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This document consists of 2
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L. Szilard
June 12, 1943

Memorandum on Metallurgical Problems Connected with the Power Unit which is Cooled by Liquid Metal

The possibility of using a liquid bismuth, liquid lead and bismuth-lead alloys for cooling both graphite and heavy water power units is at present under investigation. Of particular interest is the eutectic alloy of bismuth and lead which has a melting point of about 130°C; and at the first step, it might be advisable to use this alloy between 150°C up to 300°

1. No particular metallurgical problems arise in connection with graphite power unit if uranium is used in the form of uranium carbide.

It will, however, be desirable to determine at what velocities does true erosion occur, if at all, in graphite and uranium carbide under the conditions of flow which may be expected to exist in the power unit

CLASSIFICATION CANCELLED
Date 10/3/56
For The Atomic Energy Commission
Director, Division of Classification

2. If uranium is used in the form of uranium metal, we obtain wetting of the uranium by the eutectic Bi-Pb alloy. An experiment is being prepared for seeing if uranium is soluble in the liquid eutectic. It is known that uranium is soluble in liquid bismuth and an experiment is being prepared to determine whether uranium is soluble in liquid lead in order to determine whether there is any hope that bismuth-lead alloys, sufficiently rich in lead, can be used in direct contact with uranium.

3. If it should prove impossible to use uranium metal in direct contact with bismuth-lead alloys, the uranium metal will have to be protected by some other material. It is also of interest to see what materials other than uranium can be used to form tubes through which the bismuth-lead alloys can be led through the power unit. The following materials are under discussion: graphite, beryllium, aluminum, iron.

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Graphite appears to be safe from the point of view of chemical action or carbide formation at low temperatures. Carbon is insoluble in bismuth and no bismuth carbide is known to exist.

Beryllium does not appear to be wetted by eutectic lead-bismuth alloys at 400°C. It would be desirable to see if beryllium is soluble in liquid bismuth, liquid lead and bismuth-lead alloys. No such experiments have been prepared so far.

Aluminum does not appear to be wetted at 400°C by the eutectic bismuth-lead alloy. Aluminum is not soluble in liquid lead but is slightly soluble in liquid bismuth. An experiment has been planned to determine whether or not aluminum is soluble in the eutectic bismuth-lead alloy. It appears likely that aluminum will prove to be insoluble in bismuth-lead alloys which are sufficiently rich in lead.

Iron is not soluble in either liquid bismuth or lead and it is expected that it is insoluble in lead-bismuth eutectic. Iron could be used in the form of a thin coating to protect the uranium and iron tubes have been successfully ground down by Creuts to .01 inch. It is expected it would be possible to grind down iron tubes from .022 inch which is a commercial size to .005 inch.

The behavior of 18-8 stainless steel and of duraluminum has a certain degree of interest and an experiment has been prepared to see whether the lead-bismuth eutectic wets either of these substances.

CC: Reading File
    J. Chipman
    F. Foote
    E. Wigner
    E. Creuts
    H. Smyth
    S. Allison

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July 19, 1943

TO: F. York

FROM: L. Szilard

If I understand correctly, one of the most important questions in evaluating the patent situation is the question whether my disclosures of February 1940 would have enabled a man, skilled in the art, to built a chain reacting pile. It is my contention that this is so, and I told you that I believe I could bring out this fact if I were permitted to put questions to various men whom you have heard in connection with this matter. It seems to me that by going through a form of mock trial in which witnesses could be cross-examined by me on one hand, and by someone representing the opposite point of view on the other hand, we could develop a rather clear picture. A transcript of such a mock tril could then be sent to Captain Lavender for close study of the case. I am listing in the following, a number of points which I think I could establish by such a procedure.

1. I submit that the disclosures which are available in the form of postmarked photocopies dated February 21, 1940 and which are substantially identical with A-55, teach a man skilled in the art how to built a lattice of uranimm in graphite that will have a multiplication factor larger than 1. In particular this disclosure teaches that uranium metal spheres of 5 cm radius can be used for building a lattice that will be operative. It also teaches that uranium metal spheres of 8 cm radius can be used to build up a lattice which will be operative at 900°C. The disclosure further teaches that an operative lattice can be built from spheres between cm radius by using a ratio of uranium to carbon which is given by equation 33a. It subsequently recommends a weight ratio of uranium to graphite of 3200 for spheres of 5 cm radius.

The radius of 5 cm at room temperature and 8 cm at 900°C are arrived at in the following way:

Equation 26 shows, at a glance, that the most favorable conditions will be obtained by making ε as large as possible. Equation 20a gives ε as a function of the radius of the uranium sphere and by using the cross sections and other values given in the paper (please note that μ or σ_i do not enter into the expression of defining ε) one can calculate the value of R for which ε becomes a maximum. One then that the maximum occurs at room temperature for a radius slightly above 5 cm. The same calculation gives at 900°C a radius of about 8 cm.

Equation 25 teaches that the best uranium to carbon ratio is obtained if we have one half of the neutrons which are lost absorbed by graphite, and, accordingly, the other half which is lost absorbed by uranium at resonance. This condition which is correct with very good approximation leads to equation 33a if we use for the resonance absorption, the approximate formula given by equation 9. Equation 33a gives for the size of spheres contemplated in the disclosures, a ratio of uranium to carbon for which the lattice is operative. In comparison with equation 33a, equation 36 is less accurate since it represents an approximation for very large values of ε as it is clearly stated in the text.

2. I submit that a man, skilled in the art, who had read the February 1940 disclosure would have had no difficulty on the basis of the knowledge then available to determine the critical size at which the chain reaction becomes divergent by empirical methods.

Ever since the discovery of the neutron emission of uranium in March, 1939, physicists have been trying to devise a system which will give a multiplication factor larger than 1; but nobody ever expressed any fear that ~~th~~ if such a system is found it would be difficult empirically to determine the critical dimensions. For this purpose, there were three methods which were readily available and all of them were discussed, and some of them published at that time.

a. The first method which is the crudest makes use of the fact that if a neutron source is placed in the center of a sphere which contains material that has a multiplication factor above 1, the neutron radiation emanating from the sphere will be more intense as a neutron radiation which would come from the neutron source in the absence of the sphere. If the chain reacting system is made larger and larger, the neutron radiation will approach infinity as will come cloze to the critical radius.

b. A more refined method which was known by men skilled in the art was to surround a potentially chain reacting sphere with water or paraffin, putting the neutron source in the center of the sphere and compare the number of neutrons which are absorbed in the water with a number of neutrons which are emitted by the source alone. According to whether the number absorbed in the water around the chain reacting layer is larger or small than the number emitted by the s

source the multiplication factor can be taken as larger or smaller than unity and in case the multiplication factor is larger than unity, the critical radius can be computed from the results of such measurements.

c. By measuring the neutron density inside the potentially chain reacting sphere, one can determine whether or not the multiplication factor is larger than 1 and if so, the approximate critical radius can be deduced.

