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Esther Allison
Julia Carlson
Norris Nereson
Pearl Norwood
Dorothy Squires

Report written by:

Norris Nereson

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Abstract

Experimental techniques are described for the spectral measurement of a collimated fast neutron beam. A hydrogen filled cloud chamber, proton recording nuclear plates, and threshold fission foils were used as neutron detectors in the measurements. As an application of the above techniques, the energy distribution and absolute flux of the fast neutron beam emerging from port 5W of the Los Alamos fast reactor has been measured from 0.1 Mev to 18 Mev. The result shows a spectral curve possessing a maximum between 0.25 and 0.30 Mev and having an exponential decrease at energies above 1.5 Mev. The mean energy of the distribution is at 0.55 Mev and the slope of the exponential section is 3.1 ± 0.1 Mev per decade of intensity decrease.

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the port 5W beam. The repeated fission foil measurements agreed reasonably well (within 15%) with the previous values so the neutron spectrum was assumed not to have changed significantly.

II. EXPERIMENTAL RESULTS

A. Cloud Chamber

The experimental arrangement for all three of the neutron detectors is shown in Fig. 1. The 7/8 inch i.d. steel collimator was used in the case of the cloud chamber measurement in order to more effectively utilize the cloud chamber volume; for the same reason, the cloud chamber was placed about 12 feet back of the port opening so as to permit the diverging (1°) neutron beam to spread out and occupy most of the chamber volume. The cloud chamber in use was the same one as that used by T. W. Bonner² to measure the low energy region of the fission spectrum of U^{235} . This chamber had a cylindrical gas volume which was enclosed by a 1/4 inch thick glass cylinder about 9 inches high and 12 inches in diameter. Expansion was accomplished by suddenly reducing the air pressure beneath a neoprene diaphragm. The expansion ratio was 1.3 and the cycle time was about one minute.

In the present experiment, the chamber was filled with hydrogen and saturated water vapor to a pressure (expanded condition) of 32 cm of Hg at 25°C . Proton recoil tracks ranging from 0.8 to 15 cm in length were measured and, at the above pressure and temperature, this corresponds to an energy range of 0.10 to 0.80 Mev. The standard proton range-energy curves published by Bethe³ were used. It would have been desirable to go lower in energy but the above range was selected to overlap the nuclear plate data sufficiently so that the chamber data could be reliably matched into the plate data (which has a practical lower energy limit of 0.5 Mev).

The proton recoil tracks in the chamber were photographed with a Sept camera having a stereoscopic attachment. The tracks were photo-

² T. W. Bonner, LA-715 (1948).

³ H. A. Bethe, BNL-T-7 (1949).

graphed against a background of porous black velvet cloth located immediately above the neoprene diaphragm. Afterwards, light was projected through the same camera and the tracks measured with the aid of a ruler and white cardboard situated in the position previously occupied by the effective chamber volume. Tracks were measured if they satisfied three conditions: 1st, they must originate within a volume element $7 \times 7 \times 7$ cm located in the forward region of the chamber volume, 2nd, they must be contained within a cone having a half-angle of 15° , and 3rd, they must be sharp or new tracks and not fuzzy or old tracks which may have formed before the expansion took place. A total of about 2100 tracks were measured. The above data was accumulated in three parts, each part averaging about 700 tracks; satisfactory agreement existed between these three sets of data. For further details on the cloud chamber measurements, the reader is referred to LA notebook #2939.

The data is tabulated in Table I. It was necessary to apply a correction factor for long tracks (> 9 cm) leaving the effective track forming region in the cloud chamber gas; the calculation of this correction factor is shown in LA notebook #2939. The conversion of proton recoil energy back to neutron energy is discussed by Livingston and Bethe⁴; the correction (addition) to the proton energy to convert to neutron energy is given as $\frac{1}{2} E_p \theta^2$ where θ is the angle in radians in which recoil protons are accepted. In the present experiment, the correction amounted to $0.035 E_p$.

The cloud chamber data in Table I is plotted in Fig. 2. The spectral curve shows a maximum between 0.25 and 0.30 Mev. The depression around 0.4 Mev occurred in all three sets of data mentioned above and is believed to be real. This dip is believed to be caused by the neutrons passing through the $1/4$ " thick glass wall of the cloud chamber; this explanation seems logical since glass is composed of mainly oxygen, and oxygen has a prominent scattering resonance around 0.4 Mev. The last point at 0.8 Mev must be suspiciously regarded since sometimes the track ends of these long tracks were fuzzy and the question arose as to

⁴ M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. 9, 290 (1937).

whether or not these tracks really ended in the track forming region of the cloud chamber gas. This last point has been ignored both in drawing the curve and also in later use of the cloud chamber data.

B. Nuclear Plates

1. Proton recoils within nuclear plates

The nuclear plate camera method (described in section 2 below) could have been used exclusively for determining the high energy region of the spectrum. However, the method of measuring proton recoils in the forward direction which arise from neutrons striking hydrogen atoms within the emulsion volume was employed for two reasons: 1st, the method had been extensively used in previous work⁵ and these results had shown that the derived absolute neutron flux figures could be trusted and, 2nd, for matching into the cloud chamber data, a nuclear plate measurement was desired which would go to as low an energy as possible. The proton recoil method is reliable to a slightly lower energy than the nuclear plate camera method. Furthermore, quantitative experiments on the reliability of the present method at low neutron energies had already been performed⁶.

Ilford C2 plates were exposed to the 5W neutron beam by placing the plates in the beam with their emulsion surfaces parallel to the beam (see Fig. 1). The 3/8" x 3/8" steel collimator was used in this experiment. Details covering the plate exposure time, plate thickness, volume analyzed, etc. are listed in Table II. The original experimental details are recorded in LA notebook #2178, page 93.

The plate analysis was identical to that described in previous reports⁵. The only item concerning the analysis which might be mentioned is that the swath length was restricted to a length of 0.5 cm as measured from the plate edge facing the incoming neutron beam. A

⁵ N. Nereson, LA-1123, and LA-1192 (1950).

⁶ N. Nereson and F. Reines, Rev. Sci. Inst. 21, 534 (1950).

length of 0.5 cm corresponds to about 1/5th of a mean free path in the nuclear emulsion for a 1 Mev neutron. Within the above distance, the nuclear emulsion has negligible effect on distorting the spectrum. The above effect is further diminished on account of the facts that the beam diverges by 1° and that the plate surfaces were probably not aligned perfectly parallel ($\pm 2^\circ$) with the beam.

The results of the above analysis are tabulated in Table III and graphed in Fig. 3. An inset graph in Fig. 3 shows a comparison of the results of the two microscopists who analyzed this data; the agreement is satisfactory except for one point at 0.48 Mev. In the combined data, the point C_1 at 0.48 Mev has been increased by 10% over the original value O_1 in order to adjust for emulsion inefficiency at low energies⁶. The point O_2 at 0.37 Mev has not been used on account of the unreliability of nuclear plate data at this low energy.

On the same graph in Fig. 3, the cloud chamber data has been matched to the nuclear plate data in the energy region from 0.45 to 0.75 Mev. The shape of the spectral curve shown by the two detectors is within experimental error in the above energy region. A plot of this same spectral curve on semi-log paper (Fig. 4) shows that beyond 1.5 Mev the curve is an exponential which decreases by a factor of ten in intensity for every 3.1 Mev of neutron energy. The average or mean neutron energy of the spectral curve shown in Fig. 3 is 0.55 Mev; also, $2/3$ of the total number of neutrons are below 0.9 Mev and $3/4$ of the neutrons are below 1.2 Mev.

It is possible to calculate the absolute neutron flux from the data on proton recoils in the forward direction within the emulsion by use of the following equation:

$$N_p(E_p) \times C = N_n(E_n) \times \sigma_p(E_n) \times n_H \times G$$

where

$N_p(E_p)$ = number of forward proton recoils per 0.1 Mev per sec.
per KW per cm³ of unprocessed emulsion.

