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MEASUREMENTS OF NEUTRON AND GAMMA-RAY SPECTRA FROM IRON AND TUNGSTEN SPHERES BOMBARDED WITH NEUTRONS FROM THE $^2\text{H}(t,n)^4\text{He}$ REACTION

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E. D. Arthur, G. F. Auchampaugh, and D. M. Drake

ABSTRACT

Gamma-ray and neutron spectra produced by pulsed sources of $^2\text{H}(t,n)^4\text{He}$ neutrons in the centers of iron and tungsten spheres have been measured using time-of-flight techniques. Identical experimental arrangements, except for detectors, were used for both neutron and gamma-ray measurements. Results of the measurements are presented in formats that can be compared easily with Monte Carlo calculations.

INTRODUCTION

Neutron and gamma-ray spectra emitted from spheres of iron and tungsten have been measured using the $^2\text{H}(t,n)^4\text{He}$ reaction as a pulsed neutron source in the centers of the spheres. The measured spectra are to be compared with Monte Carlo calculations for both gamma-ray production and neutron transport. The iron sphere was chosen because the cross sections are relatively well known and extensive work on iron neutron spectra has been done at the Lawrence Livermore Laboratory.¹ Interest in the tungsten measurement arises from its use in shielding and weapons. It is expected that the tungsten measurement will also provide a severe test of the Monte Carlo Code, MCN, and of the cross sections used, than will iron.² Except for the detectors, the neutron and gamma-ray measurements were made with identical experimental arrangements including neutron source, spherical samples, and collimators.

EXPERIMENTAL ARRANGEMENT

1. The Neutron Source

The Los Alamos Scientific Laboratory's vertical Van de Graaff accelerator was used to produce a pulsed beam of neutrons from the $^2\text{H}(t,n)^4\text{He}$ reaction. The initial energy of the triton beam was 2 MeV. The beam passed through a 0.079-mg/mm² molybdenum foil, emerged with an energy of about 1.07 MeV, and stopped in the deuterium gas cell. The neutron intensity was measured at 0° using a proton recoil telescope, and agreed to within 3% with an approximate calculation based on the d,t cross section, taking account of the neutron production variation as the triton beam passes through the gas cell. The calculated relative 90° neutron intensity as a function of position in the gas cell is shown in Fig. 1. As the energy of the tritium beam changes in passing through the gas cell, the $^2\text{H}(t,n)^4\text{He}$ cross section changes. The 90° intensity in the laboratory system is very nearly equal to the center of mass intensity which is isotropic for these triton energies.

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MASTER

Fig. 1.

Relative neutron intensity perpendicular to the tritium beam as a function of reaction position in the gas cell.

2. The Sphere Samples

Figure 2 shows the positions of the tungsten and iron spheres relative to the deuterium gas target and gives their dimensions. The iron sphere (2.7 kg) was borrowed from LLL; the major impurities are 0.3 wt% carbon, 1.0 wt% manganese, and 0.3 wt% phosphorus. The tungsten sphere weighed about 6.2 kg, and spectrochemical analysis showed two major impurities, 3.0 wt% nickel and 2.7 wt% copper.

Fig. 2.

Sphere dimensions and positions relative to the deuterium gas cell.

3. The Collimating System

The sphere and gamma-ray detector collimating system is shown in Fig. 3.

4. The Gamma-Ray Spectrometer

The gamma-ray spectrometer consisted of two NaI crystals in an anti-Compton arrangement. The 150-mm-diam by 250-mm-long center crystal fits into a 300-mm-diam by 300-mm-long NaI annulus. The gamma-ray and neutron detectors each subtended a solid angle of 2.13×10^{-4} steradian.

5. The Neutron Detector

The neutron detector, a 125-mm-diam by 25.4-mm-thick liquid scintillator (Pilot Chemical PSD #2) mounted on an RCA 8854 photomultiplier tube, replaced the NaI detector shown in Fig. 3. Pulse shape discrimination was used to reduce the gamma-ray background.

DATA COLLECTION

1. Gamma-Ray Data

Pulses in the gamma-ray spectrometer that were caused by prompt gamma rays were separated from pulses caused by other sources by time-of-flight

Fig. 3.

Collimation arrangement for neutron and gamma-ray detectors. The neutron detector was located in the same position as the NaI crystal.

techniques. Figure 4 shows the time spectrum of the gamma-ray spectrometer. The two large peaks in this spectrum correspond to prompt gamma rays from the sample and neutron interactions in the NaI detector caused by undegraded source neutrons. A computer was used to record pulse height spectra corresponding to different time gates and to subtract the time-independent background spectrum from the prompt gamma-ray spectrum. Runs were made with and without the spheres in place. The spheres tend to shield sources of gamma rays that are directly behind them, and some adjustment of the bare source background is necessary. To estimate the magnitude of this effect, the background (without sphere) for the tungsten run was normalized to the foreground (with sphere) tungsten run at high gamma-ray energies at which only a few sample-associated gamma rays are expected. This correction reduced the background for tungsten by 50%. For lower energy gamma rays, the tungsten sphere is more efficient as a shield. The background was therefore reduced linearly to 25% of its value at the lowest gamma-ray energy recorded. Similarly, the background for the iron run was reduced by 33%. Because the background is only about 10% of the iron foreground, only a small uncertainty is introduced into the iron data by this procedure. The

Fig. 4.

