LA-11151-MS

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Background Radiation from Fission Pulses

Los Alamos

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

Prepared by Alice Mutschlecner, Group T-2

This work was supported by the US Department of Energy and the US Department of Defense.

LA-11151-MS

UC-34C
Issued: May 1988

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CONTENTS

FIGURES

TABLES

TABLES (APPENDIX B)

BACKGROUND RADIATION FROM FISSION PULSES

by

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ABSTRACT

Extensive source terms for beta, gamma, and neutrons following fission pulses are presented in various tabular and graphical forms. Neutron results from a wide range of fissioning nuclides (42) are examined and detailed information is provided for four fuels: ^{235}U, ^{238}U, ^{232}Th, and ^{239}Pu; these bracket the range of the delayed spectra. Results at several cooling (decay) times are presented. For β^- and γ spectra, only ^{235}U and ^{239}Pu results are given; fission-product data are currently inadequate for other fuels. The data base consists of all known measured data for individual fission products extensively supplemented with nuclear model results. The process is evolutionary, and therefore, the current base is summarized in sufficient detail for users to judge its quality. Comparisons with recent delayed neutron experiments and total β^- and γ decay energies are included.

I. INTRODUCTION

Two, and occasionally more, neutron rich nuclides remain following a neutron induced fission, as illustrated in Fig. 1. These fission products can be any one of approximately 1300 species, and they are all present in varying amounts following a sufficiently large number of fissions. Most nuclides are radioactive and coupled by their decay, as shown in Fig. 2 for 20 of the 1300 products. The initial amount of each product following a fission pulse is described by a probability per fission, or fission product yield, that varies with the fissioning species and with the initial neutron fission energy. Figure 3 is a simplified illustration of the distribution of the initially yielded products where Zp is the most probable product per mass chain. Figures 4a and 4b show the location of Zp and delayed neutron precursors for ^{235}U fast fission.

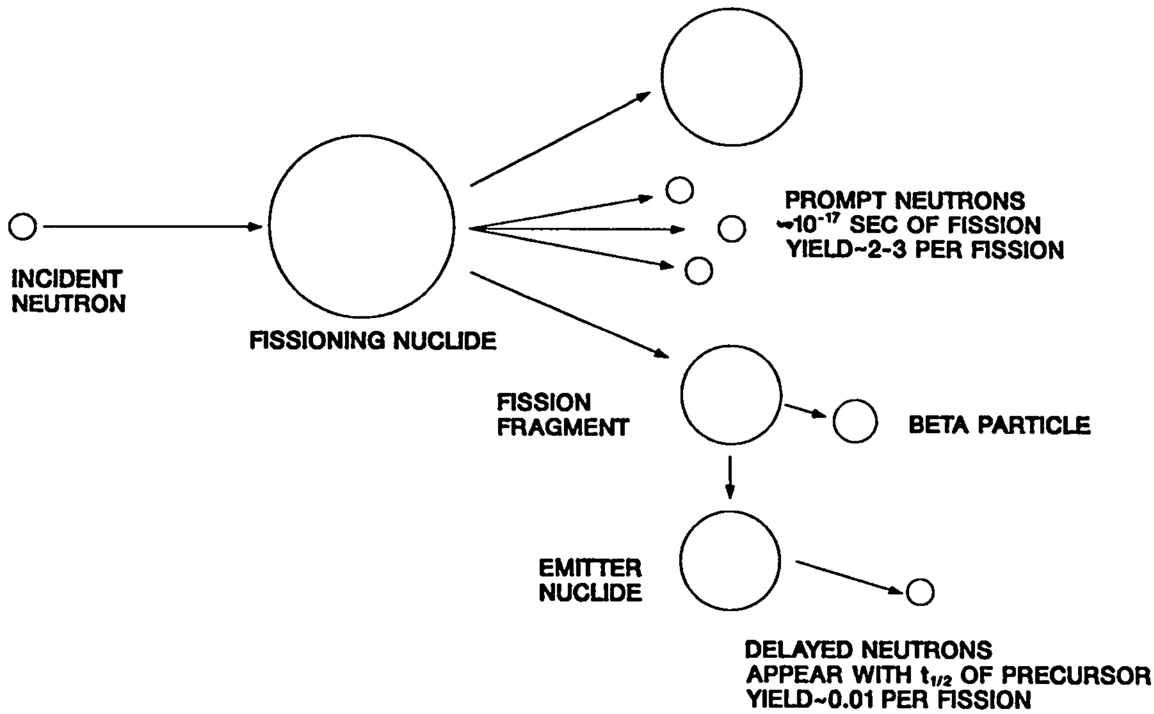

Fig. 1. Delayed neutrons from fission.

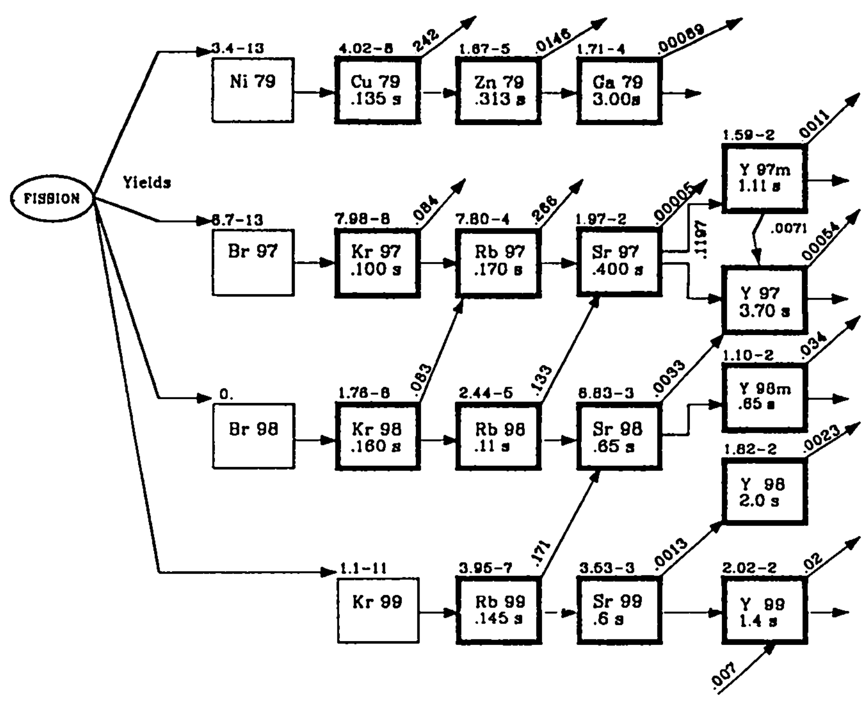

Fig. 2. Some explicit fission-product chains.

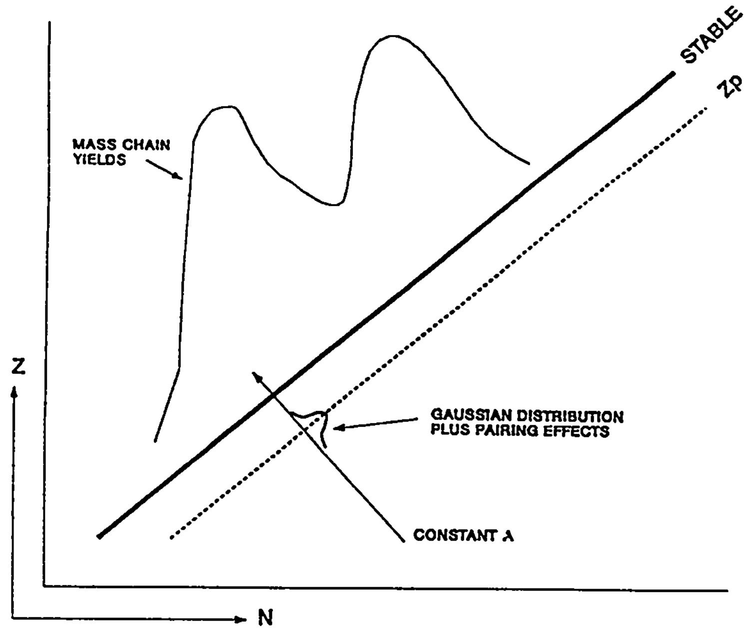

Fig. 3. Schematic of yield distribution.