- $N_n(E_n)$ = number of neutrons per 0.1 Mev per sec. per KW per cm^2 emerging from port 5W with $3/8" \times 3/8"$ collimator,
 C = correction factor for proton recoil tracks leaving the emulsion surfaces (see Table III),
 G = geometry factor expressing the ratio of proton recoils proceeding within the experimental angle in the forward direction to all proton recoils; for the present angular limits this factor is 0.09,
 $\sigma_p(E_n)$ = scattering cross section of hydrogen for neutrons of energy E_n (see Table III),
 n_H = number of hydrogen atoms per cm^3 of unprocessed nuclear emulsion = 0.034×10^{24} .

The absolute flux scale given for the ordinate in Fig. 3 was derived using the above equation. For example, in the proton energy range from 1.4 to 1.5 Mev, 67 proton recoils were observed in an unprocessed emulsion volume of $2 \times 10^{-3} \text{ cm}^3$ for an exposure of 2.5 KW-min. Therefore, $N_p = 67 / (2 \times 10^{-3} \times 2.5 \times 60) = 224$. The neutron energy corresponding to the midpoint of the 1.4 to 1.5 Mev proton recoil interval is 1.55 Mev⁵. Since $\sigma_p = 3.4 \times 10^{24}$ and $C = 1$ at this energy,

$$N_n \text{ at } 1.55 \text{ Mev} = \frac{224}{3.4 \times 10^{-24} \times 0.034 \times 10^{24} \times 0.091} = 21.3 \times 10^3.$$

2. Nuclear plate camera method

The nuclear plate camera method was used for obtaining the very high energy region ($> 5 \text{ Mev}$) of the port 5W neutron spectrum. Various nuclear plate camera geometries were employed and they are illustrated in the inset figures in Fig. 9; the original experimental geometries are shown in LA notebook #2178, pages 94 to 109. Briefly, this method consists in placing a thin section of hydrogenous material directly in the neutron beam and then recording some of the recoil protons emitted from this radiator by a nuclear plate situated just outside the beam with its emulsion surface almost parallel to the emitted protons. This means that all of the proton tracks to be measured will start in the emulsion surface and possess a small angle of dip and/or

The energy of a neutron, E_n , which produced a proton recoil of energy E_p in the nuclear plate can be obtained as follows by referring to the inset diagrams in Fig. 9:

- E_n = original neutron energy in port 5W beam,
- E_{p2} = $E_n \cos^2\theta$ = proton energy within radiator just after being hit by neutron
- E_{p1} = E_{p2} - proton energy loss in 1/2 radiator thickness = average proton energy after emerging from radiator,
- E_p = E_{p1} - proton energy loss in entire aluminum stopper = average proton energy after emerging from aluminum stopper,
- E_p = proton energy spent in nuclear plate.

To be exact, a final step should involve a correction on the measurement of the length of the track, i.e. the track length, $l(E_p)$, corresponding to the energy E_p was not measured but rather the horizontal projection, $l(E_p) \cos \theta$ was measured. The latter correction was overlooked in the beginning of the experiment and has been left out of the analysis. However, the correction is small, usually amounting to only 2%.

The energy loss of the proton in traversing the parawax or polythene radiator $(CH_2)_n$ was determined from Hirschfelder and Magee's values⁸ and the proton energy loss in aluminum was obtained from Bethe's curves². Complete tables of the conversion of E_n to E_p are shown in the LA notebooks listed in Table II. Representative values of the above energy corrections for the #141 plate are shown below:

E_n	E_{p2}	E_{p1}	E_p	$l(E_p)$	$l(E_p) \cos \theta =$ $l_{meas.}$
5.0 Mev	4.88 Mev	4.14 Mev	3.63 Mev	103 microns	100 microns
6.0	5.86	5.26	4.82	163	158
11.0	10.74	10.38	10.13	577	560

As mentioned previously, it is important to make certain that the high-

⁸ J. O. Hirschfelder and J. L. Magee, Phys. Rev. 73, 207 (1948).

est proton energy measured did not produce a track which left the emulsion limits. For example, in the above plate #141, the longest track which can enter the plate at 14° and be contained within the 180 micron thick emulsion is equal to 745 microns. The longest measured track (577 microns in the above case) should be well within this limit since neutrons can enter the plate at slightly larger or smaller angles (approximately $14^\circ \pm 4^\circ$ for plate #141) on account of: 1st, the finite size of the radiator and 2nd, small angle scattering in the aluminum and emulsion.

The absolute neutron flux can be calculated from the nuclear plate camera data as follows:

$$N_p(E_p) = N_n(E_n) \times \sigma_p(E_n) \times (n_p \times a) \times Q \times \frac{A \sin \theta \times 4 \cos \phi}{4\pi R^2}$$

where

- $N_n(E_n)$ = number of neutrons per 0.1 Mev per sec. per KW per cm^2 emerging from port 5W,
- $N_p(E_p)$ = number of proton recoils per 0.1 Mev measured over a plate area of $A \text{ cm}^2$,
- $\sigma_p(E_n)$ = scattering cross section of hydrogen for neutrons of energy E_n ,
- n_p = number of protons per cm^3 in radiator,
- a = area of radiator subtended by port 5W beam,
- θ = average angle between plate surface and incoming protons,
- ϕ = average angle between neutron beam direction and recoil protons,
- R = average distance of radiator to center of analysis region on plate,
- Q = exposure quantity in KW-sec.

The constant experimental quantities above are listed in Table II for the various plates. If these constants are substituted into the above equation and if σ_p is given in barns, the following simplified equations result:

For plate #137: $N_n = N_p / \sigma_p \times 1000$
 For plate #138: $N_n = N_p / \sigma_p \times 109$
 For plate #141: $N_n = N_p / \sigma_p \times 9.7$
 For plate #152: $N_n = N_p / \sigma_p \times 0.83$
 For plate #153: $N_n = N_p / \sigma_p \times 0.063$

The data for the above plates are tabulated in Tables IV to VIII and plotted on semi-log paper in Fig. 4 to 8. The comparison graph in Fig. 4 shows that good agreement exists between the proton recoil data and the nuclear plate camera data. All of the spectral plots in Fig. 4 to 8 show approximately the same type of curve above 1.5 Mev, i.e. an exponential spectrum which decreases by a factor of 10 in intensity over an energy range lying somewhere between 2.9 and 3.4 Mev.

A background run was taken for plates #141, #152 and #153. This consisted of placing a nuclear plate diametrically opposite the data plate and interposing a 1/32" thick aluminum piece in the proton path to the plate (see Fig. 9). This prevented protons originating in the radiator from reaching the background nuclear plate. The background data has been plotted on the graphs for the same area of analysis as the regular data. If the background exceeded 10% of the data point value, the data point was not used in drawing the spectral curve.

Most of the background tracks probably arise from neutrons which are scattered by the radiator into the nuclear plates and then collide with a proton near the surface of the emulsion. Although the event of a scattered neutron producing a proton recoil near the emulsion surface and proceeding within prescribed angular limits is rare, it must also be remembered that the low energy neutrons, which are primarily responsible for the background, have factors of 10^4 to 10^6 in intensity over the high energy neutrons being studied. A rough calculation shows that the background observed in connection with the high energy regions of the spectrum is reasonable. The percentage of background tracks increased as higher energy regions of the spectrum were studied. Evidently this effect was due to the thicker radiator used at higher energies and to the decreased distance between radiator and plate; both of

these factors would increase the number of neutrons scattered by the radiator into the plate.

A brief study was made of the effect of proton small angle scattering in the aluminum stopper and in the nuclear emulsion. In order to ascertain the magnitude of this effect, proton tracks were grouped according to two different angular criteria. One grouping comprised the selection of proton tracks which were contained within angular limits as calculated from the camera geometry, i.e. the maximum and minimum angles of the dip and horizontal divergence of the tracks were determined from the size of the radiator, position of the plate, and the section of area analyzed on the plate. The other grouping involved the selection of proton tracks which lay outside of the above geometrical angular limits, i.e. these tracks should represent protons scattered out of their normal angular limits. The angular limits chosen for these scattered protons were approximately twice the normal geometrical limits. It is realized that the above scattering study is rough since the scattered tracks are grouped into only one large angular interval and no differentiation is made between scattered out and scattered in events.

The measurements were carried out only in the case of plate #152d which provides data for the 8 to 13 Mev region of the spectrum. The two criteria giving the angular limits for the two groupings are shown below.

Criteria A $\equiv$ angular limits as calculated from camera geometry.

