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MEMORANDUM

On the Cooling of the Power Plant

L. Szilard
June 15, 1942

The purpose of this memorandum is to illustrate by means of the attached sketches certain general principles which ought to be applied in designing a cooling system for a chain reacting uranium-graphite power unit. These principles should universally apply to such systems in which the cooling medium is in direct heat contact with the uranium.

Cooling Media.--Liquid bismuth and helium were the first cooling media to be considered. The latter as well as hydrogen was first suggested by Fermi. These two media appear to be the safest from the point of view of chemical inertness at high temperature. In the case of helium, direct contact between the helium and uranium metal may be permitted. In the case of bismuth, a direct contact between liquid bismuth and uranium oxide or uranium carbide may be permitted, but a direct contact with uranium metal will probably lead to chemical interaction unless the surface of the metal was protected by an inert surface layer.

Other gases which might be considered as cooling agents are hydrogen and air. Hydrogen might be suitable for large power units in dissipating heat of the order of magnitude of 10^6 KW, but the reactions between hydrogen and uranium metal and hydrogen and carbon might limit the temperature range and offset such advantage as hydrogen would otherwise have over helium. Air as a cooling medium is at present being considered only as an expedient in the present emergency. We could have a 30,000 KW unit cooled with air, probably in operation within much shorter time than a helium cooled unit of the same capacity. The only advantage of air over helium lies in the fact that the air need not be passed through a heat exchanger but can be blown out of the plant. The danger of poisoning by radioactive material carried by this air current might however prevent this mode of operation. This question is at present being studied by E. P. Wigner, and action along this line ought to be suspended pending the outcome of his investigation.

<u>General Requirements.</u>--The following mode of operation would be desirable: A power plant producing about 10^6 KW should be allowed to run for a long period of time, perhaps 6 months or longer. Then the chain reaction would be shut off and the cooling would be kept on for another period of time, perhaps one month. After this period the uranium may be dissolved in situ by circulating a solvent through the power unit. If necessary the uranium metal could be burned to uranium oxide in situ before it is dissolved. The solution would be pumped into a tank, and if possible the uranium would be precipitated together with element 94 as peroxide. The remaining solution which would contain most of the fission products could be pumped away. The uranium oxide could be redissolved and reprecipitated several times until it is sufficiently inactive to permit a suitable chemical separation of element 94 from the uranium. In order to prevent the fission products from precipitating in quantity together with the uranium peroxide, it may be necessary to add fairly large quantities of the stable isotopes of the fission products to the solution each time before the uranium is

precipitated as peroxide.

It should be noted, however, that the principles illustrated in the attached sketches are also consistent with a different mode of operation, i.e., the removal of the uranium from the power unit at frequent intervals for the purpose of dissolving the uranium outside the power plant.

<u>Orders of Magnitude.</u>--While it is desirable to have, ultimately, power units which dissipate 10^6 KW, power units dissipating up to 300,000 KW are at present considered as the immediate objective. A structure containing 40 tons of uranium metal in a graphite pile of 6 m x 6 m x 6 m which may have a cubic, cylindrical, or spherical shape, might be necessary to make the power unit operative. The cubic shape of the pile being the least favorable, will in the following be assumed in order to arrive at conservative estimates. The cooling ducts in the pile will be assumed to take up about 10 percent of the cross section of the pile, that is, about 3.6 m^2 out of 36 m^2.

The uranium metal may be present in the form of sticks about 3 mm. in diameter and 5 to 8 cm. long.

It is estimated that such a structure if operated at a friction loss of the cooling medium in the power unit of 3-4000 KW is capable of dissipating the following quantities of power:

1. At 10 atmospheres of helium, 300,000 KW; input 200° C, output 500° C.

2. At 7 atmospheres of helium, 250,000 KW; input 200° C, output 500° C.

3. At one atmosphere of helium, 100,000 KW; input 200° C, output 500° C.

4. At one atmosphere of air, 30,000 KW; input 25° C, output 150° C.

A 30,000 KW helium unit could be operated at atmospheric pressure with a fraction loss of 3-400 KW in the power unit.

Form of Uranium Plugs.--Figure 1 shows various forms in which the uranium metal could be used. Some of these forms are also suitable for fused uranium oxide or fused uranium carbide.

Figures A, B and C show forms which may be called clusters, whereas Figure D shows a short cylindrical block of uranium with a number of holes going axially through the cylinder. Such a uranium block could be cast by using beryllium oxide sticks as cores in the casting process.

Figure 1A is a cluster which has the contour of a cube and which consists of square bars of uranium.

Figure 1B is a cluster which has the contour of a short cylinder of about equal diameter and length. This configuration is easily constructed by bundling together a number of thin sticks of uranium. Sticks of about 3 mm. diameter and 5-8 cm. length, are most likely to prove suitable.

Figure 1C shows a cluster which has the contour of a short cylinder of about equal length and diameter. This cluster may be formed of balls of uranium oxide or uranium carbide. More or less regularly shaped granules can take the place of such balls. In the case of gas cooling the arrangement shown in Figure 1C is less favorable than the arrangement shown in Figure 1B and will be considered only if fused uranium dioxide or fused uranium carbide cannot be obtained in some such shapes as shown in Figures 1A, B, and C. The arrangement of Figure 1C would have no important disadvantage in the case of bismuth cooling from the point of view of friction loss, but it would have disadvantage from the point of view of the multiplication factor.