Time-of-flight spectrum for the gamma-ray spectrometer. The time-independent background is at least a factor of 100 lower than the prompt gamma rays.

ratio of background to foreground for the tungsten data varies with gamma-ray energy but is about 0.16 near 2 MeV. The uncertainty introduced into the tungsten data at this energy should be no more than 5%. Figures 5, 6, and 7 show gamma-ray pulse height spectra for the bare source, iron sphere, and tungsten sphere, respectively.

Fig. 5.

Pulse height spectrum for prompt gamma rays from the bare neutron source. This spectrum and those in Figs. 6 and 7 are normalized to the same number of neutrons produced in the target.

Fig. 6.

Pulse height spectrum for prompt gamma rays with the iron sphere surrounding the neutron source.

Fig. 7.

Pulse height spectrum for prompt gamma rays with the tungsten sphere surrounding the neutron source.

2. Neutron Data

The time-of-flight technique was used to measure the energy distribution of the neutrons transported through the metal spheres. The flight path was 4.98 m and the channel width in the EG&G TDC-100 clock was 1/2 ns. The time spectrum was routed into different halves of the memory, depending upon whether the event was a gamma ray or a neutron.

DATA ANALYSIS

1. Gamma-Ray Data

After appropriate backgrounds are subtracted, the gamma-ray pulse height spectra are unfolded by a computer code, using response functions obtained from monoenergetic gamma rays, corrected for efficiency. The number of gamma rays per 100-keV energy interval is computed. The gamma-ray spectrometer's efficiency for a 1.33-m source-to-detector distance had been measured previously. A 100- μ Ci ^{22}Na source was used to obtain a scale factor for the efficiency at 4.98 m. The efficiency curve shape was

assumed to be the same as that at 1.33 m. Corrections for electronic dead time were about 9% for the iron sphere and 6% for the tungsten sphere. The collimating arrangement shields part of the spheres from the full solid angle subtended by the crystal, and a correction for this less than 2% effect has been applied to the data.

The response functions for the gamma-ray spectrometer consist of a full-energy peak and a relatively insignificant flat tail for the range of gamma-ray energies analyzed. The unfolded spectra, therefore, have almost the same shape as the pulse height spectra.

2. Neutron Data

The neutron data results are presented as counts per nanosecond for the sphere-in spectrum divided by the sum of the number of counts from 84.3 to 134.8 ns (the time interval in which source neutrons arrive at the detector) of the sphere-out spectrum.

Because a neutron can scatter within the sphere several times, its energy is not strictly correlated with the time of flight. For spheres used in this experiment, the effect is small, but the Monte Carlo code accounts for the extra time a neutron spends in the sphere and makes the proper correction. Therefore, the data reported here were not corrected for neutron detector efficiency.

The neutron detector efficiency was measured using monoenergetic neutrons generated by the $^3\text{H}(p,n)^3\text{He}$ (2.3- to 8.8-MeV neutrons) and $^2\text{H}(t,n)^4\text{He}$ (15.8-MeV neutrons) reactions. The number of neutrons per steradian produced at 0° was calculated for the $^3\text{H}(p,n)^3\text{He}$ reaction using known cross sections, charge collection, and target thickness. The neutron yield at 0° for the $^2\text{H}(t,n)^4\text{He}$ reaction was measured with a proton recoil telescope.

The neutron efficiency as shown in Table I, at the end of this report, was obtained by passing a smooth curve through the experimental points and reading off values at 0.5-MeV intervals.

RESULTS

The gamma-ray results are listed in Table II. The neutron results are presented as graphs in Figs. 8-10, and as tabulated data in Table III.

In Table II, the numbers in columns 2, 3, 5, and 6 represent the number of gamma rays per steradian emitted at 0° in 100-keV intervals divided by the total number of neutrons per steradian emitted at 0° from the neutron source. The first column lists the center of

Fig. 8.

Neutron time-of-flight spectrum from the bare neutron source.

Fig. 10.

Neutron time-of-flight spectrum with the neutron source surrounded by iron.

Fig. 9.

Neutron time-of-flight spectrum with the neutron source surrounded by tungsten.

each 100-keV interval. A scale factor of 10^4 is included as indicated in the column headings. In Table III, the first column lists the energy of a neutron corresponding to the time of flight given in column 2. Column 3 lists the number of neutron counts per 0.5 ns for a bare source. Columns 4 and 5 represent the number of neutron counts per ns, divided by the number of neutron counts in the undegraded bare source peak for the iron and tungsten spheres, respectively.

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2. E. C. Cashwell, J. R. Neergaard, W. M. Taylor, and G. D. Turner, "MCN: A Neutron Monte Carlo Code," Los Alamos Scientific Laboratory report LA-4751 (Jan. 1972).