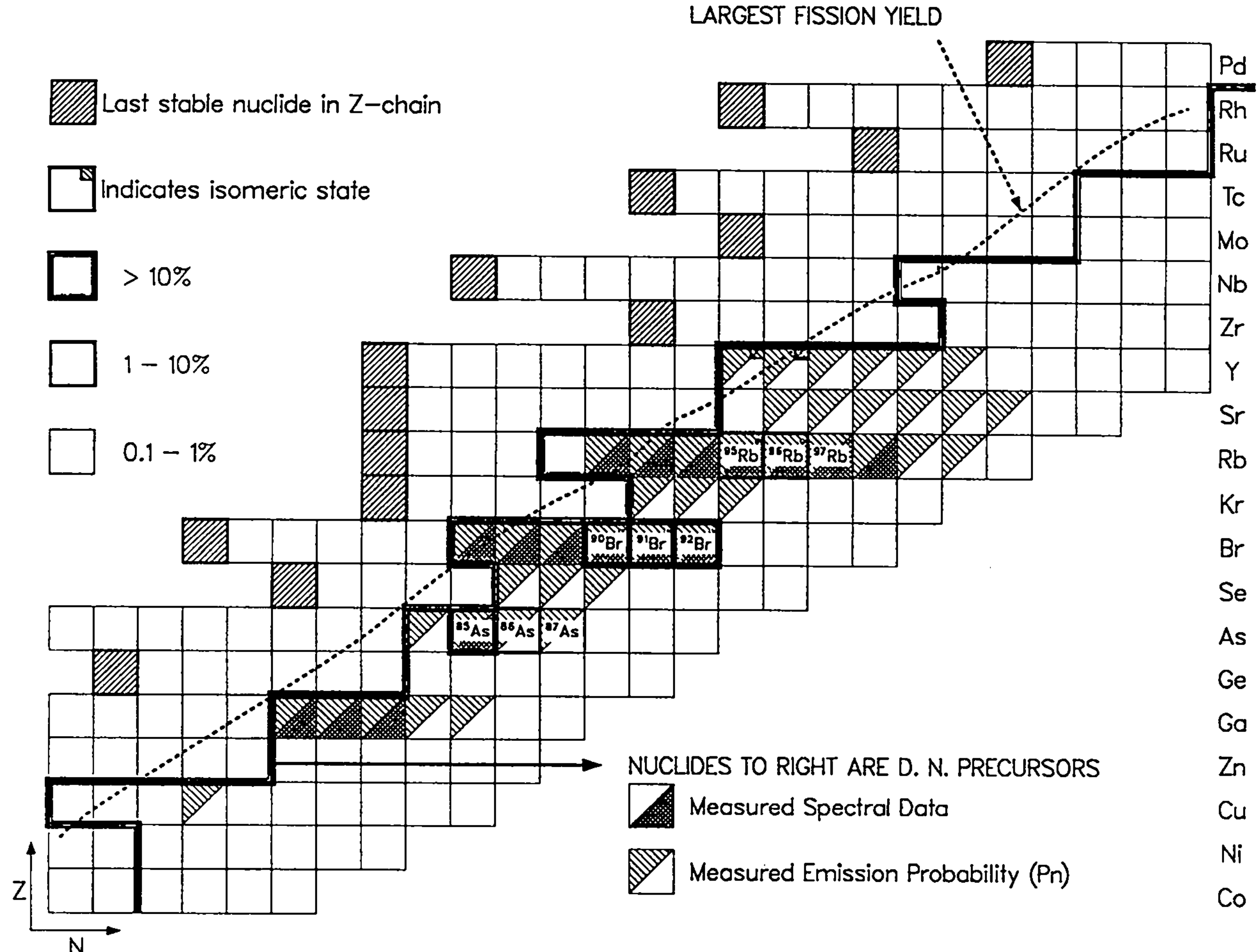

Fig. 4a. Location of fission-product and delayed neutron precursors.

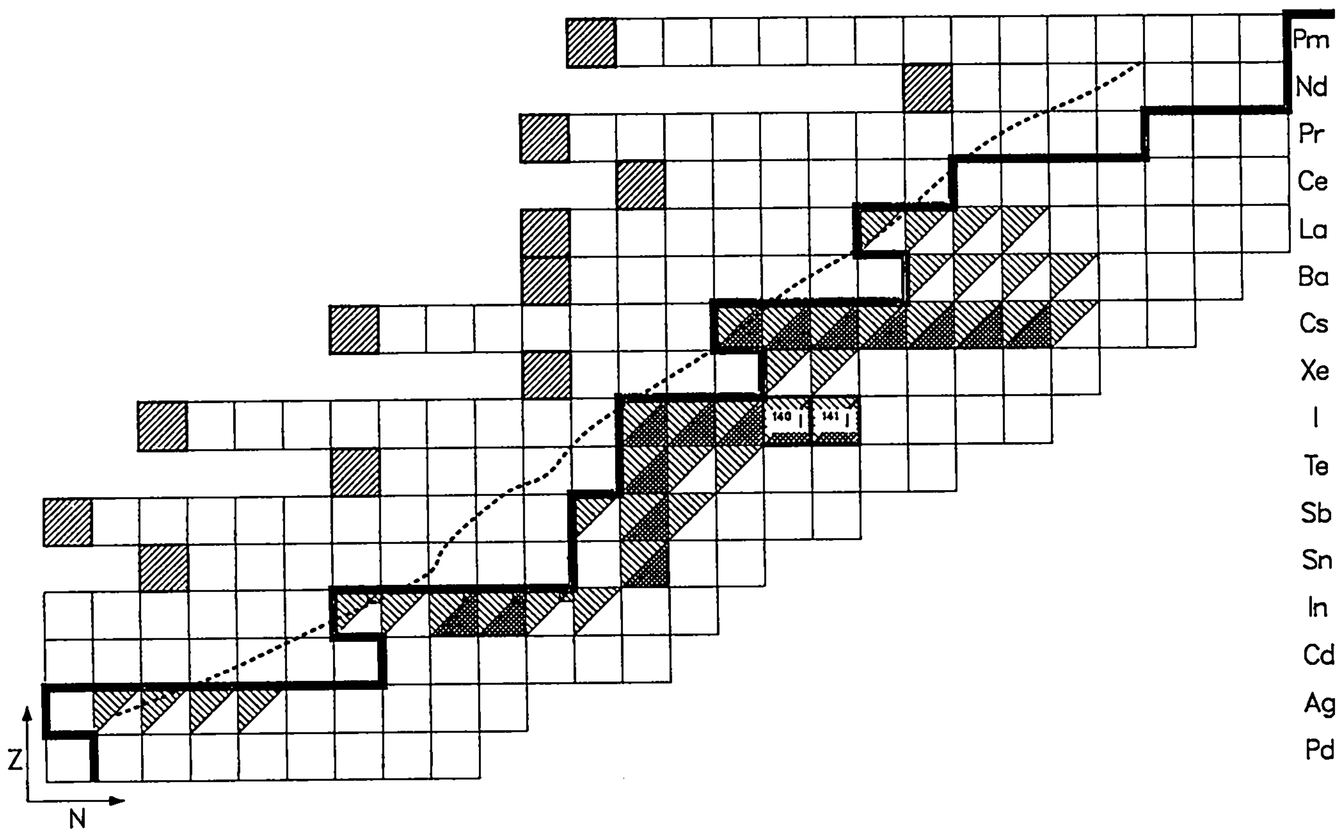

Fig. 4b. Location of fission product and delayed neutron precursors.

The total population of this plexus of products remains a constant in time equal to approximately twice the number of fissions in the pulse. However, the amount of each product changes continuously because of decay couplings, as do radiations associated with decay. Most of the decays are initiated by β^- transitions to excited states of the daughter product and are immediately followed by cascading gammas to lower energy states. In some cases (~ 150), the lower energy states are long-lived and can decay by either β^- or an additional cascade of gammas to the ground state. In approximately 270 of the initial products, some of the β^- transitions leave the daughter product in an excited state exceeding the binding energy, S(n), of a neutron and hence each such decay probably results in the emission of neutrons. In a very few cases (< 10), the parent nuclide of the neutron rich products decays by the emission of an alpha particle; however, the usual decays and radiations are illustrated in Fig. 5. Each of the β^- transition energies is actually a mixture of energies (in some continuous probability) of an electron and anti-neutrino and not a discrete value for either particle.

