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NEUTRON SPECTRAL MEASUREMENTS BY MAGNETIC ANALYSIS OF RECOIL PROTONS

by

C. M. Cialella
J. M. Connor
C. W. Hoffman

May 1967

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BALLISTIC RESEARCH LABORATORIES

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ANALYSIS OF RECOIL PROTONS

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Terminal Ballistics Laboratory

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1841

CMCialella/JMConnor/CWHoffman/ilm
Aberdeen Proving Ground, Md.
May 1967

NEUTRON SPECTRAL MEASUREMENTS BY MAGNETIC
ANALYSIS OF RECOIL PROTONS

ABSTRACT

The spectral distribution of neutrons from the TRIGA Mark F Reactor at the U.S. Army Harry Diamond Laboratories was measured with a magnetic neutron spectrometer. This instrument is a broad range, low deflection spectrometer which utilizes the magnetic analysis of protons recoiling from a thin polyethylene radiator. The spectrometer will cover an energy range from 0.5 to 17 MeV with a single magnetic field setting. The spectrometer has an array of 40 solid-state detectors placed along the focal line and includes the associated electronics. This provides the instrument with the capability of measuring the entire spectrum from either pulsed or steady state sources.

Measurements of the neutron spectrum with the reactor in the steady state mode were made using four radiators of different thicknesses. Measurements were made of the power output of the reactor in the pulse mode. The width of the reactor pulse was measured to be 11.0 ms (full width at half maximum).

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INTRODUCTION

The effects of neutrons on materials and the shielding effectiveness of neutron shields are both dependent on the energy of the incident neutrons. When a reactor is used as a source of neutrons in studies to determine these effects, it is essential that the spectral distribution of neutrons be known in order to properly interpret results. It is also important that the reactor spectrum be measured under the same conditions that the experiment was performed.

This report presents the results of measurements of the neutron spectrum of the Harry Diamond Laboratories' (HDL) TRIGA Mark F Reactor as determined with a magnetic neutron spectrometer. A detailed description of the reactor and facility may be found in References 1 and 2.* The design and calibration of the magnetic neutron spectrometer prototype is described in References 3 and 4. The instrument is a broad range, small-angle, deflection spectrometer which utilizes the magnetic analysis of protons recoiling from a thin homogeneous radiator to determine the incident neutron spectrum. The instrument will cover an energy range of 0.5 to 17 MeV with a single magnetic field setting.

DESCRIPTION OF THE SPECTROMETER

Figure 1. Schematic diagram of the magnetic spectrometer

*
References may be found on page 36.₉

Figure 1 is a schematic diagram of the spectrometer. A collimated beam of neutrons is incident on a thin polyethylene foil which, through neutron collisions with hydrogen atoms, emits recoil protons. The energy of the recoiling proton is related to the energy of the incident neutron by the relation

$$E_p = E_n \cos^2 \theta ,$$

where θ is the angle of the recoil proton path with respect to the direction of the incident neutron. From this relation it is seen that a proton recoiling in the same direction as the incident neutron ($\theta = 0$) has received the full energy of the neutron. A small forward cone of protons is allowed to enter a uniform magnetic field. The protons are deflected in circular paths whose radii of curvature are proportional to the momenta of the protons. They then emerge from the magnetic field in fans of energy bands which focus at some distance from the pole pieces. The focal line is straight and makes an angle of 10° with the pole-piece edge.

The magnet design was based on the attainment of a 10 kilogauss (kG), homogeneous magnetic field across a 3.81-cm gap. To attain a low magnet-assembly weight, the spectrometer was designed around a uniquely shaped pole piece. This is a rectangular parallelepiped with a deflection angle of 105° , as noted in Figure 1. Its dimensions are 10 by 50 cm, and it will focus beams out to a 60-cm radius of curvature. This extends the energy range (at 10 kG) for protons out to 17.2 MeV. The magnet has a C-frame core and housing and a set of low impedance tape-wound copper coils. The uniformity of the magnetic field over the entire pole-piece surface is approximately 1 part in 1000 at 10,000 gauss (G). The maximum field attainable is 14,000 G. Figure 2 is a photograph of the magnet assembly.

