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FAST NEUTRON FISSION OF U^{238} AND THE PRODUCTION OF ELEMENT 94^{239} FROM U^{238}

(Preliminary Report)

L. Szilard

March 26, 1943

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The possibility of burning U^{238} in the chain reaction by way of its conversion into element 94^{239} was first mentioned by Turner in the spring of 1940. Turner thought that if uranium enriched in U^{235} were used in a chain reacting system in which the neutrons are slowed down by water the transformation of U^{238} into element 94^{239} might compensate for the loss of U^{235} through fission and the chain reaction might be kept going, burning in the long run essentially U^{238}.

If the number of neutrons emitted in the fission of element 94 is about 2.2, this would not be sufficient to permit the use of Turner's idea in its original form for the production of element 94 from U^{238} after the initial quantity of U^{235} is exhausted. However, by making use of the fast neutron fission in U^{238} in a lattice of uranium spheres of more than 8 cm radius or in a lattice of cylindrical rods of a correspondingly large diameter, we might, in a graphite system, perhaps reach a net gain of .3 atom of 94 per thermal fission in U^{235} or 94. This means that after the initial stage in which 235 is used up and 94 is produced, the reaction would settle down to a production of about .3 atom of 94 per thermal fission of an atom of 94 or that .3 kg of 94 per day would be produced if the reaction is kept going at the rate of somewhat over one million kw. The use of such large uranium spheres or rods would involve the use of a gap geometry to avoid too great impoverishment of

the thermal neutrons near the uranium and would also involve a long range stabilization of the chain reaction which is based on the increase of the uranium-carbon ratio with increasing enrichment in 94. Otherwise the construction could follow previously discussed patterns and there seems to be no need to go into further details at the present time.

The purpose of the present memorandum is rather to discuss a method for producing 94 from U^{238} which is based on a fast neutron chain reaction in uranium that is either enriched in U^{235} or enriched by the addition of a certain quantity of 94^{239} to the point at which we have a composition that is capable of maintaining a chain reaction without the use of slowing down agents.

Such a fast neutron chain reaction can be stabilized almost as conveniently as a chain reaction in a graphite-uranium system. One way of stabilizing the chain reaction is to make use of the fact that a liquid alloy of bismuth and lead for instance if introduced in sufficient amounts into the chain reacting units will slow down by inelastic collisions an appreciable fraction of the neutrons below the fission threshold of U^{238}. The attached figures 4A and 4B illustrate such a control system which consists of a number of communicating tubes going vertically through the chain reacting unit which are connected by means of one or more electrodynamic pumps to tanks outside the chain reacting unit. By raising or lowering the level of the bismuth-lead alloy within the chain reacting unit, the multiplication factor of the unit can be changed.

The time of response of the control is fortunately independent of the life time between two successive generations of instantaneously emitted neutrons and is determined solely by the delayed neutron emission as long

as we remain close above the critical conditions of the chain reacting unit. This dominant role of the delayed neutron emission with respect to the time within which the controls have to respond had been recognized since the very first beginnings of our work and was responsible for our continued interest in the fast neutron reaction for purposes of power production.

The chain reacting unit can be built in the form of a lattice of uranium rods of about 1 cm diameter. One such rod is shown in Fig. 1 and the lattice structure is indicated in Fig. 2. 12, 13 and 14 in Fig. 3A show how these uranium rods are mounted in the chain reacting unit. Figs. 3A and 3B show the chain reacting unit. Helium at a high pressure or a bismuth-lead alloy can be used as a cooling agent and the flow of the cooling agent is indicated by arrows in Fig. 3A.

If uranium enriched in U^{235} or enriched by the addition of element 94^{239} is used and if the composition is so chosen to have a multiplication factor in an infinite system of about 1.1 the conditions are about as follows:

Slightly above two neutrons are emitted in the fission process of U^{235} or 94. For every atom of 94 which undergoes fission about $\frac{1}{2}$ atom of U^{238} undergoes fission by fast neutron fission process which contributes on the average about one neutron. In these circumstances about three neutrons are liberated for one atom of U^{235} or 94 which disappears. Of these three neutrons one neutron is required to carry on the chain and the two remaining neutrons are utilized to form two atoms of 94 from U^{238}. One of these two atoms just compensates for the loss of the original atom of U^{235} or 94 which underwent fission and the remaining atom of 94 can

be considered as net gain. If the outer layers of the chain reacting units are composed of natural uranium, there is practically no loss of neutrons through leakage. Thus 94 may be produced at the rate of about 1 kg of 94 per day if the chain reaction is maintained at a rate of 1.5 million kw.

[365 16 A]

L. Szilard
November 18, 1943

Remarks to the Enclosed Preliminary Report of March 26, 1943. "Fast Neutron Fission of U-238 and the Production of Element 94-239 from U-238."

