Liberation of Fast Neutrons in the Nuclear Explosion of Uranium Irradiated by Thermal Neutrons*

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Abstract

Fission neutrons liberated from uranium induced by neutron irradiation were studied concerning the *separated* effect due to thermal neutrons alone. Uranium oxide was either screened from primary thermal neutrons or exposed to them by use of a cadmium sheet shield interposed between the neutron source and uranium oxide. The comparison between the photographically recorded counts of neutrons per definite time interval measured with and without the cadmium shield allowed us to detect and measure the net gain in the number of the fast neutron release from uranium. By a number of sets of such alternating measurements it was possible to ascertain the remarkable *net increase* of the secondary fast neutrons caused by absorbing the thermal neutrons alone. In this way, the average number of the fast neutrons liberated per fission of uranium induced by thermal neutron was found to be *2.6*. From the considerations of the order of the amount of energy—about 10 Mev.—involved in the fission neutrons, it is probable that the neutron release takes place *immediately* after the main division of the compound nucleus instead of simultaneously with the explosion.

As was first discovered by Hahn and Strassmann,[1] uranium under neutron irradiation is split by absorbing neutrons into two lighter elements of roughly equal weight and charge, the division being accompanied by an enormous amount of energy release. It follows, then, that these fission fragments produced would contain *considerable excess* of neutrons** as compared with the corresponding heaviest stable isotopes with the same nuclear charges, provided that the division takes place only into two parts. In fact, a part of these excess neutrons was

* A short description of this work has been published in the *Review of Physical Chemistry of Japan*, **13**, 145 (1939).

** For example, the assumption of a division of $^{239}_{92}U$ into $_{56}Ba$ and $_{36}Kr$ leads to the expectation of an excess of about 15 neutrons. The excess of these neutrons should be got rid of by possible processes to bring back to the neutron-proton ratio of the stable nuclei.

1. O. Hahn and F. Strassmann, Naturwiss., **27**, 11 (1939).

2. Numerous β-*active* products, for example, with atomic numbers lying between *35(Br)* and *57(La)* were revealed by chemical work.

I. Curie and P. Savitch, Compt. rend., **208**, 343 (1939). O. Hahn and F. Strassmann, Naturwiss., **27**, 89 and 163 (1939). P. A. Heyn, A. H. W. Aten jun. and C. J. Bakker, Nature, **143**, 516 (1939). P. Abelson, Phys. Rev., **56**, 1 (1939) and numerous subsequent reports.

found to be disposed of by the subsequent β-ray transformations of the fission products,[2] but another reasonable possibility of reducing the neutron excess seems to be associated with a *direct emission* of the neutrons, which would either be emitted as a part of fission products at the moment of the nuclear splitting or escape from highly excited nuclei of the fission heavy fragments after the main division of the compound nucleus. It may, therefore, be supposed that the fission process results in the liberation of more than one secondary neutron per nuclear splitting.

Following the discovery of this new type of reaction, it has been attempted by several workers[3–8] to observe this pronounced emission of neutrons from uranium irradiated by neutrons. It is now of interest to find more accurately whether and to what extent the emission of neutrons takes place in uranium by absorbing neutrons, especially *thermal* ones,[9] and also to estimate the number of the neutrons released per fission in connection with the possibility of a cumulative process of exo-energetic transmutation chains.

In some of the previous experiments[3,4,5,8] a comparison was drawn between the numbers of thermal neutrons present in a large water tank with and without uranium under the irradiation of photo-neutrons from a Ra γ -Be source at the centre of the tank, and this comparison was made by measuring the activity induced in neutron detector in the water. On such a principle, von Halban, Joliot and Kowarski[3] have been able to observe an increase of about five percent for the thermal neutron density in the water, when uranium was present in its aqueous solution, and they have estimated the corresponding yield to be 3.5 neutrons per fission. Anderson, Fermi and Szilard[5] have also quite recently reported a striking increase of even about ten percent, in the case when about 200 kg of U_3O_8 was arranged around the photo-neutron source of 2.3 grams Ra situated at the centre of a vessel containing a large amount of ten percent aqueous $MnSO_4$ solution, the activity induced in manganese being taken as a measure of the number of thermal neutrons present.

