F-51

Szilard Memo

May 20, 1944

SECRET

Depot

Mr. E. P. Wigner

Mr. L. Szilard

MUC-LS-22

This document consists of 2 pages and 1 figures

No. 3 of 13 copies, Series A

No RD

Peristaltic method for purifying plutonium

I wish to submit to your kind scrutiny the following method for purifying plutonium which is a sort of a "peristaltic" method.

A long tube of tantalum is filled with plutonium. The plutonium may be, for instance, internally heated by sending alternating current through it. If so heated the plutonium adjacent to the tantalum may always be frozen so that we can avoid having liquid plutonium in contact with the wall. The cooling through the tantalum wall is arranged in a periodic manner so that if one moves along the axis of the tube from left to right one subsequently encounters frozen and liquid sections of plutonium in the interior of the tube. The cooling is so arranged that these alternate solid and liquid sections are not stationary but move from left to right vaguely reminiscent of a peristaltic motion. The speed of this peristaltic motion can be made high provided that the ~~liquid~~ plutonium in the liquid pockets or sections is kept in lively circulation. This can for instance be achieved by keeping the tube rotating around its axis. Under the action of the gravitational field created by this rotation the liquid adjacent to the solid sections will move radially outward and will move in the center of the liquid section radially inward. Impurities which have a solubility appreciably higher in the liquid phase than in the solid phase will move to the right and are transported to the right end of the tube. If the solubilities were ~~reversed the foreign substance~~ would move to the left of the tube.

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The attached figure indicates the principle of such a "peristaltic" apparatus. The cooling is effected by a cooling agent, for instance air, which according to the figure is permitted to come into contact with alternate sections of the tube, the sections in between being protected from contact with the cooling liquid. The whole cooler can slide on the tubes and it moves slowly from left to right until displacement corresponds to one identity period. Then the cooler tube suddenly jumps back to its original position and again moves slowly to the right, etc.

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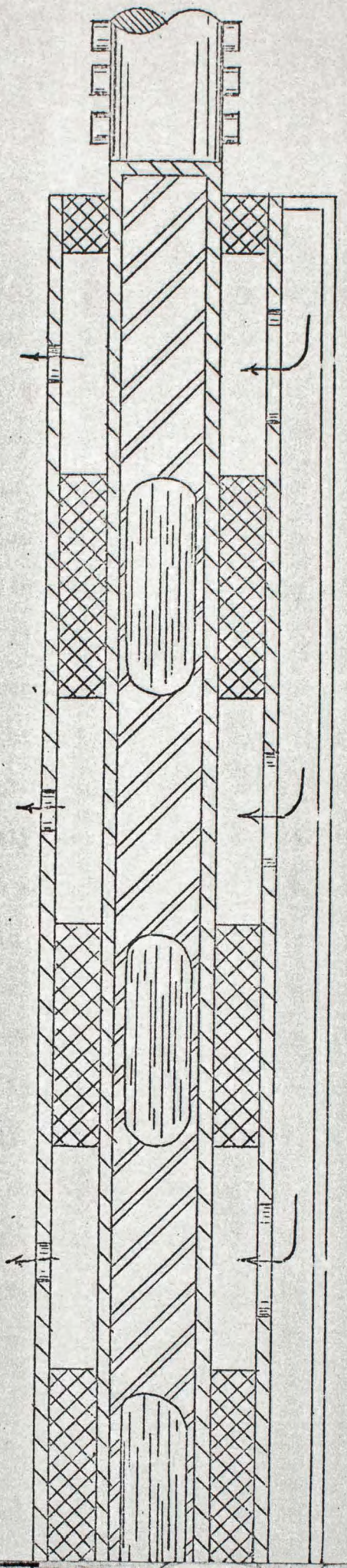


b.b.s. 1

SECRET

METALLURGICAL LABORATORY
P. O. Box 5207
Chicago 80, Illinois

MUC-LS-28
This document consists of pages. No. 9 of 20 copies. Series A.
July 7, 1944

Mr. W. W. Watson
P. O. Box 159, Station H
Montreal, Quebec
Canada

Dear Mr. Watson:

I am writing to you to summarize some of the conversations which I had with you and others in the Metallurgical Laboratory in the course of this last month of June.