	<u>Unprocessed emulsion</u>	<u>Processed emulsion</u>	<u>Track criteria in microscope field</u>
Limits on dip angle of track.	$14^{\circ} \pm 4^{\circ}$	$6^{\circ} \pm 2^{\circ}$	7 to 15 microns of track in clear focus.
Limits on hor- izontal angle of track.	$0^{\circ} \pm 5^{\circ}$	$0^{\circ} \pm 5^{\circ}$	Track divergence within 10° reticule angle.

Criteria B $\equiv$ angular limits used in investigating proton scattering.

	<u>Unprocessed emulsion</u>	<u>Processed emulsion</u>	<u>Track criteria in microscope field.</u>
Limits on dip angle of track.	$8^{\circ} \pm 2^{\circ}$, $28^{\circ} \pm 10^{\circ}$	$3^{\circ} \pm 1^{\circ}$, $12^{\circ} \pm 4^{\circ}$	3.5 to 7 microns or 15 to 30 microns of track in clear focus.
Limits on hor- izontal angle of track.	$7.5^{\circ} \pm 2.5^{\circ}$	$7.5^{\circ} \pm 2.5^{\circ}$	Track divergence out- side of 10° reticule angle but within 20° reticule angle.

A shrinkage factor of 2.5 was used to convert angles in the unprocessed emulsion to angles in the processed emulsion. Since the angles have been rounded off to the nearest whole angle, the ratio between the angles may deviate slightly from the above factor. An angle engraved on an eyepiece reticule was used to determine the horizontal angle of the track. The vertical angle of the track was judged by the length of track in clear focus in the microscope field; in employing this method, one micron was used as the depth of focus of the microscope^{5,6}.

The following data was obtained from the above analysis on plate #152d; the original data (taken by D.S.) is contained in LA notebook #3400, page 8:

<u>E_n</u>	<u>Track length</u>	<u>Number of tracks</u>	
		<u>Criteria A</u>	<u>Criteria B</u>
7.5 - 8.0 Mev	32 - 73 microns	75	23
8.0 - 8.5	73 - 114	46	4
8.5 - 9.0	114 - 155	31	0
9.0 - 9.5	155 - 195	22	1
9.5 - 10.0	195 - 242	10	0
10.0 - 10.5	242 - 293	4	0
10.5 - 11.0	293 - 343	4	0
11.0 - 11.5	343 - 395	1	0
11.5 - 12.0	395 - 445	2	1
12.0 - 12.5	445 - 502	3	0
12.5 - 13.0	502 - 560	1	0

thickness of the emulsion and there is an increased probability that the track can leave the emulsion surface by a small angle scattering.

The individual sets of data on the port 5W beam spectrum have been combined in Fig. 9. Except for the cloud chamber data, each set of data has been plotted in terms of absolute neutron flux as calculated from the equation on page 11. The agreement between various sets of data in the overlapping regions is satisfactory if one considers the statistical errors and other uncertain quantities which are present in the experiment. Errors other than statistical are estimated to be as follows: a - 6%, n_p - 5%, Q - 5%, θ and ϕ - 5% each and R - 3% which give a combined error of about 12%. The straight line section of the curve beyond 1.5 Mev has an average slope of 3.1 ± 0.1 Mev per decade of intensity decrease.

C. Threshold Fission Foils

Threshold fission foils, N_p^{237} and U^{238} , were exposed to the 5W beam spectrum chiefly to check the nuclear plate and cloud chamber results; a U^{235} foil was exposed in order to obtain an approximate idea of the number of neutrons below the cloud chamber limiting energy of 0.1 Mev. These experiments were carried out by placing the fission foils over an Eastman NTC nuclear plate and then exposing this combination in the 5W beam with the surface of the foil and plate perpendicular to the neutron beam. The fission tracks on the plate were then counted and from several experiments an average figure of tracks (or fissions) per fissionable atom per KW per sec. of exposure was obtained. The 7/8" i.d. steel collimator was used in all of these exposures in order to provide a beam of large cross section so that the three foils could be exposed at the same time. The most accurate work with the fission foils was done in the case of the peripheral loading and a summary of these experiments is given in LA notebook #2178 page 90. After reloading the pot in the summer of 1950, the fission foil experiments were repeated to see if the spectrum had changed; a summary of the latter experiments is given in LA notebook #3526 page 110. The fission foil results, before and after reloading the pot, are presented below:

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Fission foil	Fissions/atom/KW/sec. for 7/8" i.d. collimator = A	Calculated fissions/atom/KWsec. for 3/8" x 3/8" collimator = A/4.
U^{235}	$8.0 \pm 0.2 \times 10^{-18}$	$2.0 \pm 0.05 \times 10^{-18}$
N_p^{237}	$3.9 \pm 0.1 \times 10^{-18}$	$1.0 \pm 0.02 \times 10^{-18}$
U^{238}	$6.1 \pm 0.1 \times 10^{-19}$	$1.5 \pm 0.03 \times 10^{-19}$

Centralized loading of only plutonium - present loading:

	Fissions/atom/KW/sec. for 7/8" i.d. collimator = B	Calculated fissions/atom/KW/sec. for 3/8" x 3/8" collimator = B/4.
Fission foil		
U^{235}	$7.0 \pm 0.3 \times 10^{-18}$	$1.8 \pm 0.08 \times 10^{-18}$
N_p^{237}	$3.3 \pm 0.2 \times 10^{-18}$	$0.8 \pm 0.05 \times 10^{-18}$
U^{238}	$6.7 \pm 0.3 \times 10^{-19}$	$1.7 \pm 0.08 \times 10^{-19}$

The fission foil values obtained for the 5W spectrum before and after reloading the pot do not agree within the given statistical errors. However, the two sets of values do agree within 15% of each other and, using the extreme limits of the statistical errors, the values differ by a maximum of 8%. Probably this is as good an agreement as can be expected in view of the facts that 1st, only about one-half as many fission foils were examined for the present loading as for the previous peripheral loading, 2nd, there was considerable uncertainty in the reactor power or exposure quantity given in the experiments just after reloading and 3rd, the reading of the NTC plates used in the later experiment was made difficult by the presence of alpha tracks which the plates unfortunately recorded. To summarize, one can say that the fission foil results show that the integrated flux values of the 5W neutron spectrum after the pot reloading are probably not different by more than 10% from the previous integrated flux figures.

It is interesting to compare the fission foil results with the values obtained by integrating the 5W spectrum drawn in Fig. 9. If one

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numerically integrates $\int N_n(E) \sigma_f(E) dE$, where N_n is the spectral curve of Fig. 9 and σ_f is the fission cross section⁹ of the particular foil metal, the following values are obtained:

$$\int_0^{\infty} N_n \sigma_f(235) dE = 2.1 \times 10^{-18} \text{ fissions/atom of metal/KW/sec.}$$

$$\int_0^{\infty} N_n \sigma_f(237) dE = 1.0 \times 10^{-18} \quad " \quad " \quad " \quad " \quad "$$

$$\int_0^{\infty} N_n \sigma_f(238) dE = 1.5 \times 10^{-19} \quad " \quad " \quad " \quad " \quad "$$

The practical limits of the integration were from 0.05 to 10 Mev instead of from 0 to ∞ Mev; the dotted line drawn below 0.1 Mev in Fig. 3 was used for values of N_n below 0.1 Mev. LA notebook #3106 page 39 contains the actual numerical integrations.

Since N_n in Fig. 9 is for the $3/8" \times 3/8"$ collimator, the above integrations must be compared with the fission foil values for the same collimator. The fission foil results for the $3/8" \times 3/8"$ collimator can be calculated from the experimental values for the $7/8"$ i.d. collimator merely dividing the latter values by 4 as this is the ratio of the areas of the two collimators, i.e. the collimators see an extended neutron source which is primarily the "pot". Excellent agreement exists between the fission foil values (peripheral loading) and the integrated values of the $5W$ spectrum.

The U^{235} foil provides useful information by showing that it is satisfactory to complete the 5W spectrum curve by extrapolating from the first cloud chamber point around 0.1 Mev down to 0 Mev. Apparently, the 5W spectrum contains a negligible number of thermal or low energy

⁹ The fission cross sections used in the calculations were taken from LA-994.