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3. H. von Halban, F. Joliot and L. Kowarski, Nature, **143**, 470 and 680 (1939).
4. H. L. Anderson, E. Fermi and H. B. Hanstein, Phys. Rev., **55**, 797 (1939).
5. H. L. Anderson, E. Fermi and L. Szilard, Phys. Rev., **56**, 284 (1939).
6. L. Szilard and W. H. Zinn, Phys. Rev., **55**. 799 (1939).
7. G. von Droste and Reddemann, Naturwiss., **27**, 371 (1939).
8. J. L. Michiels, G. Parry and G. P. Thomson, Nature, **143**, 760 (1939).
9. It has been suggested by Bohr—*Phys. Rev.*, **55**, 418 (1939)—that the fission process caused by the *thermal* neutrons is to be ascribed to the neutron capture by the rarer isotope ^{235}U rather than the abundant one ^{238}U.

Since in those experiments (made in such a system as a mixture of uranium and water) part of the neutrons are considered to be absorbed into uranium and to induce the fission process before reaching down to thermal energies, it seems desirable to make measurements on the *separated* effect due to thermal neutrons alone. The object of the present experiment is to obtain some information regarding a net increase in the number of fast neutrons released from uranium by absorbing the primary thermal neutrons alone.

Experimental Method

In order to ascertain a net gain in the number of secondary neutrons from uranium caused by the action of thermal neutrons, we carried out the following experiments. The experimental arrangement is shown in Fig. I.

To obtain thermal neutrons, a cylindrical paraffin block, 20 cm in diameter and 25 cm in height, was made, in the central cavity of which was placed the usual neutron source of *50 mg radium α -beryllium* enclosed in a platinum container.

The container of uranium oxide powder was a double walled, cylindrical copper vessel, 25 cm in the outer diameter, 21 cm in the inner diameter and 25 cm in height, and the cylindrically zonal space between the double walls contained the fine powder of U_3O_8. The paraffin block (with neutron source) was placed inside the innerwall of this vessel.

The outer surface of the vessel was completely covered on all sides by the cadmium sheet shields 1 mm thick, which prevented thermal neutrons from escaping to affect the detector. An *inner cadmium* sheet cylinder (about 20.5 cm in diameter) was also placed, if desired, so as to cover the whole cylindrical surface of the paraffin block, and served as a shield to prevent the slowed down source neutrons from interacting on uranium. Accordingly, uranium oxide could be either *screened* from the action of the thermal neutrons or *exposed* to it by simply setting this inner shield in place or taking it away.

As a detector for slow neutrons, a *boron* cylindrical ionization chamber, 2.2 cm in diameter and 20 cm in length, lined with a thin layer of boron was used. The ionization pulses from the chamber were fed to a grid of a linear amplifier of Wynn-Williams-type,[10] through

10. B. Arakatsu, K. Kimura and Y. Uemura, Memoirs of the Faculty of Science and Agriculture, Taihoku Imperial University, **18**, 83 (1936).