Figure 2. A photograph of the magnet assembly

Figure 3. A sketch of the prototype spectrometer

The original prototype spectrometer had three vacuum sections as shown in Figure 3. The first section contained the radiator and slit assemblies. The radiator holder was moved by means of a rotary seal without breaking the vacuum and had space for mounting four radiators. The variable slits could be opened externally to 1.9 cm. The central chamber contained the pole pieces which actually made up part of the chamber walls in order to utilize the entire 3.81-cm gap width. The detector chamber housed the detector system which was mounted on a scotch-yoke assembly. A single solid-state lithium-diffused junction-type detector was used for the original calibration. The sensitive depth of the detector was 100 μ , and the side dimensions were 4 x 50 mm. The detector was moved along the focal line and perpendicular to it by means of two externally controlled rotary seals. Figure 4 presents the experimentally determined energy resolution as a function of incident neutron energy for three radiator thicknesses. Figure 5 presents the experimentally determined efficiency of the spectrometer as a function of incident neutron energy for the same three radiator thicknesses. The efficiency was also calculated for the 0.002-inch thick radiator and is plotted as the solid line in Figure 5.

To provide the spectrometer with the capability of simultaneously measuring the entire spectrum from either a pulsed or a steady state source, a linear array of 40 solid-state multi-diffused junction detectors was mounted along the focal line. The detectors had a depletion depth of at least 300 μ and were 4 cm long. The widths of the detectors varied so that each had a constant resolution ($\Delta E/E$) of 6 percent. The actual widths ranged from 0.243 to 1.50 cm. There was a fixed spacing of 3.0 mm between the active portions of the detectors. Table I presents the physical widths and energy widths of the 40 detectors, and Figure 6 is a photograph of the detector array.

To house the array of detectors, a new vacuum chamber was fabricated which replaced the original central vacuum chamber and the single detector chamber. This was matched with the original radiator and slit assembly

Figure 4. Energy resolution of the magnetic spectrometer

Figure 5. Neutron efficiency of the magnetic spectrometer

Table I. Dimensions and Energy Widths of the Detector Array

Detector No.	Width (cm)	Midpoint Energy (MeV)	Energy Limits (MeV)	Energy Width (MeV)
1	0.24	0.50	0.48 - 0.52	0.04
2	0.26	0.57	0.55 - 0.59	0.04
3	0.28	0.65	0.63 - 0.67	0.04
4	0.29	0.73	0.71 - 0.75	0.04
5	0.31	0.82	0.79 - 0.84	0.05
6	0.33	0.92	0.90 - 0.95	0.05
7	0.35	1.04	1.01 - 1.07	0.06
8	0.37	1.16	1.13 - 1.20	0.07
9	0.39	1.27	1.23 - 1.31	0.08
10	0.41	1.43	1.38 - 1.47	0.09
11	0.43	1.58	1.53 - 1.63	0.10
12	0.46	1.75	1.70 - 1.80	0.10
13	0.48	1.94	1.88 - 2.00	0.12
14	0.50	2.13	2.07 - 2.20	0.13
15	0.53	2.34	2.27 - 2.41	0.14
16	0.55	2.57	2.49 - 2.65	0.16
17	0.58	2.82	2.73 - 2.90	0.17
18	0.60	3.09	3.00 - 3.18	0.18
19	0.63	3.37	3.27 - 3.47	0.20
20	0.66	3.68	3.57 - 3.79	0.22
21	0.69	4.02	3.90 - 4.14	0.24
22	0.72	4.38	4.25 - 4.51	0.26
23	0.75	4.76	4.62 - 4.90	0.28
24	0.78	5.18	5.03 - 5.34	0.31
25	0.82	5.62	5.45 - 5.79	0.34
26	0.85	6.10	5.91 - 6.28	0.37
27	0.89	6.62	6.42 - 6.82	0.40
28	0.92	7.17	6.95 - 7.38	0.43
29	0.96	7.76	7.53 - 7.99	0.46
30	1.00	8.39	8.14 - 8.64	0.50
31	1.04	9.07	8.80 - 9.34	0.54
32	1.08	9.79	9.49 - 10.08	0.59
33	1.12	10.57	10.25 - 10.88	0.63
34	1.16	11.40	11.06 - 11.74	0.68
35	1.21	12.28	11.91 - 12.65	0.74
36	1.25	13.38	12.98 - 13.78	0.80
37	1.30	14.25	13.82 - 14.68	0.86
38	1.35	15.34	14.88 - 15.80	0.92
39	1.40	16.50	16.00 - 17.00	1.00
40	1.45	17.74	17.21 - 18.27	1.06