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neutrons; if this were not the case, the U^{235} foil result would not check so well with the extrapolated low energy end of the spectrum. Also, the ratio U^{235} (without Cd)/ U^{235} (with Cd) was found to be 1.00 ± 0.01 for this spectrum.

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Fig.1- Experimental Arrangement for Measurement of Port 5W Neutron Spectrum

Fig.2 Cloud Chamber Measurement of Neutron Spectrum from Port 5W

Fig 3 Combined Cloud Chamber and Nuclear Plate Measurements Utilizing Forward Proton Recoils to Measure Port 5W Neutron Spectrum

Fig. 4 Comparison of port 5W neutron spectrum data obtained by forward proton recoil method and by nuclear plate camera method

Fig.5 Nuclear plate camera measurement of port 5W neutron spectrum over 3 to 9 Mev region

Fig.6 Nuclear plate camera measurement of port 5W neutron spectrum over 5 to 11 Mev region.

Fig.7 Nuclear plate camera measurement of port 5W neutron spectrum over 8 to 13 Mev region

Fig.8 Nuclear plate camera measurement of port 5W neutron spectrum over 12 to 18 Mev region

Fig. 9 Combined data on measurements of neutron beam spectrum from port 5W of fast reactor

Proton recoil energy interval	No. of measured proton recoil tracks per 50 Kev = N_p	Correction factor, C_c , for tracks leaving cloud chamber vol.	Average E_n (in Mev)	σ_p at E_n (in barns)	Corrected proton recoil tracks per 0.1 Mev/ $\sigma_p \times 10^{24}$. ($2 N_p \times C_c / \sigma_p \times N_n$)
0.10 - 0.15 Mev	233	1.00	0.13	11.9	39.2 $\pm$ 2.5
0.15 - 0.20	235	1.00	0.18	10.4	45.2 $\pm$ 2.9
0.20 - 0.25	307	1.00	0.23	9.2	66.7 $\pm$ 3.8
0.25 - 0.30	293	1.00	0.29	8.3	71.0 $\pm$ 4.1
0.30 - 0.35	239	1.00	0.34	7.6	62.9 $\pm$ 4.1
0.35 - 0.40	153	1.00	0.39	7.1	43.2 $\pm$ 3.5
0.40 - 0.45	158	1.00	0.44	6.6	47.9 $\pm$ 3.8
0.45 - 0.50	166	1.00	0.49	6.2	53.5 $\pm$ 4.2
0.50 - 0.55	108	1.00	0.54	5.9	36.6 $\pm$ 3.6
0.55 - 0.60	91	1.00	0.60	5.6	32.6 $\pm$ 3.4
0.60 - 0.65	55.5* (37)*	1.17	0.65	5.4	24.1 $\pm$ 4.0
0.65 - 0.70	46.5 (31)	1.51	0.70	5.2	27.1 $\pm$ 4.9
0.70 - 0.75	30.0 (20)	1.64	0.75	5.0	19.6 $\pm$ 4.4
0.75 - 0.80	36.0 (24)	1.80	0.80	4.9	26.6 $\pm$ 5.4

* The figures in parenthesis represent the number of measured proton recoils for 2/3 of the entire data. Therefore, these figures have been multiplied by 1.5 to make them correspond with the rest of the data; the results are the numbers at the left of the column. The latter figures are, of course, used for computing the neutron flux, whereas the figures in parenthesis are only used for computing the statistical errors.

TABLE I. Data Obtained by Measuring Forward Proton Recoils in Cloud Chamber Exposed to Port 5W Neutron Spectrum.

Plate number in LA notebooks	Analysis method	Nuclear plate type	Emulsion thickness		Unprocessed emulsion volume or area analyzed	Exposure to 5W neutron beam	Number of tracks leaving emulsion surfaces	Microscopists and LA notebook num- bers
			Unprocessed	Processed				
134	Recoils in for- ward direction within nuclear plate.	Ilford G2 100 microns	90 microns	37 microns	$2 \times 10^{-3} \text{ cm}^3$	2 1/2 KW-min.	59	E.A. #2909, #3189 D.S. #2910, #3106
137	Surface tracks in nuclear plate camera.	"	90 microns	36 microns	0.85 cm^2	162 KW-hrs.	4	D.S. #3106
138	"	"	90 microns	36 microns	0.405 cm^2	162 KW-hrs.	0	P.N. #3130
141	"	Ilford G2 200 microns	180 microns	75 microns	0.20 cm^2	307 KW-hrs.	18	P.N. #3130 E.A. #3189 D.S. #3400 J.C. #2674
152, 152d	"	"	185 microns	80 microns	1.55 cm^2	316 KW-hrs.	30	J.C. #2674 D.S. #3400, #3106
153, 153d	"	"	185 microns	77 microns	5.32 cm^2	350 KW-hrs.	52 out top 18 out bottom	P.N. #3346 D.S. #3400, #3106

Plate number in LA notebooks	Parawax or polythene radiator	Radiator area subtended by port 5W neutron beam	Distance of radiator to nuclear plate center	Average angle of protons to 5W neutron beam	Average angle of protons to emulsion surface	Aluminum absorber for proton range reduction
137	0.12 mg/cm^2	0.85 cm^2	15.0 cm	10°	10°	None
138	2.20 "	0.85 cm^2	15.0 cm	10°	10°	None
141	14.7 "	0.82 cm^2	13.0 cm	9°	14°	7.5 mg/cm^2
152, 152d	20.6 "	0.85 cm^2	13.0 cm	9°	14°	72.3 "
153, 153d	36.7 "	0.80 cm^2	7.4 cm	14°	9.5°	140 "

TABLE II. General Information on Nuclear Plates Exposed to Port 5W Neutron Beam.

