MEMORANDUM

It has now become feasible to demonstrate the possiblity of a nuclear chain reaction and to maintain such a chain reaction in a large quantity of certain mixtures of uranium and other elements. Experiments carried out at Columbia University were performed on small quantities of material of the order of a few kilograms. In view of the far reaching petential consequences of this development it would appear necessary to carry out large-scale experiments as speedily as possible, and for this reason it is required that experiments be started at once with tons of material rather than the small quantities hitherto used.

1.) The experiments at Columbia University were financed partly by the Physics Department and partly by the Association for Scientific Collaboration. The proposed experiments will make it necessary to appeal for funds either through University Laboratories or through the above-mentioned Association. Such an appeal should be directed in the first place to public-spirited private persons; if that fails an attempt might be made to enlist the co-operation of the leading industrail firms of the electrical and chemical industry.

2.) It appears to be desirable that a large stock of pitchblend, which is the common ore of both radium and uranium, be brought over from Belgium or directly from Belgian Congo and be stored in this country for future possible use.

In taking action along this line it would not be necessary to disclose that the uranium content of the ore is the point of interest, and action might be taken on the ground that it is of value to secure the ore on account of its radium content for possible future extraction of the radium for medical purposes. Perhaps it might be possible to obtain a large quantity of this ore as a token reparation payment from the Belgian Government; at present this ore is practically without commercial value.

In the circumstances it appears advisable to keep the Administration of the United States informed of these developments so that they should be able to take action along this line if required.

It also appears desirable that the Belgian Government be advised at once of the potential value of the pitchblend in Belgian Congo, so that it be in the position to prevent the supply of this ore to countries which must be considered potential enemies both of Belgium and the United States.

[ca. 1940]

SUMMARY

Recent experimental work and calculations based on its results make it appear possble that in the immediate future a nuclear chain reaction might be set up under certain well specified conditions in a system composed of uranium oxide and graphite. In view of this and other possibilities it seems desirable

1. that it should be made the responsibility of some person or persons to watch on behalf of the government the further develpment of this branch of research, so that the government should be at any time in the position of taking such action as it deems appropriate;

2. that some person or persons who have the confidence of the government should take upon themselves the task of furthering this branch of research, of insuring that it should not suffer from lack of facilities, and of preparing the grounds for experiments on a large scale, which might become necessary.

Observation to the above.

The fairly large quantities of material, which might be required for performing large - scale experiments, might perhaps be secured, without drawing on existing funds, by enlisting the assistance of certain industrial firms in the U.S.A. and of the Union Minière du Haut Katanga. Most of the amterials required are produced by large corporations who own uranium mines and would therefore directly benefit if the present development created a market for uranium. Some of these firms could be approached now with a view of obtaining the promise of their assistance.

THE POSSIBILITY OF A LARGE-SCALE EXPERIMENT

IN THE IMMEDIATE FUTURE.

At present it appears quite possible that a nuclear chain reaction could be set up in a system composed of uranium oxide (or uranium metal) and graphite. The graphite would have to be piled up in a space of perhaps 4 x 4 x 4 metres and might weigh about 100 metric tons. Perhaps 10 x 20 tons of uranium oxide would have to be used, embedded in some such pile of graphite.

The probable success or failure of such large-scale experiment can not be forecast at present with any degree of assurance, The properties of a system composed of uranium and graphite have been calculated independently, for a homogeneous mixture by Fermi, for a lattice of spheres of uranium oxide, or uranium metal, embedded in graphite, by myself. The results of these two independent calculations are in reasonable agreement and show that the two independent calculations are in reasonable agreement and show that the two arrangements have different properties. For instance, in the case of using a lattice of spheres a great advantage could be obtained by using uranium metal instead of uranium oxide, whereas in the case of the homogeneous mixture the use of uranium metal would be of no great advantage. In spite of these calculations, we ca: cannot foretell with certainty whether or not a nuclear chain reaction can be maintained in such a system because the absorption cross-section of carbon for slow neutrons is not sufficiently known.

In order to remove this incertainty Fermi and I have devised two different experimetns by means of which the absorption cross-section of carbon, which is very small, could be measured. It is assumed that one of these experiments, or both of them, will be started at Columbia University as soon as the facilities required can be obtained.

If the absorption of carbon should turn out to be comparatively large we could conclude that the large-scale experiment is bound to fail, and in this case it need not be started. If the absorption of carbon should prove to be exceedingly small the large-scale experiment would appear to be very promising, and it can be assumed that everybody will then be in favor of starting it without delay.

Unfortunately, we must be also prepared to find an inter - mediate value for the carbon absorption. Inthis case a large-scale experiment will have to be performed in order to find out whehter or not a nuclear chain reaction can be achieved with a combination of uranium and graphite. So we may have ro make the experiment and risk its possible failure.

It should be borne in mind that a negative result of the large-scale experiment could also be of value by showing with certainty that a chain reaction cannot be achieved with simple means in the near future. Otherwise there remains an ever present potential threat arising out of experiments on uranium, which are carried out in certain other countries. Therefore, in my personal opinion a large-scale experiment ought to be performed unless the possibility of its success can be excluded with reasonable assurance o n the basis of experiments which are designed to determine the absorption of carbon, or other similar experiments which can be carried out on a moderately small scale.

RECOMMENDATIONS CONCERNING LARGE-SCALE EXPERIMENTS.

No expenses need be incurred in connection with large-scale experiments until the absorption of carbon has been measured. On the other hand, steps ought to be taken now in order to prepare the ground for a large-scale experiment, so that this can be started without delay at the proper time. For instance, the possibility of converting uranium oxide into uranium metal ought to be explored. An attempt ought to be made to obtain a promise on the part of certain industrial corporations to supply at the proper time the quantities of the materials, which are required. If possible, these materials ought to be loaned wihtout any financial consideration. Barring an accident in the case of a successful large-scale experiment most of the materials used would remain unaffected and could be returned after the experiment is completed.

100 metric tons of graphite represent a value of about ∅ 33.000 at the rate of ∅ .15 perlb. If a purer brand of graphite has to be used, which rates at ∅ .24 per lb, the value involved would be ∅ 53.000.-

20 metric tons of uranium oxide represent a value of ∅ 100.000 at the rate of ∅ 2.50 per lb. If it need not be converted into uranium metal but can be used in the form of oxide in the large-scale experiment, this material could be kept pure and could be returned undamaged. It would be desirable to have up to 50 tons of uranium oxide readily available for experiments in the United States.

STATEMENT CONCERNING THE POTENTIAL ASSISTANCE OF THE UNION MINIERE DU HAUT KATANGA.

It would be of particular value to enlist the assistance of this Belgian corporation which is to some extent controlled by the Belgian Government. It appears to be the only corporation which could supply at short notice 20 metric tons of uranium oxide, and probabl even 50 tons. I understand that the Managing Director, Mr.E. Sengier is on a short visit in America.

From conversations which Professor G.B. Pegram of Columbia University had with a representative of the Eldorado Gold Mines, Ltd. it appears that this Cancadian corporation might be able to supply uranium oxide for our purposes at the rate of 1 ton per week. If the uranium oxide were to be bought rather than obtained as a gift or a loan, it might be secured from Canada probably just as easily as from Brlgium. On the other side, the Canadian corporation is rather small and can hardly be asked to give away large quantities of material without financial compensation.

So far, radium up to about 2.5 grams was used in our experiments, and we had to pay high rent to a subsidiary of the Union Minière, the only corporation from which large quantities of radium can be readily rented in this country. An attempt oight to be made to obtain radium for the purposes of such experiments rent-free from the Union Minière in the future.

Carnotites containing uranium are mined in the U.S.A. by the U.S. Vanadium Corporation which is owned by the Union Carbon and Carbide Corporation. A conversation which I recently had with William F. Barrett, Vice-President of this corporation, did not encourage the hope of obtaining large quantities of uranium oxide from this firm, but the issue could perhaps be reopened.