Figure 6. A photograph of the detector array

chamber. Figure 7 is a sketch of the present spectrometer. The new chamber was fabricated from a solid piece of aluminum thereby eliminating all vacuum weld-joints. All ports and openings were sealed by "O" rings, and the result was a leak-free vacuum system of much smaller dimensions than the prototype.

Figure 7. A sketch of the present magnetic spectrometer

Figure 8. A photograph of the readout system electronics

A solid-state readout system was incorporated into the spectrometer. This system independently amplifies and shapes the charge deposited in each detector so that it can be recorded by oscilloscopes, scalars, and other standard recording equipment. The readout system consists of 30 identical electronic modules and a 30-channel detector bias supply. Figure 8 is a photograph of the readout system electronics. Each of the 30 modules will accept pulses from a solid state detector in the array. Each of the 30 modules has two distinct modes of operation, a pulse mode (for steady state source), and a current mode (for pulsed source). Figure 9 is a block diagram of one of the modules of the readout system. The 30 modules are identical in design and may be used with any of the multi-diffused junction detectors. A detailed description of the readout system may be found in Reference 5.

Figure 9. Block diagram of one module of the readout system electronics

The following is a brief description of the module operation.

Pulse Mode (Steady State Source)

The pulse mode electronics consist of a charge sensitive preamplifier, linear amplifier, and a variable amplitude pulse discriminator. The charge sensitive preamplifier has a voltage output directly proportional to the charge deposited in the detector by the charged particle. The output is approximately 7 mV for a 1 MeV energy particle. The gain of the preamplifier is fixed, and the emitter follower output drives a variable gain linear amplifier which has an adjustable gain from 6 to 400. The linear amplifier output is connected to an integral discriminator which has a lower level of 0.3 volt and an upper level of 10.0 volts. The output of the discriminator is a 10.0 V positive pulse, 1 μ sec wide. This output is fed into a scaler.

Current Mode (Pulsed Source)

The current mode electronics consist of a direct current operational preamplifier with 10 theoretical integrating time constants of 100, 50, 10, 5, and 1 ms and 20, 10, 5, 2, and 0 μ sec. Actually, the shortest time constant available is approximately 5 μ sec due to internal capacitances in the direct current preamplifier. The short time constants are used during operation in the "power" current mode. This mode will follow the time-rate-of-change of a burst, as from a pulsed reactor, down to approximately a 40- μ sec half width (full width at half maximum). The longer time constants are used to integrate the current produced by an extremely short burst of the order of several microseconds or less. The discriminator is disconnected from the linear amplifier when the spectrometer is operating in either current mode. The output is then fed into an oscilloscope and photographed.

CALIBRATION OF THE SPECTROMETER

Calibration of the Pulse Mode (Steady State Source)

The detector-amplifier combinations were each initially calibrated absolutely by irradiating the detector with monoenergetic Americium-241 alpha particles (5.48 MeV) and establishing the output in volts per MeV at a given gain setting. The energy deposited in a 300- μ thick detector was determined for protons from 0.5 to 17 MeV. From this, the gain setting of each detector-amplifier channel was established. Each discriminator was then calibrated with a mercury pulser. The pulser was energy-calibrated by matching the pulse height produced in the detector with that produced by the Americium 5.48 MeV alpha particles at the same gain. Once the pulser was energy calibrated, each discriminator was then calibrated in MeV per volt and the discriminator settings for each detector channel were fixed.