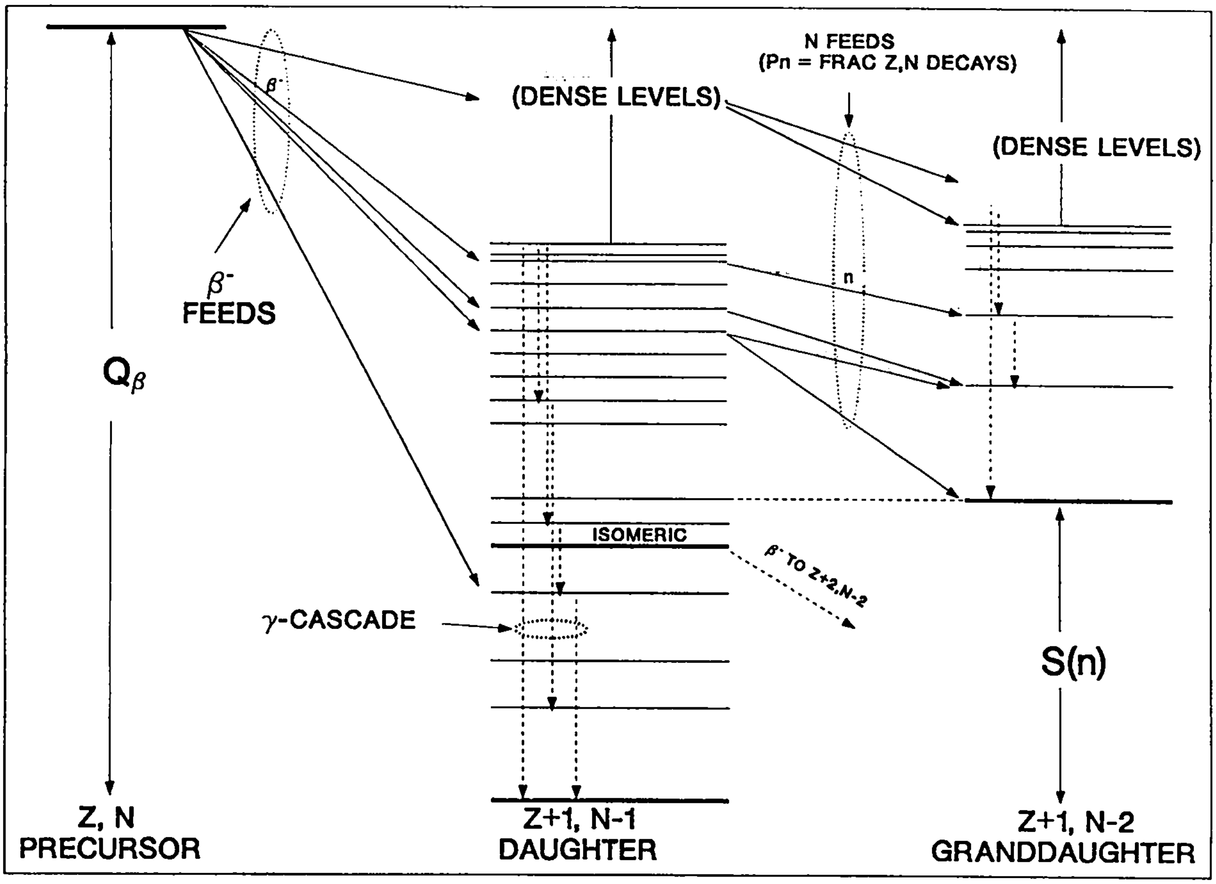

Fig. 5. Schematic of decay plus delayed neutron emission.

If we knew the fission-product yield, decay halflife, probability of each type of decay or branching fraction, and associated energy spectrum for each type of radiation, it would be possible to describe the time-dependent behavior and radiation field of the fission-product debris. We now have codes, notably, a version of CINDER[1] and associated codes based on it, capable of calculating the time-dependence of each nuclide and each type of radiation for any mixture of fissioning nuclides. Basically, we first calculate the time-dependent quantity of each product and its activity and then fold in the various spectral types and sum these into an aggregate spectrum. The process is exact and the accuracy is limited by the uncertainties of the input data, some of this being based on measurements and some on nuclear models.

In this report, we describe the input source data of the nuclides available through fiscal year 1987 and present aggregate, time-dependent results of the total ensemble for the principal radiations (β^-, γ, and n). These form the dominant background radiations for any observer or instrument. The neutrons constitute a major portion of the discussion in this report.

The information in this report is intended as source data for further studies. For example, any detector will see additional temporal changes due to expanding debris, depending on its location. Here, all results describe isotropic radiation from a point source. The relative importance of the spatial expansion of the debris is dependent on each detector's location and is not considered here. The detectors are assumed to be shielded against the initial prompt neutron, x-ray, and gamma pulse sources. These can be calculated for any particular device, but they are not being included in this discussion. Here, the source terms apply to the continuously changing interference environment or background remaining following the fission pulse.

The background is device-dependent because of the mixture of fissioning nuclides and number of fissions. Except where noted, we have assumed that each pulse contains 1.3×10^{26} fissions, or approximately the equivalent of 1 MT, if all energy is from the fission of a single fissioning species.

The reader should be aware that measurements and improvements in nuclear models are currently in progress and results from these could significantly alter data for particular fission products. While changes in the aggregate total radiations are less likely to be significant, values at the large radiation energies could certainly change. The information in this report can be considered as the most extensive estimates of the radiation background to date and should serve as a reference or fiducial report for further studies.

II. DATA BASE

Calculations require fission-product yields, nuclide halflives, decay branching fractions to isomeric and ground states of the daughter products and branching by those neutrons following beta decay (i.e., "delayed neutrons" or ν_d) and the beta, gamma, and neutron energy spectra for each nuclide. Except for spectra, all parameters are used to form chains of nuclides coupled, as in Fig. 2. (For fission pulses, we do not require neutron cross sections, but for extended irradiations, cross sections are required and these, like the delayed neutrons, cross couple the mass chains.)

A. Yields

The fission-product yields in use are a preliminary, unpublished version for ENDF/B-VI,[2] described in Ref. 3; mass chain yields are listed in Ref. 3 as well. All yield data are being updated and reevaluated prior to issue in Version VI of ENDF/B; the data in use are the most recent available and are current to about mid-1983. For this study, we did alter the ^{238}U fast-fission yields primarily in their distribution along the mass chains. The method of evaluation and the distribution models are described in Ref. 3. (Only the ^{238}U proton pairing parameter was changed from values listed in that reference. The change was based on recent unpublished measurements made at Grenoble, France, and it resulted in a significant alteration in the calculation of delayed neutrons; however, it is less important to other aggregate quantities.)

Most high-energy neutron yields are based on nuclear models and systematics, not on measurements.

B. Halflives and Decay Branching

Except for neutron branching (denoted as Pn), these data are taken from ENDF/B-V[2] and are listed in the summary document of Ref. 4. As noted in a later section, we now have sufficient tests to believe in their validity and the yield data can be assessed as generally very good.

C. Beta/Gamma Spectra and Their Decay Energies

Earlier testing of these ENDF/B-V data[2] demonstrated that measured nuclide spectra were usually deficient for many high-Q transitions.[5,6] An earlier version of ENDF/B that relied more on nuclear model generated spectra showed better agreement with benchmark experiments than Version V. Other countries have also discovered the deficiency and the only reasonable recourse in the near future for individual nuclides is an augmentation of spectra using nuclear models.[7] As discussed later, this has already been accomplished for total β^- and γ decay energies, but not spectra, by the Japanese,[8,9] with excellent results. As related to this report, the total β^- and γ energies recommended by the Japanese are used in place of those in ENDF/B-V. Here, however, our primary interest is in aggregate spectra. For this purpose, we use 18- and 19-group functions fitted to our calculated spectra[6] after some adjustment based on the measured spectra of Dickens[10,11] reduced to a fission pulse. These functions also compare very well with measurements of total decay energies but apply only to ^{235}U and ^{239}Pu fission. We have no measured spectra for ^{238}U to use for similar fits. In any case, we need improved spectra for individual products if we are to use our developed capability for general spectra calculations for any fissioning nuclide.

D. Pn Values and Delayed Neutron Spectra

These data were simply inadequate in any known evaluation/compilation. A very incomplete set of Pn values (delayed neutron branching fractions), but no individual spectra, exist in the ENDF/B files. Therefore, a large part of our effort to date on the nuclear background has been toward compiling, evaluating, and generating a complete set of delayed neutron data. The method of evaluating measured Pn's is described in Ref. 12. These data have now been revised through 1985 and appear in Section III. Measured Pn's now exist for 85 nuclides, but there are > 270

nuclides having Q_β values exceeding the neutron binding energy S(n) based on nuclide masses. All are assumed to be delayed neutron precursors. This assumption is very reasonable; to date, all nuclides having the sufficient energetics (illustrated in Fig. 5) have been found to be neutron precursors.

Thirty-four of the precursors have one or more known spectral measurements. However, we have found no measured spectra prior to the beginning of this study that extend above 3 MeV, although many precursors have sufficient energetics for higher energy delayed neutrons. In these cases, it is necessary to augment the measurements with nuclear model calculations and to use models for the 237 unmeasured spectra, as was done in Ref. 13 for 76 spectra. Some model spectra can be important because of their large energy emission, but some are included simply for completeness, being relatively unimportant as a result of small Pn and/or yield values.

All measured spectra are normalized; also, prior to normalization, experimental data were generally missing at both low and high energy values. With the exception of 4, all of the 34 measured spectra had to be augmented with model values. Thus, 241 of the 271 precursor spectra include some model values and 237 are based totally on models.

Table I summarizes the experimental spectra source and Table II, the general content of the data base. This extensive base is a dominant part of this report and will be further described in Section III. Reference 14 also provides a summary of the effort through September 1986; also a dissertation in preparation by a co-author of this report,[15] will provide detail relevant to each change made to date in measured spectra. (The dissertation is primarily concerned with aggregate steady-state spectra < 3 MeV important to reactors. Spectra at larger energies for some individual precursors will be discussed in the dissertation only because of the need to extend spectra to obtain a proper normalization. For this purpose, it will contain some information from Refs. 14 and 16).

The extensive Los Alamos data base for delayed neutrons is summarized in more detail in the following section. It results from national and international cooperation with periodic research over the past ten years and from an intensive effort over the past three years.

A general bibliography for delayed neutrons is attached as Appendix A of this report.

