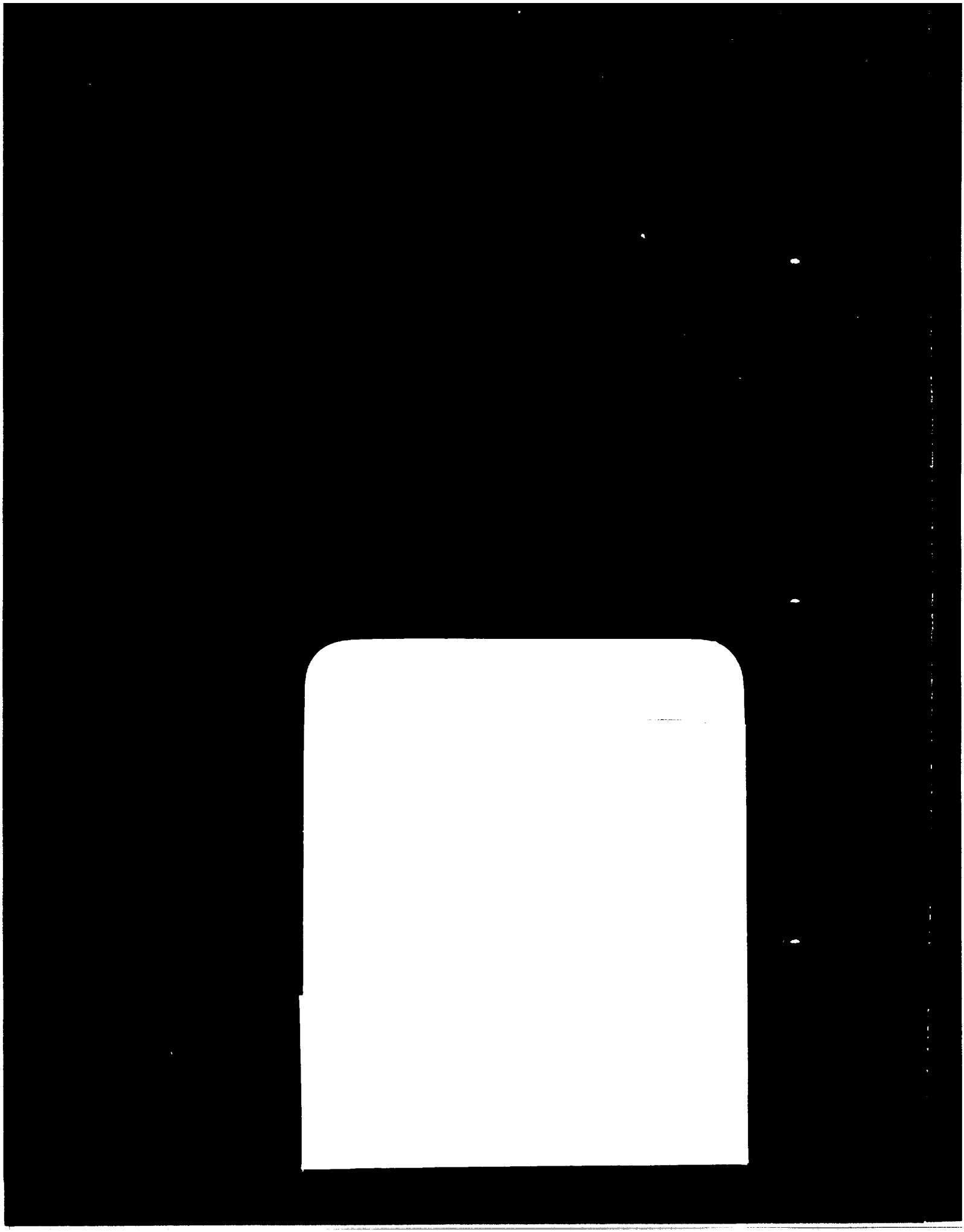

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CAPTURE CROSS SECTION OF U^{238} FOR NEUTRONS OF VARIOUS ENERGIES

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ABSTRACT

The radiative capture cross section of U^{238} for neutrons between 5 and 1310 kev has been measured. In this interval it varies from 0.82 to 0.1×10^{-24} cm^2.