Calibration of the Current (Power-Integrate) Mode

To simulate the reactor burst, a variable width pulser was used to gate a pulse train from a second pulser. A gate width of 11 ms was used to simulate the expected reactor pulse width. The heights of the pulses in the pulse train were fixed to match the expected proton pulse heights in each detector channel. Then the pulse repetition rates were varied; the gate was single triggered, and the output pulse trace on the oscilloscope was photographed. Figure 10 is a typical series of photographs of output pulses as a function of pulse repetition rates for 5.0 V pulses. Figure 11 is a series of photographs of output pulses as a function of pulse height for a fixed burst width and number of pulses per burst. Figure 12 is a plot of these data in current versus number of pulses per burst. Figure 13 is a plot of these data in current versus pulse height. Thus the current (power) mode was calibrated in terms of total energy deposited at various pulse heights versus number of particles per burst.

The spectrometer was then recalibrated with monoenergetic neutrons provided by the Ballistic Research Laboratories' (BRL) 3-MeV Van de Graaff Positive Ion Accelerator. Figure 14 presents the response of the instrument to 6 MeV neutrons through a 0.002-in. and a 0.004-in. radiator.

Figure 10. Output of the spectrometer in the current mode versus number of pulses per burst for a fixed pulse height and burst width

Figure 11. Output of the spectrometer in the current mode versus pulse height for a fixed burst width and number of pulses per burst

Figure 12. Current versus number of pulses per burst for 5.0-volt pulse in a 11.0 millisecond burst

Figure 13. Current versus pulse height for a fixed burst width and number of pulses per burst

Figure 14. The response of the magnetic spectrometer to monoenergetic neutrons

Calibration points were checked at 2, 4, 4.5, 5, 5.5, 6, and 16.7 MeV incident neutrons. The response of the spectrometer was then calculated over the energy range from 0.5 to 17.0 MeV for radiator thicknesses of 0.0003, 0.001, 0.002, and 0.004 inches. The experimentally determined response functions were used to check the calculations. A 30×30 response matrix was then formulated for each of the 4 radiator thicknesses. The Oak Ridge "FERDO" code was then used to unfold the data.

EXPERIMENTAL PROCEDURE

Figure 15 presents the sectional elevation of the DORF Reactor Facility. Figure 16 is a plan view of the DORF Exposure Room and shows the location of the spectrometer and associated shielding, the collimator, and the reactor. Figures 15 and 16 are both from drawings in Reference 2. Thus the experimental arrangement placed the reactor center 242 cm from its nearest position to the exposure room inside the "dimple." The collimator, a hollow aluminum cylinder 25.4 cm in diameter and 213.4 cm long, was placed between the reactor and the reactor-pool wall. The polyethylene radiator within the spectrometer was located 1 m from the wall of the reactor pool inside the exposure room. Approximately 30.5 cm of lead and 30.5 cm of borated paraffin were placed between the spectrometer and the reactor-pool wall. A square collimating hole approximately 10 cm on each side was provided in the shield. This large area collimating hole was used because of the uncertainty in positioning of the spectrometer. Additional shielding of paraffin and lead was placed adjacent to the detector array. Figure 17 is a photograph of the spectrometer from the rear; the figure also shows the vacuum pump system and the 30 channels of electronics for the detectors.

The initial measurements were made with the reactor in the steady state mode. The background counts on each channel before reactor operation were found to be negligible. The magnetic field was set at 14 kG, and the spectrometer was energy checked at 5.48 MeV with the Americium-241 alpha source. The reactor was then operated at 250 kW, and the gamma ray background was found to be exceedingly high. Additional shielding