TABLE I

SUMMARY OF EXPERIMENTAL SPECTRA

Studsvik measurements:

^{3}He spectrometers
On-line isotope separator
Measurements for ~ 25 precursor nuclides
Energy range ~ 100 keV - 2 MeV

Mainz measurements:

^{3}He spectrometers
On-line isotope separator
Measurements for ~ 23 precursor nuclides
Energy range ~ 40 keV - 3 MeV

INEL measurements:

Proton-recoil spectrometer
On-line isotope separator (TRISTAN-ISOL)
Measurements for 8 precursor nuclides
Energy range ~ 10 keV - 1300 keV

TABLE II

CONTENT OF CURRENT DATA BASE

→ 271 PRECURSORS (BASED ON ENERGETICS)←

- Pn - DN Emission Probabilities
  - 85 Evaluated measurements
  - 186 From systematics (fit to Kratz-Hermann equation)
- Spectra (10 keV Bins)
  - 34 Measured (30 augmented with Beta Code)
  - 237 From model calculations (Modified Evaporation Model)
- FP Yields, $t_{1,2}$, β^-, and γ Branchings
  - Yields from a preliminary ENDF/B-VI version
  - Branchings from ENDF/B-V

III. DELAYED NEUTRONS: CURRENT DATA EVALUATION

As noted in Section II(D), of the 271 probable delayed precursors, only 34 have measured spectra and 85 have measured emission probabilities (Pn values). Such number comparisons can be misleading. As stated in Ref. 13, we found that 29 precursors having spectral measurements account for 70-82% of the total delayed neutron emission rate at equilibrium. For fission pulses, the 34 measured precursors account for 75-99% of the total rate at various cooling times. (The percentage increases monotonically with cooling time.) Furthermore, most measured spectra do not cover the complete energy range and some unmeasured short-lived precursors are likely to produce a large fraction of the neutrons at high energies. In addition, complete Pn data are needed in fission-product yield evaluations.

Precursor Data

Table III lists Pn values for 271 nuclides and provides details on the bases of data for these and each spectra in the current data files. The table is important because it is a succinct record of the augmentations made in measured spectral data and in the origin of major data sources used in the systematic and nuclear models. For example, under the column labelled "Spectra Source," the notation for ^{95}Rb is (m) GO.2M1.8B. The "(m)" denotes that the spectra are based primarily on measurements; but, for reasons to be described, the spectral shape below 0.2 MeV comes from INEL measurements by Greenwood and Caffrey,[17] and, above 1.8 MeV [up to Q_β - S(n) = 4.952 MeV], the shape is based on the BETA code model.[18] The dominant part of the emitted neutrons come, in this case, from measurements at the University of Mainz and are supplied by K. -L. Kratz,[19] and other cases use data supplied by G. Rudstam.[20] The 4.952-MeV energy window is based on mass tables referenced under columns M1, M2, and M3, where MN refers to Möller-Nix,[21]and W81 refers to a preliminary unpublished version of the W83 Wapstra and Audi 1983 mass table (published in 1985).[22] Q_β depends on the parent and daughter masses [sources under M1 and M2, and S(n) on the daughter and granddaughter masses (sources under M2 and M3)]. Values listed under "Norm Area" define the range used to renormalize the low- and high-energy spectra to the experimental data.

Only the notations under "Spectra Source" require such a detailed explanation. In general, the G, M, and R, respectively, refer to the INEL, Mainz, and Studsvik measurements, B to the BETA code, and EVAP to an evaporation model to be described. Only 4 of the 34 measured spectra have no modification. [These have "MAINZ" or "RUDSTAM" indicated following the "(m)"]. The reasons for modification are discussed later in this section.

TABLE III

PRECURSOR EMISSION PROBABILITIES (Pn), SOURCES OF DATA, AND TYPES OF SPECTRA MODIFICATIONS[a]

CS	ID	HL	Pn	dPn	GP	Pn Source		Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
Co	270720	0.1235	11.5322	0.0000	6	sys.		EVAP(398.9)	15.030	7.391	MN	MN	MN		
Cu	290720	6.4891	<0.0001	0.0000	3	sys.		EVAP(41.8)	8.964	8.880	MN	W81	W81		
Co	270730	0.1290	25.1220	0.0000	6	sys.		EVAP(430.7)	12.800	3.771	MN	MN	MN		
Ni	280730	0.4906	0.0047	0.0000	5	sys.		EVAP(95.0)	8.170	7.731	MN	MN	MN		
Cu	290730	5.1136	0.5588	0.0000	3	sys.		EVAP(159.1)	6.174	4.942	MN	W81	W81		
Co	270740	0.0920	17.4326	0.0000	6	sys.		EVAP(442.5)	16.440	6.781	MN	MN	MN		
Ni	280740	0.9002	0.3560	0.0000	4	sys.		EVAP(167.8)	5.980	4.591	MN	MN	MN		
Cu	290740	0.6482	0.2949	0.0000	5	sys.		EVAP(179.1)	10.221	8.638	MN	W81	W81		
Co	270750	0.0817	31.3124	0.0000	6	sys.		EVAP(476.6)	14.810	3.451	MN	MN	MN		
Ni	280750	0.2312	1.0022	0.0000	6	sys.		EVAP(224.9)	9.560	7.031	MN	MN	MN		
Cu	290750	0.9274	3.4700	0.6300	4	meas.		EVAP(252.5)	8.055	4.866	MN	W81	W81		
Ni	280760	0.3046	3.5113	0.0000	5	sys.		EVAP(262.0)	7.700	4.221	MN	MN	MN		
Cu	290760	0.2602	2.8418	0.0000	6	sys.		EVAP(275.0)	12.004	8.171	MN	W81	W81		
Ni	280770	0.1033	4.7115	0.0000	6	sys.		EVAP(302.9)	11.050	6.341	MN	MN	MN		
Cu	290770	0.3052	12.3119	0.0000	5	sys.		EVAP(332.1)	10.185	4.522	MN	W81	W81		
Ni	280780	0.1318	9.2984	0.0000	6	sys.		EVAP(323.4)	9.070	3.631	MN	MN	MN		
Cu	290780	0.1179	9.9093	0.0000	6	sys.		EVAP(355.0)	13.673	7.119	MN	W81	W81		
Zn	300780	1.9855	0.0041	0.0000	4	sys.		EVAP(85.6)	6.010	5.629	W81	W81	W81		
Cu	290790	0.1351	24.2057	0.0000	6	sys.		EVAP(374.1)	10.770	3.399	MN	MN	W81		
Zn	300790	0.3130	1.1459	0.0000	5	sys.		EVAP(222.7)	9.465	6.854	MN	W81	W81		
Ga	310790	3.0000	0.0890	0.0200	4	meas.	(m)	BO.11R	6.770	5.740	W83	W83	W83	0.11,0.21	
Cu	290800	0.0899	15.0430	0.0000	6	sys.		EVAP(422.0)	16.680	7.181	MN	MN	MN		
Zn	300800	0.4873	1.0983	0.0000	6	sys.		EVAP(206.9)	7.087	4.803	MN	W81	W81		
Ga	310800	1.6600	0.8300	0.0700	4	meas.	(m)	BO.11R1.06B	10.000	7.920	W83	W83	W83	0.11,0.21	0.90,1.00
Cu	290810	0.0742	52.9504	0.0000	6	sys.		EVAP(497.8)	14.900	1.521	MN	MN	MN		
Zn	300810	0.1227	5.7372	0.0000	6	sys.		EVAP(321.1)	12.125	6.559	MN	W81	W81		
Ga	310810	1.2300	11.9000	0.9400	4	meas.	(m)	BO.07R1.69B	8.320	4.990	W83	W83	W83	0.07,0.17	1.45,1.65
Zn	300820	0.1268	21.2264	0.0000	6	sys.		EVAP(381.2)	10.420	2.477	MN	MN	W81		
Ga	310820	0.6000	21.1000	1.8300	5	meas.		EVAP(327.0)	12.993	7.149	MN	W81	W81		
Zn	300830	0.0836	22.8749	0.0000	6	sys.		EVAP(415.9)	13.710	4.141	MN	MN	MN		
Ga	310830	0.3100	56.2000	9.9000	5	meas.		EVAP(399.9)	11.970	3.119	MN	MN	W81		
Ge	320830	1.9000	0.0235	0.0000	4	sys.		EVAP(117.2)	8.640	7.880	W83	W83	W83		
Ga	310840	0.0984	28.0232	0.0000	6	sys.		EVAP(425.9)	15.130	4.971	MN	MN	MN		
Ge	320840	1.2000	5.2055	0.0000	4	sys.		EVAP(283.0)	8.855	4.369	MN	W81	W81		
As	330840	5.3000	0.0860	0.0430	3	meas.		EVAP(145.8)	9.872	8.681	W83	W83	W83		
Ga	310850	0.0870	44.9654	0.0000	6	sys.		EVAP(447.7)	13.390	2.031	MN	MN	MN		
Ge	320850	0.2500	16.4540	0.0000	6	BETA		EVAP(347.0)	11.050	4.226	MN	MN	W81		
As	330850	2.0300	70.9250	7.7026	4	meas.	(m)	M2.8B	8.910	4.540	W83	W83	W83	1.30,1.60	2.30,2.80
Ge	320860	0.2470	15.2148	0.0000	6	sys.		EVAP(337.7)	9.450	2.911	MN	MN	MN		

(Continued)

[a]See page 17 (end of table) for General Notes.

Table III (Cont.)