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CAPTURE CROSS SECTION OF U^{238} FOR NEUTRONS OF VARIOUS ENERGIES

The radiative capture cross section of U^{238} for neutrons of various energies has been measured by comparing it with the fission cross section of U^{235} for neutrons of the same energies. The capture of a neutron by U^{238} leads to the well-known beta-active isotope U^{239}; this activity has been used to count the number of captures occurring. In order to avoid the difficulties connected with absolute beta-activity measurements, we have compared the ratio

$$\rho = \sigma_r(28)/\sigma_f(25)$$

measured at various energies to the same ratio measured with thermal neutrons in a graphite block. This thermal value has been measured by several independent methods some [1] involving and some [2] not involving absolute beta counts. The value assumed in these computations is

$$\rho_{th} = 0.0047$$

The general experimental procedure was the following. A sample of U_3O_8 was irradiated with Li (p,n) neutrons produced by the electrostatic generators of group R-2. The neutron beam was monitored with a U^{235} fission chamber which also contained the U_3O_8, as shown in Fig. 2. After being irradiated, the U_3O_8 was purified of UX_1 and fission products and mounted in a standard way on a Chicago-type Geiger-Muller tube. Its activity was measured and reduced to a specific activity for infinite irradiation by the appropriate corrections, the mass of the mounted sample being determined by the growth of UX_2 observed in the same.

If n_o is equal to the initial number of U^{239} disintegrations per atom of U^{238} after infinite irradiation, and f_o is the number of fissions in the monitor per atom of U^{235}, both per unit time, then

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$$n_o/f_o = \rho(E_n) = \left[\sigma_r(28)/\sigma_f(25)\right] E_n \quad \ldots \qquad (1)$$

The direct measurements of the specific beta activity and the specific fission counts do not give $\rho(E_n)$ because the efficiency of the beta counter, the efficiency of fission chamber etc. are unknown. However, the ratio of these specific activities is some quantity $A = \eta\rho$ proportional to ρ. By referring all runs to a standard thermal run, it follows that

$$\rho(E) = \left[A(E)/A(th)\right] \rho(th) \quad \ldots\ldots\ldots\ldots \qquad (2)$$

and

$$\sigma_r(28) = \rho(E)\ \sigma_f(25)_E \quad \ldots\ldots \qquad (3)$$

In Table I which follows are given the results of these measurements for $\rho(E_n)$ and $\sigma_r(E_n)$. The latter are obtained by multiplying $\rho(E_n)$ by the values for $\sigma_f(25)$ given in LA 150.

TABLE I

E_n kev.	$\rho(E_n)$	$\sigma_f(25)$ barns	$\sigma_r(28)$ barns
5	0.165	4.94	0.815
18	0.170	3.70	0.629
40	0.199	3.01	0.599
90	0.125	2.41	0.301
170 mean of 5 + 5°	0.113	1.98	0.224
196	0.102	1.89	0.193
380 mean of 7 + 7°	0.088	1.52	0.134
400	0.092	1.49	0.137
560	0.103	1.35	0.139
615	0.105	1.34	0.141
770 mean of 10 + 10°	0.115	1.32	0.152
1310 mean of 11 + 11°	0.073	1.30	0.095
2800			< 0.04

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EXPERIMENTAL PROCEDURE

A. Irradiation. The U_3O_8 was prepared by calcinating ether-extracted uranyl nitrate. It was packed to a thickness of 740 mg/cm^2 in a container as shown in Fig. 2. The same figure shows the relative position and dimensions of the monitor, which consists of a layer of enriched U_3O_8 electroplated on a platinum disc 0.005 cm thick. The diameter of the plated area is 3.1 cm; the plate contains 0.760 mg of U^{235} and 0.250 mg. of U^{238}, and was analyzed by Chamberlain.