The enclosed preliminary report deals mainly with a power unit based on a fast neutron chain reaction in a large mass of uranium metal, having uranium enriched by addition of element 94 in the core of the power unit. Since the enclosed preliminary report was written, experiments were performed which allowed us to give a better estimate for the liberation of neutrons from U-238 by means of fast fission neutrons. On the basis of these experiments which were carried out with Ra-B neutrons, it is now estimated that in a mixture of U-238 and element 94, we obtain about 1.185 neutrons from U-238 for every neutron emitted from element 94. This value holds for the limit of very low concentration of element 94 only, and would be somewhat lower for the concentrations which are required. If we now assume that two neutrons are emitted by fission from element 94, we obtain a total of 2.37 neutrons for every atom of 94 which is destroyed. Of this number, 1 neutron is needed to carry on the chain, 1 neutron must be allowed to reproduce one atom of 94 and since some slight absorption of neutrons may be encountered in constructional parts, we may thus be left with .3 neutrons which may be allowed to leak out of the enriched mixture in the center of the chain reacting unit and be absorbed in the outer layers of the chain reacting units which consist, to start with, of natural uranium. Clearly, if we want the 94 fully to reproduce in the inner enriched core of the chain reacting unit, we will have to keep the multiplication factor in that enriched material down to less than about 1.15. The necessity for doing this rules out the possiblity of having small sized power units with a very highly enriched core of uranium surrounded with outer layers of natural uranium.

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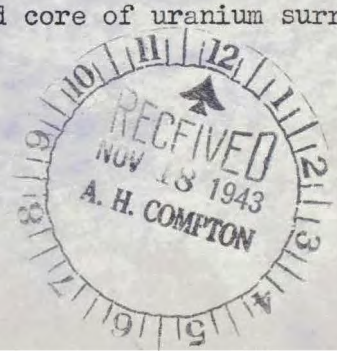

Clearly, in such a small power unit, the enriched small core would have a large multiplication factor, and therefore there would be a great leak of neutrons from the core of the power unit, a rapid loss of 94 in the core, and a corresponding increase of 94 in the non-enriched outer layers of the power unit. Such a power unit, after a certain time of operation, would then stop operating and the ~~uranium~~ 94 contained in it would have to be subjected to a chemical separation in order to redistribute ~~the 94~~ it in the power units. This is undesirable and we have therefore rather considered power units which operation with a mixture that has a low multiplication factor, and accordingly will require several hundred kg of 94 ~~will be required~~ for the enrichment of the correspondingly large core.

While under conditions like these the fast neutron reaction can be used as described in the attached preliminary report for the large scale production of power from U 238, it does not seem to be a very practical method for producing an excess of element 94. It would, therefore, not be easy to use such power units for producing enough 94 in excess of the 94 destroyed to be able to set up additional power units by means of the 94 produced. If the number of neutrons emitted by 94 per fission were larger than ~~two, it would, of course, improve the~~ 2 chances of producing, in an industrially economical manner, 94 from U-238 would be correspondingly improved. —

Clearly, in such a small power unit, the enriched small core would have a large multiplication factor, and therefore there would be a great leak of neutrons from the core of the power unit, a rapid loss of 94 in the core, and a corresponding increase of 94 in the non-enriched outer layers of the power unit. Such a power unit, after a certain time of operation, would then stop operating and the 94 contained in it would have to be subjected to a chemical separation in order to redistribute it in the power unit. This is undesirable and we have, therefore, rather considered power units which operate with a mixture that has a low multiplication factor, and accordingly, will required several hundred kg of 94 for the enrichment of the correspondingly large core.

Using the figure obtained from experiments with boron neutrons of 1.185 neutrons liberated from U^{238} for every fission neutron, and using a value of 2 for the number of neutrons emitted per fission of an atom of element 94, we would obtain, at the most, .37 excess neutron which, if absorbed in U^{238} will thus produce and excess of .37 atom of 94 for every atom of 94 which undergoes fission and is ~~replaced by a new atom of element 94 produced~~ at the same time regenerated from U^{238}. Therefore, about three (1.1/0.37=3) fission processes will occur for every atom of 94 which is produced in excess and thus we would have to dissipate about 3 million kw in order to produce 1 kg of 94 pr day. These values are less favorable for the production of 94 than the values given in the report dated March 26, and the change in our forecast is (mainly) due to the values obtained in the study of the fast neutron fission of U^{238} by means of Ra-B neutrons.