TABLE I**INTRINSIC EFFICIENCY OF NEUTRON
DETECTOR FOR 2.0- to 16.0- MeV
NEUTRONS**

Neutron Energy (MeV)	Efficiency (%)
2.0	0.045
2.5	0.100
3.0	0.118
3.5	0.124
4.0	0.120
4.5	0.115
5.0	0.110
5.5	0.103
6.0	0.096
6.5	0.092
7.0	0.086
7.5	0.082
8.0	0.077
8.5	0.072
9.0	0.068
9.5	0.064
10.0	0.060
10.5	0.057
11.0	0.054
11.5	0.052
12.0	0.049
12.5	0.047
13.0	0.044
13.5	0.043
14.0	0.041
14.5	0.039
15.0	0.038
15.5	0.037
16.0	0.036

TABLE II

GAMMA-RAY YIELDS FROM THE
IRON AND TUNGSTEN SPHERES

Center of Gamma-Ray Energy Interval (MeV)	Gamma Rays from the Iron Sphere ($\times 10^4$)	Gamma Rays from the Tungsten Sphere ($\times 10^4$)	Center of Gamma-Ray Energy Interval (MeV)	Gamma Rays from the Iron Sphere ($\times 10^4$)	Gamma Rays from the Tungsten Sphere ($\times 10^4$)
0.45	320	77	4.05	17	6.3
0.55	260	83	4.15	16	5.7
0.65	190	73	4.25	16	5.1
0.75	270	78	4.35	16	4.2
0.85	420	75	4.45	16	3.9
0.95	190	74	4.55	15	3.3
			4.65	15	3.3
1.05	120	74	4.75	15	2.5
1.15	150	76	4.85	15	2.5
1.25	220	68	4.95	15	2.0
1.35	140	60			
1.45	70	55	5.05	14	1.8
1.55	50	50	5.15	15	1.6
1.65	43	47	5.25	15	1.3
1.75	66	45	5.35	14	1.3
1.85	61	42	5.45	14	1.2
1.95	51	39	5.55	14	1.0
			5.65	15	0.77
2.05	48	36	5.75	14	1.0
2.15	44	34	5.85	14	0.81
2.25	37	31	5.95	14	0.42
2.35	36	29			
2.45	39	27	6.05	14	0.50
2.55	43	25	6.15	14	0.36
2.65	39	23	6.25	15	0.42
2.75	31	21	6.35	14	0.53
2.85	27	19	6.45	13	0.31
2.95	28	17	6.55	13	0.53
			6.65	14	0.47
3.05	29	16	6.75	13	0.36
3.15	29	14	6.85	12	0.35
3.25	29	13	6.95	12	0.29
3.35	29	12			
3.45	29	11			
3.55	28	10			
3.65	21	9.1			
3.75	24	8.6			
3.85	20	8.0			
3.95	19	7.1			

TABLE II (cont)

Center of Gamma-Ray Energy Interval (MeV)	Gamma Rays from the Iron Sphere ($\times 10^4$)	Gamma Rays from the Tungsten Sphere ($\times 10^4$)
7.05	12	0.25
7.15	12	0.19
7.25	11	0.09
7.35	11	
7.45	11	
7.55	10	
7.65	10	
7.75	10	
7.85	9.3	
7.95	9.1	
8.05	8.7	
8.15	9.3	
8.25	8.8	
8.35	8.5	
8.45	8.6	
8.55	7.6	
8.65	7.7	
8.75	7.6	
8.85	7.0	
8.95	6.6	

TABLE III
NEUTRON SPECTRA VS ENERGY

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
.903	378.8	50	.000026	.000062
.905	378.3	14	.000035	.000088
.908	377.8	15	.000033	.000073
.910	377.3	16	.000066	.000066
.913	376.8	15	.000051	.000077
.915	376.3	8	.000062	.000075
.918	375.8	19	.000020	.000053
.920	375.3	16	.000060	.000091
.922	374.8	17	.000044	.000086
.925	374.3	20	.000018	.000086
.927	373.8	15	.000064	.000104
.930	373.3	14	.000053	.000108
.932	372.8	22	.000046	.000102
.935	372.3	8	.000046	.000130
.937	371.8	19	.000062	.000141
.940	371.3	22	.000048	.000148
.942	370.8	12	.000073	.000150
.945	370.3	21	.000060	.000106
.948	369.8	21	.000053	.000137
.950	369.3	13	.000068	.000117
.953	368.8	18	.000099	.000150
.955	368.3	19	.000088	.000161
.958	367.8	7	.000095	.000183
.960	367.3	23	.000079	.000157
.963	366.8	17	.000079	.000186
.966	366.3	22	.000079	.000199
.968	365.8	20	.000095	.000181
.971	365.3	17	.000097	.000210
.974	364.8	17	.000079	.000245
.976	364.3	18	.000106	.000247
.979	363.8	16	.000095	.000230
.982	363.3	19	.000086	.000239
.985	362.8	13	.000126	.000232
.987	362.3	19	.000139	.000223
.990	361.8	20	.000110	.000183
.993	361.3	17	.000137	.000265
.995	360.8	28	.000095	.000261
.998	360.3	20	.000097	.000305
1.001	359.8	12	.000161	.000318
1.004	359.3	20	.000128	.000351
1.007	358.8	30	.000130	.000305
1.009	358.3	24	.000161	.000347
1.012	357.8	19	.000165	.000411
1.015	357.3	22	.000176	.000345
1.018	356.8	23	.000174	.000336
1.021	356.3	21	.000216	.000371
1.024	355.8	26	.000223	.000387
1.027	355.3	22	.000190	.000415
1.029	354.8	27	.000150	.000369
1.032	354.3	19	.000207	.000422