It seems to me that a very good method for producing plutonium on a large scale would consist of using a uranium lattice in light water as a chain reacting unit with a uranium lattice in heavy water in the core of the unit and a reflector outside the light water lattice. Composite units with a heavy water seed or a seed containing enriched metal were, I believe, first proposed by the British group and if I am not mistaken, by Halban, in the early days of our project. For the reasons stated below it seems to me that serious attention ought to be paid at present to the possibility of using composite units with a heavy water seed.

The cause of this renewed interest is, generally speaking, the favorable development of the multiplication factor of the light water lattice which has been demonstrated under the instigation of Mr. Wigner's section and particularly under the instigation of Weinberg. Important

for the purpose of these considerations is also the fact that the migration length in the light water lattice is about one-half the migration length in the heavy water; this leads to a very favorable distribution of the heat production within the composite unit and permits satisfactory utilization of the metal.

I believe composite heavy water units of fairly simple construction could conveniently produce 100,000 to 150,000 kw, each unit containing about 3 tons of heavy water and 100 tons of metal. Eighteen tons of heavy water would thus be sufficient for six units and produce between 600 and 900 gms of plutonium per day. The holdup of the metal in the production units would not exceed 100 days unless we were willing to feed metal into the chemical separation plant which would be considerably more active than it is customary to contemplate. For this reason it does not seem reasonable at present to aim at a higher power production per ton of metal but this would be quite feasible if it became desirable.

Pilot Plant.--In view of this situation it would seem to be desirable to build such a composite unit as a pilot plant being of the same type of construction as the production units which might be built later but dissipating only 10,000 kw. As a rough guess it would seem that it should be possible to build such a pilot plant with about 3 tons of heavy water and perhaps 60 tons of metal. The existence of such a pilot plant would make it possible to build a number of units of the same construction as the pilot plant and operate them as production units between 100,000 and 150,000 kw each should the need for a large scale production of plutonium arise in this war.

Experimental Unit.--In order to be able to determine the amount of heavy water and metal that would be required for the pilot plant it would seem desirable to build up as soon as possible such a composite unit to the point where it becomes chain reacting and possibly also run it as a chain reacting unit at an exceedingly low power. No shielding or cooling would then be necessary and information could be obtained which we are lacking at the present time. The metal used in this unit could be used again for the pilot plant.

Simple Considerations.--I am submitting a few simple considerations which lead me to believe that we may anticipate favorable conditions for dissipating heat at a high rate per ton of heavy water and at a satisfactory rate per ton of uranium metal. [It is assumed that the multiplication factor in the light water lattice is about 1.] One significant feature in this respect is the fact that the migration length in the light water lattice is about half of the migration length in the heavy water lattice. This tends to shift the balance of the heat production between light water lattice and heavy water lattice in favor of the light water lattice. This may be illustrated for instance by considering a composite system which has a spherical shape. In the core there is a heavy water lattice with the radius $r = R$ surrounded by a light water lattice between $r = 1R$ and $r = 2R$. Writing then q_1 and q_2 for the number of fission neutrons produced per cc and sec in the heavy water lattice and in the light water lattice respectively, q obeys in the interior of the media the equations

$$M_1^2 (rq_1)'' + (k_\infty - 1)(rq_1) = 0$$

$$M_2^2 (rq_2)'' + (k - 1)(rq_2) = 0$$

We may derive from this the ratio of the heat produced in the light water lattice and in the heavy water lattice without entering into a discussion of the boundary condition which connects q_1 and q_2 at $r = R$. Whatever that boundary condition may be the flux of neutrons leaving the heavy water lattice at $r = R$: $\left[4\pi R^2 M_1 q_1'(R)\right]$ is equal to the flux of the neutrons entering the light water lattice at $r = R$: $\left[4\pi R^2 M_2^2 q_2'(R)\right]$. Obviously in both media the ratio of the total number of fissions/sec (given by the integral of q over the volume) to the flux at $r = R$ is determined by the shape of $q(r)$ alone and since the flux is the same for both media the ratio of the above mentioned ratios will give the ratio of the total number of fissions/sec in the light water lattice and the heavy water lattice. In this way we obtain in the absence of a reflector and if $k = 1$ for the light water lattice:

$$\frac{\text{Fission in } H_2O}{\text{Fission in } D_2O} = \frac{1}{3}\left(\frac{M_1}{M_2}\right)^2 (aR)^2 \text{ where } a = \sqrt{\frac{k_1 - 1}{M_1^2}} \qquad (1)$$