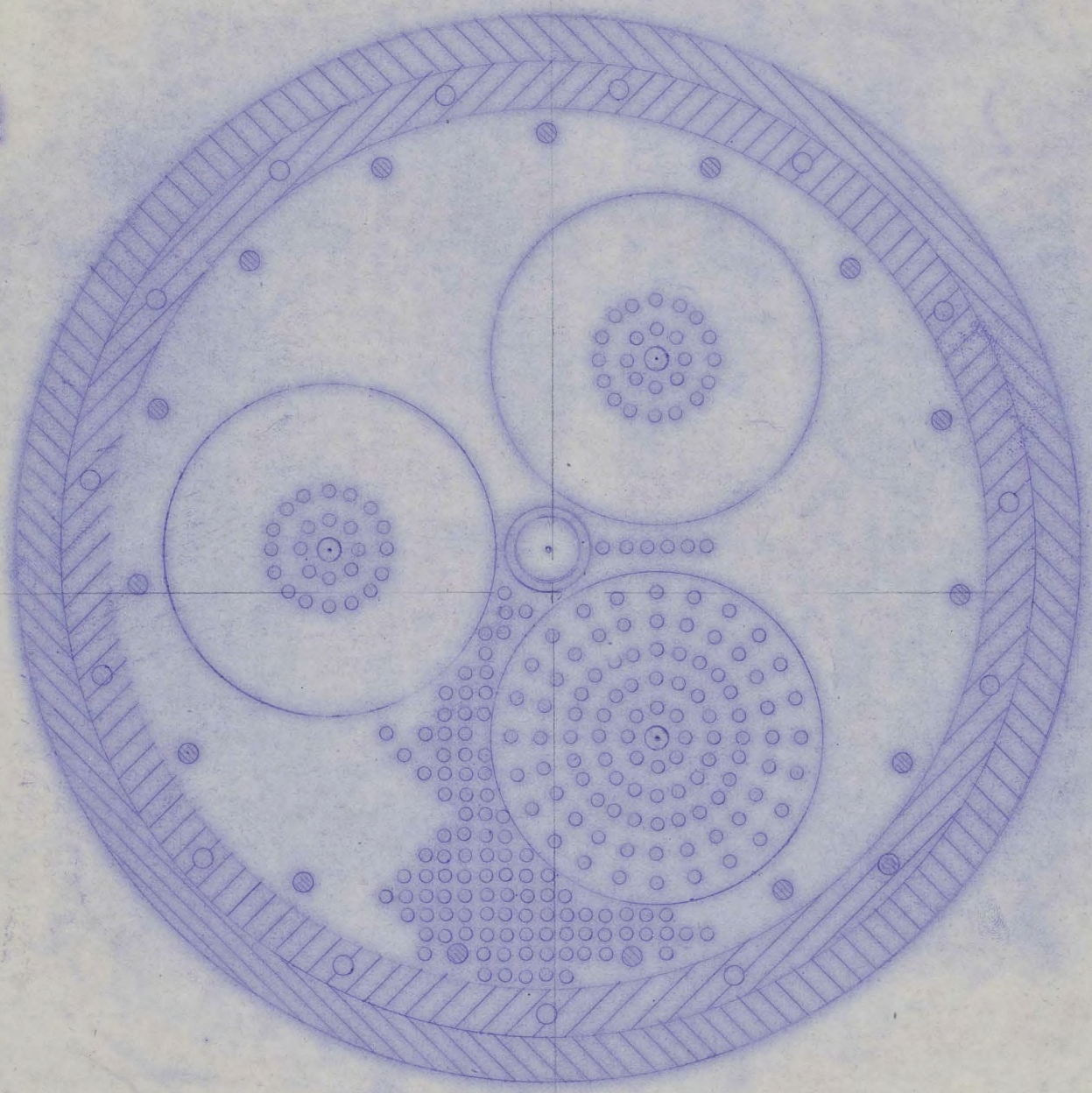

Fig. 1

Top

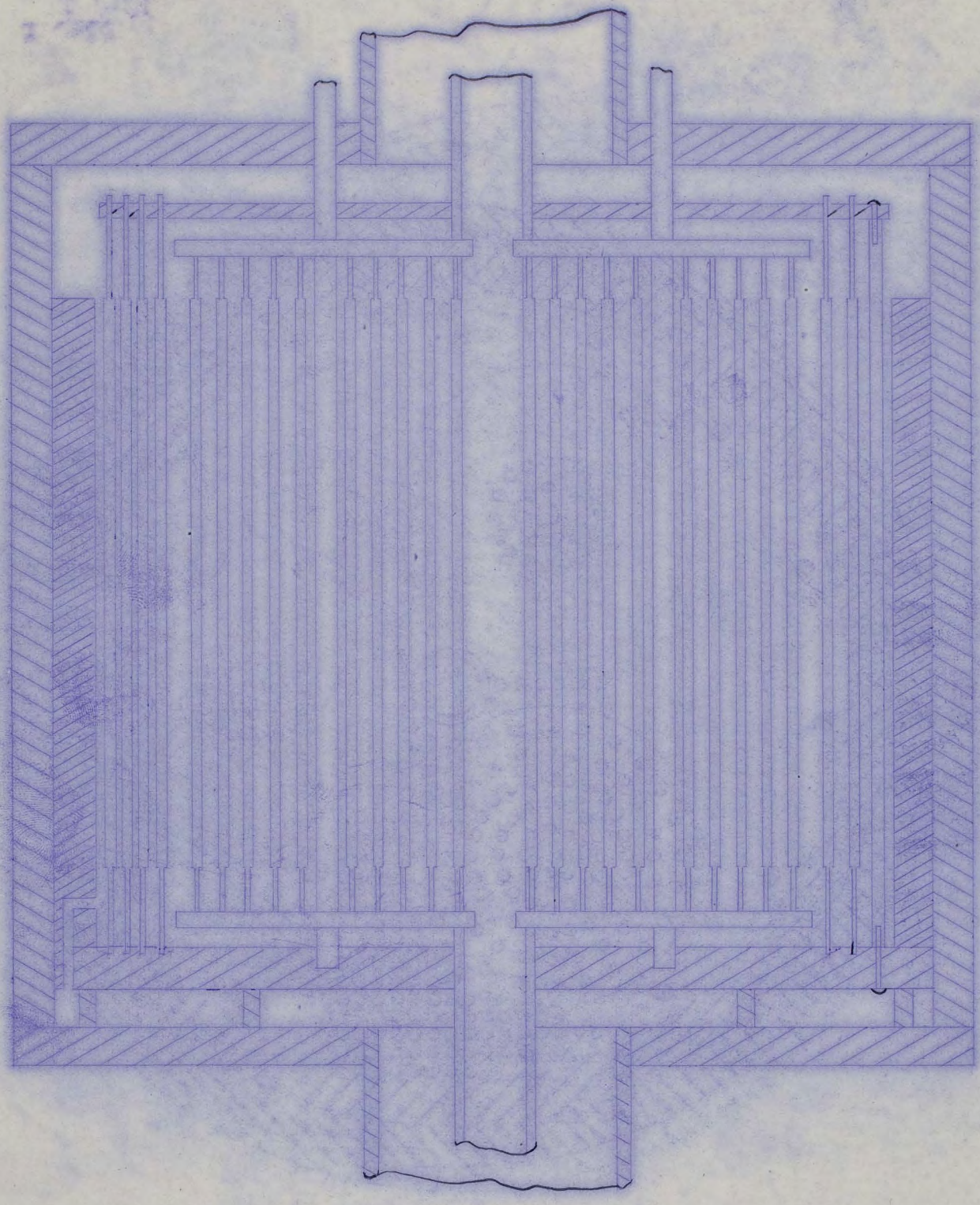