Proton recoil energy inter- val (E_p)	Number of tracks			Averaged E_p interval	Correction factor for tracks leaving surfaces	Average E_n	σ_p at E_n	Corrected tracks per $0.1 \text{ Mev}/\sigma_p \times 10^{24} \text{ cm}^2 N_n$		
	by R.A.	by D.S.	Total					by R.A.	by D.S.	Total
				(Mev)		(Mev)	(barns)			
0.3 - 0.4 Mev	324	313	637	0.3 - 0.4	1.00	0.37	7.30	44.4 * 2.5	42.9 * 2.4	87.3 * 3.5
0.4 - 0.5	412	323	735	0.4 - 0.5	1.00	0.48	6.27	65.7 * 3.2	51.5 * 2.9	117.2 * 4.3
0.5 - 0.6	274	257	531	0.5 - 0.6	1.00	0.59	5.65	48.5 * 2.9	45.5 * 2.8	94.0 * 4.0
0.6 - 0.7	172	212	384	0.6 - 0.7	1.00	0.70	5.18	33.2 * 2.5	40.9 * 2.8	74.1 * 3.8
0.7 - 0.8	135	153	288	0.7 - 0.8	1.00	0.86	4.70	22.0 * 1.5	25.4 * 1.7	47.5 * 2.2
0.8 - 0.9	72	86	158							
0.9 - 1.0	88	68	156	0.9 - 1.1	1.00	1.07	4.20	19.0 * 1.5	15.4 * 1.4	34.4 * 2.0
1.0 - 1.1	72	61	133							
1.1 - 1.2	52	74	126	1.1 - 1.3	1.00	1.28	3.83	13.8 * 1.3	14.1 * 1.4	27.9 * 1.9
1.2 - 1.3	54	34	88							
1.3 - 1.4	31	44	76	1.3 - 1.5	1.00	1.50	3.49	9.0 * 1.1	11.5 * 1.3	20.5 * 1.7
1.4 - 1.5	31	36	67							
1.5 - 1.6	27	33	60	1.5 - 1.7	1.00	1.71	3.23	6.8 * 1.0	8.8 * 1.2	15.6 * 1.5
1.6 - 1.7	17	24	41							
1.7 - 1.8	32	9	41	1.7 - 2.0	1.00	1.98	2.95	9.8 * 1.0	6.3 * 0.8	16.2 * 1.4
1.8 - 1.9	34	27	61							
1.9 - 2.0	21	20	41							
2.0 - 2.1	12	20	32	2.0 - 2.5	1.03	2.41	2.63	5.5 * 0.7	6.2 * 0.7	11.7 * 1.0
2.1 - 2.2	18	17	35							
2.2 - 2.3	13	21	34							
2.3 - 2.4	7	10	17							
2.4 - 2.5	20	11	31							
2.5 - 2.6	8	11	19	2.5 - 3.0	1.07	2.94	2.32	3.2 * 0.5	5.0 * 0.7	8.2 * 0.9
2.6 - 2.7	7	10	17							
2.7 - 2.8	13	13	26							
2.8 - 2.9	4	9	13							
2.9 - 3.0	3	11	14							
3.0 - 3.1	10	3	13	3.0 - 3.5	1.14	3.48	2.10	2.4 * 0.5	2.0 * 0.5	4.4 * 0.7
3.1 - 3.2	3	6	9							
3.2 - 3.3	3	4	7							
3.3 - 3.4	2	4	6							
3.4 - 3.5	4	2	6							
3.5 - 3.6	1	3	4	3.5 - 4.0	1.15	4.01	1.90	1.2 * 0.4	2.1 * 0.5	3.3 * 0.6
3.6 - 3.7	2	3	5							
3.7 - 3.8	4	3	7							
3.8 - 3.9	3	7	10							
3.9 - 4.0	0	1	1							
4.0 - 4.1	3	3	6	4.0 - 4.5	1.34	4.55	1.74	1.1 * 0.4	0.9 * 0.4	2.0 * 0.6
4.1 - 4.2	1	0	1							
4.2 - 4.3	0	0	0							
4.3 - 4.4	2	3	5							
4.4 - 4.5	1	0	1							
4.5 - 4.6	2	2	4	4.5 - 5.0	1.52	5.08	1.60	0.8 * 0.4	1.7 * 0.6	2.5 * 0.7
4.6 - 4.7	0	1	1							
4.7 - 4.8	2	3	5							
4.8 - 4.9	0	2	2							
4.9 - 5.0	0	1	1							
5.0 - 5.1	1	0	1	5.0 - 5.5	1.74	5.62	1.49	0.2 * 0.2	1.2 * 0.5	1.4 * 0.6
5.1 - 5.2	0	0	0							
5.2 - 5.3	0	2	2							
5.3 - 5.4	0	1	1							
5.4 - 5.5	0	2	2							
5.5 - 5.6	0	0	0	5.5 - 6.0	2.01	6.15	1.40	0	0.6 * 0.4	0.6 * 0.4
5.6 - 5.7	0	1	1							
5.7 - 5.8	0	0	0							
5.8 - 5.9	0	1	1							
5.9 - 6.0	0	0	0							
6.0 - 6.1	0	0	0	6.0 - 6.5	2.30	6.69	1.32	0.4 * 0.4	0	0.4 * 0.4
6.1 - 6.2	1	0	1							
6.2 - 6.3	0	0	0							
6.3 - 6.4	0	0	0							
6.4 - 6.5	0	0	0							
6.5 - 6.6	0	1	1	6.5 - 7.0	2.62	7.22	1.25	0.8 * 0.6	0.8 * 0.6	1.6 * 0.8
6.6 - 6.7	0	1	1							
6.7 - 6.8	0	0	0							
6.8 - 6.9	1	0	1							
6.9 - 7.0	1	0	1							
7.0 - 7.1	1	0	1	7.0 - 7.5	2.90	7.76	1.20	1.0 * 0.7	0	1.0 * 0.7
7.1 - 7.2	0	0	0							
7.2 - 7.3	1	0	1							
7.3 - 7.4	1	0	1							
7.4 - 7.5	1	0	1							
7.5 - 7.6	1	0	1							
7.6 - 7.7	1	0	1							
7.7 - 7.8	1	0	1							
							8.29			

TABLE III. Data Obtained by Measuring Forward Proton Recoils in Plate (# 134)
Exposed to Port 5W Neutron Spectrum.

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Neutron energy interval (E_n)	Number of tracks by D.S.	σ_p at E_n (barns)	Number of tracks/ $\sigma_p \times 10^{24}$	Averaged neutron energy interval	Average number of tracks per $0.1 \text{ Mev}/\sigma_p \times 10^{24}$
0.3 - 0.4 Mev	149	7.50	19.9	0.3 - 0.4 Mev	19.9 ± 1.6
0.4 - 0.5	798	6.50	122.8	0.4 - 0.5	122.8 ± 4.3
0.5 - 0.6	549	5.85	93.8	0.5 - 0.6	93.8 ± 4.0
0.6 - 0.7	426	5.37	78.3	0.6 - 0.7	78.3 ± 3.8
0.7 - 0.8	253	5.02	50.4	0.7 - 0.9	57.3 ± 2.4
0.8 - 0.9	269	4.72	57.0		
0.9 - 1.0	196	4.46	43.9	0.9 - 1.1	38.0 ± 2.1
1.0 - 1.1	136	4.25	32.0		
1.1 - 1.2	162	4.05	40.0	1.1 - 1.3	33.5 ± 2.0
1.2 - 1.3	104	3.86	26.9		
1.3 - 1.4	72	3.70	19.5	1.3 - 1.5	26.1 ± 1.9
1.4 - 1.5	116	3.55	32.7		
1.5 - 1.6	69	3.42	20.2	1.5 - 2.0	18.7 ± 1.1
1.6 - 1.7	72	3.3	21.8		
1.7 - 1.8	55	3.18	17.3		
1.8 - 1.9	55	3.07	17.9		
1.9 - 2.0	48	2.99	16.1		
2.0 - 2.1	44	2.89	15.2	2.0 - 2.5	13.1 ± 0.9
2.1 - 2.2	38	2.80	13.6		
2.2 - 2.3	40	2.73	14.7		
2.3 - 2.4	24	2.66	9.0		
2.4 - 2.5	34	2.60	13.0		
2.5 - 2.6	20	2.54	7.9	2.5 - 3.0	8.8 ± 0.8
2.6 - 2.7	27	2.48	10.8		
2.7 - 2.8	28	2.42	11.6		
2.8 - 2.9	19	2.36	8.1		
2.9 - 3.0	14	2.30	6.1		
3.0 - 3.1	22	2.27	9.7	3.0 - 3.5	6.9 ± 0.8
3.1 - 3.2	9	2.23	4.0		
3.2 - 3.3	14	2.18	6.4		
3.3 - 3.4	16	2.14	7.5		
3.4 - 3.5	15	2.10	7.1		
3.5 - 3.6	7	2.06	3.4	3.5 - 4.0	3.6 ± 0.6
3.6 - 3.7	7	2.02	3.5		
3.7 - 3.8	11	1.99	5.5		
3.8 - 3.9	6	1.95	3.1		
3.9 - 4.0	5	1.92	2.6		
4.0 - 4.1	3	1.89	1.6	4.0 - 4.5	3.3 ± 0.6
4.1 - 4.2	7	1.85	3.8		
4.2 - 4.3	8	1.83	4.4		
4.3 - 4.4	7	1.80	3.9		
4.4 - 4.5	5	1.76	2.8		
4.5 - 4.6	6	1.74	3.4	4.5 - 5.0	1.9 ± 0.5
4.6 - 4.7	5	1.71	2.9		
4.7 - 4.8	1	1.68	0.6		
4.8 - 4.9	3	1.66	1.8		
4.9 - 5.0	1	1.63	0.6		
5.0 - 5.1	2	1.61	1.2	5.0 - 5.5	0.9 ± 0.3
5.1 - 5.2	0	1.58	0		
5.2 - 5.3	2	1.56	1.3		
5.3 - 5.4	2	1.54	1.3		
5.4 - 5.5	1	1.52	0.7		
5.5 - 5.6	1	1.50	0.7	5.5 - 6.0	0.8 ± 0.3
5.6 - 5.7	1	1.48	0.7		
5.7 - 5.8	0	1.46	0		
5.8 - 5.9	1	1.45	0.7		
5.9 - 6.0	3	1.44	2.1		
6.0 - 6.1	0	1.42	0	6.0 - 6.5	0.3 ± 0.2
6.1 - 6.2	1	1.40	0.7		
6.2 - 6.3	0	1.38	0		
6.3 - 6.4	1	1.36	0.7		
6.4 - 6.5	0	1.34	0		
6.5 - 6.6	1	1.33	0.8	6.5 - 7.0	0.5 ± 0.3
6.6 - 6.7	0	1.32	0		
6.7 - 6.8	1	1.31	0.8		
6.8 - 6.9	0	1.3	0		
6.9 - 7.0	1	1.29	0.8		

TABLE IV. Nuclear Plate Camera Data (Plate # 137) Obtained from Exposure to Fort SW Neutron Beam.