The value of aR for which the composite system is capable of sustaining a chain reaction and which has to be inserted in the above formula (1) cannot be given with certainty at the present time. (If we knew the correct boundary condition linking q_1 to q_2 at $r = R$ we could give for aR its correct value, on the basis of diffusion theory.) However, we know in any case that the highest value which aR can attain is π (if

all neutrons escape from the heavy water lattice at r = R) and that the lowest value for aR which in the circumstances might be expected would be about $\pi/2$. Making a rough guess in the present case by putting aR = 2 we find on account of $\frac{M_1^2}{M_2^2} = 4$

$$\frac{\text{Fission in } H_2O}{\text{Fission in } D_2O} = \frac{1}{3} \frac{M_1^2}{M_2^2} (aR)^2 = 5.3$$

i.e., 5.3 times as much fission takes place in the ordinary water as in the heavy water and therefore 6.3 times as much fission takes place in the whole unit than in the heavy water core alone.

If we now wish to compare such a composite unit with an ordinary heavy water unit from the point of view of the amount of heat that can be extracted per ton of heavy water, we must keep in mind that this value is determined not by the average value of $\bar{q}$ in the heavy water but rather the maximum value q_o in the center of the arrangement. Our composite unit is in this respect about twice as favorable as the ordinary heavy water unit (for which $q_o/\bar{q}$ is about 3) and therefore for equal average density of metal in the heavy water in the two types of units we may expect 2 x 6.3 = 12.6 times as much heat per m^3 of heavy water from a composite unit than from an ordinary heavy water unit. If the volume ratio in the heavy water in the composite unit is chosen to be 15 to 1 and we compare such a composite unit with an ordinary heavy water unit where the volume ratio of heavy water to metal is 30 to 1, we gain another factor of 2 so that about 25 times as much heat can be dissipated per m^3 of heavy water in the composite unit.

For instance, Young estimated (see report CE-1034) for an ordinary P-9 unit containing 10 tons of heavy water and 6 tons of metal (volume ratio 33:1 rather than 30:1) that he could dissipate 50,000 kw. He assumed a film drop of 40° C, a ratio of $\frac{q_o}{\bar{q}} = 2.5$ (rather than $\frac{q_o}{\bar{q}} = 3$), uranium rods of 1 cm radius, and a water velocity of 10 meters. Our composite unit having in the heavy water core a volume ratio of 15 to 1 would dissipate per ton of heavy water $25 \times 2.5/3 \times 33/30 \sim 23$ times more heat than Young's unit per m^3 of heavy water, i.e., $23 \times 5000 = 115{,}000$ kw/m^3 D_2O. Such a composite would have per m^3 of heavy water 20/15 tons of metal in the core. In the light water lattice we may have 1/3 of the volume occupied by metal or 5 times more metal per unit volume than in the heavy water and the light water lattice has 7 times the volume of the core; therefore the total weight of metal per m^3 D_2O is $(5 \times 7 + 1) \frac{20}{15} = 48$ tons. 115,000 kw would thus be produced in the composite units per 48 tons of uranium metal.

Role of Reflector.--Mr. Friedman and I have been discussing the fact that a light water lattice may be expected to respond much more favorably to a reflector than a heavy water lattice. This is due to the high average metal density in the light water lattice leading to a strong absorption for thermal neutrons which keeps the leak of thermal neutrons into the reflector down to a low value. This effect is so pronounced that we may consider using bismuth or even lead as a reflector outside the light water lattice. Mr. Feld and I made a rough estimate for a bismuth and lead reflector which looks quite favorable.

The effect of the reflector can be represented by a length, P. P is defined as the number of neutrons which leak out 1 cm^2 of the boundary of the light water lattice if one fission neutron is produced per cc and sec near the boundary within. As a rough guess for the value of P which we can attain we shall use the value of P = 2 cm.