Fig. 2

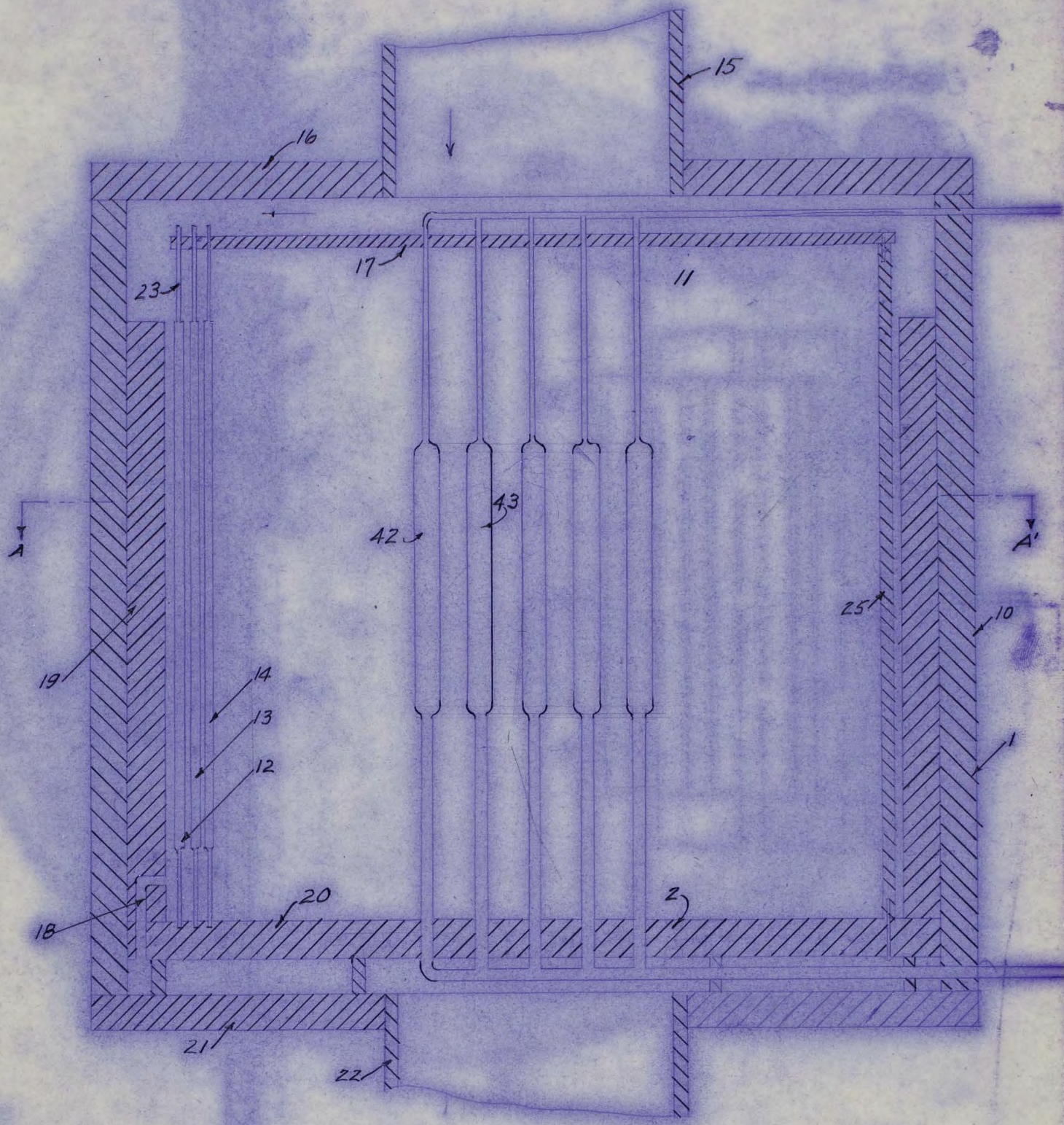

FIG. 3a

