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Lawrence Livermore Laboratory

MEASUREMENTS OF THE NEUTRON-INDUCED FISSION CROSS SECTIONS
OF ^{240}Pu AND ^{242}Pu RELATIVE TO ^{235}U

J. W. Behrens
J. C. Browne
G. W. Carlson

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ABSTRACT

Our present work represents a continuation of the fission-cross-section ratio measurements in progress at the Lawrence Livermore Laboratory. We provide preliminary results for the $^{240}\text{Pu}/^{235}\text{U}$ and $^{242}\text{Pu}/^{235}\text{U}$ ratios from 0.02 to 30 MeV and 0.1 to 30 MeV, respectively. Using the threshold-cross-section method, we normalized the ratios to the values 1.368 ± 0.030 and 1.116 ± 0.025 , respectively, from 1.75 to 4.00 MeV.

PRELIMINARY RESULTS

We measured fission cross sections of ^{240}Pu and ^{242}Pu relative to the fission cross section of ^{235}U by using ionization fission chambers at the Lawrence Livermore Laboratory's 100-MeV electron linear accelerator. The time-of-flight technique was used to measure these cross-section ratios as functions of neutron energy over the energy range 0.001 to 30 MeV. Results are presented from 0.02 to 30 MeV for the $^{240}\text{Pu}/^{235}\text{U}$ ratio and from 0.1 to 30 MeV for the $^{242}\text{Pu}/^{235}\text{U}$ ratio. Using the threshold-cross-section method, we normalized the ratios to the values 1.368 ± 0.030 and 1.116 ± 0.025 , respectively, from 1.75 to 4.00 MeV.

To reduce the effect of spontaneous fission backgrounds from the ^{240}Pu and ^{242}Pu samples, we conducted the measurements at the 15.8-m time-of-flight station, instead of the usual 34.3-m station. Various reports¹⁻⁵ provide details of our experimental setup and procedures.

Figures 1 and 2 show and Table 1 lists our preliminary data for the $^{240}\text{Pu}/^{235}\text{U}$ ratio. The line shown in these figures was obtained using files of evaluated fission cross sections from ENDF/B-IV.⁶ Figures 3 and 4 show and Table 2 lists our preliminary data for the $^{242}\text{Pu}/^{235}\text{U}$ ratio. Figure captions and table footnotes discuss experimental errors.

The Cross Section Evaluation Working Group, responsible for the upcoming ENDF/B-V evaluations, requested this brief report. We plan a more complete and formal disclosure of our work.

NOTICE
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Table 1. Fission-cross-section
ratio of ^{240}Pu to ^{235}U .