In support of my contention under this point, I wish to state the following:

At a metting of an advisory comittee to the uranium committee which was held under the official chairmanship of Urey at the request of Dr. Brinks, and in which Pegram, Bride, Fermi, Wigner, myself and others participated, a concensus of opinion was reached that the critical dimensions could be determined by making measurements on a lattice containing about 40 tons of graphite and a corresponding amount of uranium on the assumption that the quantity may represent perhaps 1/5 of the quantity required to make the chain reaction going. There was a consensus of opinion that the physicist could, by making measurements on such an intermediate scale as we then called it, determine the approximate value of the critical dimensions. This proves that, in the opinion of men skilled in the art, the empirical determination of thd critical dimensions was considered as a natural way of proceeding. Incidentally, the so-called exponential experiment was mentioned at the meeting by Fermi as one of the possible methods by means of which the intermediate scale pile could be investigated.

That such an intermediate scale pile could be investigated by measurements performed outside the pile in water or paraffin wax was common knowledge and an example for such measurements can be found in the paper by Halban, Joliot, Kowaski, Journ de Phys. 10 pp. 428-429 (1939). This paper is quoted in A-55.

In support of the condition mentioned under a. in this section, I am submitting exhibit A which contains a disclosure that is available in postmarked photocopies stamped March 9, 1939. In connection with the question of this section, the following facts may also be pertinent. The existence of the critical dimensions and the variation of the thermal neutron density inside a potentially chain reacting sphere was first disclosed by me filed in England in 1934. There is subsequently disclosed by me as shown in exhibit B which is available in postmarked photocopies stamped March 9, 1939. Following that these last were published by F. Perrin in 1939 at a time when they were considered to be known by men skilled in the art. The neutron density goes in a potentially chain reacting spherical body with

$$\frac{\sin r/A}{r}$$

If the multiplication factor is larger than 1 and with

$$\frac{e^{r/A} - e^{-r/A}}{r}$$

If the multiplication factor is smaller than 1. The latter case holds for graphite from which we have removed all the uranium. An important quantity is the length A and my letters to Fermi in July and also A-55 gives a method how to determine A by measuring the thermal neutron density inside a phere. This method is described on pages 24 and 25 in A-55. It is described in connection with graphite only, and it is not explicitly stated that it can also be used for graphite-uranium systems. The general principle of this method which was new at the time of its disclosure in July 1939 was applied by Fermi to a rectangular system for the purpose of measuring the absorption of graphite in April, 1940 and the application of this method to uranium-graphite system was proposed by Fermi in June, 1940 at the above-mentioned conference.

from Szilard

July 21, 1943

To
Dr. Dempster

~~Dear Dr. Dempster:~~

I have read your analysis of report A-55 dated July 9, 1943 and you and I have since that time gone jointly over report A-55. In the following I am giving you a resume of the statements I made to you in connection with report A-55:

1. A-55 gives a recipe which permits to determine for a lattice of uranium spheres in graphite for what radius R of uranium spheres and for what ratios of uranium to carbon for any given R the multiplication factor can be expected to be close to its highest possible value. By using the formulae and the constants given in the paper one finds for room temperature and density of 15 grams per cc for the best radius R, a value slightly above 5 cm. Similarly, for 900°C one finds for the best radius R, a value of about 8 cm. All examples given in the paper refer either at 5 cm spheres at room temperatures or to 8 cm spheres at 900°C.

The corresponding ratios or uranium and carbon can be easily calculated from the formulae given in A-55. No ratio of uranium to carbon is explicitly given for 8 cm spheres at 900°C but this could be obtained simply by putting the set of values given on page 20 in A-55 into the formulae given in the paper. For 5 cm spheres at room temperature a ratio of uranium weight to graphite weight of 3 to 10 is given in A-55.

It is my contention that for all the R values, and all weight ratios recommended in A-55, the multiplication factor is larger than 1 and that A-55 teaches how to obtain a lattice which is capable of sustaining a chain reaction.

The theory given in the paper for the determination of the most favorable sizes and mixtures is an approximation which holds only for small uranium spheres, say spheres below 8 cm radius. The theory neglects various factors which counteract each other and thereby leads to very simple formulae.

a) The theory ~~proven~~ given in A-55 permits to calculate for any given Radius R between 5 and 8 cm the most favorable ratio of uranium to carbon in the following manner:

The value of ε is calculated from R, the radius of the uranium spheres, by means of equation (20a). The value of all physical constants occuring in equation (20a) are given in the paper. Having obtained the value of ε the value of ρ_m can be calculated either from equation (26) or from equation (27). Having obtained ρ_m the most favorable ratio of uranium to carbon corresponding to the chosen value of R can be obtained from equation (33a).

An alternative method which is mathematically identical gives the uranium-carbon ratio of calculating in addition to ε and ρ_m also φ from equation (19) and then substituting the values of ε, φ, and ρ_m into equation (33).

If the uranium graphite ratio has been calculated we may obtain the distance between neighboring uranium spheres in a cubic close-packed lattice from equation (34) or more directly from equation (35).

(Please note that the distance of $L =$ 51 cm given on p.12 is not the distance corresponding to a physically real case, but is a maximum distance which can be gotten from equation (35) by means of a set of values which are most pessimistically chosen, among all the values occurring on p. 20 for the purpose of demonstrating that there is no danger of this distance L becoming larger compared to the distance $\sqrt{r^2}$ which is about 50 cm. See in this connection the first paragraph on p.11.)

b) In order to get the most favorable multiplication factor we have according to A-55 to choose R so as to make ε a maximum. This is obvious from equation (26) which shows that ξ_m increases with increasing ε. ~~[illegible]~~ A 55 says on page 7: „the value of R may be so chosen as to make this [illegible] a maximum." Accordingly in order to make the multiplication factor a maximum we have to choose R so as to make ε as given by experession (20a) a maximum. As stated before, the maximum of ε is at room temperature slightly above R=5 cm for uranium density of 15 gms per cc. If the temperature is increased to 900°C, the absorption and capture cross sections are reduced by a factor 2 and the maximum for R shifts by a factor of $\sqrt{2}$ into the neighborhood of R=8 cm.