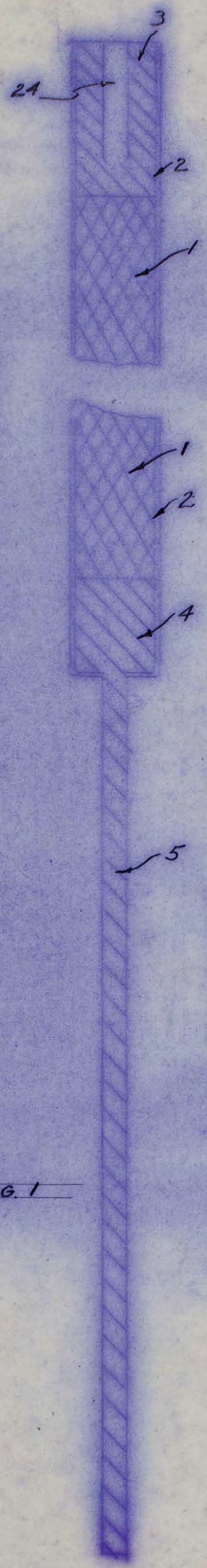

FIG. 1

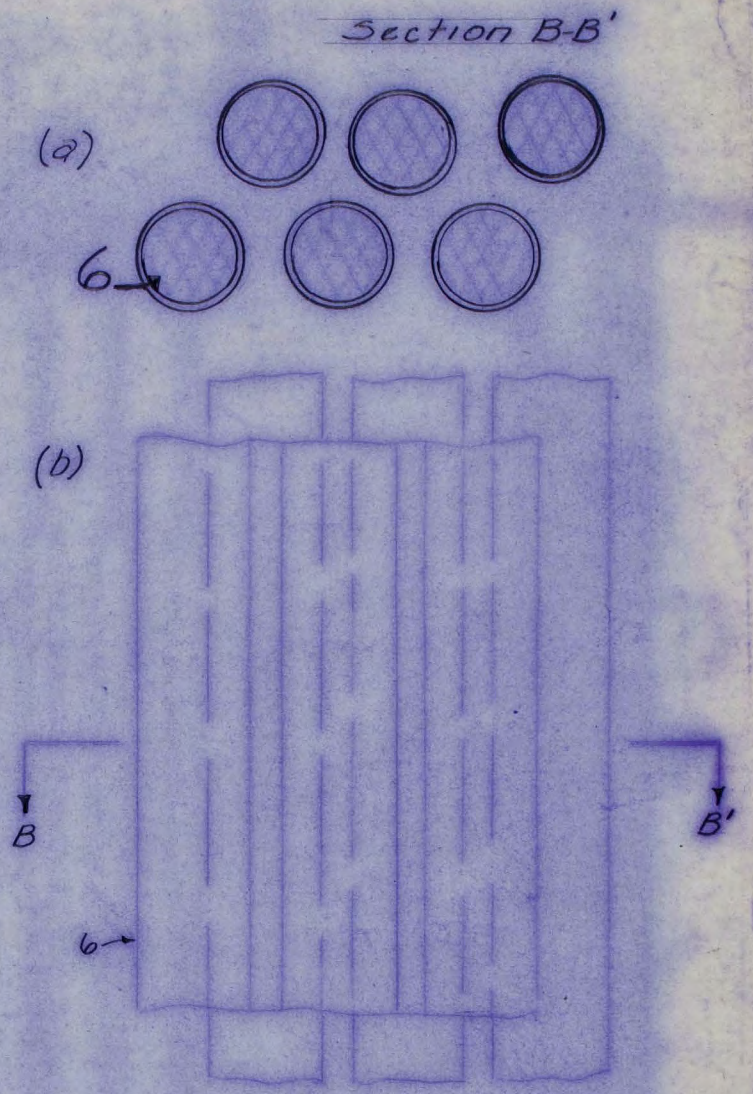