Double Stream Method.--Figure 3 and 3A show the cooling of the power unit by a double stream method. The gas enters the graphite pile on one side, for instance at the top, and the cold gas flows through ducts designated by 2 into the graphite pile. From duct 2 the gas passes through one or more uranium plugs designated by 4 and the hot gas enters duct 3, which leaves the graphite pile at the opposite side of the pile, for instance, at the bottom. The uranium plugs are located in the graphite column 6 which, if required, can be removed as a whole.

The modification shown in Figure 3A has a greater flexibility than the modification shown in Figure 3. This flexibility is needed to meet the particular requirements of a chain reacting unit. As Wigner repeatedly pointed out, it is necessary to have a cooling system which is adapted to deal with ~~the~~ a specific power production three to four times (according to whether the power unit has a spherical or cubic shape) as large in the center of the power unit as the average value within the power unit. The arrangement shown in Figure 3A makes it possible to have throughout the whole power unit the same temperature increase of the gas when it passes from duct 2 to duct 3. In order to achieve this one has to vary the number of uranium plugs which are connected in series, according to the position which the graphite column 6 occupies in the pile and also according to the position of the particular uranium plugs within the particular graphite column.

In the center of the pile the gas may flow from duct 2 to duct 3 by passing through one single uranium plug and the temperature of the gas may rise during this passage by same value, for instance, 300° C. In another region of the pile where the neutron density is smaller by a factor $1/k$ than in the center we may obtain the same rise of temperature of the gas which passes from duct 2 into duct 3 by passing the gas through n uranium plugs in series.

If the pressure difference between ducts 2 and 3 has the same value for each graphite column 6 and if it does not vary along the column, the velocity of the gas in the plugs will be proportional to $\sqrt{n}$ and in order to have the same temperature of the gas at entrance into duct 3 we have to choose

$$n \approx k^{2/3}$$

L. Szilard

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ON THE COOLING OF THE POWER PLANT

Addition to the Memorandum Dated
June 15, 1942

L. Szilard

June 24, 1942

Correction of Typographical Error on Page 6 of Memorandum Dated June 15, 1942.

The last paragraph of the memorandum should read as follows:

"If the pressure difference between ducts 2 and 3 has the same value for each graphite column 6 and if it does not vary along the column, the velocity of the gas in the plugs will be proportional to $\sqrt{n}$ and in order to have the same temperature of the gas at entrance into duct 3 we have to choose

$$n \approx k^{2/3}$$ ".

Continuation of the Discussion of the Double Stream Method.

Figure 3 B shows an arrangement similar in function to the arrangement shown in Figure 3 A, but differing in construction. The construction shown in Figure 3 B makes it possible to remove the uranium from a graphite column without removing an appreciable amount of graphite. In this figure we see a graphite column having a square cross section and a length which is large compared to the sides of the square, and which may extend if desired throughout the whole graphite pile. This graphite column has three bores, one of them representing duct 2, another of them representing duct 3, and the third bore, in which are placed the uranium plugs 4. The possible constructions for the uranium plugs are shown in Figure 1. Figure 1 B might be the most suitable if uranium metal is used. Perforated graphite plates 9 keep the parts which constitute the uranium plug 4 in position. These perforated graphite plates are similar to the perforated graphite plates shown in Figure 1 C. Between each two uranium plugs 4 we have a graphite rod 5 and a bore in the center of the graphite rod 5 connects two adjacent uranium plugs. Whereas, the example shown in Figure 3 A had groups of three uranium plugs connected in series, and these groups connected in parallel the example shown in Figure 3 B has all uranium plugs connected in parallel. This, of course, will apply only in the center of the pile, and the construction shown in Figure 3 B permits to have groups of several uranium plugs connected in series and the groups connected in parallel as it is necessary to have in other parts of the pile. The cooling agent enters from duct 2 through a bore 8 into the interior of the graphite rod 5, passes through a uranium plug 4 into the interior of another graphite rod 5, and enters through a bore 7, into duct 3. Naturally, the cross section of ducts 2 and 3 will vary along the graphite column, the radius of duct 3 decreasing along the path of the cooling agent while the radius of duct 2 increases correspondingly. If the graphite column is vertical, the graphite rods 5 and the uranium plugs 4 will simply fall out of the pile under the action of gravity if their support is removed.

MEMORANDUM

ON THE COOLING OF THE POWER PLANT

Addition to the Memorandum dated
June 15, 1942

L. Szilard

June 24, 1942

Correction of typographical error on page 6 of memorandum dated June 15, 1942. The last paragraph of the memorandum should read as follows:

Continuation of the Discussion of the Double Stream Method.

Figure 3 B shows an arrangement similar in function to the arrangement shown in Figure 3 A, but differing in construction. The construction shown in Figure 3 B makes it possible to remove the uranium from a graphite column without removing an appreciable amount of graphite. In this figure we see a graphite column having a square cross section and a length which is large compared to the sides of the square, and which may extend if desired throughout the whole graphite pile. This graphite column has three bores, one of them representing duct 2, another of them representing duct 3, and the third bore, in which are placed the uranium plugs 4. The possible constructions for the uranium plug are shown in Figure 1. Figure 1 B might be the most suitable if uranium metal is used. perforated graphite plates 9 keep the parts which constitute the uranium plug 4 in position. These perforated graphite plates are similar to the perforated graphite plate shown in Figure 1 C. Between each two uranium plugs 4 we have a graphite rod 5 and a bore in the center of the graphite rod 5 connects two adjacent uranium plugs. Whereas, the example shown in Figure 3 A had three uranium plugs connected in series. The example shown in Figure 3 B has all uranium plugs in parallel. This, of course, will apply only in the center of the pile, and the construction shown in Figure 3 B permits to have several uranium plugs connected in series as it is necessary to have in other parts of the pile. The cooling agent enters from duct 2 through a bore 8 into the interior of the graphite rod 5, passes through a uranium plug 4 into the interior of another graphite rod 5, and enters through a bore 7, into duct 3. Naturally, the cross section of ducts 2 and 3 will vary along the graphite column. The radius of duct 3 decreasing along the path of the cooling agent while the radius of duct 2 increases correspondingly. If a graphite column is vertical, the graphite rods 5 and the uranium plugs 4 will simply fall out of the pile under the action of gravity if their support is removed.