Figure 15. Sectional elevation of DORF Reactor

Figure 16. Plan view of DORF Exposure Room

Figure 17. A photograph of the spectrometer assembly
in the exposure room

was added; although the number of counts in each detector with the radiator out of normal position was still very high, we believed the data to be sufficient to give a reasonable spectrum, especially in the central portion of the spectrum. Measurements were made with radiator thicknesses of 0.0003, 0.001, 0.002, and 0.004 inches. At each radiator thickness several alternate measurements of 10 minutes duration were made with the radiator in normal position, then out of position. Because of a lack of sufficient number of scalers, the spectrum for each radiator thickness had to be covered in two exposures. However, detectors 21, 22, and 23 were used in every measurement. The sum of the counts in these three detectors was used to normalize the measurements between high and low energy runs and also to normalize between runs to account for the drift in the reactor output. Table II presents a typical set of data consisting of 10 runs with a radiator thickness of 0.002 in. From these data one can see the low and high energy ends of the spectrum contain the most statistical uncertainties but that the portion of the spectrum from detector 10 to 30 (approximately 1.5 to 8.5 MeV) appears to be fairly consistent. This holds for all the measurements.

Because of the very high gamma radiation background, no attempt was made to measure the neutron spectrum in the reactor burst mode. However, to check the operation of the spectrometer in the current mode and also to measure the pulse width of the reactor, measurements were made with the reactor in the burst mode; each of the 10 time constants available was used.

RESULTS AND DISCUSSION

Table III presents the spectra in neutrons per MeV obtained with three of the radiator thicknesses. The data obtained with the 0.0003-in. thick radiator were too inconsistent and therefore not usable. The average of the three sets of measurements was determined, and the average spectrum is plotted in Figure 18. The error bars indicated in the figure are the spread of the values obtained from the three measurements for each energy interval. Those points having no error bars are results of a single radiator measurements; therefore, no range can be indicated.

Figure 18. Neutron spectrum of the DORF TRIGA Mark F Reactor

It is believed that the resultant spectrum is reliable from approximately 2 to 10 MeV within the limits indicated at each energy point. The data above and below this energy band are extremely uncertain and could not even be determined in some of the runs.

Figures 19a and 19b present the results of the measurements in the reactor burst mode, and Table IV lists the conditions for each measurement. The pulse width of the reactor burst was measured to be 11.0 ms (full width at half maximum). All of the shorter time constants in the power current mode followed the pulse, and each measured the same pulse width. The shortest time constant in the integrate mode (1 ms) also followed the pulse. The next four longer time constants in the integrate mode deviated from the actual pulse width in progressively greater amounts.

Two conditions affecting the output spectrum, under which these measurements were made, should be stated. First, there was approximately 2 to 4 inches of water between the reactor core and the collimator. Second, primarily due to the end plates of the collimator, there was approximately 1 in. of aluminum between the reactor core and the spectrometer radiator in addition to the wall material separating the reactor pool and the exposure room. These conditions will affect primarily the lower end of the energy spectrum.

In retrospect, the greatest single problem encountered in these measurements was in collimation and shielding. In general, the spectrometer and associated equipment operated well. The optimum collimator design should view the entire reactor core and taper down to approximately 1 cm at the opposite end to allow the radiation beam to pass in between the pole pieces and out the thin exit port of the spectrometer with a minimum of collisions. We believe that if this were done, the water in the pool would provide sufficient shielding for both neutrons and gamma rays and that a minimum of shielding would be required immediately surrounding the spectrometer.

1

2

3

4

5

LEGEND:

- 1 - THEORETICAL TIME CONSTANT = 0 MICROSECS
- 2 - THEORETICAL TIME CONSTANT = 2 MICROSECS
- 3 - THEORETICAL TIME CONSTANT = 5 MICROSECS
- 4 - THEORETICAL TIME CONSTANT = 10 MICROSECS
- 5 - THEORETICAL TIME CONSTANT = 20 MICROSECS

Figure 19a. Spectrometer output pulse from a single burst of the DORF Reactor

6

7

8

9

10

LEGEND:

- 6-THEORETICAL TIME CONSTANT = 1 MILLISEC
- 7-THEORETICAL TIME CONSTANT = 5 MILLISECS
- 8-THEORETICAL TIME CONSTANT = 10 MILLISECS
- 9-THEORETICAL TIME CONSTANT = 50 MILLISECS
- 10-THEORETICAL TIME CONSTANT = 100 MILLISECS

Figure 19b. Spectrometer output pulse from a single burst of the DORF Reactor

Table II. Normalized Data for the 0.002-Inch Radiator Measurement

(All counts are for 10 minutes.)