FIG. 2

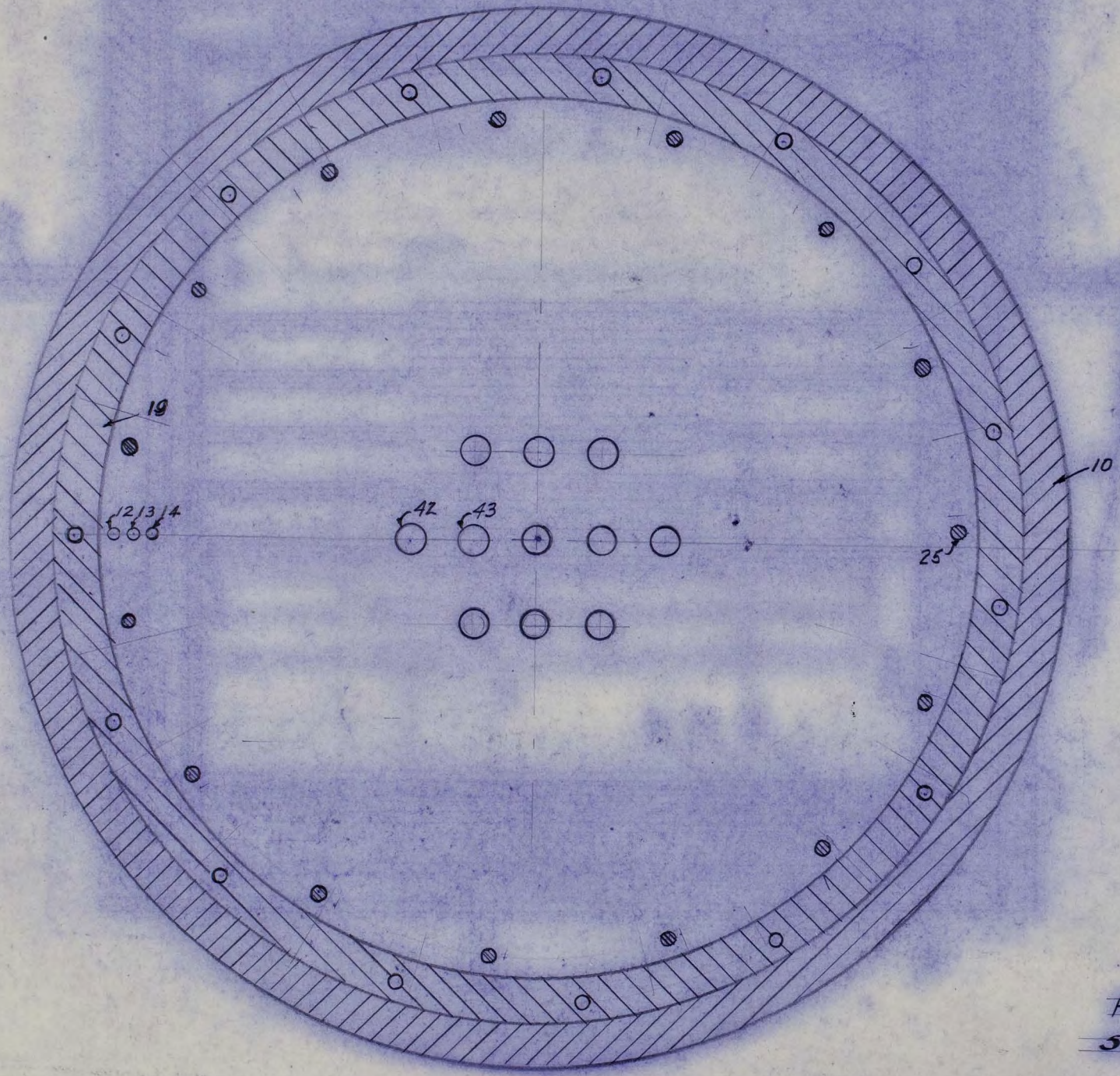

FIG 3b
Section A-A'