2. A-55 as so far discussed in the present memorandum deals only with the question of how to obtain the optimum size for the uranium spheres and the optimum ratios of uranium to ca5bon. It is, however, also of interest to know whether for the optimum case, the multiplication factor will be larger than 1. In this respect, A-55 most emphatically asserts that this will be the case and gives on p.21 for room temperature ~~a rough guess of~~ $(\mu q-1) = 1/8$ ~~being 1/8~~ which corresponds to a multiplication factor of μq = 1.125. This corresponds to ~~gm~~ $q_m = .6$ value given on p.21~~)~~ for spheres of 5 cm radius at room temperature) and a value of μ = 1.87, which is in accordance with the value of μ given on p.17 if we take into account the explicitly stated experimental error given on p.17 for p.

It should be noted that only the product μq enters into the determination of the critical radius $\mathcal{R}$ and that it is indifferent from the point of view of the chain reaction in what way this product is split into

~~tXXXXXXXXXX~~

the two factors μ and q.

Similarly, Joliot's experiment which is discussed in the paper does not directly measure μ but measures a combination of constants something close to $\mu \times (1-p)$. p is connected with the resonance absorption of uranium, and A-55 emphasizes that its value is very badly known. Although it is, therefore, somewhat uncertain in what way this product has to be split into μ and 1-p this uncertainty does not affect the results of Joliot's experiments inasmuch a it shows that uranium-water mixtures may have a multiplication factor which is, rather close to 1.

At the time when the paper was written I knew from experiments made on heterogenous and homogenous systems of uranium and water that such systems have a multiplication factor which in the most favorable cases comes rather close to 1 but most probably stays below 1. If one now replaces as a slowing agent, one hydrogen atom with 25 to 30 carbon atoms one should expect a system in which the loss of neutrons due to uranium resonance is about equal to loss of resonance in the hydrogen our system. ~~Since~~ The absorption of 25 to 30 carbon atoms of a cross section of .005 each is only about .13 to .15 whereas the thermal absorption cross section of a hydrogen atom is about .3. So it may be seen that the uranium-graphite system is more favorable and can be expected to have a multiplication factor above 1, but cannot be expected to have a multiplication factor very much above 1 unless the carbon cross section should be considerably lower than .005.*

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*(Please note that if the carbon absorption cross section were .01, then the above consideration would show that carbon and hydrogen are just about equal. I stated this fact in my letter to Fermi, July 3, 1939 and my statement was based on the consideration given above. Even so, carbon would have an advantage over hydrogen is used in a Heterogeneous system, for reasons which were given in my

At the time when A-55 was written the best value for μ appeared to be about 2. This would have led to a multiplication factor which was obviously far too high above 1 had I not made a very pessimistic assumption about the resonance absorption of small spheres of uranium and assumed that ~~rich~~ such uranium spheres absorb at resonance considerably more than any other known element which has an even atomic number. Only in this way could I obtain for $\sigma_c(C) = 0.005$ sufficiently <u>small</u> value for qm to give a product μq not too far above 1.

The quantity of resonance absorption enters into A-55 by means of a length $\bar{B}$ which A-55 took to be 6.5 cm. The assumption of such a large resonance absorption leads to very low values of qm but if we multiply q with μ in order to obtain the multiplication factor we come out with the approximately correct result. Had I at the time when A-55 was written used the correct value for the resonance absorption of uranium in conjunction with the value of $\mu = 2$ I would have come out with far too high values for the multiplication factor which would not have fitted with my knowledge that the graphite-uranium system can only be slightly better than the water-uranium system and, therefore, cannot have a multiplication factor very much above 1, unless the use of carbon were much smaller than 0.005.

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letter to Fermi, July 5, 1939, which reads as follows: "carbon would also have an advantage over hydrogen in so far as there is no change in the scattering cross section, in the transition from the resonance region to the thermal region. Consequently, if layers of uranium oxide of finite thickness are used, the diffusion of the thermal neutrons produced in the carbon to the uranium layer is not adversely affected as in the case of hydrogen by such a change." It is due to this fact that we can use fairly large spheres of uranium and fairly large distances between these spheres in the graphite and that is the reason why A-55 was justified in stating

~~The assumption of B=6.5 cm in A-55 has only a slight falsifying effect on the recipe which leads to the selection of the most favorable im weight ratiod and, therefore, these recipes lead to sizes and weight ratios which are close to giving the highest possible multiplication factor.~~

c. I submit that it is not justified to criticize A-55 on the ground that if the value of certain constants used in the paper is replaced by modern values for those constants while the value of other constants used in the paper is left untouched one comes out with entirely wrong results. A-55 uses the constants only in certain combinations and the constants were so adjusted to each other as to make those combinations come out right.

3. On page 21, a formula is given for the critical radius ℓ. Using the value of 50 cm given on p.21 have $\sqrt{\overline{r}^2}$ one may write,

$$\ell = \sqrt{\frac{7500}{\mu q-1}}$$

~~$(\mu q-1) = \frac{1}{8}$ or~~

This formula is correct in terms of μq and gives for $\mu q=1.125$, $\ell = 250$ cm corresponding to about 100 tons of graphite. ~~This corresponds to $\mu = 1.09$ as given on page 21 $f = 0.6$~~

In view of the general statements made in the paper concerning the inaccuracy of some of the constants involved, and in view of the great sensitivity of the formula for ℓ to changes in the multiplication factor, it must be obvious to any one who reads A 55 that the statement $\ell = 250$ cm indicates only the approximate size of the proposed chain reacting system. It is my contention, which I do not propose to discuss here, that in February, 1940, there were methods available and known to men skilled in the art of inducing radioactivity by neutrons which permitted to determine the accurate size by making measurements on structures which were smaller than the accurate size.

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that even if the carbon cross section were as high as .01, the graphite-uranium system would give a multiplication factor just slightly above 1, in the case of the most favorable conditions.)

fav

Sbs 19

D

July 23, 1943

TO: F. York

FROM: L. Szilard

~~After Captain Lavender left Chicago,~~ Lately I had a conversation with Dr. Dempster from which I saw that the interpretation of various pertinent points in A-55 is controversial. I am now going through A-55 with Dr. Dempster, and I believe that Dr. Dempster will be in a position by Tuesday of next week to reevaluate this disclosure.