We may now consider a spherical composite unit of radius 2R with a heavy water lattice core extending to r = R and a reflector surrounding this composite unit. Mr. Feld and I find for the total number of fission in such a composite unit per unit volume of heavy water and for q_o neutron produced per cc and sec in the center

$$\frac{\int q \, d\tau}{q_o \frac{4\pi}{3} R^3} = \left[\frac{M_1^2}{M_2^2} \left(1 + \frac{7}{\frac{4RP}{M_2^2}}\right) + \frac{3}{(aR)^2} \right] \left(\frac{\sin aR}{aR} - \cos aR \right)$$

for a reasonable set of values, i.e.: $\frac{RP}{M_2^2} = 2$ and $aR = 2$; this gives

$$\frac{\int q \, d\tau}{q_o \frac{4\pi}{3} R^3} = 7.2$$

The corresponding expression for a non-composite P=9 unit with same reflector may be about $\frac{1}{2.5}$, so that if a reflector is used the composite unit can dissipate 2.5 x 7.2 = 18 times as much heat per m^3 D_2O than the non-composite unit for the same metal to D_2O ratio in the heavy water lattice in both types of units. This has to be compared with the value 12.6 for the reflectorless composite unit so that we may expect to improve the utilization of D_2O and uranium metal by a factor 18/12.6 = 1.4 by using a reflector. This would then correspond in the example given above to 1.4 x 115,000 = 160,000 kw per m^3 D_2O

and 48 tons of metal.

Practical Considerations.--The above given rates of power production of 115,000 and 160,000 kw per 48 tons of metal for spherical composite units without and with reflector are unnecessarily high and no useful purpose would be served to aim at such a high rate of power production. It appears reasonable to aim at a lower specific power production and to put the emphasis on simplicity of construction and safety of operation. In order to increase the safety of operation more conservative figures ought to be chosen than those upon which Young based his estimate in report CE-1034 and which we have used above for the sake of having a basis of comparison. For the sake of the simplicity of the construction one will not build spherical composite units but rather cylindrical units in which the heavy water core goes all the way from top to bottom. This will require more heavy water than would a spherical composite unit. Certain types of construction offer considerable advantages but do not permit to reach as high velocity of the cooling water in the heavy water core as in the light water lattice. This further reduces the amount of heat which can be dissipated per ton of metal.

Practical considerations of this type are the reason why the estimates given for the heat dissipation in the first two pages of this letter are considerably lower than the figures obtained by the above simple considerations. A rough guess for such a composite unit of a certain type of construction might be as follows: Diameter of cylindrical heavy water core, 70 cm; diameter cylindrical composite unit without reflector, 250 cm; diameter of composite unit with reflector, 350 cm; height of composite unit, 300 cm; amount of metal in

heavy water core, 2 tons; amount of metal in light water lattice, 90 tons; amount of cooling water in heavy water core, 5% of the heavy water; average metal density in heavy water core, 1/15 of the density of uranium metal; average metal density in the light water lattice, 1/3 of the density of uranium metal; velocity of the cooling water, 7 meters. Fraction of water moving, 1/2; volume of flow, 10 m^3/sec.

The above figures represent, insofar as the critical condition is concerned, nothing but an exceedingly rough guess giving approximate conditions for the composite unit. It would be comparatively easy if it is decided to move in this direction, to make a much better estimate of the critical condition on the basis of available evidence. We need not wait, however, for these data in order to proceed with this work. Clearly the determining considerations are considerations of constructional and operational simplicity and not the exact critical conditions. Since constructional considerations go beyond the scope of the present letter they will be dealt with at another place.

The major weakness of this composite unit consists in the fact that it is necessary to pump through the light water lattice a large volume of water in order to have the high velocities needed for good heat transfer. If a heat exchanger is used this means that a large volume has to be circulated through the heat exchanger. If no heat exchanger is used then it appears best, as discussed before in a similar case, to have a parasitic or shunt circulation so that the fresh water influx and water outflow is a small fraction of the total circulating

water volume. This has the disadvantage that the temperature of the water in the lattice will be comparatively high. The difficulty arising out of this situation does not, however, appear to be too serious.

Leo Szilard

LS:ls

b.b.s, -1

EPW-83

SECRET

May 23, 1944

Mr. S. K. Allison

Mr. E. P. Wigner

I am enclosing a memorandum of Mr. Szilard's on the method for purifying Plutonium, about which we spoke this morning.

As I mentioned this morning, it seems to me that it would be worthwhile doing some research on Mr. Szilard's method. He suggested that as a first step, two low melting materials such as bismuth and lead could be separated, and I wish to submit this to you for consideration.

EPW:jjp
enc.