The fissions produced in the monitor were counted with a standard amplifier connected to a scale of 8, both of which were constructed by C. E. Wiegand. A curve of fission counts versus bias taken with this apparatus shows a plateau whose slope indicates that over 95 percent of the fissions were counted. A correction to the fission count due to thickness of the U^{235} foil was determined from this slope and by considering absorption measurements of Wiegand and Segre[3]. It was found to be 2 $\pm$ 1 percent.

The bombarded area of the Li target had a diameter of about 0.45 cm. The position of the chamber with respect to the target and proton beam is given for each run in Table II. The angle α is the angle between the proton beam and the axis of the chamber, and d is the distance between the target and fission monitor. A correction is made in the computation of the runs to take into account the different distance from the target of the irradiated sample and of the monitor. The runs are arbitrarily numbered; the ones with numbers primed are repetitions of the unprimed runs, and give an indication of the reproducibility of the results. The neutron energies are given as the average energies at the center of the monitor, taking into account target thickness. The spread of energy is given as the total spread due to target thickness and angle subtended by the sample at the target. The irradiations all lasted from 30 to 60 min. and the

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smallest total fission count registered in any such period was 3000 counts. Care was taken to observe that occasional sparks from the electrostatic generators were not registered in our apparatus.

TABLE II

Run	E_p Mev.	E_n kev.	Target Thickness kev.	α	d cm.	$\rho = \sigma_r(28)/\sigma_f(25)$
1	1.927	5^{+7}_{-4}	7.5	120°	5.8	0.165
2	1.960	18^{+10}_{-7}	10	120°	5.9	0.171
2'	1.959	18^{+10}_{-7}	7.5	120°	5.9	0.169
3	1.907	40^{+30}_{-25}	4.6	60°	3.6	0.199
4	1.948	90 ± 30	4.6	60°	3.8	0.125
5	1.960	170 ± 25	30	0°	2.9	0.121
5'	1.958	170 ± 25	20	0°	2.9	0.106
6	1.974	196 ± 25	35	0°	2.9	0.102
7	2.127	380 ± 30	40	0°	2.9	0.095
7'	2.127	380 ± 30	40	0°	2.9	0.081
8	2.130	400 ± 30	34	0°	3.3	0.092
9	2.300	560 ± 30	60	0°	2.9	0.103
9'	2.337	615 ± 25	34	0°	3.3	0.105
10	2.496	765 ± 30	60	0°	2.9	0.122
10'	2.480	770 ± 30	22	0°	2.9	0.108
11	3.000	1310 ± 40	35	0°	2.9	0.076
11'	2.996	1310 ± 35	18	0°	2.9	0.071
12	-	2800 ± 200		0°	3.7	$\sigma_r(28) < 0.04$ barns
			ρ (thermal) = 0.0047			

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B. Purification and preparation of sample for beta counting.

Immediately after the end of irradiation the U_3O_8 was dissolved in hot nitric acid, the excess acid neutralized with sodium hydroxide, and a saturated solution of sodium acetate added. This precipitates sodium uranyl acetate which was filtered out using a Buchner funnel. The precipitate was dissolved in 5_n nitric acid and these operations repeated three or four times. This purification was performed in about 8 min. and of the original uranium approximately half was recovered.

The last precipitate was dried with acetone and approximately 5 grams of it were suspended in a solution of collodion and ether. The suspension was poured onto a filter paper and restricted by a brass frame to a region of about 7 x 9 cm (approximately equal to the area of the sensitive region around the Geiger counter). This was dried on a hot plate and formed with scotch tape into a cylinder around a cellophane covered brass tube, the outside diameter of which is slightly greater than that of the counter. The ends of the filter paper were fastened with scotch tape to the protruding ends of the cellophane cylinder, so that the sample was completely sealed between cellophane and filter paper. The brass cylinder was extracted and the sample, thus mounted, was slipped over the counter. This mounting process required about 10 min. so that about 20 min. usually elapsed between the end of irradiation and the beginning of the beta counting. Fig. 1 shows the actual observed beta activity for the run numbered 2'. Fig. 1a shows the decay of U^{239} after the observed activity has been corrected for growth of the UX_2 activity.