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
3.0052E+01			
2.7807E+01	2.8896E+01	1.055	3.99
2.5807E+01	2.6779E+01	1.087	3.77
2.4018E+01	2.4888E+01	1.062	3.59
2.2411E+01	2.3193E+01	1.136	3.31
2.0961E+01	2.1667E+01	1.127	3.14
1.9649E+01	2.0289E+01	1.178	2.90
1.8457E+01	1.9039E+01	1.135	2.74
1.7372E+01	1.7902E+01	1.120	2.58
1.6380E+01	1.6865E+01	1.108	2.43
1.5472E+01	1.5916E+01	1.142	2.28
1.4638E+01	1.5046E+01	1.150	2.16
1.3870E+01	1.4248E+01	1.087	2.10
1.3161E+01	1.3508E+01	1.116	2.04
1.2505E+01	1.2827E+01	1.174	1.95
1.1898E+01	1.2196E+01	1.260	1.84
1.1334E+01	1.1610E+01	1.234	1.77
1.0809E+01	1.1067E+01	1.264	1.68
1.0320E+01	1.0560E+01	1.305	1.58
9.8640E+00	1.0089E+01	1.308	1.51
9.4375E+00	9.6472E+00	1.260	1.44
9.0382E+00	9.2346E+00	1.284	1.35
8.6638E+00	8.8480E+00	1.274	1.29
8.3124E+00	8.4854E+00	1.294	1.23
7.9819E+00	8.1446E+00	1.301	1.18
7.6709E+00	7.8241E+00	1.281	1.16
7.3778E+00	7.5222E+00	1.302	1.15
7.1012E+00	7.2375E+00	1.317	1.14
6.8399E+00	6.9687E+00	1.304	1.14
6.5929E+00	6.7147E+00	1.322	1.16
6.3590E+00	6.4743E+00	1.311	1.21
6.1374E+00	6.2467E+00	1.389	1.24
5.9272E+00	6.0309E+00	1.451	1.28
5.7277E+00	5.8262E+00	1.407	1.33
5.5378E+00	5.5381E+00	1.400	1.09
5.0226E+00	5.1861E+00	1.424	1.11
4.7181E+00	4.8668E+00	1.387	1.13
4.4405E+00	4.5761E+00	1.393	1.13
4.1867E+00	4.3108E+00	1.401	1.13
3.9542E+00	4.0680E+00	1.391	1.13
3.7405E+00	3.8451E+00	1.424	1.11
3.5437E+00	3.6401E+00	1.392	1.11
3.3621E+00	3.4511E+00	1.379	1.10
3.1941E+00	3.2765E+00	1.393	1.08
3.0384E+00	3.1148E+00	1.414	1.05
2.8938E+00	2.9648E+00	1.372	1.03
2.7594E+00	2.8254E+00	1.370	1.01
2.6341E+00	2.6956E+00	1.383	0.96
2.5171E+00	2.5746E+00	1.335	0.92
2.4078E+00	2.4616E+00	1.347	0.89
2.3055E+00	2.3558E+00	1.324	0.88
2.2095E+00	2.2567E+00	1.342	0.84
2.1195E+00	2.1638E+00	1.317	0.81
2.0348E+00	2.0765E+00	1.361	0.81
1.9551E+00	1.9944E+00	1.344	0.78
1.8806E+00	1.9170E+00	1.291	0.76
1.8092E+00	1.8441E+00	1.313	0.73

Table 1 (continued)

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
1.7423E+00	1.7753E+00	1.303	0.74
1.6790E+00	1.7102E+00	1.300	0.75
1.6191E+00	1.6487E+00	1.270	0.73
1.5624E+00	1.5904E+00	1.316	0.71
1.5086E+00	1.5352E+00	1.278	0.70
1.4576E+00	1.4828E+00	1.261	0.70
1.4091E+00	1.4330E+00	1.273	0.70
1.3629E+00	1.3857E+00	1.274	0.70
1.3190E+00	1.3407E+00	1.26	0.67
1.2772E+00	1.2979E+00	1.262	0.65
1.2374E+00	1.2571E+00	1.264	0.64
1.1994E+00	1.2181E+00	1.266	0.63
1.1631E+00	1.1810E+00	1.269	0.63
1.1284E+00	1.1456E+00	1.285	0.64
1.0953E+00	1.1117E+00	1.292	0.63
1.0636E+00	1.0793E+00	1.277	0.61
1.0332E+00	1.0483E+00	1.244	0.62
1.0042E+00	1.0186E+00	1.261	0.63
9.7634E-01	9.9012E-01	1.230	0.64
9.4963E-01	9.6285E-01	1.231	0.64
9.2401E-01	9.3669E-01	1.241	0.64
8.9941E-01	9.1158E-01	1.230	0.65
8.7578E-01	8.8747E-01	1.197	0.67
8.5306E-01	8.6431E-01	1.149	0.70
8.3123E-01	8.4204E-01	1.149	0.73
8.1022E-01	8.2062E-01	1.047	0.76
7.8999E-01	8.0001E-01	1.054	0.76
7.7052E-01	7.8016E-01	1.014	0.76
7.5175E-01	7.6105E-01	0.949	0.78
7.3367E-01	7.4263E-01	0.922	0.80
7.1623E-01	7.2487E-01	0.865	0.85
6.9940E-01	7.0774E-01	0.863	0.86
6.8316E-01	6.9121E-01	0.810	0.87
6.6748E-01	6.7525E-01	0.805	0.88
6.5233E-01	6.5984E-01	0.795	0.89
6.3770E-01	6.4495E-01	0.744	0.97
6.2355E-01	6.3056E-01	0.693	1.03
6.0986E-01	6.1665E-01	0.663	1.07
5.9663E-01	6.0319E-01	0.656	1.07
5.8382E-01	5.9017E-01	0.624	1.08
5.7141E-01	5.7756E-01	0.574	1.12
5.5940E-01	5.6536E-01	0.551	1.14
5.4776E-01	5.5354E-01	0.536	1.18
5.3649E-01	5.4208E-01	0.475	1.26
5.2555E-01	5.3098E-01	0.419	1.41
5.1495E-01	5.2021E-01	0.433	1.37
5.0467E-01	5.0977E-01	0.407	1.33
4.9469E-01	4.9964E-01	0.370	1.39
4.8500E-01	4.8981E-01	0.329	1.48
4.7560E-01	4.8027E-01	0.310	1.51
4.6647E-01	4.7100E-01	0.286	1.64
4.5759E-01	4.6200E-01	0.277	1.77
4.4897E-01	4.5325E-01	0.241	1.92
4.4059E-01	4.4475E-01	0.235	2.02
4.2452E-01	4.3245E-01	0.213	2.25
4.0931E-01	4.1661E-01	0.193	2.83
3.9491E-01	4.0202E-01	0.169	1.90
3.8125E-01	3.8799E-01	0.154	2.05
3.6829E-01	3.7463E-01	0.144	2.17
3.5598E-01	3.6206E-01	0.145	2.27