STATEMENT ABOUT URANIUM ORE.

As far as I was able do find out, pitchblend ,which is an ore rich in uranium, is mined in Czechoslovakia, Canada and

Belgian Congo. The total content of uranium in the deposit in Czechoslovakia is estimated to be between 1000 and 1500 tons. T he Canadian deposit visibly contains a total of 3000 tons. The amount of pitchblend in the Belgian Congo is not known, but it is believed to be very much larger. In the United States uranium occurs chiefly in the form of carnotites, which is an ore poor in uranium , and is mined for the sake of its vanadium content. The total deposit is estimated to contain 3000 tons of uranium oxide. (Perhaps there are in the United States larger quantities of ore containing a very small amount of uranium which are not included in the above estimate.)

RECOMMENDATION CONCERNING URANIUM ORE.

Steps to secure a stock of uranium ores for the government can hardly be recommended at the present time if such steps would involve financial commitments in the part of the government. It might, however, be advisable to begin to study the question in what manner the government could secure such a stock at a later date if required.

For instance, the question has been raised whether it might not be possible to obtain for the government a large quantity of pitchblend from Belgium as a token reparation payment. Such a transaction would not cause alarm abroad if it were arranged before the world learns of th e results of some successful large-scale experiment. The transaction could be justified wihtout reference to the uranium content of the ore. Pitchblend is also the ore of radium, and action could be taken on the ground of securing the ore of radium, and action could be taken on the ground of securing the ore for the sake of its radium content, with a view of extracting the radium at some future date for medical purposes. Action taken on this ground alone might in fact be entirely justified.

MEMORANDUM:

The sale of arms by Czechoslovakia to Egypt in exchange for cotton deliveries might turn out to be a blessing if it forces the statesmen to face the problem of enforcing a limitation on armaments of the smaller nations even before it becomes possible for the great powers to disarm. Cash and carry might have represented the quintessence of a legitimate commercial transaction before the war, and the principle of cotton and carry is hardly different from it; but times have changed and an arms race between the smaller powers who are not completely controlled by either Russia or America or their close allies might well lead to an all out atomic catastrophy.

COTTON AND CARRY

The sale of arms by Czechoslovakia to Egypt in return for cotton deliveries might turn out to be a blessing if it forces the statesmen to realize that it is necessary to re-adjust our thinking to the realities of the atomic age.

Before the war, some people might have felt in America that to sell arms on long-term credit to another nation might represent an intervention, particularly if the other nation was on the brink of war. No one seemed to doubt that if the principle of cash and carry was observed, the sale of arms represented legitimate commercial transactions rather than military intervention.

Before the war, it used to be cash and carry. Nowdays, it is sometimes cotton and carry. The principle is the same. The times have changed. For if arms anarchy is permitted to continue, where is the limit if tanks and guns are sold by the great powers to small nations in commercial transactions? Why not also atomic bombs? And if there are local arms races engaged in by small nations, how are we going to prevent a local war in which neighboring nations may join and in which, in the end, Russia and America might be compelled to join on opposite sides?

This, it seems to me, is the likely path towards an all out atomic catastrophy, much more so than a direct attack of Russia on America, or vice versa. Such a direct attack would indeed be exceeding the unlikely once America and Russia reach the point where their strategic air forces are sufficiently dispersed and protected so that no sudden massive attack can appreciably decrease the power of the other to retaliate. Once this state is reached, we have a true strategic stalemate between Russia and the Soviet Union and if certain precautions are taken to prevent an accidental triggering of an attack against each other, a comparatively stable situation would be reached. The danger of an all out atomic catastrophy would still be with us if in the absence of a political settlement America and Russia may very well line up on opposite sides in the war that starts out as a local conflict. If atomic bombs are then used by Russia and America in the tactical area, things can easily go from bad to worse. No one will be able to say "up to here and no further", and in the end, an all out atomic catastrophy might ensue. Neither America nor Russia can possibly want an all out atomic catastrophy and we may assume that they are exercising restraint and also be able to restrain those nations whom they supply with arms and whom they control.

But what about the nations who buy arms on a cash and carry or cotton and carry basis? And what about the world in which a number of smaller independent nations have acquired stock piles of atomic bombs and means for their delivery?

General disarmament may be a long way off, and in any case, such disarmament once agreed upon cannot be enforced against such giants as the United States or Russia. The best we can hope in this respect is that secret violations of the disarmament provisions would be detected without delay and that the disarmament provisions which are secretly violated would be promptly abrogated by the other nations. But long before general disarmament is accomplished, it may be necessary to have some form of enforcement to prevent the smaller nations from endangering each other and the peace of the world through an uncontrolled arms race. What form can such enforcement take? And what is the legitimate level of conventional arms which Israel, for instance, ought to have, and to how much arms is Egypt entitled? Either country can legitimately want what they regard as a safe margin of superiority. If the race for the arms between Egypt and Israel is indeed the mutual fear of an attack by the other, why not have Egypt and Israel agree on five to seven nations to supply small but highly mobile forces, stationed partly in Egypt and partly in Israel, manned by the nations selected but armed and equipped and financed in part by the great powers and in part by Egypt and Israel. This mobile force, armed with conventional weapons, need not be large and yet it could prevent forcible territorial changes; for in case of an attack of one country against the other, it could penetrate to the capital and arrest officials of the offending government and it could penetrate to military headquarters and arrest the commanding generals. With the fear of an attack gone, Egypt and Israel might have not been permitted to buy as much conventional equipment as they wished if they choose to waste their resources in such a manner, provided only that the equipment they buy is inferior in fire power to the original force.

MEMORANDUM ON COOLING OF THE POWER PLANT

A number of different cooling systems have been considered. It was considered desirable to transfer about 10^6 KW in machine which contains 50 tons of uranium. This is, however, not the upper limit that can be reached. Methods have been devised to transfer 10^6 KW per ten tons of uranium. Though one could transfer without much difficulty larger amounts of heat, there does not seem to be any immediate necessity for pushing the figure higher. Every cooling system is characterized by a number of features. Obviously there is a large combination of these features possible, but only a limited number of the combinations appears to be of interest. In the following these features will be enumerated and briefly described:

1. The following cooling agents were considered: Air, hydrogen, helium, water, liquid bismuth.

2. Direct cooling in which the liquid agent is in direct contact with uranium. Only helium and bismuth appear to be perfectly safe to be used in this way.

3. Indirect cooling in which the heat is transferred from the uranium to graphite and from graphite to the cooling agent. In the case of indirect cooling the cooling agent need not be in direct contact with graphite. For instance, it can be lead through pipes of beryllium, Karbade, or aluminum through the graphite.

4. Contact transfer to graphite, that is, a method of indirect cooling in which the heat is transferred from uranium metal direct to graphite.

5. Bismuth transfer to graphite, that is, a system of indirect cooling in which the heat is transferred from uranium metal, uranium oxide, or uranium carbide to the graphite by a slow stream of liquid bismuth.

6. A system of indirect cooling in which air is lead in beryllium, Karbade or aluminum tubes through the graphite pile.

7. A system of indirect cooling in which there is an intermittent flow of water through beryllium, Karbade, aluminum, or lead tubes through the graphite pile. If this system is used it might be advisable to build twin machines which are exposed to each others neutron radiation.

8. A system of direct cooling in which we have as cooling agent either bismuth or helium. Uranium metal, oxide or carbide is arranged in form of more or less sphere-like shapes which have an internal structure so as to have a large surface for heat transfer without having a large surface for resonance neutron absorption (for instance, sphere-shaped cluster of uranium oxide in form of granules). The helium or bismuth coming in through a lead passes through one or more such clusters and follows to another lead.

