followed by a period of 2.3 days which is due element 93, and Dr. Goldhaber of Urbana, to whom I communicated in 1939 the above outline of the proposed experiment, suggested to use the 2.3-day period rather than the 24-minute period for obtaining a measure of the radiative capture.

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Whether the 24-minute period of uranium 239 is sufficiently strongly excited by our photo-neutron source to perform the proposed experiment without any chemical separation other than that which is necessary to remove the natural beta activity of uranium and the fission products, is an open question which will be decided by the experiments. The situation is more favorable in this respect if a cyclotron is used. By using the cyclotron for the production of neutrons and a carbon column for slowing down the neutrons, one could perform the proposed experiment in the following form.

A sample of uranium oxide is placed in the graphite column so far away from the neutron source that most of the radiative capture, and most of the fission which takes place in the center of the sample should be due to thermal neutrons. The activity due to fission is then measured in some arbitrary units: for instance, by measuring the activity of a cellophane layer imbedded in the uranium oxide (a technique which has been lately successfully used in Princeton). Similarly, the radiative capture is measured in some other arbitrary units: for instance, by determining the activity of the uranium 239 which is formed. The ratio of these two activities, K_o, is then noted and is considered as a characteristic measure of the balance between radiative capture and fission. Since we know that about $\nu_o = 1.5$ fast neutrons are emitted per thermal neutron, we can calculate for any other category of neutrons -- for instance, 10,000-volt neutrons--, ν the number of fast neutrons emitted for one 10,000-volt neutron which is absorbed, if the characteristic ratio K of fission to radiative capture is measured

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$$\eta = \eta_0 \frac{K(1+\beta_0)}{K_0 + \beta_0 K}$$

where $\beta_0 = \frac{\sigma_f}{\sigma_\gamma}$ which, according to Anderson and Fermi's measurements (1939), has a value of $\frac{\sigma_f}{\sigma_\gamma} = 1.18$.
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Experiments of this type may show whether or not a fast neutron chain reaction can be maintained in a large quantity of uranium metal if the neutrons are slowed down by inelastic collisions below the fission threshold of uranium 238, and are further slowed down by elastic collisions to perhaps 5,000 volts or even further to perhaps a couple of hundred of volts.

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Leo Szilard

D r a f t October 28, 1941

MEMORANDUM ON THE CONTRIBUTION OF FAST NEUTRONS TO THE CHAIN REACTION IN A URANIUM-CARBON SYSTEM

Experiments of Zinn and Szilard, Physical Review, 1939, have shown that a considerable fraction of the fission neutrons emitted by uranium under the action of thermal neutrons have velocities above the fission threshold of U238. If spheres of uranium forming a lattice are imbedded in graphite, a certain fraction of the fission neutrons emitted by a uranium sphere under the action of thermal neutrons will cause fission in U238 within the same sphere before the neutrons are slowed down below the fission threshold of U238. Inasmuch as the contribution to the multiplication factor in the chain reaction will depend on the density of the uranium sphere and may be different for metal and oxide, it is important to determine the order of magnitude of the effect involved.

The principle of the experiment which is proposed is the following: Let us assume that we have space in which we have a certain thermal neutron density but practically no epi-cadmium neutrons and no fast neutrons. A uranium fission chamber will then give a certain number of fissions if placed into this place. If the chamber is shielded with cadmium and surrounded with a thick layer of a few grams per square cm. of uranium metal, we again obtain a number of fission counts, but these are not due to thermal neutrons but to the action of

fast neutrons emitted from uranium outside the chamber under the action of thermal neutrons on the uranium. By taking into account the change in the thermal neutron density brought about by the presence of the uranium metal outside of the chamber, and by taking into account the various geometrical factors, one can thus obtain the following quantity:

In making the above statement it was assumed that the average range of fission particles from uranium is the same if fission is induced by fast neutrons as it is if fission is induced by thermal neutrons.

Unless the cyclotron is used, it will be difficult to obtain thermal neutrons in the absence of epi-cadmium neutrons. It may just be possible to do the experiment by using a photo neutron source and by shielding the fission chamber both by cadmium and a thick layer of boron. Even so, the background count may be too high to permit the observation of fission in 238. It is therefore proposed to carry out the first experiment by using a uranium fission chamber and a thorium fission chamber. The uranium fission chamber would be used for thermal neutrons, and the thorium fission chamber would be used in the same geometry surrounded with a thick layer of uranium metal in order to record the fission caused in thorium by fission neutrons which are produced in uranium by thermal neutrons. In order to

establish a correlation between the fission count of the thorium chamber and the corresponding fission count which a uranium chamber would give ~~in the absence of epi-cadmium neutrons~~ for fast neutrons, it is proposed to compare the uranium chamber and the thorium chamber by irradiating both with D + D neutrons. Apart from using a D + D source, it is proposed also to use a D + D source surrounded with a thick layer of iron, and also a D + D source surrounded by carbon or a suitable amount of paraffin wax. It is hoped that the ratio of uranium to thorium counts will be the same for D + D source and for ~~a~~ these other non-monochromatic neutron source which ~~spreads~~ runs from 100,000 volts to 2-1/2 million volts.

Intensity to be expected:

If a cyclotron can be used the exp. becomes very simple