Table 1 (continued)

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
3.4420E-01	3.5006E-01	0.146	2.51
3.3314E-01	3.3064E-01	0.133	2.29
3.2254E-01	3.2770E-01	0.123	2.37
3.1243E-01	3.1743E-01	0.110	2.56
3.0200E-01	3.0756E-01	0.105	2.64
2.9360E-01	2.9814E-01	0.106	2.90
2.8481E-01	2.8915E-01	0.109	3.08
2.7641E-01	2.8057E-01	0.104	3.19
2.6830E-01	2.7235E-01	0.103	3.50
2.6070E-01	2.6450E-01	0.099	3.69
2.5334E-01	2.5698E-01	0.093	3.70
2.4628E-01	2.4977E-01	0.084	3.94
2.3952E-01	2.4287E-01	0.070	4.42
2.3303E-01	2.3624E-01	0.065	4.02
2.2681E-01	2.2989E-01	0.069	4.77
2.2082E-01	2.2370E-01	0.074	4.51
2.1508E-01	2.1762E-01	0.061	4.73
2.0955E-01	2.1259E-01	0.072	4.67
2.0423E-01	2.0687E-01	0.071	4.69
1.9912E-01	2.0165E-01	0.059	5.00
1.9419E-01	1.9663E-01	0.057	4.57
1.8945E-01	1.9180E-01	0.064	4.46
1.8487E-01	1.8714E-01	0.054	4.66
1.8046E-01	1.8265E-01	0.050	4.20
1.7621E-01	1.7832E-01	0.056	6.35
1.7210E-01	1.7414E-01	0.054	6.69
1.6814E-01	1.7010E-01	0.060	6.61
1.6431E-01	1.6621E-01	0.064	6.41
1.6061E-01	1.6245E-01	0.061	6.82
1.5704E-01	1.5881E-01	0.044	6.50
1.5358E-01	1.5525E-01	0.047	6.57
1.5024E-01	1.5189E-01	0.053	6.45
1.4700E-01	1.4860E-01	0.039	10.67
1.4387E-01	1.4542E-01	0.049	9.04
1.4084E-01	1.4234E-01	0.052	6.67
1.3791E-01	1.3935E-01	0.061	5.63
1.3508E-01	1.3661E-01	0.052	6.80
1.3234E-01	1.3449E-01	0.049	7.07
1.2970E-01	1.3166E-01	0.034	10.95
1.2862E-01	1.3153E-01	0.041	10.04
1.2879E-01	1.3184E-01	0.043	9.39
1.2484E-01	1.2679E-01	0.048	9.28
1.2111E-01	1.2295E-01	0.035	12.64
9.7574E-02	9.9319E-02	0.022	20.81
9.4219E-02	9.5875E-02	0.026	19.01
9.1035E-02	9.2607E-02	0.040	13.86
8.8010E-02	8.9503E-02	0.040	9.52
8.5132E-02	8.6553E-02	0.060	16.29
8.2494E-02	8.3746E-02	0.060	10.24
7.9786E-02	8.1074E-02	0.058	11.07
7.4927E-02	7.7299E-02	0.036	14.99
7.0500E-02	7.2663E-02	0.043	9.75
6.6453E-02	6.8431E-02	0.050	8.10
6.2745E-02	6.4559E-02	0.047	9.41
5.9439E-02	6.1066E-02	0.037	11.54
5.6203E-02	5.7739E-02	0.043	14.11
5.3309E-02	5.4720E-02	0.027	12.48
5.0643E-02	5.1946E-02	0.018	27.79
4.8154E-02	4.9370E-02	0.024	10.00
4.5852E-02	4.6982E-02	0.060	12.14