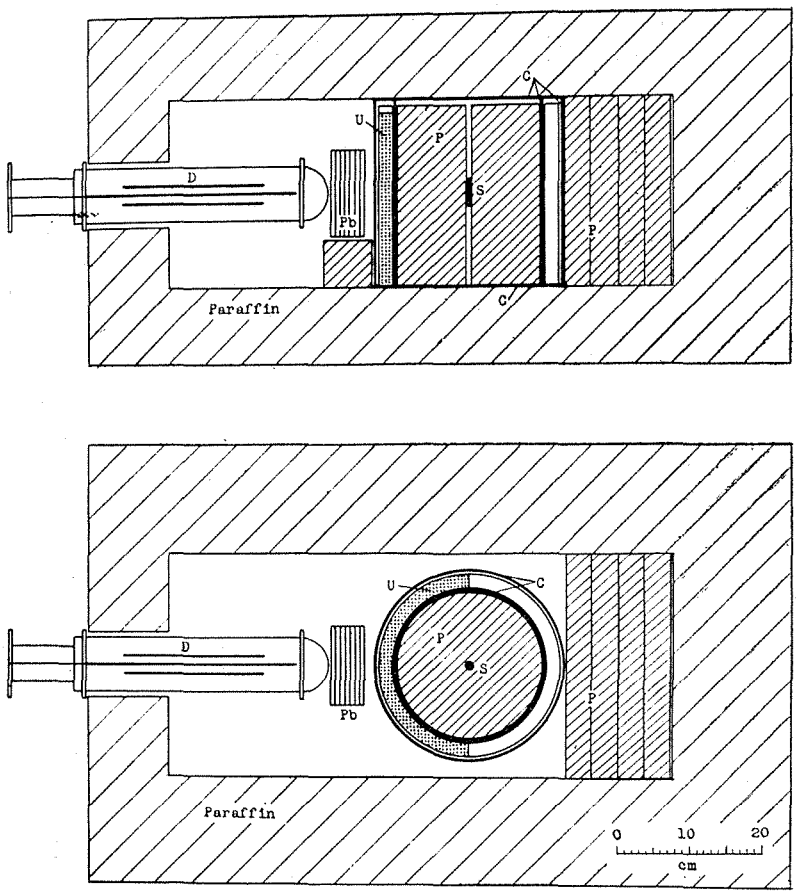

Fig. I. Vertical and horizontal sections through centre of the arrangement. S, Neutron source. P, Paraffin wax. C, Cadmium sheet shields. U, Uranium part filled with uranium oxide. Pb, Lead block shield. D, Cylindrical ionization chamber.

which the frequency of these pulses was counted from the records of kicks on the moving sensitized photographic papers by means of an ordinary oscillograph. In order to reduce the background effect due to γ-rays from the source, a disk of lead shield (5 cm thick in the axial line of the ionization chamber) and 12 cm in diameter was interposed between the uranium container and the head of the horizontally placed ionization chamber. The whole apparatus was placed in a thick walled (about 15 cm) paraffin chamber, the inside dimensions of which were $30 \times 70 \times 26$ cm, as shown in the accompanying diagram.

The present method of neutron detection is eventually based on measuring the number of the neutrons in question as that of only the neutrons which have been slowed down on the whole inner walls of the enclosing paraffin chamber after passing through the outer cadmium shields with relatively high velocities. So a simple comparison of the counts of neutrons per definite time interval measured with and without the inner cadmium shield, the outer cadmium shield being in place, would allow us to detect and measure the net increase in the number of relatively fast neutrons inside the outer cadmium cylinder. If any positive increase exists, it must be ascribed to the secondary emission of (relatively fast) neutrons from uranium by the effect (presumably fission effect) of thermal neutrons, because no appreciable effect of the presence or absence of the inner shield could be detected, when the vessel was empty and the outer shield (1 mm thick) was placed in its position.

Liberation of Secondary Neutrons from Uranium

A number of such *alternating* measurements (in the presence and absence of the inner cadmium shield) were made per 10 minutes interval on the oscillograph records, when one of the two vertical *semi-circular* halves, into which the space between the double walls of the cylindrical vessel was partitioned, was filled with *2.5 kg* of uranium