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Neutron energy interval (E_n)	Number of tracks by P.N.	σ_p at E_n	Number of tracks/ $\sigma_p \times 10^{24}$	Averaged neutron energy interval	Average number of tracks per $0.1 \text{ Mev}/\sigma_p \times 10^{24}$
		(barns)			
2.5 - 2.6 Mev	193	2.57	75.1	2.5 - 3.0 Mev	61.1 $\pm$ 2.2
2.6 - 2.7	116	2.50	46.4		
2.7 - 2.8	183	2.45	74.7		
2.8 - 2.9	119	2.40	49.6		
2.9 - 3.0	140	2.35	59.6		
3.0 - 3.1	137	2.30	59.6	3.0 - 3.5	50.9 $\pm$ 2.1
3.1 - 3.2	83	2.25	36.9		
3.2 - 3.3	117	2.20	53.2		
3.3 - 3.4	107	2.17	49.3		
3.4 - 3.5	119	2.15	55.4		
3.5 - 3.6	79	2.07	38.2	3.5 - 4.0	30.5 $\pm$ 1.7
3.6 - 3.7	56	2.04	27.5		
3.7 - 3.8	58	2.01	28.9		
3.8 - 3.9	54	1.98	27.3		
3.9 - 4.0	60	1.96	30.6		
4.0 - 4.1	56	1.92	29.2	4.0 - 4.5	23.8 $\pm$ 1.6
4.1 - 4.2	61	1.88	32.5		
4.2 - 4.3	37	1.86	19.9		
4.3 - 4.4	38	1.82	20.9		
4.4 - 4.5	29	1.77	16.4		
4.5 - 4.6	29	1.75	16.6	4.5 - 5.0	18.9 $\pm$ 1.5
4.6 - 4.7	38	1.73	22.0		
4.7 - 4.8	29	1.71	17.0		
4.8 - 4.9	29	1.69	17.2		
4.9 - 5.0	36	1.66	21.7		
5.0 - 5.1	18	1.62	11.1	5.0 - 5.5	9.3 $\pm$ 1.1
5.1 - 5.2	15	1.59	9.4		
5.2 - 5.3	16	1.56	10.3		
5.3 - 5.4	12	1.54	7.8		
5.4 - 5.5	12	1.52	7.9		
5.5 - 5.6	18	1.50	12.0	5.5 - 6.0	9.7 $\pm$ 1.1
5.6 - 5.7	8	1.48	5.4		
5.7 - 5.8	16	1.46	11.0		
5.8 - 5.9	18	1.45	12.4		
5.9 - 6.0	11	1.44	7.6		
6.0 - 6.1	12	1.42	8.5	6.0 - 6.5	6.8 $\pm$ 1.0
6.1 - 6.2	11	1.40	7.9		
6.2 - 6.3	12	1.38	8.7		
6.3 - 6.4	3	1.36	2.2		
6.4 - 6.5	9	1.34	6.7		
6.5 - 6.6	9	1.33	6.8	6.5 - 7.0	3.9 $\pm$ 0.8
6.6 - 6.7	5	1.32	3.8		
6.7 - 6.8	4	1.31	3.1		
6.8 - 6.9	2	1.3	1.5		
6.9 - 7.0	6	1.29	3.9		
7.0 - 7.1	5	1.27	3.9	7.0 - 7.5	4.2 $\pm$ 0.9
7.1 - 7.2	6	1.26	4.8		
7.2 - 7.3	5	1.25	4.0		
7.3 - 7.4	3	1.24	4.2		
7.4 - 7.5	4	1.22	4.3		
7.5 - 7.6	2	1.21	1.7	7.5 - 8.0	2.0 $\pm$ 0.6
7.6 - 7.7	3	1.20	1.7		
7.7 - 7.8	2	1.19	1.7		
7.8 - 7.9	2	1.18	1.7		
7.9 - 8.0	4	1.17	3.4		
8.0 - 8.1	4	1.16	3.5	8.0 - 8.5	1.6 $\pm$ 0.5
8.1 - 8.2	1	1.15	0.9		
8.2 - 8.3	2	1.13	1.8		
8.3 - 8.4	2	1.12	1.8		
8.4 - 8.5	0	1.11	0		
8.5 - 8.6	1	1.09	0.9	8.5 - 9.0	1.7 $\pm$ 0.6
8.6 - 8.7	1	1.08	0.9		
8.7 - 8.8	5	1.07	4.7		
8.8 - 8.9	2	1.06	1.9		
8.9 - 9.0	0	1.05	0		
9.0 - 9.1	1	1.04	1.0	9.0 - 9.5	1.4 $\pm$ 0.5
9.1 - 9.2	4	1.03	3.9		
9.2 - 9.3	1	1.02	1.0		
9.3 - 9.4	1	1.01	1.0		
9.4 - 9.5	0	1.00	0		
9.5 - 9.6	0	.99	0	9.5 - 10.0	0.2 $\pm$ 0.2
9.6 - 9.7	1	.98	1.0		
9.7 - 9.8	0	0	0		
9.8 - 9.9	0	0	0		
9.9 - 10.0	0	0	0		

TABLE V. Nuclear Plate Camera Data (Plate # 138) Obtained from Exposure to Fast SN Neutron Beam.