Table 1 (continued)

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
4.3712E-02	4.4763E-02	0.057	12.21
4.1718E-02	4.2698E-02	0.045	17.88
3.9857E-02	4.0772E-02	0.069	10.71
3.8119E-02	3.8973E-02	0.057	11.45
3.6491E-02	3.7291E-02	0.030	23.14
3.4966E-02	3.5716E-02	0.067	13.03
3.2188E-02	3.3534E-02	0.078	8.34
2.9729E-02	3.0922E-02	0.032	16.87
2.7542E-02	2.8604E-02	0.025	31.13
2.5587E-02	2.6537E-02	0.037	23.30
2.3833E-02	2.4686E-02	0.027	24.93
2.2253E-02	2.3023E-02	0.020	32.74
2.0826E-02	2.1522E-02	0.032	32.38
1.9531E-02	2.0163E-02	0.024	18.65
1.8354E-02	1.8929E-02	0.027	38.51
1.7280E-02	1.7805E-02	0.027	35.87
1.6297E-02	1.678E-02	0.044	32.94

^a Lower bound of energy interval.

^b This indicates a counting error expressed as a standard deviation. Total errors may be estimated by combining the normalization error of 2.19% and the estimated overall systematic error of 0.75% with the counting errors in the table.

Table 2. Fission cross-section ratio of ^{242}Pu to ^{235}U .

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
2.9529E+01			
2.7338E+01	2.8401E+01	0.942	3.73
2.5385E+01	2.6334E+01	0.942	3.45
2.3636E+01	2.4487E+01	0.955	3.25
2.2064E+01	2.2830E+01	0.991	3.06
2.0646E+01	2.1337E+01	1.010	2.88
1.9361E+01	1.9987E+01	1.009	2.71
1.8193E+01	1.8763E+01	1.044	2.53
1.7129E+01	1.7649E+01	0.991	2.39
1.6156E+01	1.6632E+01	1.016	2.22
1.5265E+01	1.5701E+01	0.984	2.13
1.4446E+01	1.4847E+01	0.965	2.05
1.3691E+01	1.4061E+01	0.969	1.97
1.2995E+01	1.3361E+01	0.974	1.92
1.2350E+01	1.2666E+01	0.997	1.86
1.1753E+01	1.2046E+01	1.060	1.75
1.1198E+01	1.1471E+01	1.075	1.69
1.0682E+01	1.0936E+01	1.092	1.60
1.0201E+01	1.0437E+01	1.082	1.53
9.7518E+00	9.9726E+00	1.056	1.44
9.3318E+00	9.5383E+00	1.096	1.36
8.9385E+00	9.1319E+00	1.100	1.29
8.5696E+00	8.7511E+00	1.075	1.22
8.2232E+00	8.3937E+00	1.089	1.17
7.8975E+00	8.0579E+00	1.106	1.12
7.5908E+00	7.7419E+00	1.119	1.10
7.3017E+00	7.4442E+00	1.105	1.10
7.0299E+00	7.1634E+00	1.154	1.07
6.7712E+00	6.8982E+00	1.184	1.07
6.5274E+00	6.6476E+00	1.205	1.09
6.2966E+00	6.4134E+00	1.230	1.14
6.0778E+00	6.1857E+00	1.229	1.17
5.8703E+00	5.9727E+00	1.248	1.22
5.6733E+00	5.7705E+00	1.265	1.28
5.4850E+00	5.5785E+00	1.232	1.32
5.3079E+00	5.3959E+00	1.175	1.35
5.1394E+00	5.221E+00	1.163	1.36
4.9769E+00	5.0567E+00	1.148	1.38
4.8259E+00	4.8229E+00	1.100	1.02
4.6815E+00	4.5356E+00	1.117	1.02
4.536E+00	4.2733E+00	1.138	1.03
3.9206E+00	4.0331E+00	1.114	1.03
3.7093E+00	3.8127E+00	1.122	1.01
3.5146E+00	3.6099E+00	1.137	0.99
3.3348E+00	3.4229E+00	1.119	0.98
3.1686E+00	3.2531E+00	1.116	0.97
3.0145E+00	3.0901E+00	1.123	0.95
2.8714E+00	2.9416E+00	1.117	0.92
2.7392E+00	2.8036E+00	1.113	0.90
2.6141E+00	2.6751E+00	1.127	0.86
2.4983E+00	2.5552E+00	1.119	0.84
2.3930E+00	2.4432E+00	1.097	0.81
2.2986E+00	2.3395E+00	1.106	0.79
2.1935E+00	2.2473E+00	1.095	0.76
2.1043E+00	2.1482E+00	1.101	0.74
2.0234E+00	2.0617E+00	1.097	0.72
1.9414E+00	1.9873E+00	1.119	0.70