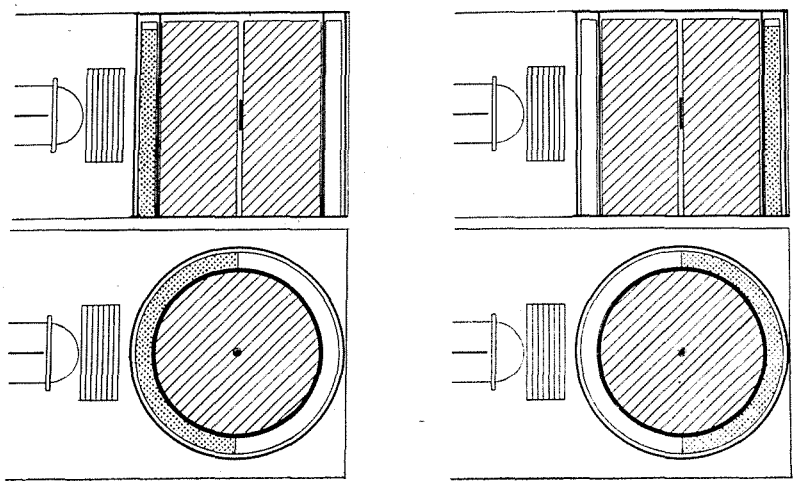

Fig. II.

Arrangement i

Uranium part is placed close to the ionization chamber.

Arrangement ii

Uranium part comes on the side opposite to the ionization chamber with respect to the neutron source.

oxide. The semi-circular uranium part was placed close to the ionization chamber as shown in Fig. II.-*i*. The front of the outer wall of the uranium part was kept, across the lead shield block, at a distance of 6.4 cm from the head of the cylindrical ionization chamber in its axial direction.

The number of recorded counts per 30 minutes was *C-i* (=*2166*, in Table I), when uranium oxide was exposed to the thermal neutrons (in the absence of the inner cadmium shield); while it was reduced to *D-i* (=*2117*, in Table I), when uranium oxide was screened from the thermal neutrons with the inner cadmium shield. The difference, *49*, between these two numbers must be ascribed to the fast neutrons emitted by uranium under the irradiation of the thermal neutrons alone.

Under such a geometry (i) of the arrangement as described above, however, only a fairly slight increase of neutrons was observed, and so the measurements were tried again under another geometry (ii) of the arrangement. 2.5 kg of uranium oxide was now put into another semi-circular zonal part of the vessel as shown in Fig. II.-*ii*., so that the uranium part came on the side opposite to the ionization chamber with respect to the neutron source and it was, at its remotest part, farther away by 25 cm (the outer diameter of the uranium vessel) from the ionization chamber, namely, the front of the part was withdrawn to 29.4 cm from the head of the ionization chamber in the axial line.

Under such a geometrical condition (ii), measurements similar to the previous ones were carried out. A count *C-ii* (=*2261*, in Table

Table I

	U_3O_8	*Cd* Shield		Number of Counts per 30 Min.	Difference of Counts per 30 Min.	
		Outer	*Inner*			
C—i	present	with	no	2166		
D—i	„	with	with	2117	$(C—D)_i$	49
C—ii	„	with	no	2261		
D—ii	„	with	with	2155	$(C—D)_{ii}$	106
A	no	no semi-circular cylinder	no	5633		
A'	„		no	5247	*A'—B*	2801
B	„	with	no	2446	*A —B*	3187
E	present	no	no	5478		
F	„	no	with	2436	*E—F*	3042

I) of the frequency of pulses per 30 minutes was found, when uranium oxide was irradiated by the thermal neutrons in the absence of the inner shield, and another count D-*ii* ($=2155$, in Table I) of pulses, when uranium oxide was screened from the thermal neutrons in the presence of the inner shield. The difference which must be attributed to the fast neutron emission, appears now to increase to the considerably large amount of *106* pulses. Here it is evident that there is a net increase in the number of the secondary fast neutrons as was presumed.

In the method of detection here adopted, there will be no occasion to take the reaction $(n, 2n)$ into account as Fermi and others[4] did, because, if there is any, it is sure to be canceled out by taking the difference of the numbers of counts for each pair of the alternating observations.