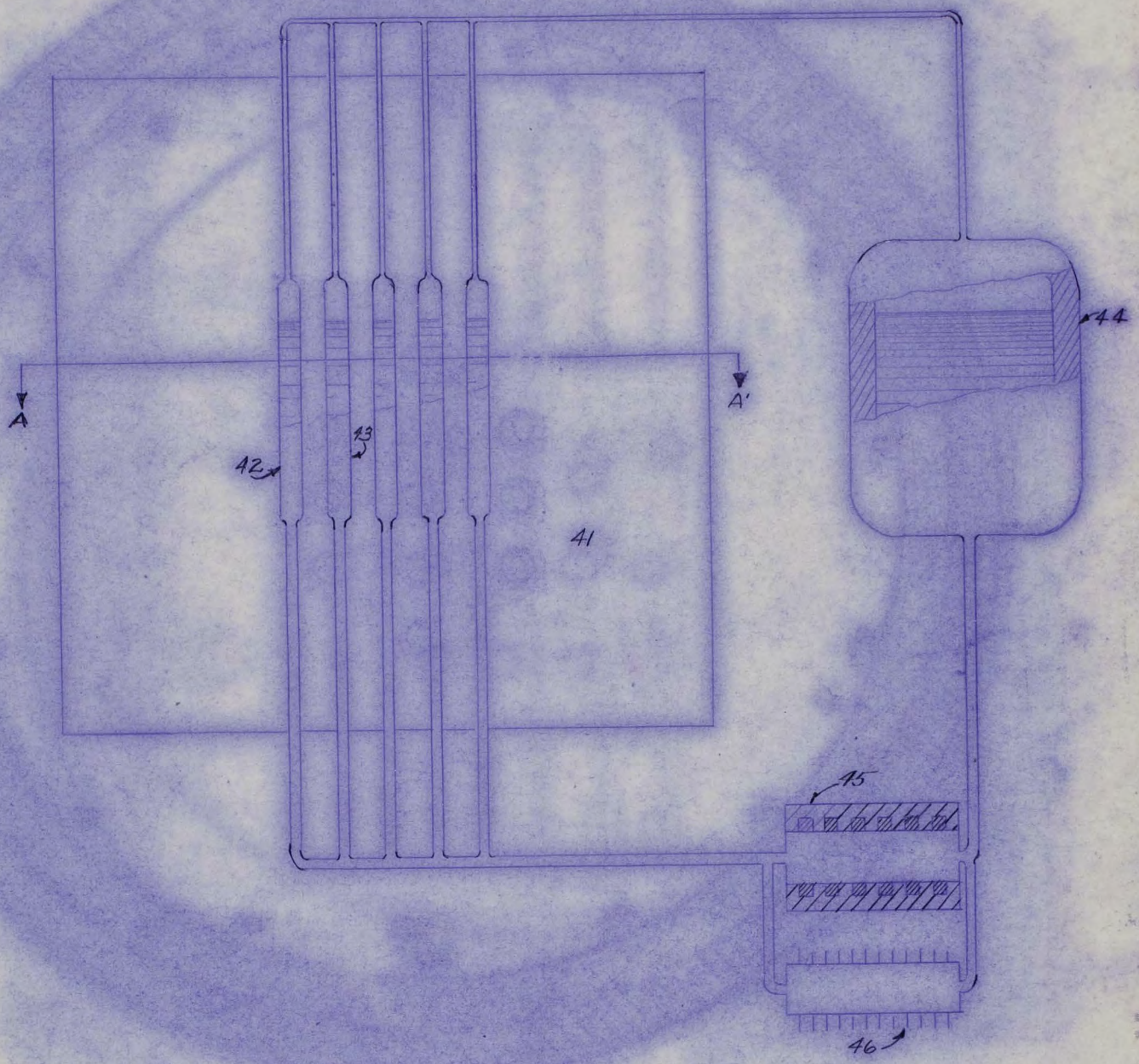

FIG 4a

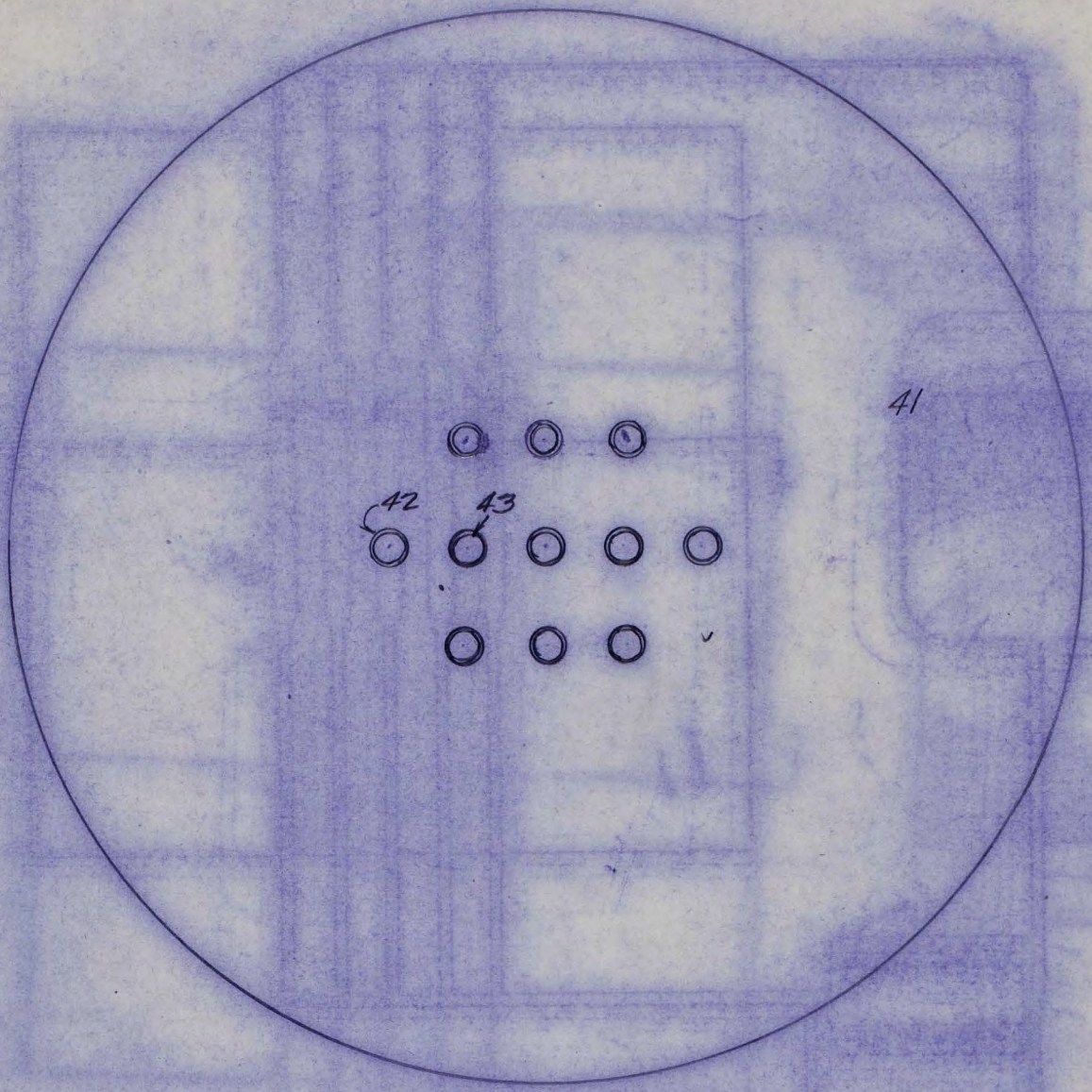

FIG 4b Section A-A'