It is my contention that a man skilled in the art of inducing radioactivity by means of neutrons was in the position to build a chain reacting pile on the basis of my disclosure February 1940. These disclosures consist essentially in a paper sent to Physical Review on February 14, 1940 and corrected pages which were written between February 14 and February 21, 1940 and which are availalbe in the form of photocopies stamped February 21, 1940 by the U.S. Post Office. This question really falls into two parts:

(1) Does the disclosure teach how to make a lattice which has a multiplication factor larger than 1, and does it give the order of magnitude for the critical radius of a chain reacting unit?

(2) Was a man skilled in the art in the position, in 1940, to determine by known measurements on a structure which was not as large ~~enough~~ as the critical size ~~to constitute a chain reacting unit,~~ whether the multiplication factor was larger than 1 and how large the structure would have to be made in order to reach the critical conditions.

Sec I

3.) ~~4)~~ fourth

A ~~third~~ question which may be pertinent is whether it was known what amount of impurities could be tolerated in the chain reaction unit.

Before going into detail, I wish to emphasize the following general point of view: Ever since the discovery of the neutron emission of uranium in March 1939, it was recognized ~~tha~~ as an important problem to find a structure which will have a multiplication factor larger than 1. Many ~~people~~ physicists expressed ~~expressed~~ doubt whether this was at all possible, and numerous suggestions were discussed and published. But to my knowledge nobody ~~expressed any~~ doubted ~~however, to my knowledge, concerning the question whether~~ that, if we had a composition and structure giving a multiplication factor above 1, we would be able to determine the critical dimensions at which the unit would become divergently chain reacting. It was taken for granted that this could be found ~~would be the case~~ and I am attaching a number of exhibits which support the ~~this~~ contention, that this was a prevailing view at the time.

Concerning A-55, I have written a memorandum which I am ~~have~~ forwarding ~~forwarded~~ to Dr. Dempster for his comment, and I am, therefore, summarizing here my contentions in connection with A-55.

A 55

1. A-55 gives the recipe for calculating a radius R' for the uranium sphere which forms the lattice element and a ratio of graphite to uranium at which the multiplication factor of the lattice will be close to the maximum possible value. The formulae give~~n~~ for room temperature, R = 5 cm as the radius of the uranium spheres at a density of 15 gms/cc; and give for 900°C a radius of R = 8 cm. The corresponding ratios

of uranium to carbon can be calculated from the formulae given in the paper. For 5 cm spheres, a weight ratio of 10 to 3 is explicitly recommended. ~~No ratio is recommended for 8 cm spheres at 000°C~~ ~~but~~ ~~the formulae would give a weight ratio between 3.8 to 1 and 4.1 to 1.~~

A-55 gives for 5 cm spheres an approximate value for the critical radius of 250 cm. It is my contention that it is obvious from the limits of error given in the paper to the various quantities involved that this radius is also given only within certain limits of error which would include the radius at which the chain reaction according to our present knowledge would actually reach the critical [illegible] point of diversion.

Critical size

2. It is my contention that men skilled in the art were fully aware of methods which enabled them to determine the critical size by empirical methods, that is, by measurements on structures which are smaller than the critical size. [illegible] II

At an official meeting held under the chairmanship of Professor Urey in June 1940, it was acknowledged after discussion in which Wigner, Fermi, Breit and I participated, that the critical dimensions can be empirically determined with reasonable certainty by measurements on a structure which contains about 1/5 as much material as would be needed to reach the point of diversion. A recommendation was adopted that measurements on such an intermediate scale should be made. Exhibit C corroborates this statement. It is the draft of a letter written by me to Fermi six days after the Washington meeting, ~~and~~ which contains a ~~note~~ sealed note ~~[illegible]~~ stating that this draft was not actually sent to Fermi. ~~It~~ The letter distinguishes between a semi-large scale experiment ~~that is~~ to be performed on structure ~~having~~ containing approximately 1/5 of the amount

materials

at which the chain reaction might become divergent; and a large scale experiment ~~that is an amount~~ ~~close~~ to be performed on a structure containing materials very close to the amount at which the chain reaction might be expected to become divergent. I submit that from this disclosure, it is evident that it was out intention to proceed in an empirical manner and the disclosure explicitly states the the nuclear constants should be measured while waiting for the arrival of the material needed for the semi-largescale experiment.

My contentions concerning the Washington meeting in June 1940 are ~~found~~ further corroborated by exhibit D which is taken out of a memorandum written by Pegram and dated August 14, 1940. I have marked on the margin the pertinent passage. I am also enclosing a photocopy, exhibit E, showing the official natur~~al~~e of the Washington meeting. I wish to state further that the following methods were available and known to men skill in the art of inducing radioactivity by means of neutrons, exploring a potentially chain reacting unit which was smaller than the critical size:

(a) Measurements of the neutron radiation emanating from the structure. This is, for instance, disclosed in exhibit B which is available in the form of a photocopy stamped March 9, 1939 by the U.S. Post Office. Exhibit B proposes to determine the critical size empirically by means of neutron radiation emitted from the structure.

(b) Measurements of the neutron density inside the chain reacting structure. The ~~loss~~ laws governing the neutron density inside a ~~[illegible]~~ structure which is potentially chain reacting ~~in~~ but not large enough to reach the point of diversion was disclosed for the first time, I believe, by me as shown in Exhibit A which is available in the form of photocopies stamped March 9, 1939 by the U.S. Post Office. There are also subsequent publications disclosing these ~~lossas~~ laws, one of them by F. Perrin in the summer of 1939.

It was quite well-known in 1939 to men skilled in the art that by measuring the neutron density inside the structure one can observe whether or not the multiplication factor is larger than 1 and ~~wx~~ determine the approximate size of the divergent chain reacting unit.

Measurements of the neutron density inside a chain reaction structure ~~were~~, for instance, published by Joliot in a paper [illegible] which is quoted in A-55.

[illegible]

(c) That by measuring the thermal neutron density within a system in which the thermal neutron density obeys the diffusion equation by means of making the thermal neutron density zero along a closed surface by the introduction of cadmium and by measuring the ~~w~~ change in the thermal neutron density inside the space as delimited by the closed surfaces and that from such measurements, one can deduce the length which characterizes the pertinent properties of the medium in which the diffusion of neutron take place was disclosed by me in letters to Fermi in July, 1939 and is also disclosed in A-55. This principle can be used for determining the critical dimension, which in the case of uranium spheres would be simply π x A. At the Washington meeting in June 1940, Fermi explicitly proposed the use of this principle for determining the critical size and described shortly the method which at present is called exponential experiment. ~~This same method~~ that an exponential experiment has been ~~applied~~ performed in April 1940 by Fermi to determin the length A in graphite which did not contain uranium.