Now, in order to know the number of the primary thermal neutrons, to which uranium was exposed from the side of the semi-circular cylindrical surface of the paraffin block, the alternating change of the counts—with and without the outer cadmium cylinder—was measured for the empty uranium vessel, when the thermal neutrons were allowed to project towards the outer cadmium cylinder by removal of the inner shield during the measurements.

A count A ($=5633$, in Table I) taken in the absence of the outer cylinder, gave the frequency of pulses caused by the total primary—thermal and nonthermal—neutrons radiated from the whole cylindrical side of the paraffin block. Another count A' ($=5247$, in Table I) was taken with a cadmium shield of semi-circular cylindrical form covering only the back half side of the vessel, so that the measure obtained contains the number of the primary thermal neutrons emitted only from the fore half side of the cylindrical surface of the paraffin block. Further, a count B ($=2446$, in Table I) was a measure of pulses in the case when the detector had been shut off from the total primary thermal neutrons by setting the outer whole circular cylindrical shield.

Both the differences, $(A'-B)=2801$ and $(A-A')=386$ of the counts then will enable us to separate the group of the primary thermal neutrons emitted from the fore half side and that of the thermal neutrons from the back half side of the cylindrical surface of the paraffin block respectively.

In this way, we found i) 1.8 percent increase of the secondary

neutrons upon this primary in the first case, and ii) 3.8 percent increase in the second case. These increases must be regarded as caused only by the secondary emission of *nonthermal* neutrons due to the absorption of *thermal* neutrons alone.

It seems now reasonable to consider that the remarkable difference of these increases of counts observed between the first and second cases may be associated with probably *high* energies of the secondary neutrons. The secondary neutrons emitted in the process concerned are considered in the *second* case to be more strongly slowed down by passing through a part of the medium of the paraffin cylindrical block 20 cm in diameter; otherwise it might happen in the first case to realize a higher yield in the net increase of the secondary neutrons on account of its apparently superior geometrical conditions.

Energy of Secondary Neutrons liberated from Uranium

In order to estimate the energies of the secondary fast neutrons, a set of paraffin sheets (30 × 26 cm, 37 mm thick, each) was interposed between uranium oxide and the ionization chamber as seen in Fig. III, and the alternating change of the counts—with and without the inner cadmium shield—was observed as in the previous cases, for every different thickness of the increased paraffin layers.

Under the same geometrical arrangement as in the first case (i), layers of the paraffin sheet 37, 74 and 111 mm thick respectively were interposed between uranium oxide and the circular lead block, so that

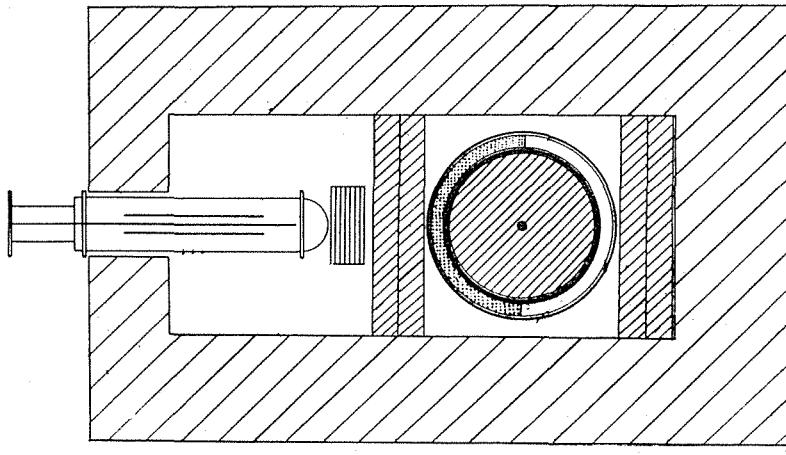

Fig. III. The paraffin sheets are interposed between the uranium oxide and the ionization chamber.

the nearest outside of the uranium part stood across the paraffin layers at a distance of 101, 138 and 175 mm respectively from the head of the ionization chamber.