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
1.035	353.8	18	.000188	.000420
1.038	353.3	15	.000190	.000486
1.041	352.8	28	.000190	.000471
1.044	352.3	26	.000225	.000457
1.047	351.8	22	.000229	.000548
1.050	351.3	21	.000247	.000570
1.053	350.8	26	.000258	.000510
1.056	350.3	21	.000263	.000550
1.059	349.8	27	.000307	.000566
1.062	349.3	29	.000236	.000541
1.065	348.8	32	.000278	.000563
1.068	348.3	30	.000271	.000530
1.071	347.8	29	.000309	.000588
1.075	347.3	30	.000311	.000543
1.078	346.8	26	.000346	.000665
1.081	346.3	36	.000399	.000687
1.084	345.8	27	.000397	.000740
1.087	345.3	36	.000348	.000685
1.090	344.8	48	.000357	.000740
1.093	344.3	43	.000362	.000650
1.096	343.8	46	.000375	.000749
1.100	343.3	50	.000446	.000738
1.103	342.8	56	.000388	.000787
1.106	342.3	49	.000417	.000731
1.109	341.8	75	.000406	.000738
1.113	341.3	68	.000388	.000802
1.116	340.8	76	.000381	.000793
1.119	340.3	64	.000487	.000789
1.123	339.8	61	.000488	.000824
1.126	339.3	55	.000516	.000811
1.129	338.8	51	.000488	.000866
1.133	338.3	57	.000543	.000899
1.136	337.8	57	.000543	.000899
1.139	337.3	33	.000574	.000996
1.143	336.8	40	.000589	.000981
1.146	336.3	39	.000563	.000950
1.150	335.8	36	.000620	.000999
1.153	335.3	26	.000682	.000948
1.156	334.8	44	.000635	.000937
1.160	334.3	38	.000677	.001072
1.163	333.8	41	.000640	.001089
1.167	333.3	36	.000644	.001098
1.170	332.8	52	.000642	.001072
1.174	332.3	40	.000651	.001111
1.177	331.8	36	.000660	.001147
1.181	331.3	48	.000602	.001178
1.184	330.8	39	.000761	.001215
1.188	330.3	36	.000708	.001215
1.192	329.8	35	.000737	.001240
1.195	329.3	33	.000721	.001235

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
1.199	328.8	31	.000671	.001310
1.203	328.3	38	.000750	.001248
1.206	327.8	52	.000693	.001310
1.210	327.3	35	.000755	.001321
1.214	326.8	44	.000733	.001299
1.218	326.3	50	.000774	.001317
1.221	325.8	45	.000796	.001403
1.225	325.3	44	.000799	.001317
1.229	324.8	34	.000821	.001361
1.233	324.3	45	.000748	.001405
1.236	323.8	48	.000843	.001379
1.240	323.3	40	.000843	.001401
1.244	322.8	47	.000869	.001516
1.248	322.3	40	.000927	.001518
1.252	321.8	43	.000865	.001522
1.256	321.3	45	.000946	.001467
1.260	320.8	38	.000839	.001695
1.264	320.3	38	.000836	.001597
1.268	319.8	47	.000940	.001533
1.272	319.3	50	.000863	.001666
1.276	318.8	34	.001030	.001655
1.280	318.3	53	.000849	.001624
1.284	317.8	57	.000854	.001469
1.288	317.3	58	.000966	.001692
1.292	316.8	63	.001070	.001578
1.296	316.3	41	.001063	.001670
1.300	315.8	52	.001059	.001673
1.304	315.3	46	.001110	.001743
1.308	314.8	57	.001041	.001739
1.312	314.3	47	.001026	.001794
1.317	313.8	56	.001070	.001728
1.321	313.3	53	.001114	.001650
1.325	312.8	59	.001147	.001779
1.329	312.3	54	.001134	.001770
1.334	311.8	51	.001180	.001763
1.338	311.3	45	.001154	.001896
1.342	310.8	64	.001094	.001776
1.347	310.3	49	.001317	.001942
1.351	309.8	53	.001185	.001953
1.355	309.3	50	.001297	.001973
1.360	308.8	58	.001284	.001977
1.364	308.3	47	.001233	.001980
1.369	307.8	55	.001249	.001973
1.373	307.3	49	.001169	.001887
1.377	306.8	59	.001280	.001989
1.382	306.3	56	.001269	.002019
1.387	305.8	64	.001269	.001927
1.391	305.3	57	.001408	.001876
1.396	304.8	53	.001357	.002028
1.400	304.3	67	.001317	.001964