MEMORANDUM

On The Cooling of the Power Plant

Addition to Memorandum dated

June 15 and 24, 1942

L. Szilard

June 29, 1942

Continuation of the Discussions of the Double Stream Method.

Figure 3 C shows an arrangement which is very similar to the arrangement shown in Figure 3 B. The only difference is that in the arrangement shown in Figure 3 B there are groups of uranium plugs connected in parallel and each group contains two uranium plugs connected in series.

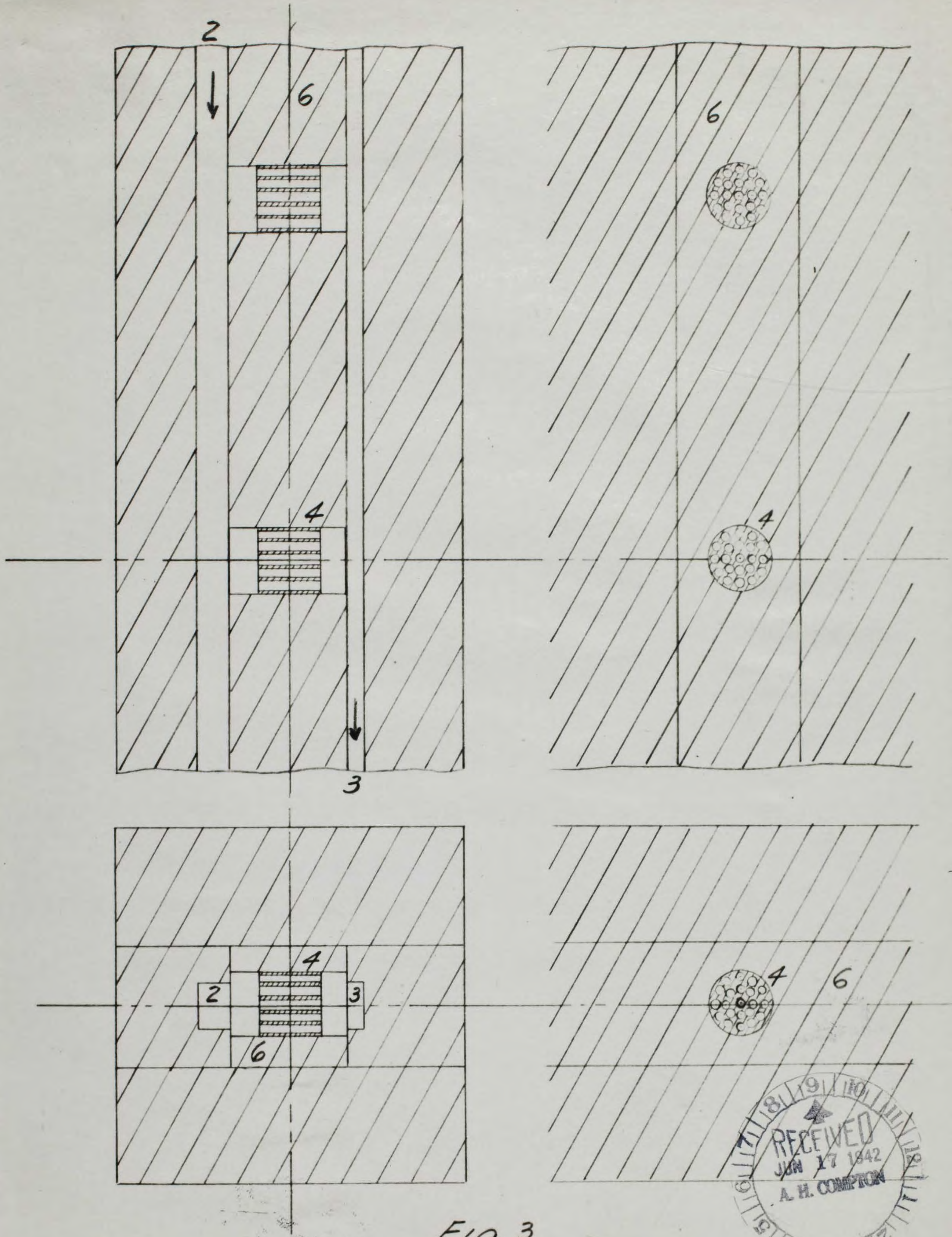
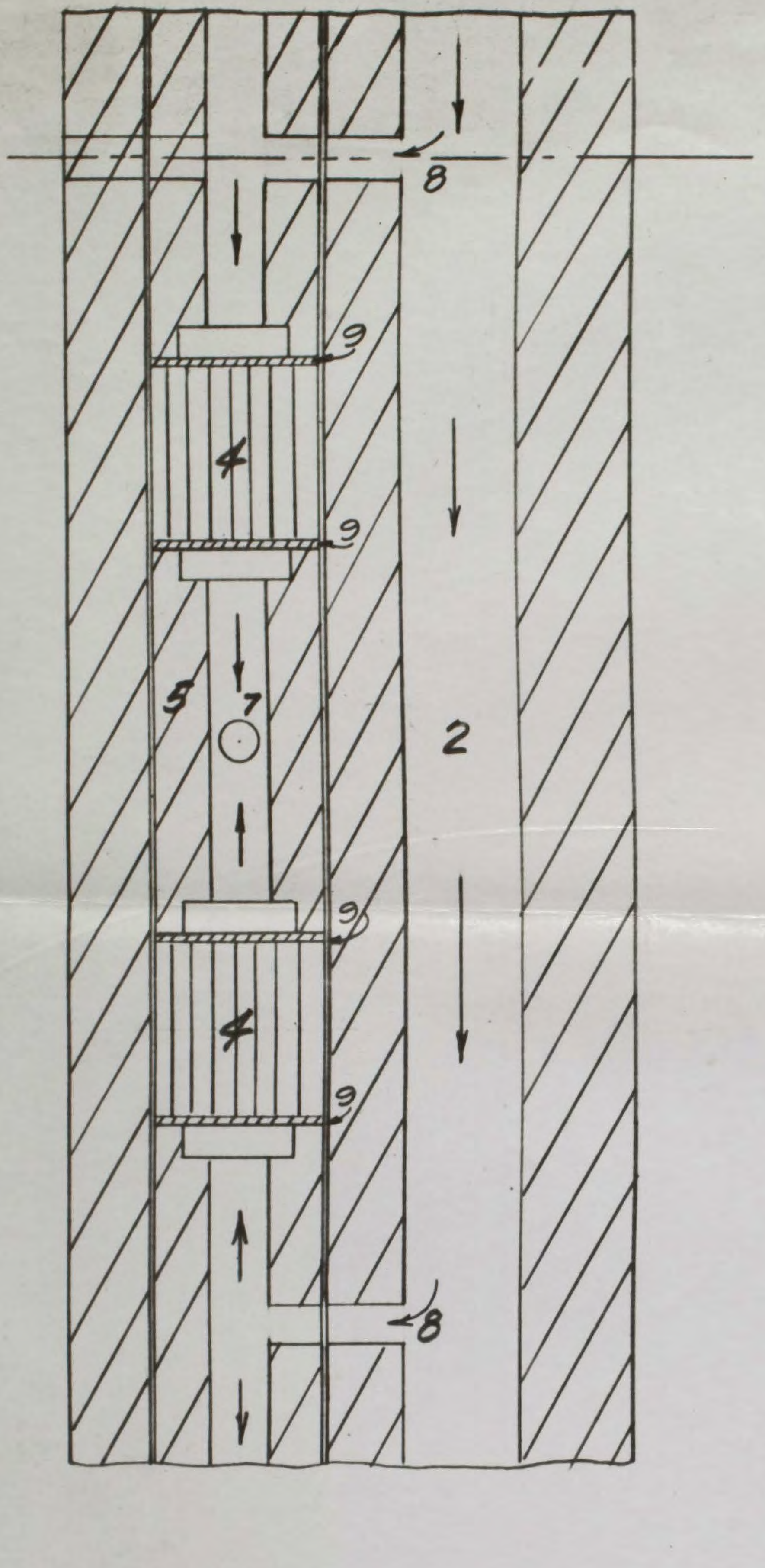
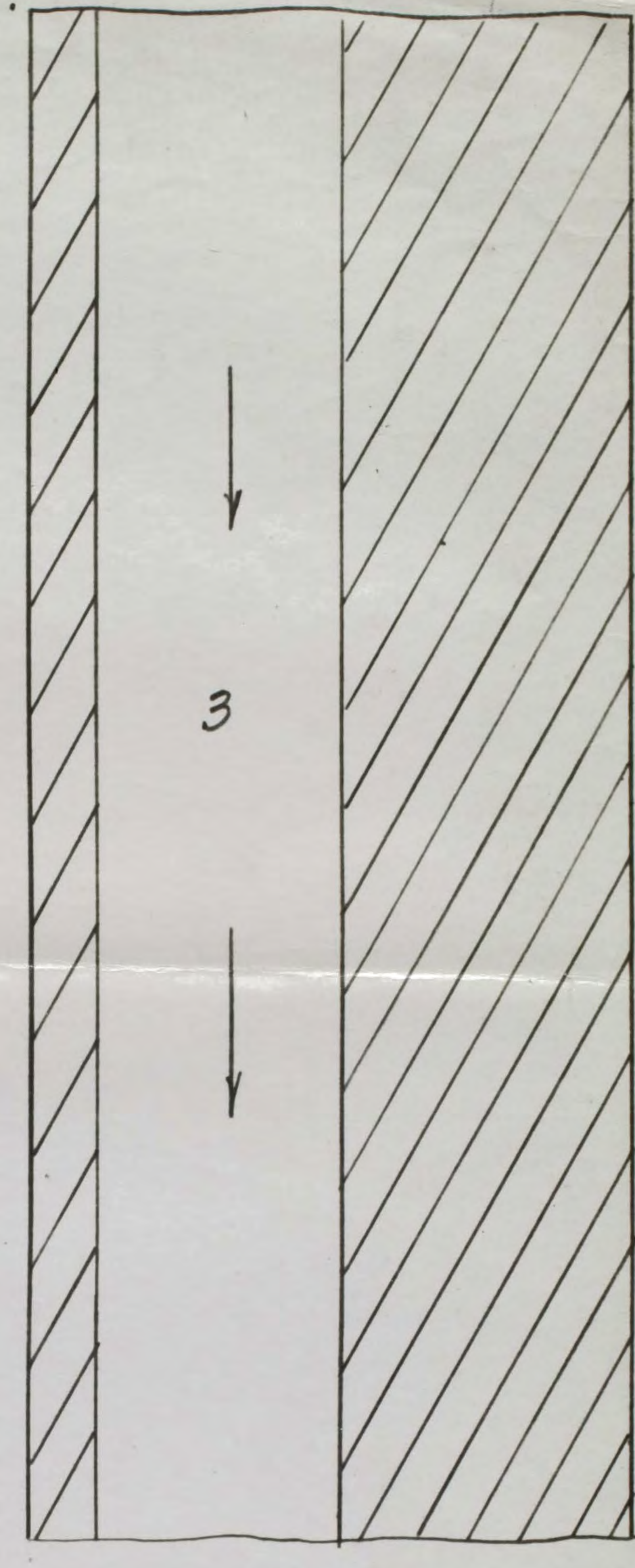