The inclosed diagram illustrates the interconnection of the various cooling systems. The most interesting alternatives can be summarized as follows: (1) direct cooling by helium or bismuth in a double ~~string~~ [illegible] cluster arrangement; (2) water cooling of an intermittent twin power plant in which the water is lead in pipes through the graphite and the heat is transmitted from the uranium to the graphite either by liquid bismuth or by direct contact between uranium metal and graphite; (3) an air-cooled indirectly cooled continuous system.

The table shows the factors which enter into the heat transfer number for bismuth, helium, air and water. The heat transfer number is given for the critical velocity,that is for the velocity at which the kinetic is equal to the heat transported for a temperature rise of . If not otherwise stated, the values are given in c.g.s. units. Is the average temperature difference which is used for calculating from h (heat tranfer number), the amount of energy actually transferred?

MEMORANDUM ON CYLINDERS

A lattice of indefinitely long cylindrical rods, shortly, "cylinders," has been considered in 1939 and again in 1940. Formulae were derived for calculating the fraction of thermal neutrons absorbed by the uranium cylinders in such a lattice. A collection of such formulae was compiled for the August meeting of the theoretical subcommittee of the uranium committee (Tables dated August 22, 1941. Photocopies available on request).

These formulae were numerically evaluated by B. Feld for cylinders of 2 to 6 cm. radius and various ratios of uranium to carbon. These computations were completed in September, 1941, and the results can be communicated to those interested. These calculations

Naturally no difference can be expected on the basis of our present knowledge between spheres and cylinders if the radii are small since both cases can be treated as quasi-homogeneous mixtures of uranium with carbon. It is of interest, however, to note that if we consider spheres of about 2 cm. radius and cylinders of $2\frac{1}{2}$ cm. and a weight ratio of carbon to uranium of 5 to 1, the thermal utilization factor for the sphere is .86, whereas for the cylinder it is only .8. This shows that we lose about a factor of 1.07 or about 7% by going over from spheres to equivalent cylinders in this range of radii. Let us also compare an 8 cm. sphere with a 6 cm cylinder which are equivalent from the point of view of average thermal neutron density inside the metal. Our data show that we have for both the same thermal utilization factor of about .82, but found different weight ratios of carbon to uranium. This ratio is 2.2 for the sphere and 1.8 for the cylinder. In spite of this the use of long cylindrical rods has not been discounted because it is possible to bring the multiplication factor for cylinders close to the multiplication factor for spheres by introducing neutron slits (see below) . Whether long cylinders or narrow spheroid bodies of uranium should be used will be ultimately determined by practical considerations connected with the cooling problem and ~~we also depend~~ must primarily depend upon the nature of the cooling agent ~~which will be used.~~ The result of certain chemical work now in progress will have to be awaited before a final stand can be taken on this subject.

Small spheres and narrow cylindrical rods

Multiplication factor

L. Szilard

~~[illegible]~~ Home

MEMO ON HEAT TRANSFER

In order to be able to compare various cooling systems it is useful to derive certain general formulae which are approximately correct under the conditions under which the projected plan would operate.

Helium

Helium Cooling

Orders of Magnitude.--10^{-6} KW plant requires flow of about 400 kilograms of helium per second. This corresponds at room temperature to 2.2 x 10^{-6} liters at one atmosphere pressure. For ten atmospheres we have 2.5 x 10^{-5} liters and would have to put up 2200 KW if we have to pump against 1/10 atm pressure difference. At 100 meter velocity the helium flow requires a cross-section of 2.2 m^2.

Characteristic Velocity.--We define as the characteristic velocity the velocity (v_0) at which the kinetic energy is 1% of the heat which the helium carries away if a temperature rise of ~~about~~ ΔT is permitted.

$$\frac{M v_0^2}{2} = \frac{5}{2} R \Delta T$$

With M = 4. R = 8.31 x 10^{-7} we have for ΔT = 300°C

v_0 = 1.7 x 10^{-4} cm. = 170 meters

The ~~absolute~~ temperature of the helium may be about ~~600 absolute or more on leaving the pile~~ twice at exit as on entry. Accordingly, the density of helium at exit will be about half, the velocity about twice, and the friction loss per unit lengths of pipe, also twice of the corresponding values at entry.

Critical Length.--The helium is flowing through a duct or pipe and we define as ~~a~~ critical length l^* the length of the pipe in which the loss due to friction is equal to the kinetic energy which corresponds to the velocity of the flow. Up to Re = 50000 we have $\lambda = \frac{0.133}{Re^{0.25}}$

$$\frac{\Delta p}{l} = \lambda \frac{1}{r} \frac{\rho v^2}{2}$$

By putting

$$\Delta p = \frac{\rho v^2}{2}$$

we find for the critical length

$$l^* = \frac{r}{\lambda} = \frac{r}{0.133} Re^{0.25}$$

We see from this equation that the critical length varies proportionately with the radius of the pipe, but inasmuch as it goes with the fourth root of Re it is practically independent of the density between 1 and 10 atmospheres.

If Re = 10,000 we have for the length l^*:

r = .1 cm.; l^* = 7.5 cm.	r = 5 cm.; l^* = 375 cm.
r = .3 cm.; l^* = 22.5 cm.	r = 10 cm.; l^* = 750 cm.
r = 1 cm.; l^* = 75 cm.	

In a pile of 3.4 x 3.4 x 3.4 meters we may have in a cross section 300 units. Each double duct serves 4 units so that we have 75 double ducts. One double duct would have an area of 300 cm.^{2} (corresponding to a radius of 10 cm. if it were a single duct, which it is not).

Taking viscosity of helium at some high temperature to be $\mu = 350 \times 10^{-6}$ we obtain for 100 meter velocity and 5 cm. radius for Re $= \frac{\rho v r}{\mu}$

$$Re \cong 2.5 \times 10^4$$

Changing Pressure.--If we keep the velocity of the helium and the geometrical arrangement but reduce the pressure by a factor 10 (and accordingly the heat transport from 10^{-6} kw. to 10^{-5} kw.) the pump work will drop by a factor of 10. The critical length as defined above does practically not change with pressure, and the pump work is therefore the same fraction of the transported heat in both cases.

MEMORANDUM ON HEAT TRANSFER

Taking as a basig figure, 10 to 6 kilowatts for 10 tons of uranium we obtain 1/8, 10 to the sec. W E per sec. per unit length for a uranium cylinder of 3 cm. radius and density 17 Gms. per c.c. or about 500 Gms. of uranium.

This would require a heat transfer from the uranium to the liquid metal of about 800 cal. per cm. sq. and sec. This would be far too much even if the heat conductivity of uranium were equal to that of copper; i.e., about 1. The heat conductivity of uranium metal appears to be 25 times less.

Clusters

In order to improve the heat transfer, the uranium can be clusterized as shown in Figure 2, if one uranium cylinder is replaced by n cylinders. The surface of the uranium is increased by a factor of and the depth is decreased by the same factor. Consequently, the amount of heat transferred for a given temperature difference between the maximum temperature in the uranium and the cooling liquid is increased by the factor n.

If the cross-section of the cooling liquid is retained, then clusterization by the factor n will decrease the symbolic radius r which enters into the pressure loss equation by a factor, .

Clusterization is desirable if the heat conductivity of the uranium compound used is small or the cooling liquid does not wet the uranium compound. The arrangement shown in Figure 3 may then be resorted to for the pur pose of keeping the velocity of the cooling liquid low and thereby keeping friction losses in moderate bounds of excessive clusterization. In this arrangement, bismuth appears to be the best choice for a cooling liquid. The bismuth transfers its heat to a good conductor such as graphite and the graphite is cooled by another stream of bismuth, or if a twin arrangement is used (see below) to some liquid metal like tin, lead, etc.