CS	ID	HL	Pn	dPn	GP	Pn Source	Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
As	330860	0.9000	8.5030	1.6104	4	meas.	EVAP(353.8)	13.372	6.196	MN	W81	W81		
Ge	320870	0.1339	15.1329	0.0000	6	sys.	EVAP(365.5)	12.610	4.861	MN	MN	MN		
As	330870	0.3000	44.3600	20.2170	6	meas.	EVAP(383.0)	10.730	2.220	MN	MN	W81		
Se	340870	5.6000	0.1880	0.0210	3	meas.	EVAP(121.8)	7.170	6.310	W83	W83	W83		
Br	350870	55.7000	2.5400	0.1600	1	meas.	(m) MAINZ	6.826	5.515	W83	W83	W83		
Ge	320880	0.1290	21.6551	0.0000	6	sys.	EVAP(376.6)	10.850	2.531	MN	MN	MN		
As	330880	0.1348	19.9068	0.0000	6	sys.	EVAP(373.8)	13.730	5.531	MN	MN	MN		
Se	340880	1.5000	0.9660	0.0210	4	meas.	EVAP(249.6)	8.567	4.912	MN	W81	W81		
Br	350880	16.0000	6.2600	0.3800	2	meas.	(m) RUDSTAM	8.967	7.053	W83	W83	W83		
As	330890	0.1212	33.2722	0.0000	6	sys.	EVAP(392.7)	11.910	2.761	MN	MN	MN		
Se	340890	0.4270	7.7000	2.4000	5	meas.	EVAP(312.8)	11.378	5.573	MN	W81	W81		
Br	350890	4.3800	14.0000	0.8400	3	meas.	(m) B.05M2.59B	8.300	5.110	W83	W83	W83	0.05,0.15	1.90,2.20
As	330900	0.0911	24.3493	0.0000	6	sys.	EVAP(403.9)	15.080	5.291	MN	MN	MN		
Se	340900	0.5550	9.1321	0.0000	5	sys.	EVAP(318.5)	10.204	4.117	MN	W81	W81		
Br	350900	1.8000	24.6000	1.8500	4	meas.	(m) B.05M2.83B	10.700	6.310	W83	W83	W83	0.05,0.15	2.30,2.80
Se	340910	0.2700	24.4382	0.0000	6	sys.	EVAP(359.8)	11.250	3.398	MN	MN	W81		
Br	350910	0.6000	18.1000	1.4800	5	meas.	(m) B.05M2.94B	11.795	4.493	MN	W81	W81	0.05,0.15	2.40,2.90
Rb	370910	58.2000	<0.0001	0.0000	1	sys.	EVAP(32.2)	5.859	5.796	W81	W81	W81		
Se	340920	0.1682	13.2333	0.0000	6	sys.	EVAP(320.5)	9.480	3.181	MN	MN	MN		
Br	350920	0.3600	42.7344	9.7464	5	meas.	(m) B.05M3.0B	13.963	5.350	MN	W81	W81	0.05,0.15	2.45,2.95
Kr	360920	0.3600	0.0332	0.0031	5	meas.	EVAP(130.4)	6.156	5.113	W83	W83	W83		
Rb	370920	4.5300	0.0099	0.0005	3	meas.	(m) MAINZ	8.120	7.366	W83	W83	W83		
Se	340930	0.0968	12.0321	0.0000	6	sys.	EVAP(340.0)	12.440	5.271	MN	MN	MN		
Br	350930	0.1760	25.0885	0.0000	6	sys.	EVAP(374.4)	12.211	3.518	MN	W81	W81		
Kr	360930	1.2900	2.0100	0.1600	4	meas.	EVAP(205.4)	8.529	5.914	W83	W83	W83		
Rb	370930	5.8600	1.3500	0.0700	3	meas.	(m) GO.2M1.8B	7.442	5.237	W83	W83	W83	0.10,0.30	1.40,1.80
Br	350940	0.1108	29.8035	0.0000	6	sys.	EVAP(382.5)	13.580	4.411	MN	MN	W81		
Kr	360940	0.2100	6.1300	2.4100	6	meas.	EVAP(256.4)	8.199	4.080	MN	W81	W81		
Rb	370940	2.7600	10.0000	0.5000	4	meas.	(m) GO.2M2.46B	10.307	6.786	W83	W83	W83	0.10,0.30	2.10,2.40
Br	350950	0.1069	27.0797	0.0000	6	sys.	EVAP(371.0)	11.990	3.271	MN	MN	MN		
Kr	360950	0.7800	7.5051	0.0000	5	BETA	EVAP(278.9)	10.078	5.151	MN	W81	W81		
Rb	370950	0.3800	8.6200	0.4200	5	meas.	(m) GO.2M1.8B	9.282	4.330	W83	W83	W83	0.10,0.30	1.40,1.80
Br	350960	0.0888	21.9195	0.0000	6	sys.	EVAP(384.6)	14.960	5.491	MN	MN	MN		
Kr	360960	0.2931	7.7473	0.0000	6	sys.	EVAP(267.7)	8.066	3.479	MN	W81	W81		
Rb	370960	0.2040	14.0000	0.7100	6	meas.	(m) GO.2M2.22B	11.750	5.860	W83	W83	W83	0.10,0.30	2.00,2.40
Sr	380960	1.1000	0.0011	0.0000	4	sys.	EVAP(60.9)	5.413	5.176	W81	W81	W81		
Kr	360970	0.1000	8.3925	0.0000	6	sys.	EVAP(284.8)	10.331	5.086	MN	W81	W81		
Rb	370970	0.1700	26.6000	1.4800	6	meas.	(m) GO.2M2.11B	10.520	3.980	W83	W83	W83	0.10,0.30	1.90,2.30
Sr	380970	0.4000	0.0054	0.0021	5	meas.	EVAP(148.7)	7.470	6.040	W83	W83	W83		
Y	390970	3.7000	0.0540	0.0028	3	meas.	EVAP(130.5)	6.680	5.579	W83	W83	W83		
Y	390971	1.1100	0.1090	0.0300	4	meas.	Y97	0.000	0.000	Y97				
Kr	360980	0.1602	8.2989	0.0000	6	sys.	EVAP(290.1)	9.480	3.980	MN	W81	W81		
Rb	370980	0.1100	13.3000	1.2000	6	meas.	(m) M2.45B	12.430	5.760	W83	W83	W83	1.90,2.20	
Sr	380980	0.6500	0.3260	0.0340	5	meas.	EVAP(161.3)	5.880	4.180	W83	W83	W83		
Y	390980	2.0000	0.2280	0.0120	4	meas.	EVAP(196.0)	8.918	6.409	W83	W83	W83		
Y	390981	0.6500	3.4100	0.9600	5	meas.	Y98	0.000	0.000	Y98				

(Continued)

Table III (Cont.)