E. P. Wigner

cc-LS

SECRET

THE UNIVERSITY OF CHICAGO

DATE May 20, 1944

TO Mr. E. P. Wigner DEPARTMENT

FROM Mr. L. Szilard DEPARTMENT

IN RE: Peristaltic method for purifying plutonium

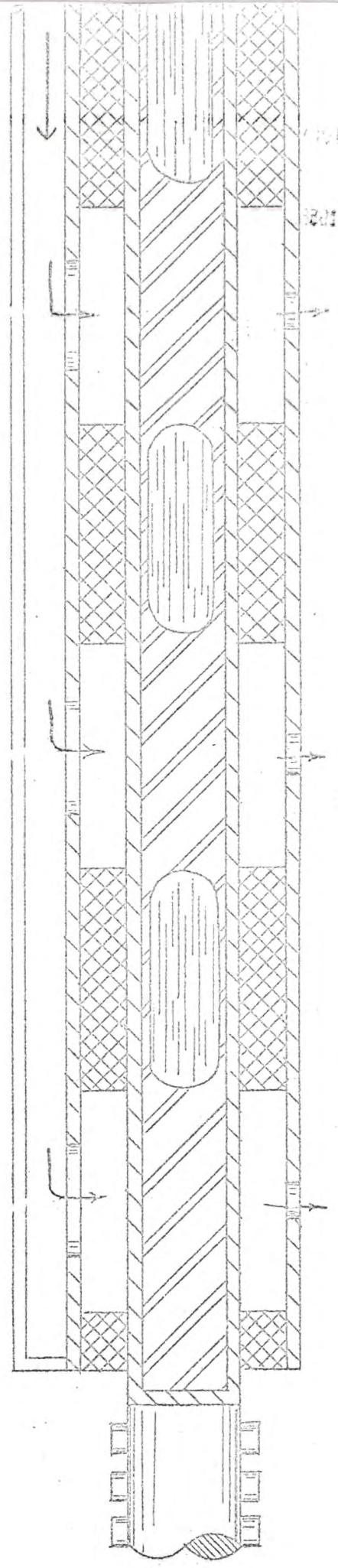
I wish to submit to your kind scrutiny the following method for purifying plutonium which is a sort of a "peristaltic" method.

A long tube of tantalum is filled with plutonium. The plutonium may be, for instance, internally heated by sending alternating current through it. If so heated the plutonium adjacent to the tantalum may always be frozen so that we can avoid having liquid plutonium in contact with the wall. The cooling through the tantalum wall is arranged in a periodic manner so that if one moves along the axis of the tube from left to right one subsequently encounters frozen and liquid sections of plutonium in the interior of the tube. The cooling is so arranged that these alternate solid and liquid sections are not stationary but move from left to right vaguely reminiscent of a peristaltic motion. The speed of this peristaltic motion can be made high provided that the ~~liquid~~ plutonium in the liquid pockets or sections is kept in lively circulation. This can for instance be achieved by keeping the tube rotating around its axis. Under the action of the gravitational field created by this rotation the liquid adjacent to the solid sections will move radially outward and will move in the center of the liquid section radially inward. Impurities which have a solubility appreciably higher in the liquid phase than in the solid phase will move to the right and are transported to the right end of the tube. If the solubilities were reversed the foreign substance would move to the left of the tube.

The attached figure indicates the principle of such a "peristaltic" apparatus. The cooling is effected by a cooling agent, for instance air, which according to the figure is permitted to come into contact with alternate sections of the tube, the sections in between being protected from contact with the cooling liquid. The whole cooler can slide on the tubes and it moves slowly from left to right until displacement corresponds to one identity period. Then the cooler tube suddenly jumps back to its original position and again moves slowly to the right, etc.

Leo Szilard

ls/s
enc.



SECRET

Asynchronous and Synchronous Transformers for Particles.

The invention concerns methods and apparatus for the production of fast charged particles, e.g. electrons or protons. All these methods, described below, are based on multiple acceleration, i.e. the velocity of the particle is exceeding the maximum voltage which arises between any two parts of the apparatus. We shall have to deal with two different methods - the method of the asynchronous transformer, and the method of the synchronous transformer. In the first case we shall deal with single action and multiple action transformers, and we shall start by dealing with the asynchronous transformer method which is based on the acceleration of a charged particle in the electric field induced around ~~the~~ a changing magnetic flux.