Another alternative arrangement is used, which is shown in Figure 3; here the bismuth flowing through a cluster unites with another direct bismuth stream This arrangement is meant for the exclusive use of bismuth only and does not foresee intermittent operation in a twin arrangement

Figure 4 and 5 of the two different simple types of cooling and Figure 6 shows a modification described in Figure 5. If a metal is used as a cooling liquid which has an absorption for neutrons too great to permit the chain reaction to continue, it is necessary to operate in an intermittent way. Such a metal, for instance, tin, is then periodically pumped into and through the graphite system and periodically drained from the graphite. The chain reaction is stopped while the tin flows through the graphite and starts again when the tin is drained out of the system. Such an intermittent operation requires, however, the use of a twin or multiple arrangement. This is necessary for the following reason: after the chain reaction is stopped the neutron density falls off quite rapidly corresponding to the increased absorption due to the presence of the cooling liquid in the system. When the cooling liquid is drained out of the graphite the chain reaction starts again but since the neutron density is very low it would take a long time to reach the required intensity. On the other hand, if two graphite systems are used (shown in Figure 7) one of the twins is drained of tin and maintains a chain reaction while the other is being cooled. The chain reaction of the first of the twins will then maintain a considerable neutron density in the second of the twins so that when during the next period the second twin is emptied there is a very short time required for the chain reaction to reach full intensity.

If an intermittent way of operation is used the length of the active period is limited by the heat capacity of the uranium and its heat output. For instance:

This being a severe limitation it is of interest to note that the effective heat capacity limiting the length of the active phase is considerably increased by using an arrangement as shown in Figure .

If a cluster arrangement is used the nuclear effects of bismuth can be taken into account by condering the cluster as a homogeneous mixture of uranium and bismuth.

The principle of the system is illustrated in Figure 1. In this Figure we see two leads; cold liquid bismuth, at a temperature slightly above the melting point is passing through Lead 1. From Lead 1, the liquid bismuth passes through a number of transverse connections into Lead 2. These transverse connections carry the bismuth through a spherically shaped cluster of granules of uranium or uranium carbide. Heat is developed in these granules and is transmitted to the bismuth in the clusters. We may figure on a temperature increase of the bismuth in the clusters of about 300 centigrades. The bismuth which is thus overheated collects in Lead 2. The flow in Lead 1 and in Lead 2 is parallel. The cross section of Lead 1 decreases along the direction of flow and the cross section of Lead 2 increases correspondingly along the direction of the flow. In this way the pressure difference driving the bismuth through the cluster may be the same for all clusters along the direction of the flow.

In order to see the various factors which have to be considered, we shall make use of an ~~assumption~~ example which is based on the assumption that 10^6 kw. are liberated by 10 tons of uranium. Each cluster contains 2 kg. of uranium and develops 50 Cal. per second. Allowing a temperature increase of 300 centigrades, we have to press 500 cc. bismuth per second through each cluster. Assuming that the cluster has a cubic shape of about 5 x 5 x 5 cm. and that $\frac{1}{4}$ of the volume of the cluster is filled with bismuth, the total cross section of the bismuth flow within the cluster is about 5 $cm.^2$. This corresponds to a bismuth velocity of 1 cm. per second within the cluster. If the energy corresponding to this velocity is lost 20 times within the cluster, then we have a pressure drop of 1 atmosphere. This will correspond to granules of about 2.5 m/m diameter.

Allowing a temperature rise of 300 centigrades, the dissipation of a heat production of 10^6 kw. requires a total flow of 2500 liters of bismuth per second. To pump this quantity of bismuth against the pressure of 1 atmosphere requires about 250 kw. (exclusive of losses).

Assuming an average velocity of $7\frac{1}{2}$ m. in the leads, the total cross section of the flow of bismuth in the leads amounts to 1/3 m^2. If we further assume that we have about 225 pairs of leads, each pair of lead would have a cross section of about 22 cm^2.

Figure 2 illustrates a device which is proposed to be used as a pump for the liquid bismuth. A device of this type has been originated by A. Einstein and L. Szilard, and various ~~motors~~ models were built and used to pump mercury and liquid alloys of potassium and sodium between 1930 and 1933. In Figure 2, 21 is a steel tube; 22 is a laminated iron core inside the steel tube, which leaves a circular gap 23. The gap 23 is filled with liquid bismuth. A number of copper ~~cores~~ coils are placed around the steel tube 21 ~~and are~~, embedded in the laminated stator of the "motor". By means of these ~~cores~~ coils, a magnetic field is generated across the bismuth in the gap between the steel tube and the iron core. The direction of the magnetic lines of force ~~near~~ in the bismuth ~~gap~~ is perpendicular to the axis of the arrangement. The magnetic field moves parallel to the axis and generates an electric current which is perpendicular to the axis and encircles the iron core. The ponderamotive force acting on the bismuth is parallel to the axis and pumps the bismuth through the tube.

It may be mentioned that if the granules are wetted by bismuth so that we have no temperature drop at the interphase, the temperature difference between the center of the granules and the bismuth is inversely proportionate to the number of granules per unit area. In our present case, was have examined 400 granules over an area of 25 cm^2. However, if the bismuth does not wet the granules and if the temperature drop at the interphase dominates, then the over-temperature of the granules will be inversely proportionate to the square root of the number of granules per square centimeter.

In the paper which I submitted to the Physical Review in February 1940, it was envisaged to cool by means of liquid bismuth a system of uranium spheres embedded in graphite. In the present memorandum, certain aspects of this system of cooling are illustrated. The estimates made in the present memorandum are based on a heat production of 10^6 kw. per 10 tons of uranium.

The ratio of the weight of uranium to carbon is assumed to be about L;10. The number of uranium spheres is 17 x 17 x 17, each sphere weighing about 2 kg., leading to a total of 10 tons. The graphite is assumed to have the shape of a cube of 3.4 x 3.4 x 3.4 m^3 or about 40 m^3 or 70 tons.

To Dr Novick from Szilard

~~Rough draft~~ – Memo on population change-over .

As long as the new strain is present at a low concentration, the concentration of tryptophane in the growth tube will be determined by the curve which gives the growth rate of the parent strain as a function of the tryptophane concentration c, and ~~and~~ we are assuming here that we are working with the generation ~~time~~ (T = ...) long enough to have the growth rate $\left(\frac{1}{T}\right)$ of the parent strain proportionate to the tryptophane concentration c. As long as the concentration of the new strain is low, the number of the bacteria of the new strain will ~~then~~ rise exponentially $\left(y = \text{Const}\, e^{\frac{g}{\Delta}}\right)$ where g is the number of generations ($\frac{t}{T}$) and Δ the number which indicates how many generations it takes for the new strain ~~when present in low concentration~~ at the current tryptophane conc. c_1 to rise by factor e.

Towards ~~To~~ the end of the population change-over, the parent strain ~~is present in a small concentration~~. The concentration of tryptophane in the growth tube is then determined by the curve which gives the growth rate of the new strain as a function of the tryptophane concentration (and will have same value c_2) ~~and~~ again we assume that for the generation time $\left(\theta = \frac{t}{T_1}\right)$ is long enough to have ~~was~~ the growth rate ~~at~~ proportionate to the tryptophane concentration.

(will have same value c_1)

Towards the end of the population change-over the parent strain will exponentially decrease ($x = C_{ons}\, e^{-\frac{f}{\Delta}}$). Clearly, for Δ we may write ($\mathcal{L}_1 = k_1 c$, $\mathcal{L}_2 = k_2 c$, $k_2 > k_1$).

In the middle of the population change-over the concentration of the new strain will be one half of n where n is the concentration of all bacteria in the growth tube. Throughout the population change-over the total concentration of the bacteria x + y remains constant because both the new strain and the parent strain require an equal amount of tryptophane for one bacterium produced.

At the mid-point of the change-over the tryptophane concentration in the growth tube will be given by c = . Consequently, at this mid-point we may write

On this basis, we may now compute for the total concentration (n^*) of the mutants resistant to T_5 $\frac{dn^*}{df}(x = \frac{n}{2}, y = \frac{n}{2})$, which gives the slope at the mid-point of the change-over for the curve which gives the total number (n^*) of mutants resistant to T_5 as the function of the number of generations f.