Fig. 3





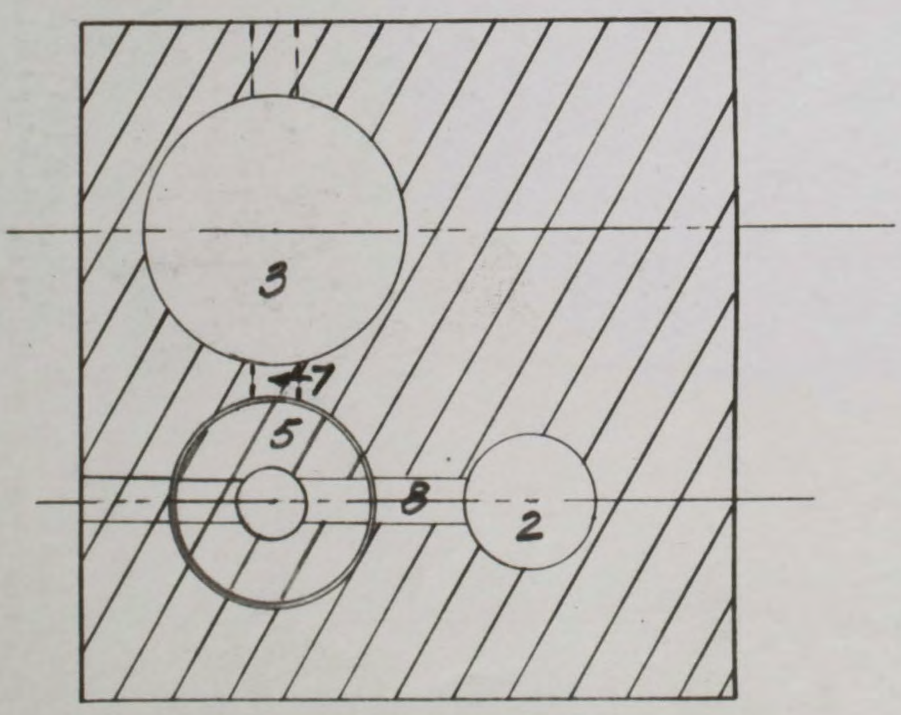


Fig. 3B

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