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten (Neutrons Detected/nanosec/ Source Neutrons Detected)
1.405	303.8	64	.001368	.001991
1.410	303.3	79	.001401	.002176
1.414	302.8	70	.001390	.002198
1.419	302.3	68	.001392	.002176
1.424	301.8	57	.001397	.002187
1.428	301.3	65	.001277	.002053
1.433	300.8	71	.001335	.002141
1.438	300.3	62	.001390	.002168
1.443	299.8	67	.001319	.002050
1.448	299.3	65	.001352	.002194
1.452	298.8	76	.001500	.002055
1.457	298.3	59	.001536	.002086
1.462	297.8	69	.001514	.002194
1.467	297.3	61	.001622	.002159
1.472	296.8	76	.001606	.002185
1.477	296.3	54	.001633	.002145
1.482	295.8	74	.001496	.002267
1.487	295.3	68	.001575	.002269
1.492	294.8	70	.001648	.002419
1.497	294.3	81	.001617	.002395
1.502	293.8	66	.001569	.002371
1.508	293.3	80	.001540	.002360
1.513	292.8	75	.001465	.002192
1.518	292.3	75	.001589	.002309
1.523	291.8	74	.001569	.002346
1.528	291.3	63	.001712	.002307
1.534	290.8	82	.001511	.002395
1.539	290.3	75	.001639	.002424
1.544	289.8	88	.001686	.002461
1.550	289.3	80	.001717	.002433
1.555	288.8	71	.001714	.002441
1.560	288.3	75	.001774	.002519
1.566	287.8	76	.001840	.002453
1.571	287.3	82	.001902	.002340
1.577	286.8	70	.001814	.002634
1.582	286.3	80	.001705	.002355
1.588	285.8	85	.001798	.002439
1.593	285.3	87	.001681	.002455
1.599	284.8	101	.001666	.002457
1.605	284.3	62	.001992	.002632
1.610	283.8	68	.001970	.002353
1.616	283.3	97	.001818	.002647
1.622	282.8	82	.002023	.002554
1.628	282.3	82	.001869	.002388
1.633	281.8	78	.002083	.002649
1.639	281.3	79	.001955	.002576
1.645	280.8	98	.001970	.002592
1.651	280.3	91	.001937	.002539
1.657	279.8	77	.001984	.002598
1.663	279.3	85	.002014	.002574

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
1.669	278.8	100	.002030	.002369
1.675	278.3	75	.002081	.002623
1.681	277.8	95	.001986	.002324
1.687	277.3	87	.002220	.002625
1.693	276.8	84	.002039	.002459
1.699	276.3	74	.002103	.002521
1.705	275.8	102	.002103	.002358
1.712	275.3	85	.002118	.002550
1.718	274.8	101	.002074	.002503
1.724	274.3	93	.002295	.002680
1.730	273.8	93	.002295	.002680
1.737	273.3	93	.002279	.002528
1.743	272.8	103	.002222	.002574
1.750	272.3	96	.002312	.002640
1.756	271.8	91	.002306	.002654
1.763	271.3	87	.002284	.002656
1.769	270.8	92	.002312	.002603
1.776	270.3	93	.002264	.002590
1.782	269.8	104	.002308	.002614
1.789	269.3	93	.002299	.002570
1.796	268.8	94	.002134	.002576
1.802	268.3	131	.002005	.002523
1.809	267.8	117	.002030	.002455
1.816	267.3	83	.002178	.002532
1.823	266.8	95	.002120	.002676
1.830	266.3	106	.002211	.002625
1.837	265.8	99	.002156	.002631
1.843	265.3	107	.002041	.002609
1.850	264.8	110	.002237	.002673
1.858	264.3	119	.002275	.002603
1.864	263.8	97	.002151	.002565
1.872	263.3	97	.002138	.002519
1.879	262.8	121	.002061	.002492
1.886	262.3	114	.002182	.002534
1.893	261.8	108	.002147	.002475
1.901	261.3	113	.002096	.002506
1.908	260.8	134	.002087	.002530
1.915	260.3	112	.002138	.002620
1.923	259.8	106	.002105	.002678
1.930	259.3	112	.002142	.002651
1.938	258.8	136	.002230	.002530
1.945	258.3	129	.002378	.002490
1.953	257.8	126	.002347	.002583
1.960	257.3	129	.002290	.002488
1.968	256.8	166	.002144	.002534
1.976	256.3	153	.002197	.002433
1.983	255.8	137	.002241	.002589
1.991	255.3	129	.002334	.002669
1.999	254.8	143	.002217	.002523
2.007	254.3	130	.002347	.002528