Neutron flow

(d) It was well-known to men versed in the art that by surrounding a potentially chain reacting unit with paraffin, water or a manganese-sulfate solution one can slow down all the neutrons emanating from the structure and by measuring the neutron density outside the structure, can determine whether or not thenumber of neutron generated by the pile increases with increasing size of the structure. Such measurements are, for instance, published by Joliot and quoted in A-55. Such a measurement is also mentioned in a letter written by Fermi to Pegram in July, 1939. It is my contention that ~~every man~~ men skilled in the art knew ~~of~~ that this method was available and that the application of this method was quite obvious and did not require any ~~mention.~~ invention

Impurities

5. It is my contention that it was known as early as July 1939 how much neutron ~~[illegible]~~ absorbing impurities we can safely tolerate. I was, in this respect, in touch both with the National Carbon Company and the U.S. Graphite Company in July 1939. ~~since~~ I was not quite satisfied with the .1% ash and the vanadium content of the ash of the graphite, offered by the National Carbon Company and the U.S. Graphite Company offered us in July 1939 graphite which had only .05% ash and which contained a much smaller prcent of vanadium than the National Carbon Company graphite. It is my contention that the absorption cross sections of all elements that occur as impurities in either graphite or uranium were sufficiently well-known at the time to enable us to ~~raise~~ write a specification for purity.

I wish to draw attention to the fact that ~~of the materials~~ the neutron absorption of the tdal amount of impurities which are dispersed in the chain reacting structure, and that it is immaterial whether these impurities are in the graphite or in the uranium. To be quite ~~more~~ precise let us state that inasmuch as the thermal neutron density in the uranium is slightly smaller than in the graphite, the harmful effect of the impurities contained ~~containing in the uranium~~ in the uranium is slightly less ~~less harmful than~~ than in the graphite. There was one great difference between the graphite and uranium, however. Uranium was available in the form of soluble salts ~~solutions~~ like, for instance, uranium nitrate which would be easily purified by recrystallization or ether extraction, both methods being well-known and a number of other methods for purification are ~~being~~ described in chemistry books. Graphite, however, cannot be brought into solution and there are not methods described in the books by which graphite could be purified. It was, therefore, our first concern to see whether pure graphite could be obtained.

In addition to this, we were informed in 1935 that uranium oxide, 99.5% pure, ~~with~~ the impurities being mostly ~~and its main impurity~~, silicon and iron, was commericially available and marketed by the Canadian Radium Mines. Ms. 3.5 Pure uranium metal had been previous manufactured by the Westinghouse Company from uranium nitrate. Uranium nitrate itself was commercially available ~~xxxxxxx~~ and its purification and conversion into oxide do not meet with any difficulty for a trained chemist.

Ms. 4 I myself was not in touch in 1939 with the Can. [illegible] [illegible]

H. S. S. [illegible] [illegible] [illegible] [illegible]

$(kf-1)=\frac{1}{8}$ or $kf = 1.125$ ~~[illegible]~~

~~[illegible]~~ the closeness of this [illegible] one

[illegible] [illegible] [illegible]

[illegible]
y the total amount of impu-
rities which can be tolerated
without appreciably increasing
the medical dose.

[565|4]

last paragraph

July 23, 1943
L. Szilard

5 and 11 (see also letter Fermi to Anderson exhibit F) (on page

In my letters to Fermi in July 1939, and also) in A-55, I disclosed a method for determining a length A which is characteristic for a system in which the thermal neutron density obeys the diffusion equation. This method consists in ~~measuring~~ determining the thermal neutron density along a closed surface and at one point in the interior of the space which is enclosed by the ~~said~~ closed surface. The thermal neutron density is then reduced to ~~0~~ zero along the closed surface by introducing cadmium, and the thermal neutron density is again measured at the said point in the interior.

By applying this ~~method~~ principle to a chain reacting mixture, one can determine the critical dimensions of a sphere ~~by multiplying the length A with π.~~ which is equal to the product $l = \pi A$) and at the Washington meeting in June 1940, Fermi explicitly proposed the use~~d~~ of this principle for determining the critical dimensions. The specific form in which Fermi proposed to ~~try~~ apply this principle is at present called ~~an~~ "the" exponential experiment, and Fermi gave a short description of the exponential experiment which he proposed at the Washington meeting in June 1940. ~~The same~~ an exponential expeŝiment has been actually performed by Fermi for the first time in April 1940 for the purpose of determing the length A in the limiting case ~~when we had~~ of pure graphite that did not contain any uranium.

S.65.14

The University of Chicago

Metallurgical Laboratory

MIDWAY 0600
EXT. 1290

July 23, 1943

Captain R. A. Lavender
1530 P Street, N. W.
Washington, D. C.

Dear Captain Lavender:

After you had left Chicago, I had various conversations with Er. Dempster concerning my inventions as disclosed in A-55. It seems that a number of the essential points ~~were interpreted by Dr. Dempster differently from what I think is the correct interpretation~~ were considered by Dr. Dempster, and I am attempting to clear up these misunderstandings by going with Dr. Dempster carefully through the whole report. I believe by Tuesday of next week, Dr. Dempster will be in a position to reevaluate A-55.

Consequently, if I were wrong about these essential points, I would have to refuse your offer on the grounds that it is too generous.

However, I have now gone carefully through my disclosures from February 1940 and was also looked into other questions which appear to be pertinent, and I am now satisfied that the paper sent to Physical Review on February 14, 1940 with those corrected pages which were written between February 14 and February 21, 1940 and which are available in the form of photocopies stamped Febryary 21, 1940 by the U.S. Post Office would have enabled a man skilled in the art of inducing radioactivity by neutrons to build a chain reacting unit. I believe that, given an opportunity, I could demonstrate this to your satisfaction. If I ~~knew~~ know which of the questions are considered pertinent in this connection, I ~~could~~ can probably also find some written statements to corroborate my contentions in my files.

In the meantime, I shall give Mr. York a short resumé of my contentions and I shall give Mr. Dempster also a written statement of my contentions concerning my disclosures in February, 1940.

I do not feel that I can proceed in this matter any further without having advice of council and I have, therefore, sent a memorandum to Dr. Compton asking that Mr. James P. Hume of the firm Wilkinson, Huxley, Byron and Knight, First National Bank Building, Chicago be cleared for this purpose. His private address is 1350 North State Street, Chicago, Illinois. I suppose his typist will also required clearance. Her name is Ellen L. Kelly, 1133 Home Avenue, Oak Park, Illinois.