FAST NEUTRON FISSION OF U^{238} IN THE PRODUCTION OF ELEMENT 94^{239} FROM U^{238}

(Preliminary Report)

L. Szilard

March 26, 1943

The possibility of burning U^{238} in the chain reaction by way of its conversion into element 94^{239} was first mentioned by Turner in the spring of 1940. Turner thought that if uranium enriched in U^{235} were used in a chain reacting system in which the neutrons are slowed down by water the transformation of U^{238} into element 94^{239} might compensate for the loss of U^{235} through fission and the chain reaction might be kept going, burning in the long run essentially U^{238}.

If the number of neutrons emitted in the fission of element 94 is about 2.2, this would not be sufficient to permit the use of Turner's idea in its original form for the production of element 94 from U^{238} after the initial quantity of U^{235} is exhausted. However, by making use of the fast neutron fission in U^{238} in a lattice of uranium spheres of more than 8 cm radius or in a lattice of cylindrical rods of a correspondingly large diameter, we might, in a graphite system, perhaps reach a net gain of .3 atom of 94 per thermal fission in U^{235} or 94. This means that after the initial stage in which 235 is used up and 94 is produced, the reaction would settle down to a production of about .3 atom of 94 per thermal fission of an atom of 94 or that .3 kg of 94 per day would be produced if the reaction is kept going at the rate of somewhat over one million kw. The use of such large uranium spheres or rods would involved the use of a gap geometry to avoid too great imp

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of the thermal neutrons near the uranium and would also involve a long range stabilization of the chain reaction which is based on the increase of the uranium-carbon ratio with increasing enrichment in 94. Otherwise the construction could follow previously discussed patterns and there seems to be no need to go into further details at the present time.

The purpose of the present memorandum is rather to discuss a method for producing 94 from U^{238} which is based on a fast neutron chain reaction in uranium that is either enriched in U^{235} or enriched by the addition of a certain quantity of 94^{239} to the point at which we have a composition that is capable of maintaining a chain reaction without the use of slowing down agents.

Such a fast neutron chain reaction can be stabilized almost as conveniently as a chain reaction in a graphite-uranium system. One way of stabilizing the chain reaction is to make use of the fact that liquid alloy of bismuth and lead for instance if introduced in sufficient amounts into the chain reacting units will slow down by inelastic collisions a fraction of theneutrons below the fission threshold of U^{238}. The attached figures 4A and 4B illustrate such a control system which consists of a number of communicating tubes going vertically through the chain reacting unit which are connected by means of one or more electrodynamic pumps to tanks outside the chain reacting unit. By raising or lowering the level of the bismuth-lead alloy within the chain reacting unit, the multiplication factor of the unit can be changed. A similar system of control in case of the uranium-carbon system has been previously described in connection with a bismuth cooled power unit.

The time of response of the control is fortunately independent of the life time between two successive generations of instantaneously emitted

neutrons and is determined solely by the delayed neutron emission as long as we remain close to the critical conditions of the chain reacting unit. This dominant role of the delayed neutron emission with respect to the time within which the controls have to respond had been recognized since the very first beginnings of our work and was responsible for our continued interest in the fast neutron reaction for purposes of power production.

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If uranium enriched in U^{235} or enriched by the addition of element 94^{239} is used and if the composition is so chosen to have a multiplication factor in infinite system of about 1.1 the conditions are about as follows:

Slightly above two neutrons are emitted in the fission process of U^{235} or 94. For every atom of 94 which undergoes fission about $\frac{1}{2}$ atom of U^{238} undergoes fission by fast neutron fission process which contributes on the average about one neutron. In these circumstances about three neutrons are liberated for one atom of U^{235} or 94 which disappears. Of these three neutrons one neutron is required to carry on the chain and the two remaining neutrons are utilized to form two atoms of 94 from U^{238}. One of these two atoms just compensates for the loss of the original atom of U^{235} or 94 which underwent fission and the remaining atom of 94 can

be considered as net gain. If the outer layers of the chain reacting units are composed of natural uranium, there is practically no loss of neutrons through leakage. Thus 94 may be produced at the rate of about 1 kg of 94 per day if the chain reaction is maintained at a rate of 1.5 million kw.

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Fast neutron fission of U^{238} and the production of element 94^{239}.

~~Preliminary~~ Report (Preliminary report)

~~MEMORANDUM ON THE PRODUCTION OF ELEMENT 94^{239} FROM U^{238} in connection with the fast neutron reaction fission~~

L. Szilard

March 25, 1943

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neutrons below the fission threshhold of U^{238}. The attached figures 4A and 4B illustrate such a control system which consists of a number of communicating tubes going vertically through the chain reacting unit which are connected by means of one or more electro-dynamic pumps to tanks outside the chain reacting unit. By raising or lowering the level of the bismuth-lead alloy within the chain reacting unit the multiplication factor of the unit can be changed. A similar system of control in case of the uranium carbon system has been previously described in connection with a bismuth cooled power unit.

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