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Neutron energy interval (E_n)	Number of tracks				ϕ_p at E_n	Number of tracks/ $\phi_p \times 10^{24}$ (by D.S., K.A., + J.G.)	Averaged neutron energy interval	Average number of tracks per $0.1 \text{ Mev}/\phi_p \times 10^{24}$ (by D.S., K.A., + J.G.)	Number of tracks by P.N. $A=0.075 \text{ cm}^2$	Average number of tracks per $0.1 \text{ Mev}/\phi_p \times 10^{24}$ (by P.N.)	Combined average number of tracks per $0.1 \text{ Mev}/\phi_p \times 10^{24}$
	$A=0.057 \text{ cm}^2$ by D.S.	$A=0.039 \text{ cm}^2$ by K.A.	$A=0.028 \text{ cm}^2$ by J.G.	Total							
$4.0 - 4.1 \text{ Mev}$	104	158	69	331	1.92 barns	172.4					
$4.1 - 4.2$	152	157	96	405	1.88	215.4					
$4.2 - 4.3$	102	123	55	280	1.86	150.5					
$4.3 - 4.4$	91	103	39	233	1.82	128.0					
$4.4 - 4.5$	142	121	73	336	1.77	189.8	$4.0 - 4.5 \text{ Mev}$	171.2	914	98.3	269.5 ± 5.3
$4.5 - 4.6$	101	96	35	232	1.75	132.6					
$4.6 - 4.7$	134	97	63	294	1.73	169.9					
$4.7 - 4.8$	87	69	49	205	1.71	119.9					
$4.8 - 4.9$	93	75	44	212	1.69	125.4					
$4.9 - 5.0$	69	69	31	169	1.66	101.8	$4.5 - 5.0$	129.9	805	94.2	224.1 ± 5.2
$5.0 - 5.1$	66	52	29	147	1.62	90.7					
$5.1 - 5.2$	75	71	41	187	1.59	117.6					
$5.2 - 5.3$	86	80	38	204	1.56	130.8					
$5.3 - 5.4$	28	12	76	116	1.54	49.4					
$5.4 - 5.5$	61	46	27	134	1.52	68.2	$5.0 - 5.5$	99.5	50.6	64.9	164.4 ± 4.6
$5.5 - 5.6$	51	33	21	105	1.50	70.0					
$5.6 - 5.7$	30	31	25	86	1.48	56.1					
$5.7 - 5.8$	39	23	16	78	1.46	53.4					
$5.8 - 5.9$	31	49	17	97	1.45	66.9					
$5.9 - 6.0$	31	22	14	67	1.44	46.5	$5.5 - 6.0$	59.0	313	42.9	101.9 ± 3.8
$6.0 - 6.1$	31	17	13	61	1.42	43.0					
$6.1 - 6.2$	39	28	13	80	1.40	57.1					
$6.2 - 6.3$	30	26	8	64	1.38	36.4					
$6.3 - 6.4$	25	16	13	54	1.36	39.7					
$6.4 - 6.5$	21	18	16	55	1.34	41.0	$6.0 - 6.5$	43.4	211	30.6	74.0 ± 3.3
$6.5 - 6.6$	27	18	7	52	1.33	39.1					
$6.6 - 6.7$	25	22	5	52	1.32	39.4					
$6.7 - 6.8$	23	25	9	57	1.31	45.5					
$6.8 - 6.9$	21	16	9	46	1.30	35.4					
$6.9 - 7.0$	14	12	11	37	1.29	28.7	$6.5 - 7.0$	37.2	128	19.5	56.7 ± 2.9
$7.0 - 7.1$	15	5	4	24	1.28	18.8					
$7.1 - 7.2$	10	8	2	20	1.26	15.9					
$7.2 - 7.3$	7	6	10	23	1.25	18.4					
$7.3 - 7.4$	9	7	5	21	1.24	16.9					
$7.4 - 7.5$	4	7	3	14	1.22	11.5	$7.0 - 7.5$	16.3	85	13.6	29.9 ± 2.2
$7.5 - 7.6$	9	9	9	27	1.21	22.3					
$7.6 - 7.7$	8	10	7	25	1.20	20.8					
$7.7 - 7.8$	7	9	5	21	1.19	17.6					
$7.8 - 7.9$	6	5	2	13	1.18	11.0					
$7.9 - 8.0$	5	7	2	14	1.17	12.0	$7.5 - 8.0$	16.7	60	10.1	26.8 ± 2.7
$8.0 - 8.1$	10	3	4	17	1.16	14.7					
$8.1 - 8.2$	6	4	2	12	1.15	10.4					
$8.2 - 8.3$	6	4	2	12	1.13	10.6					
$8.3 - 8.4$	4	2	1	7	1.12	6.3					
$8.4 - 8.5$	7	6	0	13	1.11	11.7	$8.0 - 8.5$	10.7	32	5.7	16.4 ± 1.7
$8.5 - 8.6$	4	0	2	6	1.09	5.5					
$8.6 - 8.7$	4	0	3	11	1.08	10.2					
$8.7 - 8.8$	5	0	3	8	1.07	7.5					
$8.8 - 8.9$	3	1	2	7	1.06	6.6					
$8.9 - 9.0$	2	0	1	3	1.05	2.9	$8.5 - 9.0$	6.5	29	5.4	11.9 ± 1.5
$9.0 - 9.1$	1	1	1	3	1.04	2.9					
$9.1 - 9.2$	0	6	2	8	1.03	7.8					
$9.2 - 9.3$	2	2	1	5	1.02	4.9					
$9.3 - 9.4$	1	1	0	2	1.01	1.0					
$9.4 - 9.5$	1	1	0	2	1.00	2.0	$9.0 - 9.5$	3.7	13	2.5	6.2 ± 1.1
$9.5 - 9.6$	6	2	0	8	0.99	8.1					
$9.6 - 9.7$	1	2	0	3	0.98	3.1					
$9.7 - 9.8$	0	0	0	0	0.97	0					
$9.8 - 9.9$	0	1	1	2	0.96	2.1					
$9.9 - 10.0$	0	1	2	3	0.96	3.1	$9.5 - 10.0$	3.3	6	1.2	4.5 ± 1.0
$10.0 - 10.1$	2	2	0	4	0.95	4.2					
$10.1 - 10.2$	1	0	0	1	0.94	1.1					
$10.2 - 10.3$	0	1	2	3	0.93	3.2					
$10.3 - 10.4$	0	0	0	0	0.92	0					
$10.4 - 10.5$	1	0	0	1	0.92	1.1	$10.0 - 10.5$	1.9	5	0.8	2.7 ± 0.7
$10.5 - 10.6$	0	0	1	1	0.91	1.1					
$10.6 - 10.7$	0	0	1	1	0.90	0					
$10.7 - 10.8$	1	0	1	2	0.89	2.2					
$10.8 - 10.9$	0	0	0	0	0.88	0					
$10.9 - 11.0$	1	2	1	4	0.87	4.6	$10.5 - 11.0$	1.6	2	0.4	2.0 ± 0.7
$11.0 - 11.1$	0	0	0	0	0	0					
$11.1 - 11.2$	0	0	0	0	0	0					
$11.2 - 11.3$	0	0	0	0	0	0					
$11.3 - 11.4$	0	0	0	0	0	0					
$11.4 - 11.5$	1	0	0	1	0.85	1.1	$11.0 - 11.5$	0.2	0	0	0.2 ± 0.2
$11.5 - 11.6$	0	0	0	0	0	0					
$11.6 - 11.7$	0	0	0	0	0	0					
$11.7 - 11.8$	0	0	0	0	0	0					
$11.8 - 11.9$	0	0	0	0	0	0					
$11.9 - 12.0$	1	0	1	2	0.82	2.4	$11.5 - 12.0$	0.5	1	0.2	0.7 ± 0.4

TABLE VI. Nuclear Plate Camera Data (Plate #141) Obtained from Exposure to Port 5W Neutron Beam.

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Neutron energy interval (E_n)	Number of tracks			σ_p at E_n	Total # of tracks/ $\sigma_p \times 10^{24}$	Averaged neutron energy interval	Average number of tracks per $0.1 \text{ Mev}/\sigma_p \times 10^{24}$
	$A = 0.55 \text{ cm}^2$ by D.S.	$A = 1.00 \text{ cm}^2$ by J.C.	$A = 1.55 \text{ cm}^2$ Total				
7.5 - 7.6 Mev	137	218	355	1.21 barns	293.4		
7.6 - 7.7	202	237	439	1.20	365.8		
7.7 - 7.8	173	192	365	1.19	306.7		
7.8 - 7.9	108	192	300	1.18	254.2		
7.9 - 8.0	158	190	348	1.17	297.4	7.5 - 8.0 Mev	303.5 ± 7.3
8.0 - 8.1	101	193	294	1.16	253.4		
8.1 - 8.2	101	172	273	1.15	237.4		
8.2 - 8.3	96	113	209	1.13	185.0		
8.3 - 8.4	84	137	221	1.12	197.3		
8.4 - 8.5	95	149	244	1.11	219.8	8.0 - 8.5	218.6 ± 6.1
8.5 - 8.6	72	100	172	1.09	157.8		
8.6 - 8.7	64	89	153	1.08	141.7		
8.7 - 8.8	67	95	162	1.07	151.4		
8.8 - 8.9	59	77	136	1.06	128.3		
8.9 - 9.0	39	68	107	1.05	101.9	8.5 - 9.0	136.2 ± 5.0
9.0 - 9.1	42	79	121	1.04	116.4		
9.1 - 9.2	53	62	115	1.03	111.7		
9.2 - 9.3	48	62	110	1.02	107.8		
9.3 - 9.4	42	69	111	1.01	109.9		
9.4 - 9.5	38	59	97	1.00	97.0	9.0 - 9.5	108.6 ± 4.6
9.5 - 9.6	38	44	82	0.99	82.8		
9.6 - 9.7	27	74	74	0.98	75.4		
9.7 - 9.8	20	43	63	0.97	64.9		
9.8 - 9.9	32	42	74	0.96	77.1		
9.9 - 10.0	21	43	64	0.96	66.6	9.5 - 10.0	73.4 ± 3.9
10.0 - 10.1	25	46	71	0.95	74.7		
10.1 - 10.2	10	32	42	0.94	44.6		
10.2 - 10.3	17	12	29	0.93	31.2		
10.3 - 10.4	14	25	39	0.92	42.4		
10.4 - 10.5	17	22	39	0.92	42.4	10.0 - 10.5	47.1 ± 3.2
10.5 - 10.6	17	23	40	0.91	44.0		
10.6 - 10.7	24	18	42	0.89	47.2		
10.7 - 10.8	9	14	23	0.88	26.1		
10.8 - 10.9	10	19	29	0.88	33.3		
10.9 - 11.0	11	19	30	0.87	34.4	10.5 - 11.0	37.0 ± 2.9
11.0 - 11.1	13	11	24	0.87	27.6		
11.1 - 11.2	7	11	18	0.86	20.9		
11.2 - 11.3	11	10	21	0.85	24.7		
11.3 - 11.4	4	8	12	0.85	14.1		
11.4 - 11.5	8	7	15	0.84	17.8	11.0 - 11.5	19.1 ± 2.0
11.5 - 11.6	3	6	9	0.84	10.7		
11.6 - 11.7	8	8	16	0.83	19.2		
11.7 - 11.8	4	6	10	0.82	12.2		
11.8 - 11.9	4	6	10	0.82	12.2		
11.9 - 12.0	2	5	7	0.81	8.7	11.5 - 12.0	12.6 ± 1.7
12.0 - 12.1	1	15	16	0.80	20.0		
12.1 - 12.2	5	16	21	0.79	26.6		
12.2 - 12.3	6	4	10	0.78	12.8		
12.3 - 12.4	4	2	6	0.78	7.5		
12.4 - 12.5	4	3	7	0.77	9.1	12.0 - 12.5	15.2 ± 1.9
12.5 - 12.6	3	8	11	0.77	14.3		
12.6 - 12.7	3	2	5	0.76	6.5		
12.7 - 12.8	2	2	4	0.76	5.2		
12.8 - 12.9	0	4	4	0.75	5.3		
12.9 - 13.0	1	2	3	0.75	4.0	12.5 - 13.0	7.1 ± 1.4
13.0 - 13.1	4	3	7	0.74	9.5		
13.1 - 13.2	1	1	2	0.74	2.8		
13.2 - 13.3	2	3	5	0.73	6.8		
13.3 - 13.4	0	2	2	0.73	2.7		
13.4 - 13.5	2	3	5	0.72	7.0	13.0 - 13.5	5.8 ± 1.3
13.5 - 13.6	1	1	2	0.72	2.8		
13.6 - 13.7	0	2	2	0.71	2.8		
13.7 - 13.8	0	0	0	0.71	0		
13.8 - 13.9	1	0	1	0.70	1.4		
13.9 - 14.0	0	2	2	0.70	2.9	13.5 - 14.0	2.0 ± 0.5