CS	ID	HL	Pn	dPn	GP	Pn Source	Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
Rb	370990	0.1450	17.1000	4.2000	6	meas.	EVAP(338.4)	11.320	3.760	W83	W83	W83		
Sr	380990	0.6000	0.1290	0.1110	5	meas.	EVAP(179.6)	7.950	5.820	W83	W83	W83		
Y	390990	1.4000	2.0200	1.4500	4	meas.	EVAP(213.8)	7.570	4.552	W81	W81	W81		
Rb	371000	0.0984	4.9500	1.0200	6	meas.	EVAP(339.4)	13.733	6.053	MN	W81	W81		
Sr	381000	0.6180	0.7430	0.0860	5	meas.	EVAP(174.9)	6.700	4.660	W83	W83	W83		
Y	391000	0.8000	0.8420	0.0990	5	meas.	EVAP(210.4)	9.900	6.950	W83	W83	W83		
Rb	371010	0.0939	28.3215	0.0000	6	sys.	EVAP(368.3)	12.310	3.178	MN	MN	W81		
Sr	381010	0.1941	2.4700	0.2800	6	meas.	EVAP(225.4)	9.026	5.605	MN	W81	W81		
Y	391010	0.6071	2.0500	0.2300	5	meas.	EVAP(249.6)	8.720	4.525	W81	W81	W81		
Sr	381020	0.2871	4.7600	2.2900	6	meas.	EVAP(237.2)	8.830	5.005	MN	MN	W81		
Y	391020	0.9000	5.9400	1.7100	4	meas.	EVAP(233.7)	10.442	6.727	MN	W81	W81		
Sr	381030	0.1196	8.8758	0.0000	6	sys.	EVAP(298.0)	11.590	5.491	MN	MN	MN		
Y	391030	0.2604	12.3656	0.0000	6	sys.	EVAP(268.5)	8.879	3.929	MN	W81	W81		
Zr	401030	1.3377	0.0242	0.0000	4	sys.	EVAP(98.1)	7.500	6.839	W81	W81	W81		
Nb	411030	1.5000	0.0137	0.0000	4	sys.	EVAP(74.4)	5.500	5.120	W83	W83	W83		
Sr	381040	0.1629	13.4698	0.0000	6	sys.	EVAP(312.7)	10.150	3.371	MN	MN	MN		
Y	391040	0.1283	8.7769	0.0000	6	sys.	EVAP(281.9)	11.890	6.382	MN	MN	W81		
Zr	401040	2.5730	0.1824	0.0000	4	sys.	EVAP(127.0)	5.846	4.728	MN	W81	W81		
Nb	411040	4.8000	0.0406	0.0000	3	sys.	EVAP(104.7)	8.700	7.940	W83	W83	W83		
Y	391050	0.1469	19.7529	0.0000	6	sys.	EVAP(312.6)	10.430	3.591	MN	MN	MN		
Zr	401050	0.4930	1.0879	0.0000	5	BETA	EVAP(179.5)	8.285	6.030	MN	W81	W81		
Nb	411050	2.8000	2.2322	0.0000	4	sys.	EVAP(180.1)	7.000	4.730	W83	W83	W83		
Y	391060	0.0894	15.6613	0.0000	6	sys.	EVAP(323.1)	13.100	5.721	MN	MN	MN		
Zr	401060	0.9071	1.5242	0.0000	4	sys.	EVAP(190.4)	7.230	4.667	MN	MN	W81		
Nb	411060	1.0000	0.9402	0.0000	4	sys.	EVAP(181.7)	10.099	7.766	MN	W81	W81		
Y	391070	0.0923	25.9442	0.0000	6	sys.	EVAP(344.0)	11.700	3.261	MN	MN	MN		
Zr	401070	0.2430	3.7127	0.0000	6	sys.	EVAP(235.9)	9.900	5.931	MN	MN	MN		
Nb	411070	0.7660	8.7806	0.0000	5	sys.	EVAP(241.7)	8.324	4.156	MN	W81	W81		
Zr	401080	0.3781	7.0302	0.0000	5	sys.	EVAP(256.8)	8.590	3.841	MN	MN	MN		
Nb	411080	0.2423	6.4669	0.0000	6	sys.	EVAP(249.5)	10.810	6.327	MN	MN	W81		
Mo	421080	1.5000	<0.0001	0.0000	4	sys.	EVAP(17.9)	5.251	5.228	MN	W81	W81		
Zr	401090	0.1300	7.3940	0.0000	6	sys.	EVAP(273.6)	10.940	5.501	MN	MN	MN		
Nb	411090	0,3154	12.6533	0.0000	5	sys.	EVAP(270.3)	9.340	4.031	MN	MN	MN		
Mo	421090	1.4090	0.1359	0.0000	4	sys.	EVAP(129.5)	8.189	6.970	MN	W81	W81		
Tc	431090	1.4000	0.0879	0.0000	4	sys.	EVAP(99.5)	5.900	5.180	W83	W83	W83		
Nb	411100	0.1298	10.0525	0.0000	6	sys.	EVAP(280.7)	11.900	6.121	MN	MN	MN		
Mo	421100	2.7720	1.3758	0.0000	4	sys.	EVAP(167.9)	6.010	3.942	MN	MN	W81		
Tc	431100	0.8300	0.6210	0.0000	4	sys.	EVAP(163.4)	9.646	7.689	MN	W81	W81		
Nb	411110	0.1718	18.3948	0.0000	6	sys.	EVAP(306.0)	10.710	3.781	MN	MN	MN		
Mo	421110	0.4664	1.0303	0.0000	5	sys.	EVAP(173.6)	8.280	6.051	MN	MN	MN		
Tc	431110	1.9824	5.6954	0.0000	4	sys.	EVAP(220.4)	8.147	4.552	MN	W81	W81		
Mo	421120	0.9754	2.0788	0.0000	4	sys.	EVAP(191.5)	7.060	4.321	MN	MN	MN		
Tc	431120	0.4314	5.2031	0.0000	5	sys.	EVAP(226.4)	10.010	6.184	MN	MN	W81		
Mo	421130	0.2287	3.7966	0.0000	6	sys.	EVAP(231.3)	9.940	5.911	MN	MN	MN		
Tc	431130	0.6524	7.1864	0.0000	5	sys.	EVAP(233.3)	8.590	4.491	MN	MN	MN		
Ru	441130	3.0000	0.0005	0.0000	4	sys.	EVAP(52.3)	7.391	7.185	MN	W81	W81		

(Continued)

Table III (Cont.)

CS	ID	HL	Pn	dPn	GP	Pn Source	Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
Tc	431140	0.2023	6.5358	0.0000	6	sys.	EVAP(251.5)	11.320	6.511	MN	MN	MN		
Ru	441140	8.1365	0.1039	0.0000	3	sys.	EVAP(107.6)	5.420	4.540	MN	MN	W81		
Rh	451140	1.7000	0.0020	0.0000	4	sys.	EVAP(62.8)	8.263	7.963	MN	W81	W81		
Tc	431150	0.2704	14.3371	0.0000	6	sys.	EVAP(278.1)	9.930	4.001	MN	MN	MN		
Ru	441150	0.8784	0.2276	0.0000	4	sys.	EVAP(136.0)	8.170	6.751	MN	MN	MN		
Rh	451150	8.3154	0.7746	0.0000	3	sys.	EVAP(140.4)	6.405	4.893	MN	W81	W81		
Tc	431160	0.1155	12.2226	0.0000	6	sys.	EVAP(293.4)	12.670	6.011	MN	MN	MN		
Ru	441160	1.7004	1.0811	0.0000	4	sys.	EVAP(167.1)	6.730	4.571	MN	MN	MN		
Rh	451160	0.9492	0.5379	0.0000	4	sys.	EVAP(154.0)	9.417	7.583	MN	W81	W81		
Tc	431170	0.1518	21.2499	0.0000	6	sys.	EVAP(309.7)	11.010	3.531	MN	MN	MN		
Ru	441170	0.3428	2.0509	0.0000	5	sys.	EVAP(202.5)	9.480	6.281	MN	MN	MN		
Rh	451170	1.2174	4.8201	0.0000	4	sys.	EVAP(200.5)	7.530	4.395	MN	MN	W81		
Ru	441180	0.6623	4.1092	0.0000	5	sys.	EVAP(216.6)	7.800	4.111	MN	MN	MN		
Rh	451180	0.3156	2.9167	0.0000	5	sys.	EVAP(208.5)	10.380	6.961	MN	MN	MN		
Ru	441190	0.1950	4.3580	0.0000	6	sys.	EVAP(237.1)	10.460	6.001	MN	MN	MN		
Rh	451190	0.4654	8.2971	0.0000	5	sys.	EVAP(234.9)	8.740	4.361	MN	MN	MN		
Pd	461190	1.7587	<0.0001	0.0000	4	sys.	EVAP(35.5)	7.160	7.060	MN	W81	W81		
Ag	471190	2.1000	<0.0001	0.0000	4	sys.	EVAP(29.7)	5.370	5.300	W81	W81	W81		
Ru	441200	0.3503	7.5652	0.0000	5	sys.	EVAP(251.2)	8.940	3.891	MN	MN	MN		
Rh	451200	0.1725	5.9282	0.0000	6	sys.	EVAP(246.2)	11.590	6.741	MN	MN	MN		
Pd	461200	3.9065	0.0068	0.0000	3	sys.	EVAP(72.3)	5.687	5.269	MN	W81	W81		
Ag	471200	1.1700	0.0015	0.0000	4	m<.003	EVAP(35.5)	8.210	8.109	W81	W81	W81		
Rh	451210	0.2496	13.5677	0.0000	6	sys.	EVAP(272.9)	10.160	4.151	MN	MN	MN		
Pd	461210	0.6437	0.2722	0.0000	5	sys.	EVAP(138.0)	8.331	6.795	MN	W81	W81		
Ag	471210	0.8000	0.0753	0.0048	5	meas.	EVAP(129.4)	6.400	5.050	W83	W83	W83		
Rh	451220	0.1071	8.3012	0.0000	6	sys.	EVAP(274.3)	12.900	6.781	MN	MN	MN		
Pd	461220	1.4112	0.4377	0.0000	4	sys.	EVAP(138.0)	6.280	4.731	MN	MN	W81		
Ag	471220	1.5000	0.1840	0.0110	4	meas.	EVAP(142.8)	9.427	7.768	MN	W81	W81		
Rh	451230	0.1343	17.1070	0.0000	6	sys.	EVAP(292.8)	10.990	3.961	MN	MN	MN		
Pd	461230	0.3004	0.6897	0.0000	5	sys.	EVAP(168.2)	9.410	7.091	MN	MN	MN		
Ag	471230	0.3900	0.5450	0.0340	5	meas.	EVAP(168.8)	7.730	5.394	MN	MN	W81		
Pd	461240	0.5140	2.6986	0.0000	5	sys.	EVAP(194.9)	7.500	4.361	MN	MN	MN		
Ag	471240	0.2495	2.2881	0.0000	6	sys.	EVAP(201.9)	10.780	7.411	MN	MN	MN		
Pd	461250	0.1660	2.2664	0.0000	6	sys.	EVAP(209.0)	10.310	6.671	MN	MN	MN		
Ag	471250	0.3335	6.3167	0.0000	5	sys.	EVAP(222.0)	8.830	4.721	MN	MN	MN		
Pd	461260	0.2520	5.0310	0.0000	6	sys.	EVAP(227.8)	8.690	4.331	MN	MN	MN		
Ag	471260	0.1398	4.6380	0.0000	6	sys.	EVAP(231.4)	11.500	7.001	MN	MN	MN		
Ag	471270	0.1753	9.8629	0.0000	6	sys.	EVAP(250.2)	9.840	4.541	MN	MN	MN		
Cd	481270	0.5719	0.0101	0.0000	5	sys.	EVAP(80.0)	7.720	7.178	MN	W81	W81		
In	491270	3.7600	0.6600	0.0630	3	meas.	EVAP(105.3)	6.494	5.555	W83	W83	W83		
In	491271	1.3000	<0.0001	0.0000	4	In127	In127	0.000	0.000	In127				
Ag	471280	0.0943	6.8861	0.0000	6	sys.	EVAP(250.6)	12.050	6.691	MN	MN	MN		
Cd	481280	1.0530	0.1215	0.0000	4	sys.	EVAP(109.8)	6.049	5.021	MN	W81	W81		
In	491280	0.8400	0.0610	0.0370	4	meas.	EVAP(129.5)	9.310	7.880	W83	W83	W83		
Cd	481290	0.2987	0.1519	0.0000	6	sys.	EVAP(124.3)	8.468	7.140	MN	W81	W81		
In	491290	0.9900	2.9200	0.3700	4	meas.	(m) BO.1R	7.600	5.390	W83	W83	W83	0.10,0.20	

(Continued)

Table III (Cont.)