Before the change-over the number of mutants resistant to T_5 belonging to the parent strain is given by

$$a = r f$$

After the change-over the number of mutants resistant to T_5 belonging to the

(1) $\alpha_1 = \beta_1 c$ $\beta_2 > \beta_1$

$\alpha_2 = \beta_2 c$

Assume $\Delta >> 1$

In the Chemostat

$$c_1 = \frac{1}{\tau \beta_1}$$

$$c_2 = \frac{1}{\tau \beta_2}$$

(T worked out volume)

For small y: $\beta_2 c_1 - \frac{1}{\tau} = \frac{1}{y}\frac{dy}{dt} =$

for small x: $\beta_1 c_2 - \frac{1}{\tau} = \frac{1}{x}\frac{dx}{dt}$

For small x

$$x = C_m e^{\frac{+q}{\Delta(x)}}$$

$$\frac{1}{\Delta(x)} = \frac{\beta_1}{\beta_2} - 1$$

y:

or $\frac{\beta_2}{\beta_1 \tau} - \frac{1}{\tau} = \frac{1}{y}\frac{dy}{dt}$

or $\left(\frac{\beta_2}{\beta_1} - 1\right) = \frac{1}{y}\frac{dy}{dt}\tau = \frac{1}{y}\frac{dy}{dt/\tau} = \frac{1}{y}\frac{dy}{dq}$

$$\frac{\beta_2}{\beta_1} - 1 = \frac{1}{\Delta(y)}$$

(for small y)

$$\frac{1}{x}\frac{dx}{dq} = \frac{\beta_1}{\beta_2} - 1$$

② $\left(\frac{t}{4} \ll 1\right)$

If we may write $\frac{\beta_2}{\beta_1} - 1 = \frac{1}{\Delta(\;)}$

$= \frac{\beta_2 - \beta_1}{\beta_1}$; $\frac{\beta_1}{\beta_2} - 1 = \frac{\beta_1 - \beta_2}{\beta_2} - 1$

and because $\beta_1 \approx \beta_2$ $\frac{\beta_1}{\beta_2} - 1 = -\frac{1}{\Delta(\;)}$

At mid point we may write for slow transition $\left(\frac{t}{4} \ll 1\right)$

$$\frac{c_1 + c_2}{2} = c_0$$

For y $\beta_2 \frac{c_1 + c_2}{2} - \frac{1}{\tau} = \frac{1}{y}\frac{dy}{dt}$

$$\beta_2 \left(\frac{1}{2k_1\tau} + \frac{1}{2k_2\tau}\right) - \frac{1}{\tau} =$$

no approximation

$$\frac{1}{\tau}\left[\frac{\beta_1 + \beta_2}{2\beta_1} - 1\right] =$$

$$\frac{\beta_2 - \beta_1}{2\beta_1} = \left[\frac{1}{y}\frac{dy}{dy} = \frac{1}{2\Delta y}\right]$$

③ $\frac{r-1}{r^2}$ =

For X at mid point

$\frac{1}{x}\frac{dx}{dg} = \lambda g \frac{1-r}{2\Delta x}$

(3)

$$\frac{1}{2\Delta_x} = \frac{\beta_1 - \beta_2}{2\beta_2} = \frac{r-1}{2} \qquad \frac{1}{2\Delta_y} = \frac{\beta_2 - \beta_1}{2\beta_1} = \frac{1-r}{2r}$$

$$\frac{dz^*}{dy} = n \frac{1}{1+r} \cdot \frac{r-1}{2\Delta} \lambda g$$

$$n \frac{r}{1+r} \frac{1-r}{2r} \lambda g$$

+ $n\lambda$ — etc

so old formula holds

to the new strain is given by

$$b = \lambda g - \lambda k$$

Where $\underline{k}$ represents the number of generations at which after the change over, the straight line of the T_5 resistant mutants extrapolates back on the abscissa.

During the change-over the number of mutants resistant to T_5 is given by

~~Afterxthe~~ and ~~throughout~~ therefore the slope at the mid-point of the change-over is given by

From this we may also write

$$Z^* = X x^* + Y y^*$$

$$\frac{dZ^*}{dg} = \frac{X}{2\Delta(X)} x^* + X\lambda + \frac{Y}{2\Delta(Y)} y^* + Y\lambda$$

$$= \frac{X\lambda g}{2\Delta_X} + X\lambda + \frac{Y\lambda g}{2\Delta_Y} - \frac{Y\lambda k}{2\Delta_Y} + Y\lambda + m\lambda$$

for slow transition

$$\frac{1}{m\lambda}\frac{dZ^*}{dg} = 1 - \frac{k}{4\Delta(Y)}$$

$$\frac{dZ^*/m}{dg} = \lambda\left(1 - \frac{k}{4\Delta(Y)}\right)$$

Without approximation (but still assuming stationary states throughout)

X at mid point

$$\frac{c_1 + c_2}{2} = c$$

$$\frac{X}{\beta_2} \beta_1 \frac{c_1 + c_2}{2} + \frac{y}{\beta_2} \beta_2 \frac{c_1 + c_2}{2} =$$

$$\frac{dx}{dt} = \beta_1 \frac{c_1 + c_2}{2} X + \frac{\beta_1 - \beta_2}{2\beta_2} X$$

$$\frac{dX}{dt} = \beta_1 \frac{\frac{1}{\beta_1} + \frac{1}{\beta_2}}{2} X + \frac{\beta_1 - \beta_2}{2\beta_2} X$$

$$\frac{dx}{dt} = \frac{\beta_1 + \beta_2}{2\beta_2} X + \frac{\beta_1 - \beta_2}{2\beta_2} X = \frac{\beta_1}{\beta_2} X$$

$$\frac{dy}{dt} = \frac{\beta_2}{\beta_1} y$$

$$\frac{dx}{dt} = + \frac{dy}{dt} \qquad \frac{\beta_1}{\beta_2} x = - \frac{\beta_2}{\beta_1} y$$

$$\text{or } \frac{\beta_1}{\beta_2} X + \frac{\beta_2}{\beta_1} y = 0$$

$$x + y =$$

$$y = n \frac{x}{1+x} ; \quad X = n \frac{x}{1+x} \quad n - n \frac{x}{1+x} \quad r = \beta_1 / \beta_2$$

$$\frac{dx}{dt} = \frac{\beta_1 - \beta_2}{2\beta_2} X$$

$$\frac{dy}{dt} = \frac{\beta_2 - \beta_1}{2\beta_1} y$$

$$\left\{ \frac{\beta_1 - \beta_2}{\beta_2} X + \frac{\beta_2 - \beta_1}{\beta_1} y = 0 \right.$$

$$\text{or} \quad X + y = n$$

$$\left. X \frac{\beta_1}{\beta_2} - X + \frac{\beta_2}{\beta_1} y - y = n \right\}$$

Memo on the deterioration of bacterial population

The following assumptions are made:

1) Anyone mutational step leads to a strain which has a decreased growth rate by the same factor $e^{-\beta}$. Therefore, a bacterium having n mutation steps has a growth rate of $\alpha(n) = \alpha_0 e^{-\beta n}$

2) No back mutations occur and all mutants have the same probability to go through one additional mutational step. This ~~probably~~ probabilities is constant per unit time for all values n and has a value of μ.

3) If the mutation rate is low there will be in a growing population a stationary distribution of n in the population characterized by function $f(n)$, which gives the number of mutants carrying n mutations.