I should appreciate very much if you could find how whether my request for clearance of Mr. Hume has reached the O.S.R.D. and if you could do something to accelerate ~~his~~ this clearance.

Very truly yours,

L. Szilard

Cuerin

PRIVATE and CONFIDENTIAL
and not for re-use or release.
Property of Gertrud Weiss Szilard

August 7, 1943

A. H. Compton

L. Szilard

With respect to your memorandum dated August 4, 1943 and my reply of the same date, I wish to reiterate for your convenience and for transmittal to Captain Lavender the following:

A few weeks ago, Captain Lavender made me an offer for inventions which I made prior to November 1940 and which relate to our work. I have not taken out any patents for these inventions but they are disclosed in report A-55 and some other documents. Captain Lavender offered me a lump sum of $25,000 for these inventions and added that if I did not wish to accept this offer, I could file patent applications on my own behalf and submit them to the Government as prescribed by law. He said, however, that if I should take that course, he may be compelled to suggest that my connection with the Metallurgical Laboratory be severed. The reason which he gave was the following: If I should have patents pending which relate to our work and which are not owned by the Government, these patents would come into interferenceoin the Patent Office with patents owned by the Government. The knowledge which I am acquiring through my present association with the Metallurgical Laboratory would, so he said, give me a more favorable position in the interference proceedings than I would otherwise have.

I now understand from your memorandum of August 4, 1943 that I would have to quit working in the Laboratory unless I gave an assurance that the situation which Captain Lavender wants to avoid will not arise. In the circumstances, I am willing to give such an assurance by committing myself to the ~~[illegible]~~ effect that if I do not accept Captain Lavender's offer to which I referred above, I shall refrain forever from filing patent applications on inventions made by me before November 1940. Since I am sure you would not expect me to sacrifice, for the sake of financial gain, my potential usefulness for our work, however small it may be, you will realize that I really have no choice but to give such an assurance. I have indicated to you that I would take this course earlier in a memorandum dated July 20, 1943.

Should the commitment given above not be sufficient and should Captain Lavender want me to sign a differenct commitment as a condition for my remaining at my work, I shall be pleased to receive the text of the statement which Captain Lavender would consider sufficient.

I understand, however, that the commitment given above or any other commitment which I may give now as an alternative to quitting work at the Metallurgical Laboratory leaves the way open to an appeal on my part to the Director of the O. S. R. D. and that it will be at the discretion of the Director of the O. S. R. D. to free me from such a commitment.

Leo Szilard

THIS DOCUMENT HAS BEEN
TAKEN FROM A FILE OF THE
ARGONNE NATIONAL LABORATORY
AND WAS TURNED OVER TO
DR. LEO SZILARD ON
Aug. 29, 1956.
Warren C. Johnson

The University of Chicago
Metallurgical Laboratory

MIDWAY 0800
EXT. 1290

F6x

August 11, 1943

Not sent Superseded by Aug 16, 1943 which

Copy -> [illegible]

Dr. V. Bush
1530 P Street, N. W.
Washington, D. C.

Dear Dr. Bush:

I am sorry that I have to take your time and attention in connection with a matter which has no direct bearing upon the constructive part of our work. It seems to me, however, that a question is involved which requires a ruling by you.

Captain Lavender has made me an offer for certain inventions which I made in 1939 and 1940 at a time when the uranium work was not yet supported by the Government. I was advised yesterday that unless I accepted Captain Lavender's offer I would have to stop working at the Metallurgical Laboratory.

I informed Dr. Compton that, in the circumstances, I have no choice but to commit myself and accept Captain Lavender's offer, but I stipulated that it should be at your discretion to free me from this commitment if you see fit.

I should add that I have so far not made any patent applications for the inventions which are under discussion, and that Captain Lavender told me a short while ago that if I did not accept his offer I could file patent applications on my own behalf for those early inventions. He added, however, that if I should decide to take this course, he would recommend that my connection with the Metallurgical Laboratory be severed. The reason for this, he gave as follows:

If I should apply for patents, those patent applications will come into interference in the Patent Office with applications filed by the Government, and the knowledge which I may be gaining by my present work on the Project might put me in a more favorable position in that interference than I otherwise would be in.

Since questions of this type are decided by taking into account a number of points of view of which the above-mentioned point of view of Captain Lavender is only one, I wish to ask you herewith for a ruling on the following two points:

(1) Whether or not it should be considered compatible for me to remain at my work and to file patent applications on my own behalf claiming inventions which were disclosed in 1939 and 1940 before our work received support from the United States Government.

If your ruling on the foregoing point should be favorable to my point of view, I wish to ask you to decide

(2) Whether or not I should be free from the commitment to accept Captain Lavender's offer, and whether my work in the Metallurgical Laboratory should remain unaffected if I should decide not to take Captain Lavender's offer.

With your permission, I would like to add that by asking you for these rulings, I do not wish to indicate that I am unfavorably inclined to accepting Captain Lavender's offer. It was my intention to decide about that offer, after I had the benefit of advice by counsel, and I was also considering letting the Government have these inventions free of financial consideration. As a matter of fact, I had very little inclination to file patents on my own behalf since I do not believe that patents constitute an adequate method of control in this particular field. Had I thought otherwise, I would have applied for patents long ago.

One reason for asking you to rule on the foregoing points is the fact that I do not like to be forced into any decision under penalty of discontinuing my work. Since your organization might be criticized for the attitude taken in this matter, it seems to me proper to ask the Director of the organization to take the responsibility for a ruling of this sort.

If you should not be able to come to a favorable decision on the basis of this letter, I should appreciate it if you could see Captain Lavender and me together and hear both sides of the case. This need not take more than ten minutes since the issue is really a very simple one.

Sincerely yours,

L. Szilard

Prob not sent

bb51

GWS

The University of Chicago
Metallurgical Laboratory

MIDWAY 0800
EXT. 1290

F6 X

August 11, 1943

See Aug 16, 1943
Sent?

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1530 P Street, N. W.
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Sincerely yours,

L. Szilard

Attached to
patent agreement
Dec 22, 1943

bbs 40

What is claimed is:

1. A power plant comprising a neutronic reactor, a tube extending into said reactor, a neutron absorbing liquid in said tube, and means for changing the amount of the liquid in said tube to control said reactor.

2. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a neutron absorbing liquid in said tube and means for changing the level of the liquid in said tube to control said reactor.

3. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a liquid metal in said tube and means for changing the level of the liquid metal in said tube to control said reactor.

4. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a liquid metal containing bismuth in said tube and means for changing the level of the liquid metal in said tube to control said reactor.

5. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a liquid bismuth containing a strong neutron absorber in said tube, and means for changing the level of the liquid bismuth in said tube to control said reactor.

6. A power plant comprising a neutronic reactor, a tube extending into said reactor, a neutron absorbing liquid in said tube, means for changing the amount of the liquid in said tube to control said reactor, and means for cooling the liquid.

7. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a neutron absorbing liquid in said tube, means for changing the level of the liquid in said tube to control said reactor, and means for cooling the liquid.

8. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a liquid metal in said tube, means for changing the level of the liquid metal in said tube to control said reactor, and means for cooling the liquid metal.

9. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a liquid metal containing bismuth in said tube, means for changing the level of the liquid metal in said tube to control said reactor, and means for cooling the bismuth.

10. A power plant comprising a neutronic reactor, a tube extending in a vertical direction into said reactor, a neutron absorbing liquid in said tube, an exterior tank connected to the bottom of said tube and also containing said liquid to establish a liquid level common to said tube and tank, and means for moving said liquid into and out of said tank to vary the liquid level in said tube.

11. Apparatus in accordance with Claim 10 where the normal liquid level is such as to stop the operation of said reactor.

12. A power plant comprising a neutronic reactor, a system adapted to conduct a metal normally solid at ambient temperatures through said reactor, means for heating said reactor and said system to liquify said metal, and means for circulating said liquid metal through said reactor.

13. In combination, a neutronic reactor having uranium bodies dispersed in a neutron moderator, and a liquid metal comprising bismuth in said reactor in an amount between about one-half of the weight to the total weight of the uranium in the reactor not substantially greater than the weight of the uranium in said reactor.

14. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal coolant through said reactor in contact with said bodies.

15. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal coolant through said reactor in contact with the interior of said bodies.

16. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal coolant through said reactor in contact with the exterior of said bodies.

17. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal containing bismuth through said reactor in contact with said bodies.

18. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal containing bismuth through said reactor in contact with the interior of said bodies.

19. The method of cooling a neutronic reactor having discrete bodies containing uranium disposed in a moderator comprising passing a liquid metal containing bismuth through said reactor in contact with the exterior of said bodies.

20. The method of cooling a reactor comprising passing a liquid bismuth through said reactor to remove the heat of reactor operation, shutting down the reactor, continuing the passage of said liquid bismuth and reducing the melting point of said bismuth by adding lead thereto.

21. A device for producing heat energy for power comprising bodies containing uranium geometrically arranged in an efficient, low neutron-absorbing, neutron slowing-down material, passages through said bodies, a fluid, means passing the fluid through the passages in the uranium bodies so as to extract heat from the walls of said passages, means extracting

the heat from the fluid, and means circulating the fluid in said heat exchange relationship at a sufficient rate to stabilize the temperature in said device.

22. The method of extracting heat from a self-sustaining neutron chain reacting system employing a fissionable material and an efficient neutron slowing material capable of slowing fast neutrons to thermal energy comprising passing a fluid having a danger coefficient less than one in heat exchange relationship with the fissionable material, and then removing the fluid from the system.

23. For use in a neutron chain reacting system, a uranium body having a passage therethrough for circulation of a coolant therethrough.

24. For use in a neutron chain reacting system, a fissionable material in the form of a body having a passage therethrough for circulation of a coolant therethrough.

25. For use in a neutron chain reacting system, a fissionable material in the form of a body cylindrical in form and having a passage therethrough for circulation of a coolant therethrough.

26. A neutronic reactor comprising a moderator having channels therein, masses comprising uranium and smaller in diameter than said channels positioned along the channels, said channels being adapted to conduct a coolant into contact with the masses.

27. A neutronic reactor comprising a moderator having channels therein, masses comprising fissionable material and smaller in diameter than said channels positioned along the channels, and means passing a coolant through the channels in contact with the masses.

28. In a neutronic chain reacting system, a neutron moderator having channels therein, means for passing a fluid coolant through said channels, and a plurality of uranium rods positioned in said channels.

29. In a chain neutron reacting system operating by virtue of nuclear fission of a fissionable material, means for abstracting the heat of fission comprising a body of fluid in heat exchange relationship with the fissionable material in the system.

30. The method of cooling a neutronic reactor having a moderator and uranium bodies dispersed therein comprising passing a liquid metal containing bismuth in heat exchange relation to said uranium.

31. The method of cooling a neutronic reactor having a moderator and uranium bodies dispersed therein comprising passing a liquid metal containing bismuth through the interior of said bodies.

32. The method of cooling a neutronic reactor having a moderator and uranium bodies dispersed therein comprising passing a liquid metal containing bismuth in heat exchange relation with the exterior of said bodies.

33. The method of operating a neutronic reactor comprising passing a coolant through said reactor, and removing from said coolant a radioactive element formed by neutron absorption by said coolant.

34. The method of operating a neutronic reactor comprising passing bismuth through said reactor and removing from the reactor polonium formed by neutron absorption by said bismuth.

35. The method of transmitting elements comprising repeatedly passing said elements through a neutronic reactor, removing heat from said elements between passes, and thereafter recovering from said elements different elements formed by neutron absorption during said passes.

36. A neutronic reactor comprising a moderator, uranium bodies dispersed in said moderator, coolant tubes positioned in heat exchange relation to said uranium bodies, and a liquid metal coolant in said coolant tubes.

37. A neutronic reactor comprising a moderator, uranium bodies dispersed in said moderator, coolant tubes positioned in heat exchange relation to said uranium bodies, and a liquid metal comprising bismuth in said coolant tubes.

38. A neutronic reactor comprising a moderator, uranium bodies dispersed in said moderator, coolant tubes positioned in heat exchange relation to said uranium bodies, and a liquid metal of low neutron capture cross-section in said coolant tubes.

39. A neutronic reactor comprising a moderator, uranium bodies dispersed in said moderator, coolant tubes positioned in heat exchange relation to said uranium bodies, and a liquid metal bismuth alloy in said coolant tubes.

40. A neutronic reactor comprising a moderator, uranium bodies in said moderator, and means for conducting a liquid metal coolant in heat exchange relation with said uranium bodies.

41. A neutronic reactor comprising a moderator, uranium bodies in said moderator, and means for conducting a liquid metal coolant through the interior of said bodies.