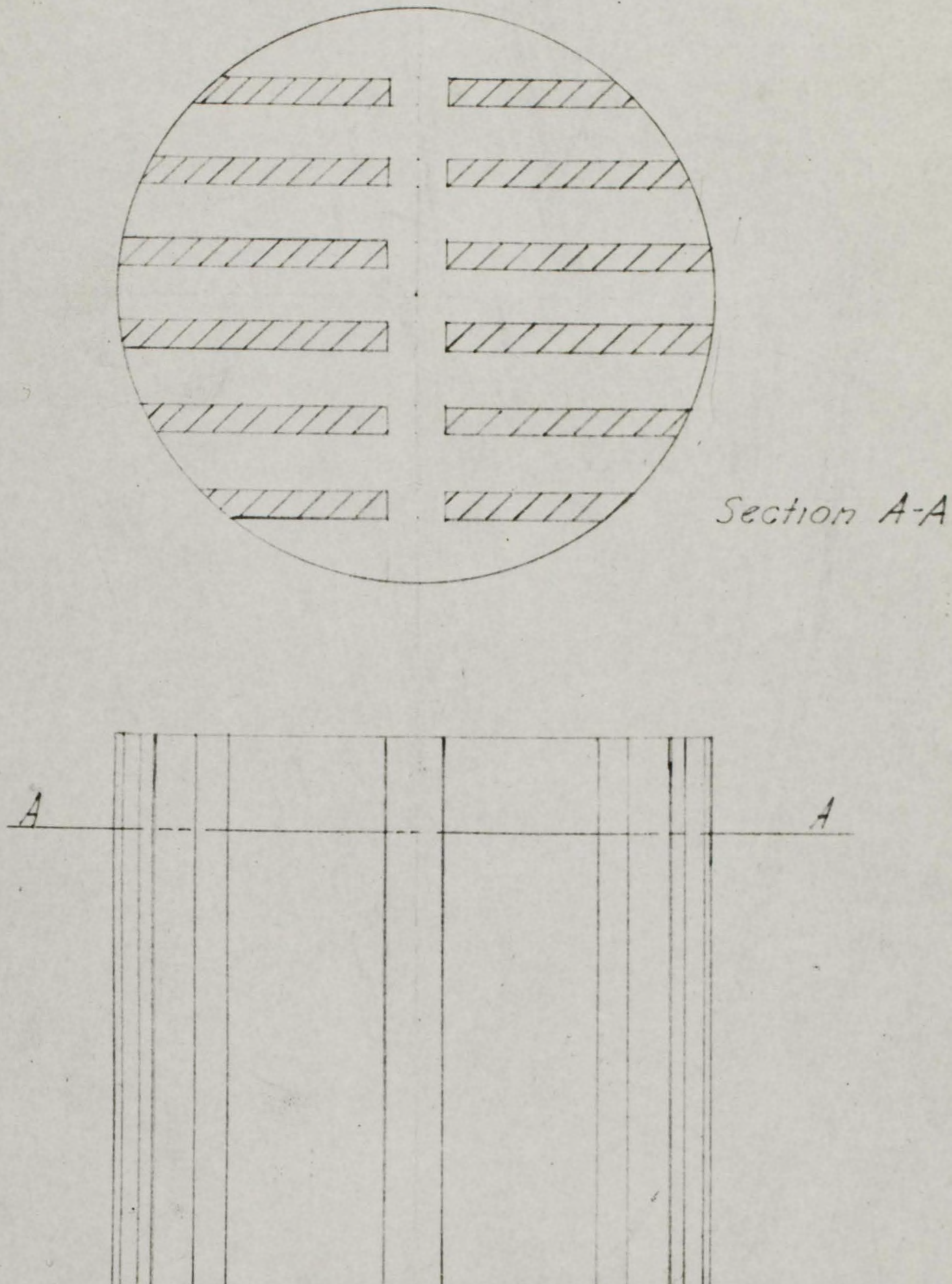
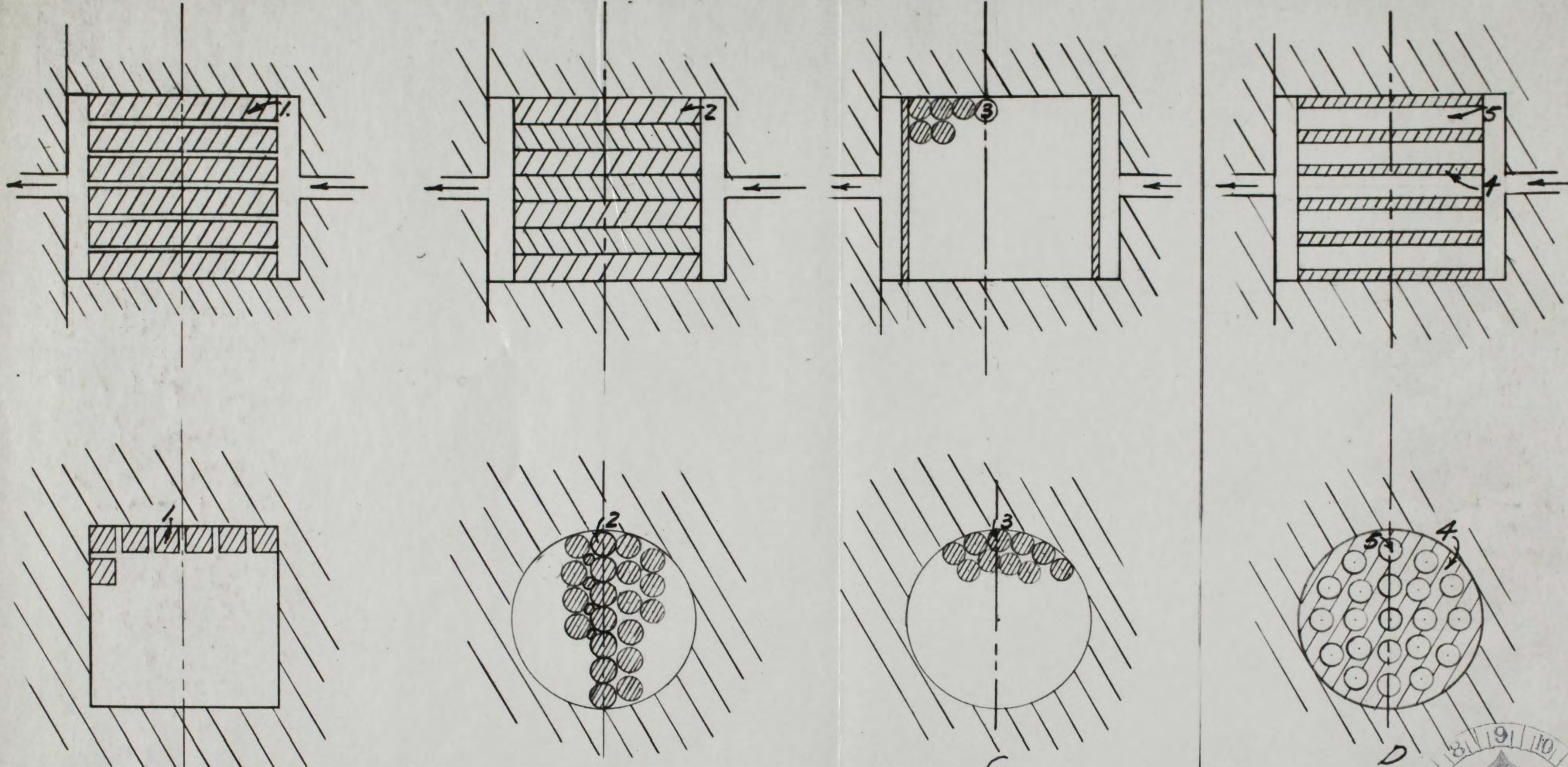