For this stationary population we have $\frac{df(n)}{dt} = \bar{\alpha} f(n)$ (1)

where $\bar{\alpha}$ is ~~the~~ independent of n and is growth rate of the stationary population and $\bar{\alpha} < \alpha_0$, $\bar{\alpha} = \frac{1}{N}\frac{dN}{dt}$ where $N = \int f(n)\,dn$

~~Writing for the growth rate of the "wild type"~~ $\alpha = \alpha_0$ ~~which should be true for~~ any (stationary or non-stationary) population ~~that~~ we have

$$\frac{df(n)}{dt} = \mu f(n-1) + \alpha_0 e^{-\beta n} f(n) \quad (2)$$

and for a stationary population we should have from (1) and (2)

$$\frac{f(n-1)}{f(n)} = \frac{\bar{\alpha} - \alpha_0 e^{-\beta n}}{\mu} \quad (3)$$

for ~~which~~ large values of n this gives irrespective of the value of beta

$$f(n) = \frac{\mu}{\bar{\alpha}} f(n-1)$$

from which we see that we obtain a stationary population ~~until if we have~~ with f going to zero for large values of n only if $\frac{\mu}{\bar{\alpha}} < 1$ and in that case $\frac{\mu}{\alpha_0}$ is also less than 1.

Memorandum on the difficulties of an over-all settlement with Russia

The premise on which this memorandum is based is expressed by these following quotation: "I do not know whether a negotiated settlement with the Soviet Union is possible. I do know, however, that no such attempt at a negotiated settlement has been made; instead we have wasted our time with polemics over isolated secondary issues which must remain insoluble as long as the basic issues remain unsettled. I also know that, in view of the present and foreseeable distribution of power between the United States and the Soviety Union, the choice before the world is between negotiated settlement and war, that is, universal destruction. I finally know that no nation can survive the ordeal of a third world war, if it can survive it at all, without being convinced in its collective conscience that it has done everything humanly possible to preserve peace. It is for these reasons that I deem it worth while and even imperative to consider seriously the possibility of a negotiated settlement with the Soviet Union." (Hans J. Morgenthau, Bulletin of Atomic Scientists, May, 1950)

Most of my colleagues though not all, will probably agree with this premise. [illegible] Opinions might differ when we go on from here and begin to examine the problems that will have to be solved if we wish to devise an over-all settlement that would lead to lasting peace. This we propose to do here.

We propose to go on from here and to examine the problems that must be solved in order to have an over-all settlement that could be expected to lead to lasting peace. It will be seen that the problems involved are difficult problems and that a solution will require imagination and resourcefulness. They are problems which will not be any easier to solve by negotiating from strengths and being in a very strong miliatry position at the time when we negotiate. While it might do no harm, it will not help very much towards arriving at a satisfactory solution. In this respect the situation which we find ourselves is very different from those of two private persons about to conclude an agreement. ~~If~~ In that case two ~~private persons are about to conclude~~ an agreement the one who can negotiate from a situation of strength has a very great advantage, for once he gets the other fellow to sign on the dotted line that man will have to preform, ~~and if he does not~~ or else he can be taken to court and be made to perform.

Indeed

war settlement with Russia based on the recognition of what atomic energy meant for war in the future a dangerous situation would arise after the war. It was evident that international control of atomic bombs would require some sort of inspection and that it would be very difficult for Russia to accept inspection. The crucial issue, therefore, appeared to be how we could get the Russian Government to see the problem in thelight which we saw it and become willing to accept the principle of inspection, assuming that the political requisites for such acceptance were offered to her within the framework of an over-all settlement.

(Some of these considerations were embodied in a memorandum written for President Roosevelt who died before this memorandum reached him. The text of the memorandum is enclosed.) When the war ended we thought the best chance of influencing the Russian Government would be through the Russian physicists with whom we had pre-war contacts. We assumed that the Russian Governement would look to its physicists for the creation of the atomic bomb in Russia and that they would be for awhile inclined to listen to them and to take their advice, so it seemed that our best chances to get the Russian Government would be to have informal and sincere discussions with Russian physicists many of whom we had known from pre-war days. This could have been accomplished best by an enclosed and informal meeting of some fifteen or twenty physicists. The plan was outlined to William Benton, at that time Assistant Secretary of State, who recognized its merits but found that Burns was opposed to the idea. Subsequently, we carried the case to the White House. Robert M. Hutchins and Rubin Gustavson saw the President in the presence of Burns who expressed opposition to the idea. The next attempt was made by the Emergency Committee of Atomic Scientists in 1947 shortly before the .... This time it was decided not to seek prior approval of the meeting by the Government but rather to answer....

Insert 1

A group of physicists with whom I was closely associated made strenuous efforts in the late fall of 1945 and early in 1946 to convince the Government that it should not take Russia very long to produce atomic bombs. The most careful estimates made by Bethe and Seitz pointed to a time of less than five years. It is now a matter of record that when it came to formulating Government policy our estimates were disregarded. In his book, Speaking Frankly, published two years ago, Mr. Byrnes relates that when he took office as Secretary of State he wanted to know--because he considered this a vital point in any system of control--how long it might take other governments to produce a bomb. "From all the information we received," he writes, "I concluded that any other government would need from seven to ten years at least to produce a bomb." Mr. Byrnes then goes on to say that because return to normal conditions was slower than he anticipated in all countries, his estimate of seven to ten years would have to be revised upward rather than downward.

This explains why we conducted the negotiations on atomic energy control in the manner we did.

When the Baruch plan was made public and raised the issue of the veto, many of my colleagues were very much disturbed, and wondered whether we really wanted an agreement on atomic bombs. I felt perhaps less badly than they did mostly because I was inclined to believe that Russia would not agree to any plan that would eliminate atomic bombs from national armaments. In case of war, so I reasoned, our production capacity in tanks, guns and bombing planes should enable us to carry the war to Russian territory from bases in Europe and the Middle East, but atomic bombs are the only weapons with which Russia could carry the war to the territory of the United States. Should we in these circumstances expect Russia to renounce the use of this weapon?

Years later, Dr. Zlotovsky, whom I met at the Physical Society meeting in 1947, showed me that I was probably wrong. Zlotovsky is a Polish physicist who had represented Poland in the United Nations Atomic Energy Committee. I knew through our French colleagues who were serving on this Committee that initially Zlotovsky had the full confidence of the Russians but that later on--at the time when I met him--they did not trust him any more.

When I explained to Zlotovsky why I thought that Russia would have rejected any agreement that would do away with the atomic bomb but Zlotovsky disagreed with me andtold me this: perhaps from a purely logical point of view the Russians should have reasoned the way I did, but their thinking was in fact rather different. In the wars which they had fought and won in the past they had always adopted defensive tactics and destroyed the armies of their enemies inside of Russia. When they were now thinking of another war they were thinking of it in terms of their past experiences. When the Baruch plan was put forward Gromyko came to see him and spoke to him about as follows: "Now Zlotovsky, you have lived among these people for a number of years, you should be able to understand them. What is behind all this? Why does Baruch put forward a plan, which you know as well as I do America itself would never accept? What is it the Americans are after?"

Zlotovsky was convinced that at the time when the negotiations started the existence of atomic bombs was a disturbing thought for the Russians and that if an acceptable proposal had been made for effectively eliminating atomic bombs Russia would not have rejected it.

We have to take into account, of course, that at the time the negotiations started Russia could not be certain that her physicists would in fact be able to produce atomic bombs, and keeping this in mind I came to the conclusion that probably Zlotovsky was right and I had been wrong. What Zlotovsky said seemed to me to be so interesting and so much at variance with what was commonly believed to be true that I arranged for him to see Mr. Einstein at Princeton.