CS	ID	HL	Pn	dPn	GP	Pn Source		Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
In	491291	2.5000	0.7600	2.5000	4	meas.		In129	0.000	0.000	in129				
Cd	481300	0.4767	0.9676	0.0000	5	sys.		EVAP(161.7)	7.295	5.029	MN	W81	W81		
In	491300	0.5800	1.0400	0.9500	5	meas.	(m)	BO.12R	10.200	7.630	W83	W83	W83	0.12,0.22	
In	491301	0.5100	1.4800	0.1050	5	meas.		In130	0.000	0.000	in130				
Cd	481310	0.1062	4.8728	0.0000	6	sys.		EVAP(249.4)	12.068	6.635	MN	W81	W81		
In	491310	0.2800	1.8400	1.0700	6	meas.		EVAP(202.2)	8.820	5.250	W83	W83	W83		
In	491311	0.1110	1.7300	0.2400	6	meas.		In131	0.000	0.000	in131				
Cd	481320	0.1357	20.5597	0.0000	6	sys.		EVAP(318.5)	11.820	2.893	MN	MN	W81		
In	491320	0.1200	5.3600	0.8300	6	meas.		EVAP(259.5)	13.235	7.308	MN	W81	W81		
In	491330	0.1116	31.6560	0.0000	6	sys.		EVAP(332.8)	12.600	2.777	MN	MN	W81		
Sn	501330	1.4700	0.2549	0.0000	4	sys.		EVAP(137.2)	9.050	7.380	W83	W83	W83		
In	491340	0.0806	33.7565	0.0000	6	sys.		EVAP(349.3)	14.740	3.841	MN	MN	MN		
Sn	501340	1.0400	18.3000	13.9000	4	meas.	(m)	BO.1R1.62B	6.925	3.091	MN	W81	W81	0.10,0.20	1.40,1.60
Sb	511340	10.2000	0.1040	0.0350	2	meas.		EVAP(100.9)	8.410	7.500	W83	W83	W83		
Sn	501350	0.4180	9.2929	0.0000	5	sys.		EVAP(237.4)	9.580	4.507	MN	MN	W81		
Sb	511350	1.8200	17.8700	2.1600	4	meas.	(m)	M2.075B	7.540	3.510	W83	W83	W83	1.575,2.075	
Sn	501360	0.7172	16.3918	0.0000	5	sys.		EVAP(254.4)	8.300	2.431	MN	MN	MN		
Sb	511360	0.8200	28.9788	3.1138	4	meas.		EVAP(234.1)	9.611	4.642	MN	W81	W81		
Te	521360	19.0000	1.1400	0.4300	2	meas.	(m)	BO.07R	5.100	3.760	W83	W83	W83	0.07,0.17	
Sb	511370	0.4780	18.0322	0.0000	5	sys.		EVAP(250.9)	9.020	3.270	MN	MN	W81		
Te	521370	3.5000	2.6900	0.6300	3	meas.		EVAP(146.1)	7.020	5.070	W83	W83	W83		
I	531370	24.5000	6.9700	0.4200	2	meas.	(m)	M1.5R1.75B	5.885	4.025	W83	W83	W83	1.20,1.50	1.35,1.75
Sb	511380	0.1734	22.0114	0.0000	6	sys.		EVAP(280.5)	11.610	4.371	MN	MN	MN		
Te	521380	1.6000	6.7800	2.2600	4	meas.		EVAP(165.5)	6.432	3.913	MN	W81	W81		
I	531380	6.5000	5.3800	0.4300	3	meas.	(m)	R1.92B	7.820	5.820	W83	W83	W83	1.42,1.92	
Sb	511390	0.2178	41.6934	0.0000	6	sys.		EVAP(292.3)	9.640	1.721	MN	MN	MN		
Te	521390	0.5800	7.9624	0.0000	5	sys.		EVAP(225.5)	9.321	4.610	MN	W81	W81		
I	531390	2.3800	9.8100	0.6200	4	meas.	(m)	R1.61B	6.820	3.640	W83	W83	W83	1.30,1.60	
Te	521400	0.8938	15.4961	0.0000	4	sys.		EVAP(234.2)	7.360	2.240	MN	MN	W81		
I	531400	0.8600	9.2700	0.7900	4	meas.	(m)	BO.09R1.76B	9.967	5.392	MN	W81	W81	0.09,0.19	1.40,1.70
Te	521410	0.2726	10.4723	0.0000	6	sys.		EVAP(243.2)	10.050	4.491	MN	MN	MN		
I	531410	0.4600	21.3000	3.2000	5	meas.	(m)	R1.68B	8.892	3.417	MN	W81	W81	1.00,1.60	
Xe	541410	1.7200	0.0353	0.0061	4	meas.		EVAP(82.8)	6.155	5.510	W83	W83	W83		
Cs	551410	24.9000	0.0474	0.0550	2	meas.	(m)	MAINZ	5.256	4.548	W83	W83	W83		
Te	521420	0.5901	15.0790	0.0000	5	sys.		EVAP(246.4)	8.330	2.581	MN	MN	MN		
I	531420	0.2000	13.8601	0.0000	6	sys.		EVAP(258.2)	11.553	5.242	MN	W81	W81		
Xe	541420	1.2200	0.4040	0.0380	4	meas.		EVAP(97.2)	5.040	4.146	W83	W83	W83		
Cs	551420	1.6900	0.0949	0.0940	4	meas.	(m)	MO.93B	7.320	6.210	W83	W83	W83	0.63,0.93	
I	531430	0.4010	38.4989	0.0000	5	sys.		EVAP(272.5)	8.900	1.819	MN	MN	W81		
Xe	541430	0.9600	3.0557	0.0000	4	sys.		EVAP(183.8)	8.510	5.289	MN	W81	W81		
Cs	551430	1.7800	1.6000	0.0800	4	meas.	(m)	GO.2M1.1B	6.280	4.240	W83	W83	W83	0.10,0.30	0.80,1.10
I	531440	0.1460	15.2394	0.0000	6	sys.		EVAP(256.4)	11.280	4.971	MN	MN	MN		
Xe	541440	1.1000	4.6118	0.0000	4	sys.		EVAP(192.0)	7.236	3.697	MN	W81	W81		
Cs	551440	1.0010	3.1300	0.1700	4	meas.	(m)	GO.2M1.175B	8.460	5.870	W83	W83	W83	0.10,0.30	0.875,1.175
I	531450	0.1934	24.0859	0.0000	6	sys.		EVAP(269.1)	9.930	2.931	MN	MN	MN		
Xe	541450	0.9000	6.1090	0.0000	4	sys.		EVAP(211.0)	9.191	4.886	MN	W81	W81		

(Continued)

Table III (Cont.)