Fig. 1 shows the principle of a method in which a magnetic flux is produced in an iron core 1, and the flux is rapidly changing its magnitude. This flux is produced by means of through the coil 2, this coil being built so as to consist of one or two windings only, and a rapidly changing electric current being sent through the coil ~~xxx~~ 2. If an electron encircles in its path several times the iron core while the flux in the core is changing its value the energy of the electron will increase at each revolution. The value of this increase in energy is determined by the

November 13, 1944

TO: Mr. E. P. Wigner

FROM: Mr. L. Szilard

You asked me how the tentative draft of a patent application came about which was repeatedly mentioned to you in the last few days by the O. S. R. D. Patent Division. The answer is as follows:

Captain Lavender asked me in 1943 to write down inventions made by me before November 1940 in the form of a draft of a patent application. The purpose of this draft was to enable Captain Lavender to investigate the value of my alleged inventions to the Government. Captain Lavender told me that he would have to investigate the validity of my claims and determine their value for the Government and that consequently I should write into that draft anything which I might consider as an invention made by me before November 1940. Practically the only written document which I had prior to November 1940 was the manuscript which I sent to the Physical Review, which is essentially identical with Report A-55. I therefore made a draft essentially based on A-55 and sent this to Captain Lavender.

After I signed the agreement transferring my inventions to the Government in December 1943, I suggested to Col. Metcalf that they prepare a joint patent application with Fermi or with yourself and Fermi as co-inventors. The draft of such a proposed patent application was submitted to me about three months ago and was dealt with by correspondence with Captain Lavender. I am inclosing the text of this correspondence for your information. Please return the inclosure to me after you have read it. If you wish I could let you have a copy of this correspondence.

LS:ls

Attached
Draft of a Patent Application
dated May 26, 1943

III bs 3

December 1, 1944

Mr. H. G. Hawkins, Jr.
U. S. Engineer Office
War Department
Chicago Area Office
P. O. Box 6140A
Chicago 80, Illinois

Dear Mr. Hawkins:

As I explained to you over the telephone, it is my intention to ask for an audit of my income tax return for 1944 immediately after filing this return. In order that the audit should be binding on the Treasury it is necessary for me to submit the text of my contract with the Government. I am advised that unless the Treasury can see the text, they cannot determine whether or not the amounts which I am about to receive from the Government are taxable as capital gain or as income nor are they able to determine in what years these amounts would be taxable.

In the circumstances I need from your office an expurgated copy of my agreement with the Government which is not secret, accompanied by a letter stating that this copy is identical with the original agreement with the exception of certain deletions and that the nature of the deletions is such that they have no bearing on any tax question that might arise in connection with the agreement.

I am advised that it is not possible to determine with certainty the Treasury's view of my tax liability which arises out of the agreement with the Government and that if I do not ask for an audit now, it might turn out years later that the Treasury does not accept my interpretation, in which case it is mandatory for the Treasury to ask for interest at the rate of 6% per annum. I am sure you will understand that I do not wish to take the risk of being called upon to pay a large additional sum plus interest three or four years hence as might be the case if I do not ask for an audit now.

Very truly yours,

Leo Szilard

LS:ls

2-559

SECRET

No. 1

This document consists of 1 page
No. 1 of 2 copies, Series A.

III bs 3

X

Metallurgical Laboratory

P.O. BOX 5207
CHICAGO 80, ILLINOIS

MUC PA 7513

28 December 1944

BUTTERFIELD 4300

NPD

Dr. Leo Szilard
330 Eckhart

Re: Case No. S-2321
Fermi & Szilard

Dear Dr. Szilard:

Your patent application identified above has been filed in the United States Patent Office. You no doubt will receive from the Patent Office a notice of issuance of an order of Secrecy under Public Law 700 requesting that the application be tendered for the use of the United States Government. You will also receive a receipt to be filled in and returned to the Patent Office.

Kindly execute and return the receipt to the Patent Office. Do NOT tender the invention in this application to the Government as requested by the notice, as you have already assigned the invention to the Government as represented by the Director of the Office of Scientific Research and Development.

Please send the request for tender to me for transmission to Captain Lavender's office in Washington. A tender by you to some other Government agency would only complicate matters in view of the fact that you have already assigned the invention to the Government.

Very truly yours,

H. E. Metcalf

H. E. Metcalf, Lt. Col. C.E.
Advisor on Patent Matters
O.S.R.D., Chicago Group

gma

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