42. A neutronic reactor comprising a moderator, uranium bodies in said moderator and means for conducting a liquid metal coolant over the exterior surface of said bodies.

43. A neutronic reactor comprising a moderator, uranium bodies in said moderator, and means for conducting a liquid metal coolant between said bodies and said moderator.

44. A neutronic reactor comprising a liquid moderator, uranium bodies dispersed in said moderator, means for conducting a liquid coolant through said moderator, means for conducting a liquid coolant through said bodies at a temperature higher than the boiling point of said moderator, and means providing heat insulation between said bodies and said moderator.

45. A neutronic reactor comprising a liquid moderator, uranium bodies dispersed in said moderator, means for conducting a liquid coolant through said bodies at a temperature higher than the boiling point of said moderator, and means providing a heat insulating space between said bodies and said moderator.

46. A neutronic reactor comprising a liquid moderator, uranium bodies dispersed in said moderator, means for conducting a liquid coolant through said bodies at a temperature higher than the boiling point of said moderator, and means providing a gaseous barrier between said bodies and said moderator.

47. A neutronic reactor comprising a liquid moderator, uranium bodies dispersed in said moderator, means for conducting a liquid coolant through said bodies at a temperature higher than the boiling point of said moderator, and means providing a space filled with helium between said bodies and said moderator.

48. A neutronic reactor system comprising a neutronic reactor, and a primary circulating system operating to cool and recirculate a coolant through said reactor to be made radioactive thereby.

49. The method of operating a neutronic reactor having discrete uranium bodies disposed in a neutron moderator comprising maintaining the uranium at a lower temperature than that prevailing in the moderator.

50. The method of operating a neutronic reactor having discrete uranium bodies disposed in a neutron moderator comprising cooling the uranium to a lower temperature than that prevailing in the moderator.

51. The features of novelty herein shown and/or described.

Compton

66s-3

NRD

THE UNIVERSITY OF CHICAGO

DATE October 7, 1942

~~SECRET~~

TO Mr. Leo Szilard DEPARTMENT

FROM A. H. Compton DEPARTMENT

IN RE: Engineering of Bismuth Cooled Plant

In accord with instructions from General Groves, I have requested Mr. Moore to proceed at once with the engineering of a bismuth cooled power plant.

May I ask you to act as consultant to Mr. Moore on the design of this plant. One of the most useful things you could do now would be to recommend to him by Friday of this week an engineer with whom you could work to advantage and who under Mr. Moore's direction would have the immediate responsibility for designing the plant.

In accord with the directive which I have been given by General Groves, the immediate objective is to design a plant that can be ready for operation by June 15, 1943. We have in mind the dissipation of roughly 100,000 kw. This figure is, however, flexible if there should arise important advantages in a plant of larger or smaller capacity.

In case it should appear impracticable at this time to design a bismuth cooled plant to be ready by June 15, work on such a plant will cease to be of the greatest urgency. Interest in it will nevertheless continue both as a possible plant for large capacity and as a possible means of utilizing the power that is developed. Studies aimed toward such developments would be continued.

A. H. Compton

KT

cc: Mr. Moore
Mr. Allison
Mr. Doan

~~SECRET~~

CLASSIFICATION CANCELLED
Date 10/3/56
For The Atomic Energy Commission
C. L. Marshall/MCK
Director, Division of Classification

~~67678~~

SECRET

MUC- LS. #1
This document consists of 2 pages and 0 figures
No. 4 of 7 copies, Series A

L. Szilard
June 12, 1943

Memorandum on Metallurgical Problems Connected with the Power Unit which is Cooled by Liquid Metal

The possibility of using a liquid bismuth, liquid lead and bismuth-lead alloys for cooling both graphite and heavy water power units is at present under investigation. Of particular interest is the eutectic alloy of bismuth and lead which has a melting point of about 130°C; and at the first step, it might be advisable to use this alloy between 150°C up to 300°

1. No particular metallurgical problems arise in connection with graphite power unit if uranium is used in the form of uranium carbide.

It will, however, be desirable to determine at what velocities does true erosion occur, if at all, in graphite and uranium carbide under the conditions of flow which may be expected to exist in the power unit

CLASSIFICATION CANCELLED
Date 10/3/56
For The Atomic Energy Commission
Director, Division of Classification

2. If uranium is used in the form of uranium metal, we obtain wetting of the uranium by the eutectic Bi-Pb alloy. An experiment is being prepared for seeing if uranium is soluble in the liquid eutectic. It is known that uranium is soluble in liquid bismuth and an experiment is being prepared to determine whether uranium is soluble in liquid lead in order to determine whether there is any hope that bismuth-lead alloys, sufficiently rich in lead, can be used in direct contact with uranium.

3. If it should prove impossible to use uranium metal in direct contact with bismuth-lead alloys, the uranium metal will have to be protected by some other material. It is also of interest to see what materials other than uranium can be used to form tubes through which the bismuth-lead alloys can be led through the power unit. The following materials are under discussion: graphite, beryllium, aluminum, iron.

SECRET

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U. S. C. 50; 31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

G7678

Graphite appears to be safe from the point of view of chemical action or carbide formation at low temperatures. Carbon is insoluble in bismuth and no bismuth carbide is known to exist.

Beryllium does not appear to be wetted by eutectic lead-bismuth alloys at 400°C. It would be desirable to see if beryllium is soluble in liquid bismuth, liquid lead and bismuth-lead alloys. No such experiments have been prepared so far.

Aluminum does not appear to be wetted at 400°C by the eutectic bismuth-lead alloy. Aluminum is not soluble in liquid lead but is slightly soluble in liquid bismuth. An experiment has been planned to determine whether or not aluminum is soluble in the eutectic bismuth-lead alloy. It appears likely that aluminum will prove to be insoluble in bismuth-lead alloys which are sufficiently rich in lead.

Iron is not soluble in either liquid bismuth or lead and it is expected that it is insoluble in lead-bismuth eutectic. Iron could be used in the form of a thin coating to protect the uranium and iron tubes have been successfully ground down by Creutz to .01 inch. It is expected it would be possible to grind down iron tubes from .022 inch which is a commercial size to .005 inch.

The behavior of 18-8 stainless steel and of duraluminum has a certain degree of interest and an experiment has been prepared to see whether the lead-bismuth eutectic wets either of these substances.

CC: Reading File
J. Chipman
F. Foote
E. Wigner
E. Creutz
H. Smyth
S. Allison

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