Under the same geometrical arrangement as in the second case (ii), we have measured in two sets of experiments, in which the counts were recorded either in the presence or absence of only a single layer of the interposed paraffin sheet (37 mm thick), the nearest side of the uranium vessel being kept at a distance 101 mm from the head of the ionization chamber in its axial direction. The results obtained in the first and second cases are summarized in Table II and III respectively.

Table II

	Cd Shield		Thickness of Paraffin Layer	Number of Counts per 30 Min.	Difference of Counts: *C*—*D* per 30 Min.
	Outer	*Inner*			
C_1—*i*	with	no	0	2166	
D_1—*i*	with	with	„	2117	49
C_2—*i*	with	no	37 mm	2207	
D_2—*i*	with	with	„	2145	62
C_3—*i*	with	no	74 mm	1408	
D_3—*i*	with	with	„	1350	58
C_4—*i*	with	no	111 mm	786	
D_4—*i*	with	with	„	791	−5

Table III

	Cd Shield		Thickness of Paraffin Layer	Number of Counts per 30 Min.	Difference of Counts: *C*—*D* per 30 Min.
	Outer	*Inner*			
C_1—*ii*	with	no	0	2261	
D_1—*ii*	with	with	„	2155	106
C_2—*ii*	with	no	0 (*Uranium part is moved back 37 mm*)	2121	
D_2—*ii*	with	with	„	2019	102
C_3—*ii*	with	no	37 mm	2304	
D_3—*ii*	with	with	„	2256	48

The results in the first case (i) show that the increased numbers of the secondary fast neutrons appear notably larger after passing through the paraffin layers 37 and 74 mm thick, while the number falls rapidly

in the case of the last thickness of 111 mm. Thus it seems probable that the number of the secondary neutrons first increases with the increased paraffin sheets and then after passing through a maximum it decreases.

The results in the second case (ii) indicate that the number of the secondary neutrons is reduced already to about one half through a paraffin sheet 37 mm thick, while the removal of this paraffin sheet exerts no appreciable influence on the predominant increase of the original count, $(C\text{-}ii - D\text{-}ii) = 106$. (under the circumstance of the uranium vessel being separated by 101 mm, instead of 64 mm, from the neutron detector).

These facts can only be regarded as clear evidence of high energies of the fast neutrons concerned. Because of the lack of precision, however, it is inadequate from these results only to draw directly any numerical value for this problem.

In view of the results obtained, however, we have some reason[11] to conclude that the secondary fast neutrons emitted from uranium exposed to thermal neutrons possess a kinetic energy of *about 10 Mev.* in order of magnitude. This leads to the recognition of a wide departure from our early view that the order of a large amount of energy, such as about 100 Mev., might be expected to be available as kinetic energy for the secondary neutrons.

In view of the present evidence of the neutron emission with such an order of the amount of energy involved, we might justly say that the neutron release takes place *immediately* after the main division of the compound nucleus rather than simultaneously with the explosion.

Delayed Emission of Neutrons from Uranium

Roberts, Meyer and Wang[12] and Booth, Dunning and Slack[13] have reported neutron emission *delayed* for about 12 sec. and 45 sec. periods, in the case when uranium is irradiated.

We also looked for such delayed fast neutrons in the *present arrangement*, but observed no positive phenomena which might be due to the delayed emission[14] after the quick removal of the source from

11. K. Kimura, Memoirs of the College of Science, Kyoto Imperial University, A, **22**, 241 (1939).

12. R. B. Roberts, R. C. Meyer and P. Wang, Phys. Rev., **55**, 510 (1939). R. B. Roberts, L. R. Hafstad, R. C. Meyer and P. Wang, Phys. Rev., **55**, 664 (1939).