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
2.015	253.8	121	.002438	.002455
2.023	253.3	105	.002370	.002596
2.031	252.8	105	.002330	.002565
2.039	252.3	120	.002356	.002534
2.047	251.8	102	.002330	.002691
2.055	251.3	122	.002330	.002510
2.064	250.8	117	.002487	.002532
2.072	250.3	129	.002429	.002508
2.080	249.8	125	.002414	.002543
2.088	249.3	122	.002403	.002678
2.097	248.8	120	.002487	.002426
2.105	248.3	118	.002354	.002475
2.114	247.8	137	.002272	.002430
2.123	247.3	126	.002374	.002629
2.131	246.8	131	.002345	.002285
2.140	246.3	136	.002453	.002340
2.148	245.8	141	.002361	.002364
2.157	245.3	137	.002414	.002262
2.166	244.8	111	.002570	.002408
2.175	244.3	154	.002422	.002331
2.184	243.8	121	.002614	.002464
2.193	243.3	147	.002376	.002404
2.202	242.8	128	.002645	.002413
2.211	242.3	123	.002601	.002362
2.220	241.8	130	.002610	.002437
2.230	241.3	115	.002487	.002430
2.239	240.8	130	.002453	.002433
2.248	240.3	116	.002667	.002408
2.258	239.8	134	.002486	.002377
2.267	239.3	132	.002436	.002220
2.277	238.8	140	.002350	.002424
2.286	238.3	115	.002608	.002276
2.296	237.8	131	.002511	.002397
2.306	237.3	124	.002542	.002369
2.316	236.8	128	.002610	.002494
2.325	236.3	113	.002615	.002466
2.335	235.8	118	.002645	.002311
2.345	235.3	123	.002376	.002289
2.355	234.8	110	.002489	.002331
2.365	234.3	106	.002480	.002377
2.376	233.8	97	.002398	.002161
2.386	233.3	116	.002231	.002282
2.396	232.8	117	.002297	.002338
2.406	232.3	126	.002328	.002212
2.417	231.8	113	.002310	.002260
2.427	231.3	123	.002275	.002234
2.438	230.8	121	.002359	.002331
2.449	230.3	106	.002493	.002375
2.459	229.8	112	.002345	.002205
2.470	229.3	121	.002407	.002324

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten (Neutrons Detected/nanosec/ Source Neutrons Detected)
2.481	228.8	125	.002621	.002207
2.492	228.3	118	.002295	.002282
2.503	227.8	115	.002427	.002229
2.514	227.3	109	.002334	.002037
2.525	226.8	107	.002361	.002221
2.536	226.3	124	.002334	.002090
2.547	225.8	123	.002374	.002128
2.559	225.3	124	.002431	.002201
2.570	224.8	119	.002475	.002084
2.582	224.3	115	.002539	.002011
2.593	223.8	103	.002392	.002125
2.605	223.3	110	.002471	.002057
2.617	222.8	128	.002403	.002059
2.629	222.3	125	.002504	.002117
2.641	221.8	129	.002588	.002046
2.653	221.3	128	.002506	.002015
2.665	220.8	130	.002599	.002121
2.677	220.3	121	.002517	.002006
2.689	219.8	139	.002418	.002033
2.701	219.3	127	.002590	.001944
2.714	218.8	123	.002562	.002055
2.726	218.3	128	.002524	.002103
2.739	217.8	130	.002590	.001986
2.752	217.3	131	.002553	.001944
2.764	216.8	119	.002537	.001882
2.777	216.3	110	.002610	.002084
2.790	215.8	122	.002436	.001847
2.803	215.3	120	.002517	.001913
2.816	214.8	156	.002308	.001781
2.829	214.3	129	.002659	.001911
2.843	213.8	153	.002716	.002050
2.856	213.3	131	.002656	.002077
2.870	212.8	158	.002537	.001935
2.883	212.3	130	.002614	.001889
2.897	211.8	124	.002372	.001814
2.911	211.3	106	.002213	.001591
2.925	210.8	105	.002107	.001538
2.939	210.3	133	.002246	.001840
2.953	209.8	133	.002246	.001840
2.967	209.3	158	.002667	.001829
2.981	208.8	156	.002650	.002002
2.996	208.3	152	.002892	.002136
3.010	207.8	130	.002734	.001991
3.025	207.3	134	.002526	.001734
3.039	206.8	124	.002279	.001520
3.054	206.3	128	.001941	.001266
3.069	205.8	115	.001864	.001206
3.084	205.3	112	.001915	.001220
3.099	204.8	123	.001913	.001383
3.115	204.3	131	.002127	.001376

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Hard Source (Neutrons Detected/ 0.5 nanosec)	Hard Source (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
3.130	203.8	132	.002217	.001511
3.145	203.3	142	.002102	.001571
3.161	202.8	142	.002147	.001635
3.177	202.3	143	.002332	.001699
3.193	201.8	157	.002453	.001524
3.209	201.3	166	.002440	.001540
3.225	200.8	166	.002345	.001544
3.241	200.3	181	.002570	.001533
3.257	199.8	178	.002497	.001604
3.274	199.3	158	.002515	.001560
3.290	198.8	157	.002555	.001560
3.307	198.3	120	.002502	.001655
3.324	197.8	139	.002339	.001469
3.341	197.3	135	.002297	.001471
3.358	196.8	121	.002286	.001456
3.375	196.3	134	.002239	.001359
3.392	195.8	126	.002149	.001467
3.410	195.3	120	.002272	.001328
3.427	194.8	146	.002239	.001429
3.445	194.3	148	.002394	.001513
3.463	193.8	147	.002427	.001507
3.481	193.3	117	.002447	.001463
3.499	192.8	146	.002149	.001365
3.518	192.3	130	.002182	.001248
3.536	191.8	146	.002058	.001279
3.555	191.3	143	.002010	.001193
3.573	190.8	117	.002080	.001259
3.592	190.3	137	.002058	.001372
3.611	189.8	152	.002138	.001337
3.631	189.3	169	.002098	.001237
3.650	188.8	159	.002237	.001306
3.669	188.3	161	.002345	.001244
3.689	187.8	180	.002080	.001211
3.709	187.3	134	.002012	.001244
3.729	186.8	140	.002045	.001167
3.749	186.3	114	.002094	.001193
3.769	185.8	130	.002050	.001058
3.790	185.3	106	.002147	.001162
3.811	184.8	129	.001937	.001191
3.831	184.3	128	.002021	.001189
3.852	183.8	134	.002213	.001257
3.874	183.3	105	.002275	.001228
3.895	182.8	136	.002144	.001175
3.916	182.3	128	.002087	.001235
3.938	181.8	108	.002078	.001089
3.960	181.3	110	.002045	.001065
3.982	180.8	114	.001977	.001186
4.004	180.3	121	.001891	.001127
4.027	179.8	108	.002072	.000992
4.049	179.3	116	.001836	.000996