It is necessary to know the ratio of the specific activity of the uranium in any such sample to that of a sample irradiated with thermal neutrons with a known nvt. This is done by inserting our fission chamber, with an identical

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U_3O_8 sample, in the graphite block near the cyclotron of group R-1, and measuring the beta activity of the uranium after purifying and mounting exactly as outlined above.

C. Treatment of Data.

Apart from corrections for finite irradiation time and for decay during the purification and mounting, which are performed for all measurements in a straightforward way, it is also necessary to make some correction to take into account the different thicknesses of the various samples after mounting. To do this, first the approximate amount of uranium contained in the sample is determined by measuring its increase in activity due to UX_2 during about an 8 hour interval. Secondly, a thickness correction for the absorption of UX_2 beta radiation in sodium uranyl acetate is used which was determined empirically by making samples containing known amounts of U_3O_8 mixed with various thicknesses of lead acetate and sodium acetate to simulate the absorption properties of the actual sample. This correction reduces the UX_2 activity as measured to the activity as it would be measured in a thin layer. The thickness correction for the beta rays of U^{239} was assumed to be 2.56 times that for the beta rays of UX_2, this being the ratio of the two absorption coefficients of the radiations in aluminum. The thickness corrections for the various samples average about 14 percent for UX_2 and 36 percent for U^{239} betas.

As an example of how the data are handled, consider the run no. 2[illegible], at a neutron energy of 18 kv., to which Fig. 1 refers. The mass of uranium determined by the growth of UX_2 is 2.38 gm to a first approximation. A thickness correction factor of 1.17 corresponding to 0.0438 gm/cm^2 brings this mass to 2.78 gm. The U^{239} decay curve (Fig. 1a) corrected for finite irradiation time and for the growth of UX_2 in the sample gives an initial activity of 4910 counts per minute. This has to be multiplied by 1.43 to correct for thickness, giving finally 2470 counts/min. per gram of uranium. The similar measurements for a

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run using thermal neutrons give 5800 counts/min. per gram of uranium. The fission monitor in the two runs gave respectively 59.8 fissions/min. and 5.49 x 10^3 fissions/min. From these data we have

$$\rho(18\text{kv.}) = \frac{A(18\text{kv.})}{A(\text{th})} \rho(\text{th}) = 0.169$$

It should be stated that this result contains also a 12 percent correction added to the fission rate of the monitor in the 18 kv. run because of the fact that the monitor is slightly farther from the Li target than the U_3O_8 sample. The values of ρ at other energies have been obtained in an exactly similar manner.

In order to check the whole procedure, an absolute determination of $\rho(\text{th})$ was attempted by trying to count on an absolute basis the beta rays of U^{239}. It was assumed that there is one electron per disintegration, and a thickness correction was made by the method given above. The efficiency of the counter for a thin layer was determined by using a weighed amount of U_3O_8 mounted in the described manner, assuming that it emits 732.5 UX_2 disintegration electrons per milligram per minute. The UX_1 electrons give a negligible effect on the Geiger counters since the aluminum wall thickness is about 35 mg/cm^2. The value found in this manner was

$$\rho(\text{th}) = 0.0046$$

in excellent agreement with the known value of 0.0047. As a matter of fact, the agreement is to be considered fortuitous because it is estimated this measurement of $\rho(\text{th})$ could be off by 25 percent.

The general accuracy of the other values of $\rho(E)/\rho(\text{th})$ should be about 15 percent. Fig. 3 shows a curve of $\sigma_f(28)$ versus energy; the indicated errors are just those of the measurements of ρ listed in Table II and do not contain the errors in the values of $\sigma_f(25)$. The highest energy point (run no. 12) at 2.8 Mev. was made with neutrons from the d-d source of group R-3.