Table 2 (continued)

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
1.8670E+00	1.9036E+00	1.115	0.67
1.7967E+00	1.8313E+00	1.116	0.65
1.7304E+00	1.7531E+00	1.112	0.68
1.6677E+00	1.6986E+00	1.127	0.67
1.6083E+00	1.6376E+00	1.101	0.64
1.5520E+00	1.5798E+00	1.100	0.63
1.4987E+00	1.5250E+00	1.128	0.62
1.4480E+00	1.4730E+00	1.121	0.62
1.3999E+00	1.4237E+00	1.123	0.62
1.3541E+00	1.3767E+00	1.129	0.62
1.3106E+00	1.3321E+00	1.141	0.60
1.2691E+00	1.2896E+00	1.168	0.62
1.2296E+00	1.2491E+00	1.195	0.61
1.1918E+00	1.2105E+00	1.201	0.59
1.1558E+00	1.1745E+00	1.247	0.59
1.1214E+00	1.1384E+00	1.260	0.58
1.0885E+00	1.1048E+00	1.260	0.55
1.0571E+00	1.0726E+00	1.272	0.55
1.0270E+00	1.0419E+00	1.220	0.57
9.9912E-01	1.0124E+00	1.187	0.59
9.7047E-01	9.8415E-01	1.166	0.58
9.4396E-01	9.5708E-01	1.139	0.58
9.1852E-01	9.3111E-01	1.082	0.61
8.9409E-01	9.0618E-01	1.031	0.62
8.7063E-01	8.8224E-01	1.030	0.64
8.4808E-01	8.5924E-01	0.923	0.65
8.2639E-01	8.3713E-01	0.919	0.72
8.0553E-01	8.1585E-01	0.812	0.77
7.8544E-01	7.9539E-01	0.800	0.75
7.6610E-01	7.7568E-01	0.733	0.78
7.4746E-01	7.5670E-01	0.707	0.81
7.2950E-01	7.3840E-01	0.631	1.87
7.1218E-01	7.2076E-01	0.569	0.92
6.9546E-01	7.0374E-01	0.548	0.93
6.7933E-01	6.8733E-01	0.542	0.94
6.6375E-01	6.7147E-01	0.494	0.99
6.4871E-01	6.5617E-01	0.448	1.07
6.3417E-01	6.4137E-01	0.433	1.13
6.2011E-01	6.2708E-01	0.447	1.15
6.0651E-01	6.1325E-01	0.380	1.25
5.9336E-01	5.9988E-01	0.366	1.25
5.8063E-01	5.8694E-01	0.340	1.29
5.6831E-01	5.7442E-01	0.320	1.35
5.5637E-01	5.6229E-01	0.281	1.44
5.4481E-01	5.5055E-01	0.292	1.40
5.3360E-01	5.3916E-01	0.269	1.53
5.2274E-01	5.2813E-01	0.225	1.75
5.1220E-01	5.1743E-01	0.224	1.67
5.0198E-01	5.0706E-01	0.214	1.62
4.9207E-01	4.9699E-01	0.187	1.74
4.8244E-01	4.8722E-01	0.173	1.86
4.7309E-01	4.7773E-01	0.182	1.67
4.6402E-01	4.6852E-01	0.172	1.97
4.5520E-01	4.5958E-01	0.154	2.15
4.4663E-01	4.5088E-01	0.130	2.46
4.3830E-01	4.4244E-01	0.124	2.61
4.3020E-01	4.3422E-01	0.103	2.99
4.2232E-01	4.2624E-01	0.107	2.99
4.1466E-01	4.1847E-01	0.122	2.81
4.0721E-01	4.1091E-01	0.116	2.67