But it is probably still true that even if the American Government had been determined to do away with atomic bombs and the Russians had been eager to accept any reasonable proposal to this effect, it would have been impossible to devise an agreement ~~limiting the~~ limited to the Atomic Bomb that would have been acceptable to both parties. This I believe to be true because the measures that have to be adopted to make certain that an agreement is not secretly violated will probably require a kind of inspection which no responsible Russian Government could accept as long as she has to reckon with war in the forseeable future as a serious possibility. Only if somehow we succeed within the framework of an over-all agreement, which ~~would~~ settles all outstanding political issues and provides for the kind of re-armament that will give Russia ~~reasonable~~ fair assurance ~~that there will be no war in the forseeable future~~ against attack, could we expect ~~[illegible]~~ that ~~the~~ genuine ~~kind of~~ inspection ~~that is required~~ may be acceptable to a reasonable Russian Government

Only within the framework of a much broader agreement could one hope to meet valid Russian objections on this score

It is inconceivable that Russia could agree where the present atmosphere of distrust prevails to the far reaching measures of "inspection" which are necessary, and that, therefore during the present administration any progress can be made towards an acceptable over-all agreement. But assuming that there is a change of administration and a change of outlook not to say a change of heart on our part, and disregarding all practical obstacles the main task of dreaming up an over-all agreement which will fulfill its function as I have mentioned above, and which ought to be acceptable at least on the assumption that the Russian government are reasonable still remains an exceedingly difficult job. While it is, of course, impossible to outline such an agreement it might be unlikely since it would require a meeting of the minds which is very difficult to achieve in the absence of all private discussions between Russians and Americans. It is perhaps possible to make some tentative considerations, enought to show what kind of difficulties will have to be overcome. Assuming that an over all political settlement has been outlined the question of disarmament will have to be dealt with and something will have to be said both about the kind and degree of disarmament. Because of the geographical situation in Europe and Russia's large manpower mere proportional reduction of armaments of all kinds will create a situation in which Western Europe will be overun in short-order if the agreement is suddenly abrogated. Europe could be given in case of abrogation a reasonable measure of security perhaps only if the disarmament would completely eliminate all heavy mobile weapons, bomb planes, tanks, etc. There would be no danger in permitting machine guns provided that several builtin in effectives were permitted so that western Europe could protect hereself as a sort of magino line in case of abrogation long enough to permit the west to rebuild its armament in case of abrogation before Russia could overrun western Europe. There need be no objections to defensive weapons such as radar,installations and fighter planes. In case of abrogation the position of the west would be satisfactory only if we could be absolutely sure that as long as the agreement is not abrogated the disarmenent clauses of the agreement are not secretly violated. To make sure of this it would probably be necessary to go far beyond any inspection system hitherto proposed. Probably nothing less short of making spying a legitmate profession could give us real assurance in this respect

MEMORANDUM ON THE USE OF CAVITIES AND CHANNELS IN A GRAPHITE - URANIUM SYSTEM.

If we have a lattice of uranium spheres embedded in graphite or some other similar system, the thermal neutron density in the neighborhood of the sphere is considerably lower than the average thermal neutron density in the graphite, particularly if large uranium metal spheres of 8 cm. radius are involved. Consequently, the fraction of the thermal neutrons absorbed by uranium would be increased if the thermal neutron density could be made more uniform in the graphite. That this can be achieved by means of channels or cavities was realized in the early stages of this development. Neutron channels are tubes or ~~gaps~~ holes leading radially towards the uranium sphere and are effective if their opening ~~are~~ is large compared to the ~~main~~ mean free path for scattering in carbon. Neutron ~~Such~~ channels were considered by Szilard in this connection in 1939 but were rejected on the ground that they would lead to an increase in the surface resonance absorption of uranium.

Cavities are empty spaces surrounding the uranium sphere which are effective because they diminish the thickness of the wall of the graphite cell. Such cavities were considered by E. Teller in 1940 but were rejected by him for the same reason ~~for which Szilard had previously rejected the use of channels.~~

In the meantime, through the work of Wigner and the Princeton group, ~~who~~ it was learned that surface resonance absorption is much less important than it had been previously assumed, and that volume resonance absorption was more dominant. Early this year Wigner and Szilard came independently to the conclusion that the use of cavities might improve the multiplication factor. More recently, Wigner put forward a scheme in which two neutron channels were leading to every sphere in the lattice.

Inasmuch as it appeared likely that the most favorable arrangement will call for large uranium spheres, if all factors which are involved, including fission by fast neutrons, are taken into consideration, it appeared of interest to consider the following points:

Can we expect considerable improvement by using cavities or channels in the case of large cells? Is the use of cavities or channels incompatible with differential cooling? In view of the fact that by using cavities or channels, we decrease the density and increase the distance which a fast neutron travels from the point of its origin until it is slowed down and absorbed as a thermal neutron by uranium, do we not need a larger quantity of graphite for a chain reaction, even though the multiplication factor may be improved?

Whereas cavities decrease the density of graphite and are therefore more harmful than channels of equal effectiveness, the neutron channels if they are at all effective will increase considerably the characteristic length l. In the circumstances, it appears likely that channels will increase rather than decrease the critical amount of graphite. It can be shown however that by using channels only in the core of the arrangements, we can obtain an average, inasmuch as the multiplication factor in the core is increased, whereas the harmful effect of the increase in the critical length l is negligible. It appears for instance quite likely that

MEMORANDUM ON WATER COOLED ~~TWIN MACHINES~~ power plant.

If we have an indirectly cooled machine in which the heat is transferred from the uranium to the graphite we have a temperature rise of about 208° C in about two minutes if fifty tons of uranium develop about 10^6 KW and if we have about 100 carbon atoms per uranium atom. Under such conditions it is quite easy to have water flow intermittently, say for a minute through the system, and have the system practically free from water, free for about one minute between two cooling periods.

Water is an absorber for the thermal neutrons and will stop the chain reaction if used in abundance. In the case of such intermittent operation the chain reaction is only when the water is out and off when the water is in.

Since under conditions in which it is safe to operate there is a long time lag between the onset of the chain reaction and the stage at which 10^6 KW are developed provided the initial neutron density is small, it might be of advantage to keep the initial neutron density high by having two piles forming a twin power unit. These two piles are exposed to each other's neutron radiation and operate in such a way that the water is withdrawn from one of the piles at the time when it is pumped into the other pile.

The neutron coupling between the two piles may be reduced by means of water shields which may be permanently installed and which shield partially the two piles from each other's radiations and there may be variable neutron coupling introduced for the purpose of regulating the rate of the reaction.

MEMORANDUM ON WATER COOLED TWIN MACHINES

If we have an indirectly cooled machine in which the heat is transferred from the uranium to the graphite we have a temperature rise of about 200° C in about two minutes if fifty tons of uranium develop about 10^6 KW and if we have about 100 carbon atoms per uranium atom. Under such conditions it is quite easy to have water flow intermittently, say for a minute through the system, and have the system practically free from water, free for about one minute between two cooling periods.

Water is an absorber for the thermal neutrons and will stop the chain reaction if used in abundance. In the case of such intermittent operation the chain reaction is only when the water is out and off when the water is in.

Since under conditions in which it is safe to operate there is a long time lag between the onset of the chain reaction and the stage at which 10^6 KW are developed provided the initial neutron density is small, it might be of advantage to keep the initial neutron density high by having two piles forming a twin power unit. These two piles are exposed to each other's neutron radiation and operate in such a way that the water is withdrawn from one of the piles at the time when it is pumped into the other pile.

The neutron coupling between the two piles may be reduced by means of water shields which may be permanently installed and which shield partially the two piles from each other's radiations and there may be variable neutron coupling introduced for the purpose of regulating the rate of the reaction.

MEMORANDUM ON COOLING OF THE POWER PLANT

A number of different cooling systems have been considered. It was considered desirable to transfer about 10^6 KW in machine which contains 50 tons of uranium. This is, however, not the upper limit that can be reached. Methods have been devised to transfer 10^6 KW per ten tons of uranium. Though one could transfer without much difficulty larger amounts of heat, there does not seem to be any immediate necessity for pushing the figure higher. Every cooling system is characterized by a number of features. Obviously there is a large combination of these features possible, but only a limited number of the combinations appears to be of interest. In the following these features will be enumerated and briefly described:

1. The following cooling agents were considered: Air, hydrogen, helium, water, liquid bismuth.

2. Direct cooling in which the liquid agent is in direct contact with uranium. Only helium and bismuth appear to be perfectly safe to be used in this way.