Channel No.	Mid Energy (MeV)	Runs 1 & 4	Runs 2 & 5	Runs 3 & 6	Runs 7 & 10	Runs 8 & 9	Averages		Net Counts
		Radiator In*	Radiator Out**	Radiator In	Radiator Out	Radiator In	Radiator In	Radiator Out	
6	0.925	373886	363541	367794	367906	364824	368830	365720	3110
7	1.04	--	--	--	--	--	--	--	--
8	1.16	239892	235649	239857	238187	237617	239120	236910	2210
9	1.29	476410	468101	474584	471979	471140	474040	470040	4000
10	1.43	120546	113447	118109	115297	118552	119060	114360	4700
11	1.58	118748	115114	119145	116323	118206	118690	115710	2980
12	1.75	44249	40915	44284	41897	44185	44239	41406	2830
13	1.94	50548	47023	50577	46849	50349	50491	46936	3560
14	2.13	39991	36131	40005	36992	39838	39944	36561	3380
15	2.34	32250	29353	32486	29585	32316	32351	29470	2880
16	2.57	--	--	--	--	--	--	--	--
17	2.82	32364	29887	32407	30104	32477	32416	29995	2420
18	3.09	27722	25299	28294	26114	28103	28039	25706	2330
19	3.37	34987	33147	35791	33475	35343	35370	33311	2060
20	3.68	--	--	--	--	--	--	--	--
21	4.02	22833	20746	22213	19869	21772	22146	20296	1850
--	--	22133	20151	21918	19992	22011	--	--	--
22	4.38	17479	15943	17626	16123	17978	17801	16032	1770
--	--	17782	16067	17867	16088	18076	--	--	--
23	4.76	19255	17793	19728	18367	19657	19619	18156	1460
--	--	19652	18267	19783	18407	19641	--	--	--
24	5.18	23812	22713	24053	23085	23972	23946	22899	1050
25	5.62	13899	13079	14127	13223	14113	14046	13151	895
26	6.10	19790	19181	19914	19160	19982	19895	19170	725
27	6.62	41926	40743	41705	41892	42902	42177	41318	860
28	7.17	17640	17368	18196	17723	18083	17973	17595	380
29	7.76	18470	18217	18768	18655	18753	18663	18436	230
30	8.39	26198	25710	26711	26529	27021	26643	26120	520
31	9.07	14481	14581	14464	14841	14989	14645	14711	neg
32	9.79	10893	10876	11119	11267	11310	11107	11072	35
33	10.57	12226	12288	12446	--	--	12336	12288	50
34	11.40	13242	13167	13249	13508	13670	13387	13338	50
35	12.28	12713	12790	12696	13213	13340	12916	13001	neg
36	13.38	20801	21116	21202	21962	21543	21183	21539	neg

* Radiator in position.