Table 2 (continued)

Low energy ^a (MeV)	Center energy (MeV)	Ratio	Error ^b (%)
3.9995E-01	4.0356E-01	0.096	1.75
3.9289E-01	3.9640E-01	0.101	1.76
3.8601E-01	3.8943E-01	0.102	1.77
3.7931E-01	3.8264E-01	0.087	1.78
3.6643E-01	3.7279E-01	0.078	1.79
3.5419E-01	3.6023E-01	0.077	1.80
3.4255E-01	3.4830E-01	0.074	1.81
3.3148E-01	3.3695E-01	0.072	1.82
3.2094E-01	3.2614E-01	0.067	1.83
3.1089E-01	3.1585E-01	0.061	1.84
2.9216E-01	3.0130E-01	0.052	1.85
2.7507E-01	2.8342E-01	0.044	1.86
2.5944E-01	2.6708E-01	0.036	1.87
2.4510E-01	2.5212E-01	0.027	1.88
2.3192E-01	2.3838E-01	0.019	1.89
2.0857E-01	2.1978E-01	0.012	1.90
1.8857E-01	1.9819E-01	0.007	1.91
1.7131E-01	1.7963E-01	0.004	1.92
1.4322E-01	1.5632E-01	0.002	1.93
1.2151E-01	1.3168E-01	0.001	1.94
1.0439E-01	1.1246E-01	0.001	1.95

^aLower bound of energy interval.

^bThis indicates a counting error expressed as a standard deviation. Total errors may be estimated by combining the normalization error of 2.24% and the estimated overall systematic error of 0.50% with the counting errors in the table.