13. E. T. Booth, J. R. Dunning and F. G. Slack, Phys. Rev., **55**, 876 (1939).

14. Further detailed evidence regarding the delayed neutrons is to be reported by other investigators in this laboratory.

the paraffin block. So it is to be considered at least that the number of the delayed emission may be much less[4,6] than the number of those secondary neutrons which have been projected into the detector during the direct irradiation of the primary neutrons, and if there is any at all, it seems actually too small to be observable in the present neutron measurements.

Possibility of Nuclear Chain Reactions

In the preceding experiments it was directly found that there is an emission of fast neutrons from uranium under the irradiation by thermal neutrons alone.

In order to detect whether or not the number of the fast neutrons so released actually exceeds the total number of the thermal neutrons absorbed in uranium oxide by all processes whatever, under the action of thermal neutrons, it is necessary to know a measure for the decrease due to the total absorption of thermal neutrons by uranium oxide layer in the same units of the present experiment. The experiments were carried out in the following way.

As was formerly done, the effects of the presence (F in Table I) and absence (E in Table I) of the inner cadmium shield were measured, other conditions being the same as in the first experiment except that the outer cadmium shield was removed from the outside of the vessel during the experiments. The difference between these two counts will give a total measure of the transmission of the thermal neutrons through uranium oxide, including even the neutrons due to the emission of the fast neutrons caused by the fission process. The fraction of the actual transmission of the primary thermal neutrons, therefore, would correspond to a number of count, $(E-F)-(C-D)-(A-A')$, which has been obtained by subtracting the fraction of the secondary emission of fast neutrons from the above total transmission and further by taking into account a fraction of the primary neutrons which, in the present arrangement, would go round back even to the neutron detector as the opposite component emitted from the back half side of the circular cylindrical surface of the paraffin block.

The difference between the number, $(A'-B)$, of the thermal neutrons emitted by the source and the number, $(E-F)-(C-D)-(A-A')$, of the neutrons transmitted through uranium oxide is due to the absorption of the thermal neutrons by uranium oxide. The total absorption cross section σ_{tot} of uranium oxide due to fission and other

possible processes in the present experimental arrangement was calculated from these results to be

$$\sigma_{tot}=9.6\times 10^{-24}\ \mathrm{cm}^2,$$

by use of the relation of the exponential absorption.

In this way, it was found that 7 percent of the primary thermal neutrons emitted by the source is absorbed by uranium oxide. Accordingly, if all these thermal neutrons absorbed were assumed to participate in the fission process alone, the observed increase of the count, 3.8 percent, would correspond apparently to no more than an average emission of about 0.6 fast neutrons for each thermal neutron absorbed.

This result means that the number of the secondary fast neutrons produced does not exceed the total number of the thermal neutrons absorbed within uranium oxide by all possible sorts of capture processes, and that the production of a chain of nuclear reactions would not be expected in the *ordinary* uranium oxide exposed to thermal neutrons alone.

Average Number of Secondary Neutrons produced per Fission of Uranium

In order to estimate the *average number* ν of the secondary fast neutrons liberated per fission of uranium induced by thermal neutron, let σ_f and a_f be the cross section and the absorption coefficient of the thermal neutrons respectively for this fission process alone, n the number of the nuclei per unit volume and r the path length of neutrons travelling through uranium oxide. Then, $\nu a_f r$, or $\nu\sigma_f n r$ should correspond to the ratio of the number, $(C-D)$, of the observed net gain of the secondary neutrons from uranium oxide to that, $(A'-B)$, of the thermal neutrons emitted by the source, *i.e.*, to $\left(\frac{k'}{k}\right)\cdot\frac{C-D}{A'-B}$, where k and k' are the average efficiency factors of the detector for *slow* neutrons and for *fast* neutrons respectively, which have been projected from the outer cadmium surface of the uranium container.