** Radiator out of position.

Table III. Neutron Spectra Obtained with Three-Radiator Thicknesses

Channel No.	Mid Energy (MeV)	Neutrons per MeV Radiator Thickness in Inches			Average (Neuts/MeV)
		0.001	0.002	0.004	
6	0.93				
7	1.04				
8	1.16				
9	1.29				
10	1.43				
11	1.58		9.56×10^{10}		9.56×10^{10}
12	1.75	1.69×10^{11}	2.94×10^{11}		2.32×10^{11}
13	1.94	1.46×10^{11}	1.26×10^{11}	7.57×10^{10}	1.16×10^{11}
14	2.13	1.95×10^{11}	1.76×10^{11}	1.50×10^{11}	1.74×10^{11}
15	2.34	1.10×10^{11}	1.69×10^{11}	7.86×10^{10}	1.19×10^{11}
16	2.57	1.60×10^{11}	1.63×10^{11}	1.40×10^{11}	1.54×10^{11}
17	2.82	1.33×10^{11}	1.13×10^{11}	2.54×10^{11}	1.67×10^{11}
18	3.09	1.08×10^{11}	1.09×10^{11}	2.19×10^{11}	1.45×10^{11}
19	3.37	9.11×10^{10}	9.25×10^{10}	1.40×10^{11}	1.08×10^{11}
20	3.68	7.93×10^{10}	8.12×10^{10}	5.16×10^{10}	7.07×10^{10}
21	4.02	8.48×10^{10}	8.62×10^{10}	1.43×10^{11}	9.51×10^{10}
22	4.38	1.22×10^{11}	$3.10 \times 10^{10*}$	8.86×10^{10}	1.05×10^{11}
23	4.76	9.50×10^{10}	1.39×10^{11}	7.92×10^{10}	1.04×10^{11}
24	5.18	1.01×10^{10}	8.53×10^{10}	7.30×10^{10}	8.64×10^{10}
25	5.62	5.56×10^{10}	7.82×10^{10}	5.13×10^{10}	6.17×10^{10}
26	6.10	3.56×10^{10}	4.62×10^{10}	3.76×10^{10}	3.98×10^{10}
27	6.62	2.56×10^{10}	4.14×10^{10}	3.36×10^{10}	3.35×10^{10}
28	7.17	1.96×10^{10}	2.26×10^{10}	2.08×10^{10}	2.10×10^{10}
29	7.76	1.22×10^{10}	1.36×10^{10}	1.32×10^{10}	1.30×10^{10}
30	8.39	6.68×10^9	7.35×10^9	9.23×10^9	7.75×10^9
31	9.07	3.28×10^9	3.95×10^9	2.68×10^9	3.30×10^9
32	9.79	1.66×10^9	2.00×10^9	1.52×10^9	1.73×10^9
33	10.57	5.46×10^8	5.46×10^9	1.67×10^9	1.06×10^9
34	11.40			6.00×10^8	6.00×10^8
35	12.28			9.77×10^7	9.77×10^7
36	13.38			1.80×10^7	1.80×10^7

*This value not averaged.

Table IV. Conditions for Current Integrating Measurements of
a Single Reactor Burst

Run No.	Integrating Time Constant Setting	Theoretical Time Constant	Oscilloscope No.	* Output	Amplifier Gain	Oscilloscope Gain (v/cm)	Oscilloscope Sweep (ms/cm)
1	P-100	0 μ sec	2	J-5	--	2	5
2	P-80	2 μ sec	2	J-11	1/32	1	5
3	P-40	5 μ sec	3	J-11	1/32	1	5
4	P-20	10 μ sec	5	J-11	1/32	1	5
5	P-10	20 μ sec	6	J-11	1/32	1	5
6	I-100	1 ms	1	J-11	1/32	2	5
7	I-80	5 ms	2	J-11	1/32	2	5
8	I-40	10 ms	3	J-11	1/32	2	5
9	I-20	50 ms	5	J-11	1/32	1	5
10	I-10	100 ms	6	J-11	1/32	0.5	5

* J-5 Output - Directly out of the Power-Integrate Preamplifier

J-11 Output - Out of the Linear Amplifier

(See Figure 9.)

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13. ABSTRACT The spectral distribution of neutrons from the TRIGA Mark F Reactor at the U.S. Army Harry Diamond Laboratories was measured with a magnetic neutron spectrometer. This instrument is a broad range, low deflection spectrometer which utilizes the magnetic analysis of protons recoiling from a thin polyethylene radiator. The spectrometer will cover an energy range from 0.5 to 17 MeV with a single magnetic field setting. The spectrometer has an array of 40 solid-state detectors placed along the focal line and includes the associated electronics. This provides the instrument with the capability of measuring the entire spectrum from either pulsed or steady state sources. Measurements of the neutron spectrum with the reactor in the steady state mode were made using four radiators of different thicknesses. Measurements were made of the power output of the reactor in the pulse mode. The width of the reactor pulse was measured to be 11.0 ms (full width at half maximum).			

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