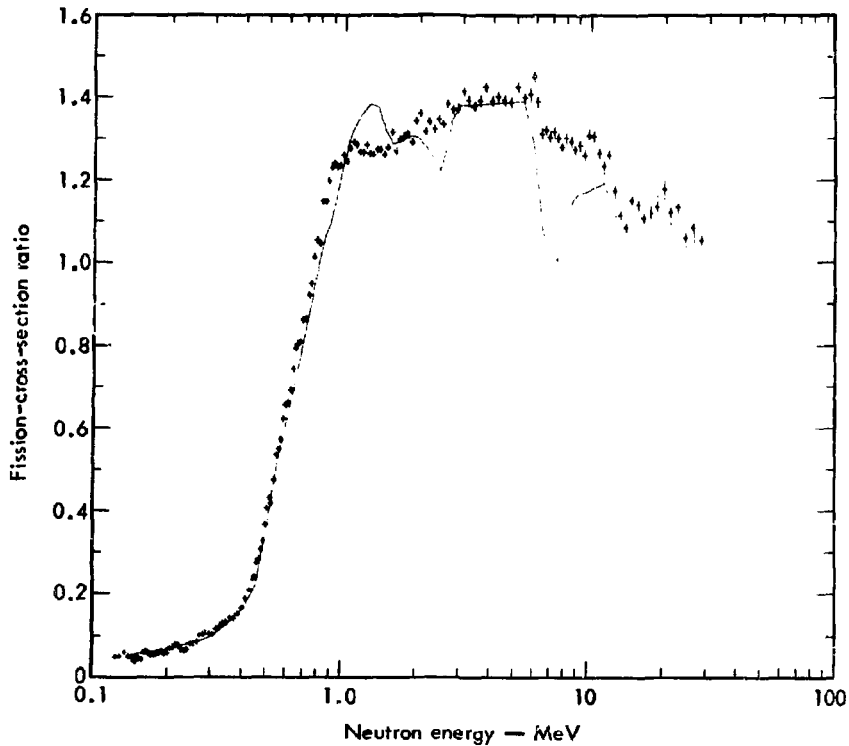


Fig. 1. Ratio of the ^{240}Pu to ^{235}U fission cross sections in the energy range 0.1 to 30 MeV. Our preliminary work is given by +. The statistical error bars, representing one standard deviation, are shown for each point. The line denotes the ^{240}Pu to ^{235}U ratio obtained using the ENDF/B-IV evaluated fission-cross-section files.

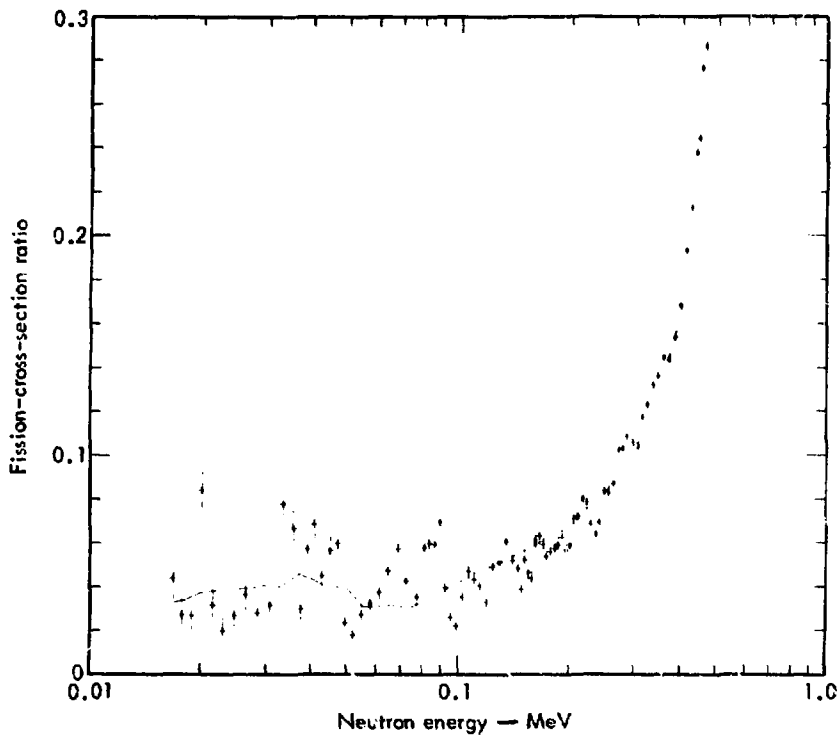


Fig. 2. Ratio of the ^{240}Pu to ^{235}U fission cross sections in the energy range 0.02 to 0.5 MeV. Our preliminary work is given by +. The statistical error bars, representing one standard deviation, are shown for each point. The line denotes the ^{240}Pu to ^{235}U ratio obtained using the ENDF/B-IV evaluated fission-cross-section files.