3. Indirect cooling in which the heat is transferred from the uranium to graphite and from graphite to the cooling agent. In the case of indirect cooling the cooling agent need not be in direct contact with graphite. For instance, it can be lead through pipes of beryllium, Karbade, or aluminum through the graphite.

4. Contact transfer to graphite, that is, a method of indirect cooling in which the heat is transferred from uranium metal direct to graphite.

5. Bismuth transfer to graphite, that is, a system of indirect cooling in which the heat is transferred from uranium metal, uranium oxide, or uranium carbide to the graphite by a slow stream of liquid bismuth.

6. A system of indirect cooling in which air is lead in beryllium, Karbade or aluminum tubes through the graphite pile.

7. A system of indirect cooling in which there is an intermittent flow of water through beryllium, Karbade, aluminum, or lead tubes through the graphite pile. If this system is used it might be advisable to build twin machines which are exposed to each others neutron radiation.

8. A system of direct cooling in which we have as cooling agent either bismuth or helium. Uranium metal, oxide or carbide is arranged in form of more or less sphere-like shapes which have an internal structure so as to have a large surface for heat transfer without having a large surface for resonance neutron absorption (for instance, sphere-shaped cluster of uranium oxide in form of granules). The helium or bismuth coming in through a lead passes through one or more such clusters and follows to another lead.

The inclosed diagram illustrates the interconnection of the various cooling systems. The most interesting alternatives can be summarized as follows: (1) direct cooling by helium or bismuth in a double string cluster arrangement; (2) water cooling of an intermittent twin power plant in which the water is lead in pipes through the graphite and the heat is transmitted from the uranium to the graphite either by liquid bismuth or by direct contact between uranium metal and graphite; (3) an air-cooled indirectly cooled continuous system.

LEO SZILARD

MEMORANDUM ON WASHINGTON

The Club which is proposed, would have a Board of Trustees, initially perhaps sixteen men, who would also be members of the Club. Any three of them may elect each year any additional trustee.

Associate members or guests of the Club would have only one obligation: - if they live in Washington they would have to dine once a week at one of the "high tables" of the Club. Each high table would seat between 15 and 20, and if one high table is filled, the next arriving guest will start the next high table. After dinner each high table retires to the common room where port might circulate and other things might be served. Dinner at the high table to start at a fixed time, say 7:30. After dinner in each common room the youngest present guest may take the chair and call on anyone of those present who wish to address the group, to have his say.

The Chairman acts as discussion leader.

Associate members of the Club residing outside of Washington and who spend less than three months a year in Washington, shall attend dinner at the high table while they are in Washington 2 or 3 times a week. Any associate member or guest of the Club can dine at the Club any day of the week and need not always dine at the high table but can dine with his friends. No specific time is set for dining at tables other than high table.

Associate members or guests of the Club shall be ex oficio the top desk men of the State Department in the "important" areas of work which shall be specified by the Board of Trustees; the members of the Foreign Relations Committee of the Senate, and the Foreign Affairs Committee of the House; members by invitation of the Board of Trustees shall be writers in the field of social problems related to foreign policy or foreign policy itself; scientists concerned with problems of foreign policy; members of the Political Science Department of our leading private universities; members of Congress who are interested in problems of foreign policy.

The guest members are selected by the trustees in the same way as new members of the Board of Trustees is selected, i.e. any three members of the Board of Trustees can select a certain number of guest members per year. Invitation to be a guest member is for the duration of five years and may be renewed. Ex oficio guest membership ceases with the official position.

The total number of guest members residing in Washington shall not exceed 225 at any time, and the number of guest members not residing in Washington shall not exceed 675.

Members of the Board of Trustees shall have the same privileges as any other guest member.

It would be desirable to serve dinner at the high table and drinks in the common room free, whereas dinner at private tables shall be served at a modest charge in order to encourage the younger members of the Club to meet there for private discussion of public problems.

Perhaps membership of the Board of Trustees -

Peterson, Philadelphia,

John Sherman Cooper,

John Cowles.

LEO SZILARD

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The Chairman acts as discussion leader.

Associate members of the Club residing outside of Washington and who spend less than three months a year in Washington, shall attend dinner at the high table while they are in Washington 2 or 3 times a week. Any associate member or guest of the Club can dine at the Club any day of the week and need not always dine at the high table but can dine with his friends. No specific time is set for dining at tables other than high table.

Associate members or guests of the Club shall be ex oficio, the top desk men of the State Department in the "important" areas of work which shall be specified by the Board of Trustees; the members of the Foreign Relations Committee of the Senate, and the Foreign Affairs Committee of the House; members by invitation of the Board of Trustees shall be writers in the field of social problems related to foreign policy or foreign policy itself; scientists concerned with problems of foreign policy; members of the Political Science Department of our leading private universities; members of Congress who are interested in problems of foreign policy.

The guest members are selected by the trustees in the same way as new members of the Board of Trustees is selected, i.e. any three members of the Board of Trustees can select a certain number of guest members per year. Invitation to be a guest member is for the duration of five years and may be renewed. Ex oficio guest membership ceases with the official position.

The total number of guest members residing in Washington shall not exceed 225 at any time, and the number of guest members not residing in Washington shall not exceed 675.

Members of the Board of Trustees shall have the same privileges as any other guest member.

It would be desirable to serve dinner at the high table and drinks in the common room free, whereas dinner at private tables shall be served at a modest charge in order to encourage the younger members of the Club to meet there for private discussion of public problems.

Perhaps membership of the Board of Trustees -

Peterson, Philadelphia,

John Sherman Cooper,

John Cowles.

Paul Hoffman

John J. McCloy

~~Allen Rush~~

Bill Jackson

Lippman

David Bruce

Bowles

Arch. Alex.

Erwin Colter

Cass Canfield

~~Humphrey~~

~~Kefauver~~

~~Wayne Morse~~

Memo to Berlin talk -- Antibody Formation

We may now attempt to understand the phenomenon observed in the formation of combining antibodies in response to the first injection of a specific antigen and in response to repeated injections of the same specific antigen.

(1) Upon the first injection the antigen diffuses into the antibody-forming cells and combines there with a certain fraction of that enzyme for which the hapten of the antigen is a chemical analogue of the enzyme's substrate. A certain fraction of the enzyme, say perhaps 10%, may remain free. As a result of the ~~tixing typin typing~~ tying up of this enzyme by the hapten of the antigen less repressor is produced, the repressor level falls, and the production of the enzyme is accelerated. In this manner the enzyme level might rise ten-fold, the enzyme antigen complex is eliminated.(?)

(2) Antigen diffuses more slowly through the nuclear membrane and combines inside the nuclear membrane with enzyme that is still hanging on the paragene. In a certain fraction of the cases which may be, for instance, 80%, the paragene will break and the break will subsequently heal, but this might occur with a slight deletion of paragene material. As a result of this the healed paragene may produce an "wnzyme" which no longer can catalyze the formation of the repressor although it can still combine ;with the hapten that is attached to the protein moiety of the antigen. This process of the creation of defective genes can go on for several weeks after the initial injection of the antigen. After several weeks there will then be a response to a secnnd injection of the same antigen ~~of~~ with a copious formation formation of defective enzymes and perhaps (?) less non-defective enzyme will be formed subsequent to the

second injection than subsequent to the first injection. This latter point is not predictable with certainty without knowing the constants involved.

(3) If antigen is injected into an embryo throughout its embryonic lifetime, and if we may assume that the permeability of the membrane is greater in the embryo, then the same paragene will be broken repeatedly and may heal repeatedly so that in the end the paragene is damaged to the point where the protein formed by the paragene has lost both the catalytic ability of the enzyme and the combining ability of the enzyme. Thus on the basis of the notions here presented, tolerance becomes understandable as an exaggerated anamnestic phenomenon.