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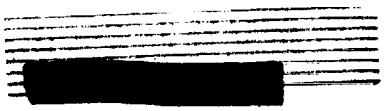

There was an insufficient neutron flux to give a measureable activity from U^{239}. However, placing an upper limit to the amount of activity that could be present and undetected by these methods and assuming $\sigma_f(28) = .5$ barns, an upper limit of 0.04 barns is obtained for $\sigma_r(28)$ at this energy.

We have learned from Dr. Teller that at the Argonne Laboratory it has been found that the $\sigma_r(28)$ between 50 and 1000 eV can be represented by the formula

$$\sigma_r(28) = \frac{128}{\sqrt{E}}$$

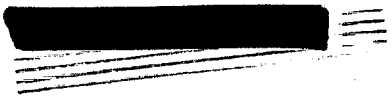

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Fig. 1

UX_2 activity, growing with the UX_1 half-period
Rate of growth = 617.5 c/m. per hour

Initial observed decay

Irradiation made with short tank of Group R-2
Beam = 40 μamp. av.
Proton energy = 1.96 Mev.
Target thickness = 7-8 kv.
Angle of chamber with forward direction = 120°
Neutron energy = 18 kv. av.
Distance from target to f-monitor = 5.85 cm.
Angular spread of energy: from 14 kv. to 24 kv.
Irradiation time = 66 min. ending at 10:09
Chemical purification completed at 10:20

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Clock Time for Sept. 26, 1944