It is here assumed that the contributions of all fast and slow neutrons of different energies to the detecting efficiency of the neutron detector in the paraffin chamber are of the same order of magnitude. But it may be generally difficult to realize such a condition in the practical arrangement used, and the above correlation will hold only approximately as it might give either too low or too high a value, according as $\frac{k'}{k}\lesseqgtr 1$, for the number of ν.

Since, however, in the geometry of the previous case (ii) at least, it is found to be possible to obtain with good approximation a condition similar to that required above, putting $k \fallingdotseq k'$, we have

$$\nu = \frac{1}{\sigma} \cdot \frac{C-D}{A'-B}, \qquad \text{where} \quad \sigma = nr\sigma_f.$$

If we assume the observed value of σ_f for thermal neutrons—the *average* value over the actual mixture of isotopes for the oxide,—given by Anderson, Booth, Dunning, Fermi, Glasoe and Slack,[15] we have $\sigma_f = 2 \times 10^{-24}$ cm^2. Since $\frac{C-D}{A'-B} = 0.038$, we find :

$$\nu = 2.5.$$

This would be, however, an average number of neutrons released per fission if the intensities of both the incident thermal neutrons and the fission neutrons produced were not reduced by the absorption along the travelling path length of the uranium oxide layer before they escaped from the whole mass.

By taking into account the effects of this reduction in the number of the neutrons within uranium oxide, this average number of ν must be increased by a certain fraction. Assuming the exponential law for these neutrons in such absorber, the magnitude of this correction factor is to be given by the following expression :

$$\frac{(\sigma_{tot} - \sigma_{fast})nr}{e^{-\sigma_{fast}nr}\left\{1 - e^{(\sigma_{fast} - \sigma_{tot})nr}\right\}},$$

where σ_{tot} is the total absorption cross section for all possible capture processes of thermal neutrons, σ_{fast} the corresponding quantity for the capture of the fast fission neutrons produced. Putting the numerical values of the quantities necessary[16] in the above expression, the value of the factor is estimated to be 1.05. Accordingly we find

$$\nu = 2.6.$$

Conclusion

Thus, by the present investigation it was made possible to decide

15. H. L. Anderson, E. T. Booth, J. R. Dunning, E. Fermi, G. N. Glasoe and F.G. Slack, Phys. Rev., **55**, 511 (1939).

16. For the estimation of the correction factor, the value of σ_{fast} is assumed to be comparable to that of the next heavy elements ($\sigma_{fast} \simeq 2.5 \times 10^{-24}$ cm^2) for fast neutrons. ($E \geq 7$ Mev.)—D. C. Grahame and G. T. Seaborg, *Phys. Rev.*, **53**, 797 (1938).

conclusively the remarkable *net increase* of the secondary fast neutrons caused only by the thermal neutrons absorbed, and also to estimate that the *mean number of* ν is 2.6, as deduced above.

Considering an order of the amount of energy—about 10 Mev.—involved in the fission neutrons, it is probable that the neutron release takes place *immediately* after the main division of the compound nucleus instead of simultaneously with the explosion.

The author is deeply indebted to Prof. B. Arakatsu for his helpful suggestions and invaluable advice so generously given during the course of this work, and to other members of the nuclear research laboratory for their active interest. His thanks are due to the Ensuiko-Sugar Company for the loan of the neutron source and to the Nippon Gakujutsu Shinkokwai for their financial support. He also wishes to express his deepest gratitude to Prof. S. Horiba for the continual interest he has taken throughout the work.

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October, 1939.

Note added in proof:—Since this manuscript was submitted for publication, a report by Mr. W. H. Zinn and L. Szilard, *Phys. Rev.*, **56**, 619 (1939), has appeared, in which the same problem was studied by recording photographically helium and hydrogen recoils due to the fission neutrons. Their experiment differs from the present work in the method of neutron detection adopted. Their value obtained for the number of neutrons emitted per fission, however, is in agreement with the author's result.