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten (Neutrons Detected/nanosec/ Source Neutrons Detected)
4.072	174.8	126	.001886	.001058
4.095	174.3	101	.001992	.001109
4.119	177.8	113	.001970	.001038
4.142	177.3	92	.001928	.001144
4.166	176.8	119	.002034	.001069
4.189	176.3	127	.002120	.001158
4.213	175.8	135	.001946	.001085
4.238	175.3	132	.001911	.001054
4.262	174.8	119	.001822	.001045
4.287	174.3	90	.001504	.000833
4.311	173.8	77	.001564	.000782
4.337	173.3	96	.001394	.000800
4.362	172.8	85	.001622	.000795
4.387	172.3	117	.001829	.000855
4.413	171.8	129	.002103	.001078
4.439	171.3	153	.002211	.001147
4.465	170.8	167	.002352	.001215
4.492	170.3	131	.002191	.001140
4.518	169.8	109	.001763	.000952
4.545	169.3	74	.001262	.000669
4.572	168.8	75	.000993	.000627
4.600	168.3	72	.001171	.000601
4.628	167.8	81	.001405	.000687
4.655	167.3	123	.001723	.000833
4.684	166.8	145	.002261	.000977
4.712	166.3	165	.002277	.001129
4.741	165.8	174	.002559	.001295
4.770	165.3	156	.002380	.001220
4.799	164.8	156	.002120	.001001
4.828	164.3	142	.002008	.001027
4.858	163.8	127	.001745	.000870
4.888	163.3	123	.001613	.000884
4.918	162.8	146	.001626	.000890
4.949	162.3	122	.001694	.000786
4.980	161.8	118	.001670	.000813
5.011	161.3	141	.001553	.000687
5.042	160.8	138	.001527	.000758
5.074	160.3	124	.001564	.000817
5.106	159.8	116	.001562	.000764
5.139	159.3	143	.001436	.000718
5.171	158.8	121	.001429	.000700
5.204	158.3	114	.001531	.000769
5.238	157.8	132	.001416	.000742
5.271	157.3	124	.001441	.000771
5.305	156.8	114	.001577	.000751
5.339	156.3	117	.001538	.000749
5.374	155.8	113	.001418	.000822
5.409	155.3	142	.001418	.000687
5.444	154.8	114	.001562	.000815
5.480	154.3	127	.001542	.000793

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron Tungsten (Neutrons Detected/nanosec/ Source Neutrons Detected)	
			Iron	Tungsten
5.516	153.8	110	.001494	.000879
5.552	153.3	130	.001489	.000784
5.589	152.8	135	.001429	.000846
5.626	152.3	132	.001370	.000784
5.663	151.8	139	.001330	.000890
5.701	151.3	150	.001328	.000811
5.739	150.8	158	.001341	.000713
5.778	150.3	138	.001352	.000764
5.817	149.8	134	.001330	.000674
5.857	149.3	156	.001306	.000612
5.896	148.8	183	.001215	.000749
5.936	148.3	182	.001215	.000713
5.977	147.8	181	.001270	.000671
6.018	147.3	198	.001284	.000713
6.060	146.8	193	.001158	.000687
6.101	146.3	187	.001198	.000722
6.144	145.8	187	.001198	.000722
6.186	145.3	161	.001297	.000762
6.230	144.8	182	.001100	.000663
6.273	144.3	151	.001167	.000736
6.317	143.8	159	.001116	.000767
6.362	143.3	123	.001253	.000857
6.407	142.8	152	.001149	.000661
6.453	142.3	140	.001196	.000698
6.499	141.8	133	.001173	.000833
6.545	141.3	115	.001187	.000784
6.592	140.8	148	.001127	.000707
6.640	140.3	125	.001167	.000771
6.688	139.8	142	.001156	.000687
6.737	139.3	140	.001132	.000784
6.786	138.8	144	.001143	.000714
6.835	138.3	142	.000937	.000676
6.886	137.8	116	.001171	.000828
6.936	137.3	133	.001048	.000784
6.988	136.8	143	.001098	.000844
7.040	136.3	170	.000988	.000749
7.092	135.8	132	.000999	.000817
7.145	135.3	148	.001101	.000709
7.199	134.8	151	.001171	.000882
7.253	134.3	156	.001145	.000773
7.308	133.8	171	.001178	.000897
7.364	133.3	174	.001160	.000828
7.420	132.8	176	.001200	.000919
7.477	132.3	178	.001112	.000899
7.534	131.8	166	.001229	.000979
7.592	131.3	184	.001136	.000882
7.651	130.8	190	.001187	.000828
7.711	130.3	172	.001116	.000948
7.771	129.8	204	.001169	.000893
7.832	129.3	189	.001143	.000935