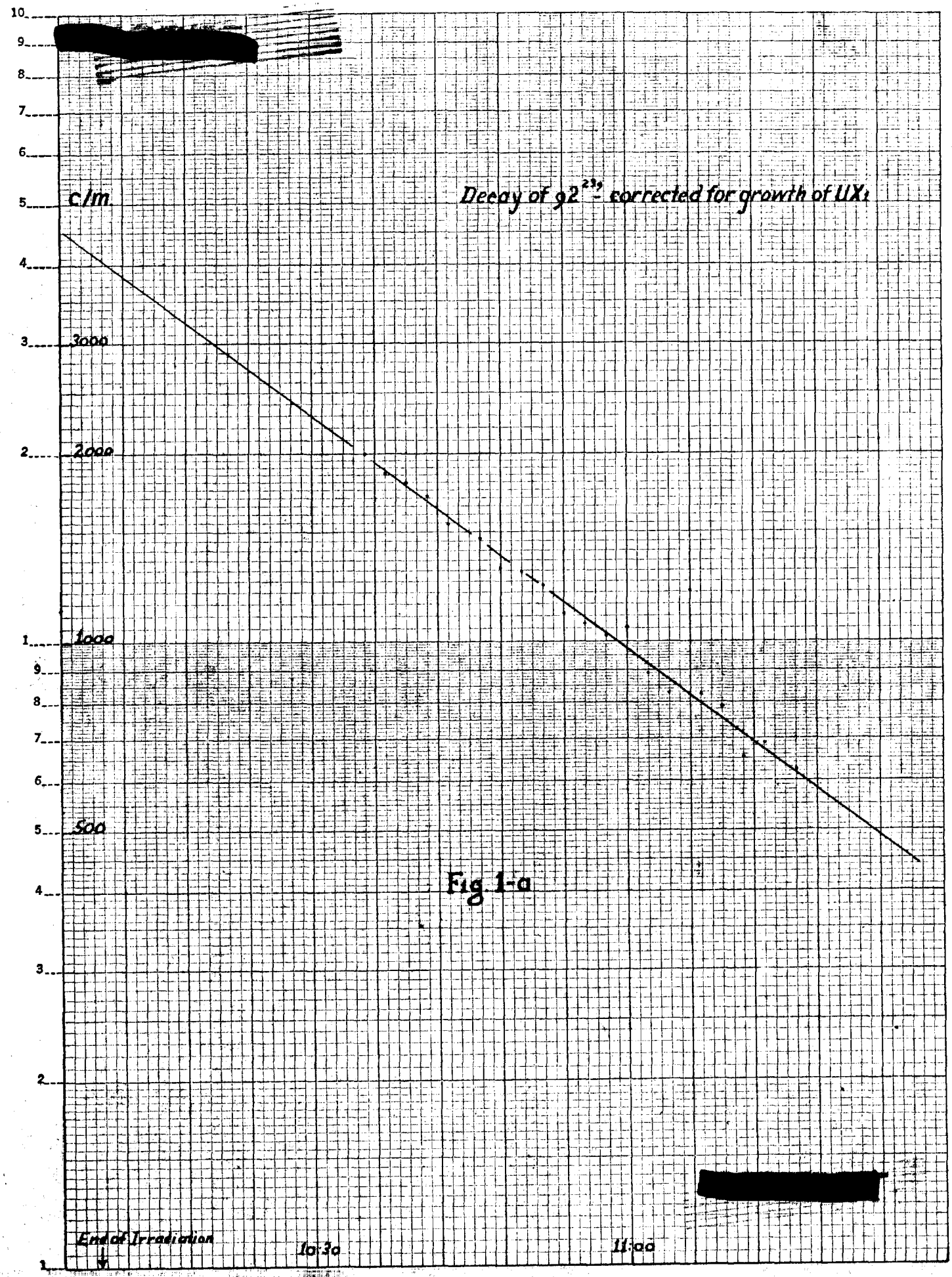

Fig. 1-a

Fission Chamber

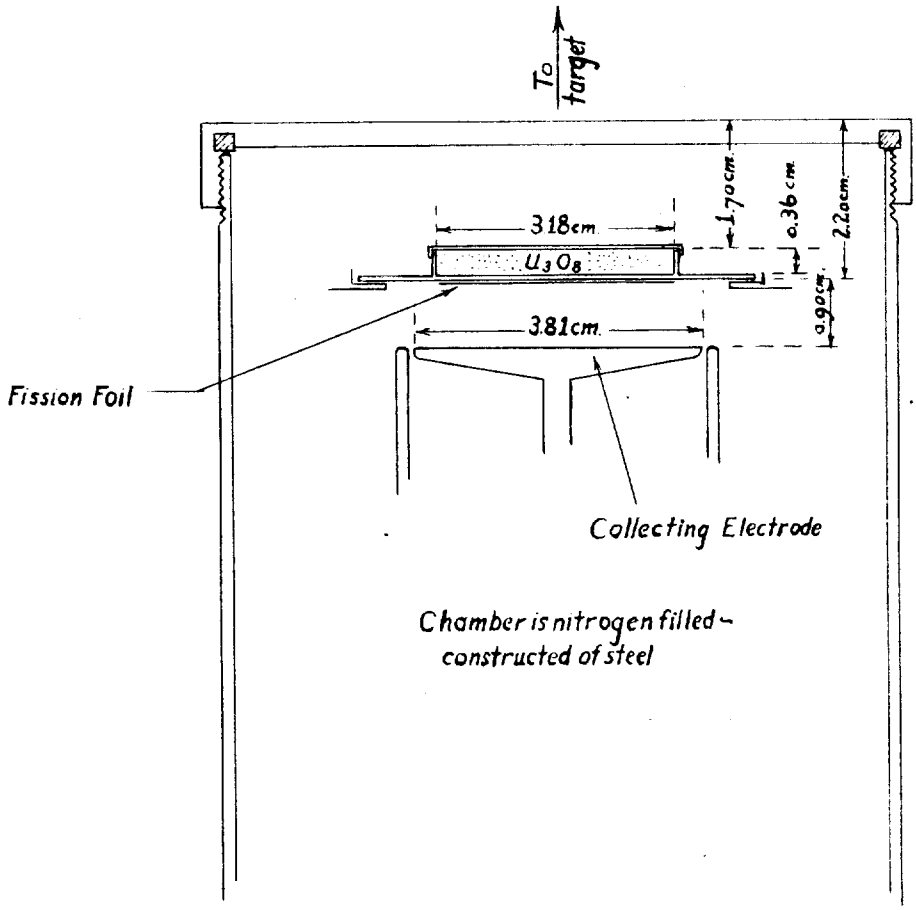

Fig. 2