FIG. 31



A B C D

Fig. 1

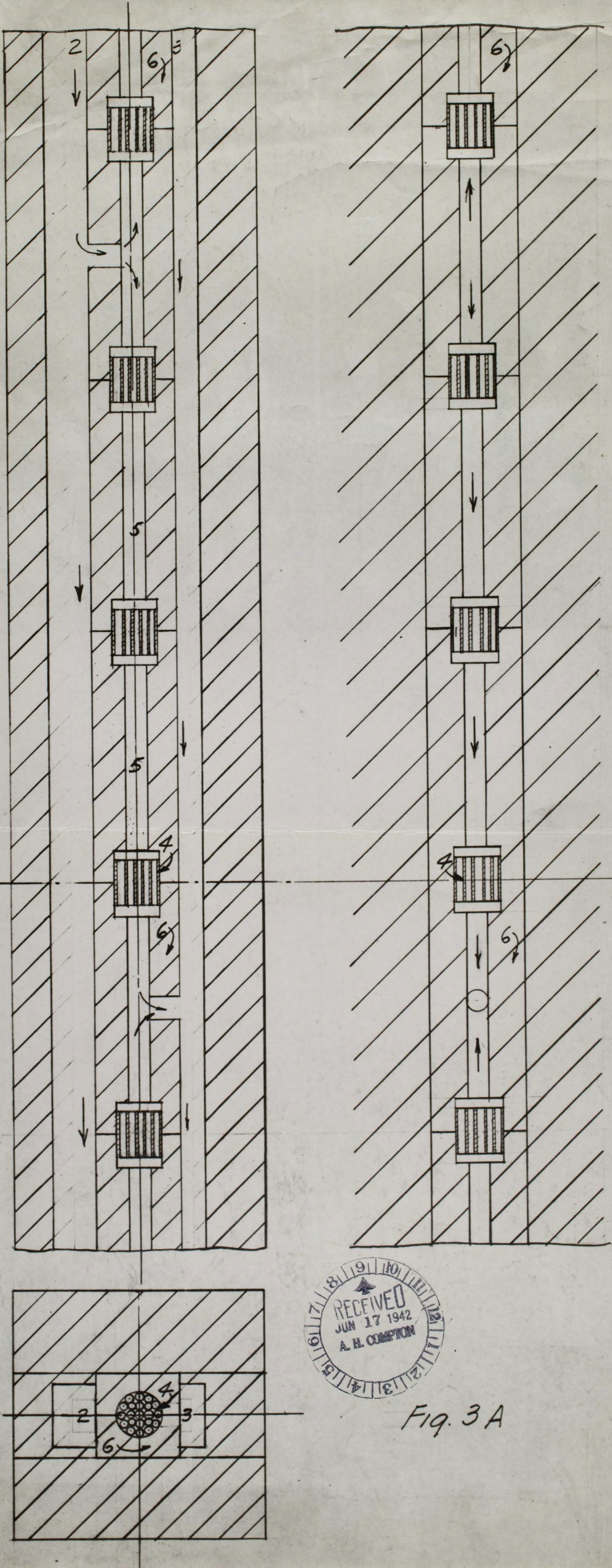


Fig. 3A

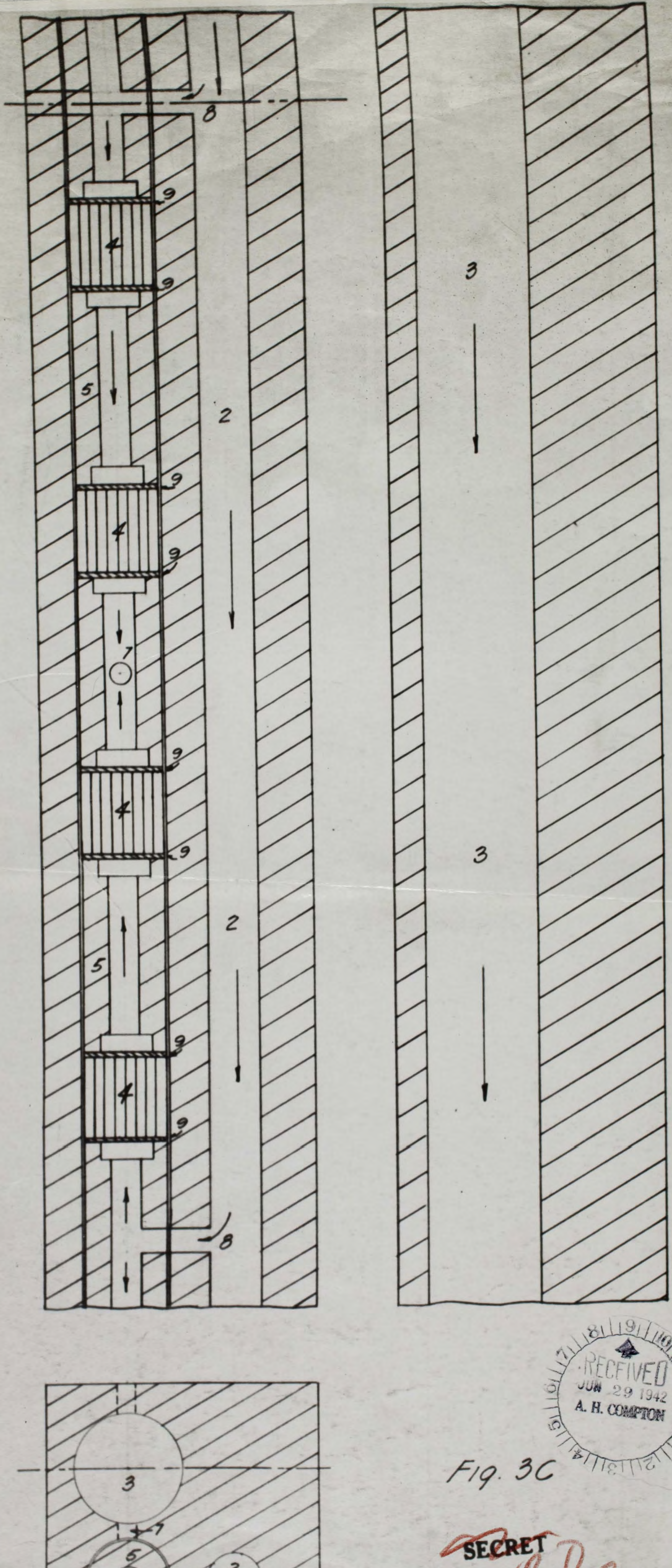


Fig. 3C

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