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten
7.894	128.8	229	.001264	.000943
7.956	128.3	199	.001116	.000972
8.019	127.8	238	.001193	.001005
8.083	127.3	212	.001198	.001010
8.148	126.8	238	.001215	.000972
8.213	126.3	240	.001105	.000979
8.279	125.8	243	.001127	.001018
8.347	125.3	212	.001087	.001060
8.414	124.8	225	.001326	.001041
8.483	124.3	229	.001218	.000939
8.553	123.8	280	.001134	.001127
8.623	123.3	271	.001149	.001087
8.695	122.8	270	.001193	.001102
8.767	122.3	290	.001182	.001065
8.840	121.8	314	.001260	.001162
8.914	121.3	300	.001169	.001195
8.989	120.8	304	.001246	.001253
9.065	120.3	346	.001255	.001253
9.142	119.8	339	.001321	.001200
9.220	119.3	365	.001286	.001213
9.298	118.8	363	.001277	.001224
9.378	118.3	387	.001231	.001299
9.459	117.8	381	.001359	.001301
9.541	117.3	367	.001434	.001390
9.625	116.8	412	.001381	.001372
9.709	116.3	447	.001427	.001343
9.794	115.8	412	.001458	.001363
9.880	115.3	443	.001527	.001361
9.968	114.8	430	.001480	.001390
10.057	114.3	468	.001498	.001478
10.147	113.8	566	.001522	.001520
10.238	113.3	492	.001419	.001467
10.330	112.8	504	.001611	.001527
10.424	112.3	526	.001511	.001520
10.519	111.8	537	.001637	.001686
10.615	111.3	602	.001686	.001606
10.713	110.8	552	.001608	.001690
10.812	110.3	629	.001776	.001626
10.912	109.8	695	.001668	.001670
11.014	109.3	709	.001761	.001684
11.117	108.8	679	.001880	.001650
11.222	108.3	665	.001928	.001807
11.328	107.8	706	.002094	.001993
11.436	107.3	750	.002107	.001818
11.545	106.8	730	.002065	.001991
11.656	106.3	788	.002343	.002050
11.769	105.8	853	.002396	.002221
11.883	105.3	836	.002518	.002232
11.998	104.8	840	.002489	.002329
12.116	104.3	851	.002546	.002461

TABLE III (cont)

Energy (MeV)	Time (nanosec)	Bare Source (Neutrons Detected/ 0.5 nanosec)	Iron (Neutrons Detected/nanosec/ Source Neutrons Detected)	Tungsten (Neutrons Detected/nanosec/ Source Neutrons Detected)
12.235	103.8	930	.002776	.002422
12.356	103.3	947	.002893	.002640
12.479	102.8	945	.003054	.002667
12.604	102.3	1020	.003210	.002978
12.730	101.8	1098	.003575	.002947
12.859	101.3	1129	.003820	.003124
12.989	100.8	1292	.004031	.003316
13.122	100.3	1351	.004420	.003829
13.256	99.8	1466	.004821	.004238
13.393	99.3	1624	.005243	.004682
13.532	98.8	2061	.005839	.005577
13.673	98.3	2469	.006763	.006562
13.816	97.8	3276	.008003	.008235
13.961	97.3	4553	.010210	.010420
14.109	96.8	6331	.012910	.013730
14.259	96.3	8750	.017470	.017950
14.412	95.8	12609	.023600	.023340
14.567	95.3	17561	.031600	.031520
14.725	94.8	24531	.042020	.041020
14.885	94.3	33196	.054990	.051970
15.048	93.8	43855	.069400	.063980
15.213	93.3	54246	.083020	.075200
15.382	92.8	63775	.094740	.085160
15.553	92.3	70212	.101400	.089620
15.727	91.8	73538	.104500	.091000
15.904	91.3	73495	.103000	.089050
16.084	90.8	71091	.097940	.084240
16.267	90.3	66679	.092180	.077930
16.454	89.8	60850	.083570	.070710
16.643	89.3	53688	.075140	.061710
16.836	88.8	45189	.063880	.051880
17.033	88.3	34906	.050650	.039720
17.232	87.8	24111	.035420	.026810
17.436	87.3	14369	.022340	.016190
17.643	86.8	7444	.011620	.008206
17.854	86.3	2924	.005073	.003268
18.068	85.8	807	.001562	.000855
18.287	85.3	181	.000342	.000203
18.509	84.8	54	.000062	.000015
18.736	84.3	14	.000007	-.000002
18.967	83.8	17	-.000018	-.000004
19.202	83.3	11	-.000011	-.000011
19.442	82.8	11	-.000004	-.000018
19.686	82.3	14	-.000007	-.000009
19.935	81.8	14	-.000007	-.000009
20.189	81.3	14	-.000018	-.000009
20.448	80.8	11	-.000018	-.000011
20.712	80.3	14	-.000013	-.000011
20.981	79.8	9	-.000022	.000004
21.255	79.3	15	-.000000	-.000018
21.535	78.8	13	-.000016	-.000007