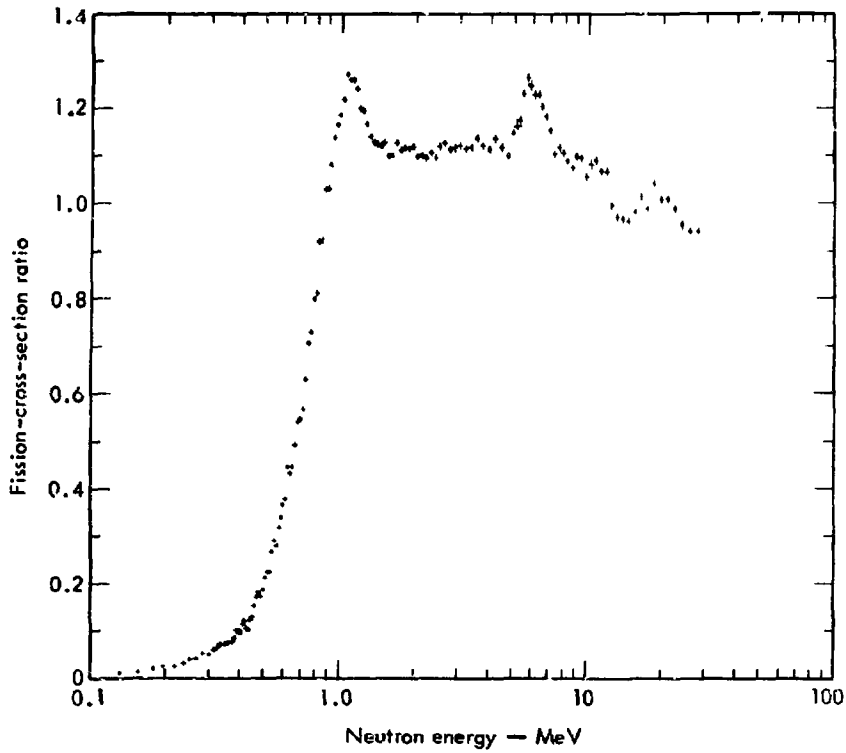


Fig. 3. Ratio of the ^{242}Pu to ^{235}U fission cross sections in the energy range 0.1 to 30 MeV. Our preliminary work is shown with statistical error bars, representing one standard deviation, on each point.

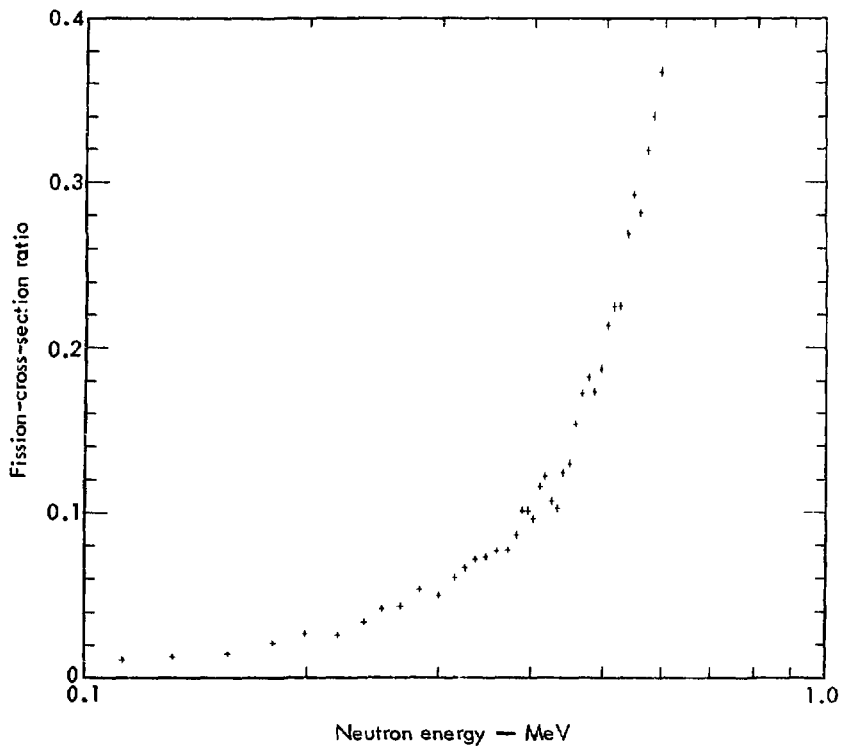


Fig. 4. Ratio of the ^{242}Pu to ^{235}U fission cross sections in the energy range 0.1 to 0.6 MeV. Our preliminary work is shown with statistical error bars, representing one standard deviation, on each point.

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