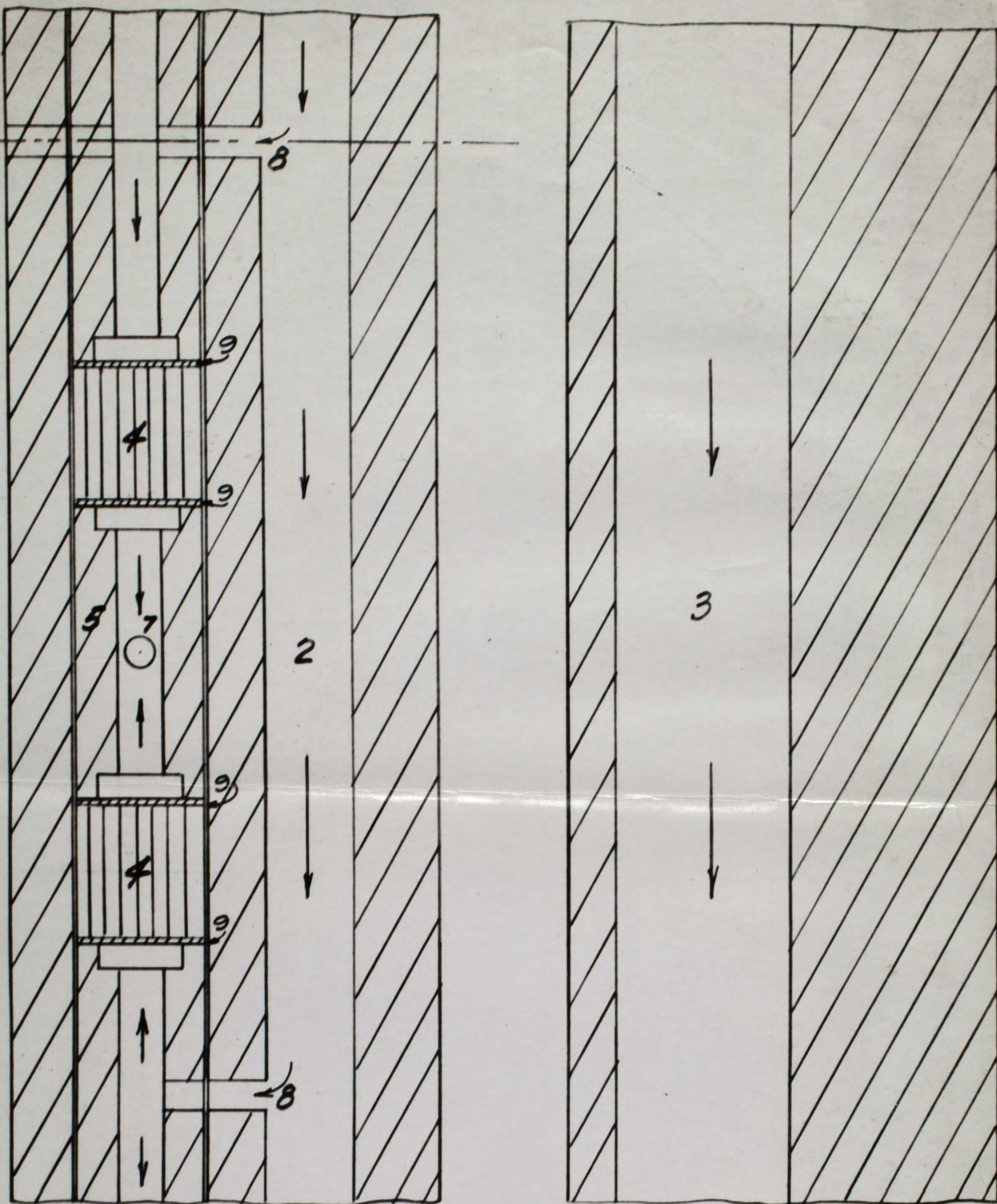

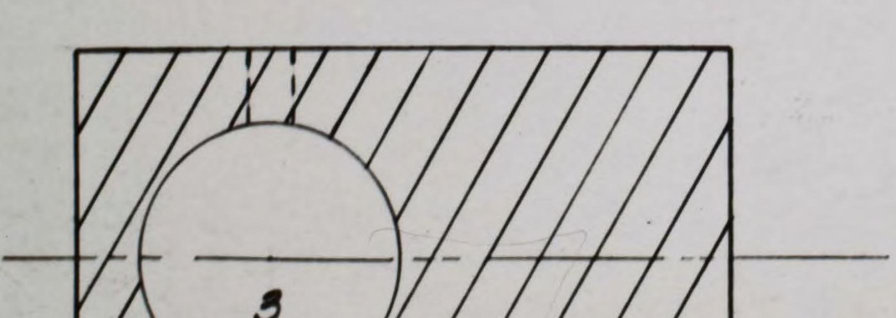

Fig. 3B

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NRD
Shen