TABLE VII. Nuclear Plate Camera Data (Plates #152 and #152d) Obtained from Exposure to Port 5W Neutron Beam.

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Neutron energy interval (E_n)	Number of tracks			σ_p at E_n	Total number of tracks $\sigma_p \times 10^4$	Averaged neutron energy interval	Average number of tracks per $0.1 \text{ Mev}/\sigma_p \times 10^4$
	$A = 3.34 \text{ cm}^2$ S153d	$A = 1.98 \text{ cm}^2$ S153 + S153	$A = 5.32 \text{ cm}^2$ Total				
11.3 - 11.4 Mev	188	246	434	0.85 barns	511.8	11.3 - 11.5 Mev	479.7 ± 16.7
11.4 - 11.5	193	183	376	0.84	447.6		
11.5 - 11.6	118	115	233	0.84	277.4		
11.6 - 11.7	124	111	235	0.83	283.1		
11.7 - 11.8	134	137	271	0.82	330.5		
11.8 - 11.9	102	81	183	0.82	223.2	11.5 - 12.0	256.3 ± 7.7
11.9 - 12.0	87	93	180	0.81	222.2		
12.0 - 12.1	74	88	162	0.80	202.5		
12.1 - 12.2	61	64	125	0.79	158.2		
12.2 - 12.3	50	71	121	0.78	155.1		
12.3 - 12.4	52	60	112	0.78	143.6	12.0 - 12.5	156.6 ± 6.3
12.4 - 12.5	47	48	95	0.77	123.4		
12.5 - 12.6	54	51	105	0.77	136.4		
12.6 - 12.7	43	59	102	0.76	134.2		
12.7 - 12.8	50	41	91	0.76	119.7		
12.8 - 12.9	45	46	91	0.75	121.3	12.5 - 13.0	125.5 ± 5.8
12.9 - 13.0	48	39	87	0.75	116.0		
13.0 - 13.1	28	33	61	0.74	82.4		
13.1 - 13.2	32	28	60	0.74	81.1		
13.2 - 13.3	32	29	61	0.73	83.6		
13.3 - 13.4	27	38	65	0.73	89.0	13.0 - 13.5	76.7 ± 4.6
13.4 - 13.5	20	14	34	0.72	47.2		
13.5 - 13.6	21	15	36	0.72	50.0		
13.6 - 13.7	25	21	46	0.71	64.8		
13.7 - 13.8	17	18	35	0.71	49.3		
13.8 - 13.9	16	16	32	0.70	45.7	13.5 - 14.0	48.2 ± 3.7
13.9 - 14.0	11	11	32	0.70	31.4		
14.0 - 14.1	9	10	19	0.69	27.5		
14.1 - 14.2	8	10	18	0.69	26.1		
14.2 - 14.3	10	9	19	0.68	27.9		
14.3 - 14.4	10	10	20	0.68	29.4	14.0 - 14.5	29.7 ± 3.0
14.4 - 14.5	11	11	22	0.67	32.8		
14.5 - 14.6	11	6	17	0.67	25.3		
14.6 - 14.7	8	10	18	0.67	26.9		
14.7 - 14.8	12	6	18	0.66	27.3		
14.8 - 14.9	4	6	10	0.66	15.2	14.5 - 15.0	21.7 ± 2.6
14.9 - 15.0	4	5	9	0.66	13.6		
15.0 - 15.1	4	4	8	0.65	12.3		
15.1 - 15.2	3	2	5	0.65	7.8		
15.2 - 15.3	3	5	8	0.65	12.3		
15.3 - 15.4	3	5	8	0.64	12.5	15.0 - 15.5	10.5 ± 1.8
15.4 - 15.5	3	2	5	0.64	7.8		
15.5 - 15.6	5	1	6	0.64	9.4		
15.6 - 15.7	1	3	4	0.63	6.3		
15.7 - 15.8	3	1	4	0.63	6.3		
15.8 - 15.9	4	3	7	0.63	11.1	15.5 - 16.0	8.9 ± 1.7
15.9 - 16.0	3	4	7	0.62	11.3		
16.0 - 16.1	2	2	4	0.62	6.5		
16.1 - 16.2	3	2	5	0.62	8.1		
16.2 - 16.3	2	2	4	0.61	6.6		
16.3 - 16.4	1	1	2	0.61	3.3	16.0 - 16.5	5.6 ± 1.3
16.4 - 16.5	1	1	2	0.61	3.3		
16.5 - 16.6	1	2	3	0.60	5.0		
16.6 - 16.7	1	1	2	0.60	3.3		
16.7 - 16.8	3	2	5	0.59	8.5		
16.8 - 16.9	3	2	5	0.59	8.5	16.5 - 17.0	5.4 ± 1.4
16.9 - 17.0	1	0	1	0.59	1.7		
17.0 - 17.1	2	1	3	0.58	5.2		
17.1 - 17.2	1	0	1	0.58	1.7		
17.2 - 17.3	2	0	2	0.57	3.5		
17.3 - 17.4	1	1	2	0.57	3.5	17.0 - 17.5	3.5 ± 1.1
17.4 - 17.5	1	1	2	0.56	3.6		
17.5 - 17.6	0	0	0	0.56	0		
17.6 - 17.7	0	0	0	0.56	0		
17.7 - 17.8	0	0	0	0.55	0		
17.8 - 17.9	0	1	1	0.55	1.8	17.5 - 18.0	0.7 ± 0.5
17.9 - 18.0	0	1	1	0.55	1.8		
18.0 - 18.1	0	0	0	0.54	0		
18.1 - 18.2	0	0	0	0.54	0		
18.2 - 18.3	2	1	3	0.54	5.6		
18.3 - 18.4	1	1	2	0.53	3.7	18.0 - 18.5	2.6 ± 1.0
18.4 - 18.5	2	0	2	0.53	3.7		

TABLE VIII. Nuclear Plate Camera Data (Plates #153 and #153d) Obtained from Exposure to Port 5W Neutron Beam.