CS	ID	HL	Pn	dPn	GP	Pn Source	Spectra Source	Q_β	S(n)	Mass Tables M1	M2	M3	Norm Area 1	Norm Area 2
Cs	551450	0.5900	13.5900	0.9000	5	meas.	(m) GO.2M1.1B	7.800	4.240	W83	W83	W83	0.10,0.30	0.80,1.10
Xe	541460	0.5627	6.5048	0.0000	5	sys.	EVAP(212.4)	8.122	3.732	MN	W81	W81		
Cs	551460	0.3400	13.3000	1.7200	5	meas.	(m) M1.3B	9.410	5.130	W83	W83	W83	1.00,1.30	
Ba	561460	2.0000	0.0100	0.0000	4	m<.02	EVAP(65.4)	4.270	3.770	**				
La	571460	11.0000	0.0035	0.0000	2	m<.007	EVAP(22.5)	6.650	6.591	MN	MN	MN		
Xe	541470	0.1991	8.7056	0.0000	6	sys.	EVAP(233.5)	10.151	4.810	MN	W81	W81		
Cs	551470	0.5460	26.1000	2.5000	5	meas.	(m) M1.8B	8.880	4.240	W83	W83	W83	1.40,1.80	
Ba	561470	1.7550	0.0210	0.0020	4	meas.	EVAP(20.2)	5.710	5.670	W83	W83	W83		
La	571470	5.0000	0.0330	0.0060	3	meas.	EVAP(85.1)	5.190	4.480	W83	W83	W83		
Cs	551480	0.2056	25.1000	2.8000	6	meas.	EVAP(246.8)	11.777	5.766	MN	W81	W81 #		
Ba	561480	3.3250	0.0060	0.0020	3	meas.	EVAP(62.9)	5.400	5.010	W83	W83	W83		
La	571480	1.3000	0.1330	0.0100	4	meas.	EVAP(42.7)	6.500	6.320	W83	W83	W83		
Cs	551490	0.2442	32.7567	0.0000	6	sys.	EVAP(269.7)	9.420	2.195	MN	MN	W81		
Ba	561490	0.6950	0.5750	0.0840	5	meas.	EVAP(157.0)	7.800	5.350	W83	W83	W83		
La	571490	2.4080	1.0600	0.1400	4	meas.	EVAP(107.6)	6.100	4.950	W83	W83	W83		
Cs	551500	0.1238	15.0881	0.0000	6	sys.	EVAP(254.1)	11.480	5.021	MN	MN	MN		
Ba	561500	0.9620	10.9278	0.0000	4	sys.	EVAP(205.8)	6.740	2.504	MN	MN	W81		
La	571500	0.6080	0.3991	0.0000	5	sys.	EVAP(114.9)	7.620	6.300	W83	W83	W83		
Ba	561510	0.3327	3.7569	0.0000	5	sys.	EVAP(187.8)	8.760	5.211	MN	MN	MN		
La	571510	0.7194	6.5495	0.0000	5	sys.	EVAP(188.6)	7.670	4.089	MN	MN	W81		
Ba	561520	0.4205	5.7209	0.0000	5	sys.	EVAP(198.7)	7.680	3.681	MN	MN	MN		
La	571520	0.2850	6.0393	0.0000	6	sys.	EVAP(198.4)	9.650	5.661	MN	MN	MN		
La	571530	0.3258	10.6885	0.0000	5	sys.	EVAP(215.5)	8.640	3.901	MN	MN	MN		
Ce	581530	1.4688	0.6219	0.0000	4	sys.	EVAP(126.6)	7.040	5.404	MN	MN	W81		
La	571540	0.1493	10.2702	0.0000	6	sys.	EVAP(227.2)	10.680	5.381	MN	MN	MN		
Ce	581540	2.0161	0.6373	0.0000	4	sys.	EVAP(127.1)	6.030	4.371	MN	MN	MN		
Pr	591540	1.0614	0.1110	0.0000	4	sys.	EVAP(94.0)	7.575	6.668	MN	W81	W81		
La	571550	0.1540	16.7592	0.0000	6	sys.	EVAP(242.7)	9.600	3.511	MN	MN	MN		
Ce	581550	0.5278	1.6004	0.0000	5	sys.	EVAP(156.1)	8.050	5.531	MN	MN	MN		
Pr	591550	1.1224	1.5427	0.0000	4	sys.	EVAP(140.6)	6.790	4.746	MN	MN	W81		
Ce	581560	0.5963	2.9922	0.0000	5	sys.	EVAP(170.4)	7.000	3.981	MN	MN	MN		
Pr	591560	0.3793	2.7170	0.0000	5	sys.	EVAP(164.3)	8.780	5.971	MN	MN	MN		
Ce	581570	0.2144	4.4528	0.0000	6	sys.	EVAP(192.5)	9.050	5.171	MN	MN	MN		
Pr	591570	0.3800	6.3874	0.0000	5	sys.	EVAP(185.7)	7.750	4.141	MN	MN	MN		
Pr	591580	0.1685	6.4230	0.0000	6	sys.	EVAP(198.9)	9.810	5.641	MN	MN	MN		
Nd	601580	2.6949	0.0053	0.0000	4	sys.	EVAP(56.7)	4.960	4.621	MN	MN	MN		
Pr	591590	0.1806	12.3634	0.0000	6	sys.	EVAP(217.4)	8.720	3.711	MN	MN	MN		
Nd	601590	0.6146	0.2361	0.0000	5	sys.	EVAP(108.6)	7.090	5.841	MN	MN	MN		
Pm	611590	3.0005	0.0185	0.0000	3	sys.	EVAP(62.9)	5.290	4.871	MN	MN	W81		
Nd	601600	0.7886	0.9469	0.0000	5	sys.	EVAP(131.7)	5.990	4.141	MN	MN	MN		
Pm	611600	0.7289	0.2676	0.0000	5	sys.	EVAP(103.8)	7.430	6.281	MN	MN	MN		
Nd	601610	0.3113	1.6982	0.0000	5	sys.	EVAP(154.4)	8.020	5.461	MN	MN	MN		
Pm	611610	0.7899	1.7504	0.0000	5	sys.	EVAP(135.4)	6.360	4.391	MN	MN	MN		
Pm	611620	0.3243	2.1452	0.0000	5	sys.	EVAP(151.8)	8.400	5.911	MN	MN	MN		
Sm	621640	1.3850	0.0124	0.0000	4	sys.	EVAP(63.4)	5.010	4.571	MN	MN	MN		
Eu	631640	1.5327	<0.0001	0.0000	4	sys.	EVAP(13.2)	6.590	6.571	MN	MN	MN		
Sm	621650	0.4536	0.2491	0.0000	5	sys.	EVAP(106.1)	6.930	5.691	MN	MN	MN		
Eu	631650	1.3546	0.1911	0.0000	4	sys.	EVAP(90.4)	5.650	4.751	MN	MN	MN		

(Continued)

[a]General Notes

This table contains the latest evaluated Pn values (10/86). Values indicated as derived from systematics are based on a least squares fit of the evaluated Pn values to the parameters in the Herrmann-Kratz equation. (The current spectral file is labeled tp3final.)

CS - chemical symbol
ID - nuclide ID = 10000*Z+10*A+S
HL - halflife in seconds (For most nuclides, these values are taken from the ENDF/B-V summary, Ref. 4.)
Pn - probability of delayed neutron emission in per cent
dPn - uncertainty in Pn value (0.0 for calculated values)
GP - indicates which of the six temporal groups the nuclide probably belongs in.
Q_β and S(n) are in MeV.

Norm Area 1 and Norm Area 2 give the energy bounds in MeV being used in normalizing the spectra that were joined at the energies indicated under spectra source where energies are also in MeV and

B - BETA Code
G - Greenwood and Caffrey experimental data
M - Mainz group experimental data (K. Kratz and progress reports)
R - Rudstam (Studsvik) experimental data
E - Evaporation model

M1 - source of mass of Z, A
M2 - source of mass of Z+1, A
M3 - source of mass of Z+1, A-1

MN - Möller-Nix (Ref. 21)
W81 - Wapstra81 (Intermediate version of Ref. 22)
W83 - Wapstra83 (Ref. 22)

If the spectrum source is "EVAP," the temperature parameter in keV is given in parentheses.

** A fictitious S(n) is given this nuclide to obtain a positive energy window. Möller-Nix masses give a negative energy window. However, this precursor has a measured Pn value.

Most evaporation spectra were calculated using W81 or MN masses; some nuclides do have Wapstra83 masses available. W83 masses agree with those used to calculate this evaporation spectra (in terms of energy difference) with the exception of those indicated by #. [For #Cs-148, the W81 values give an energy window = 0.411 MeV larger than the W83 masses (Q_β) = 10.92, S(n) = 5.6, Pn = 6.9075).]

The systematic Pn values are from the Kratz-Hermann equation using Fred Mann's fit for a and b from the Birmingham meeting, September 1986 [a = 54.0, b = 3.44.]

Pn values and uncertainties are listed in per cent. Eighty-five are based on an updated evaluation (through 1986), including recent, unpublished data by Reeder and Warner.[23] The evaluation uses the methodology we described in Ref. 12; the updating is described in Ref. 24 (to be published). The 85 Pn values have the notation "meas." under the column Pn Source. The rest use the Q_β and S(n) values in the systematic equation of Hermann and Kratz: [25]

$$Pn = a[Q_\beta - S(n))/(Q_\beta - K)]^b \quad , \qquad (1)$$

where b (= 3.44) and a (= 54.0) are fitted to the evaluated Pn's and

$$K = 0 \quad \text{even-even precursor}$$
$$= 13/A^{1/2} \quad \text{odd precursor}$$
$$= 26/A^{1/2} \quad \text{odd-odd precursor.}$$

Exceptions to these general statements are either evident or explicity noted in the table.

Some of the problems found with measured spectra and with model approximations are illustrated in Figs. 6-12. The data for the nuclides ^{94g}Rb (Figs. 6 and 7), ^{96g}Rb (Figs. 8 and 9), and ^{92g}Rb (Figs. 10 and 11) are plotted in two forms: the three different nuclide spectra are conventional histogram plots, followed by the same information plotted after its conversion to the fractional number of neutrons above the abscissa energy. The fractional plots emphasize differences at high energies, and are therefore more useful in comparison with some measurements now in progress. The range of the abscissa for these six plots is identical to the energy window, Q_β - S(n), derived from mass tables. The general shape of the experimental spectrum in Fig. 6 is typical; clearly, in measurements over the total energy range, the higher range of possible neutron energies would be very uncertain due to the relatively low counting rate. Model calculations extend over the full energy range, and in this case, follow the general shape of the measured spectra; these models cannot, however, reproduce the actual fine structure.

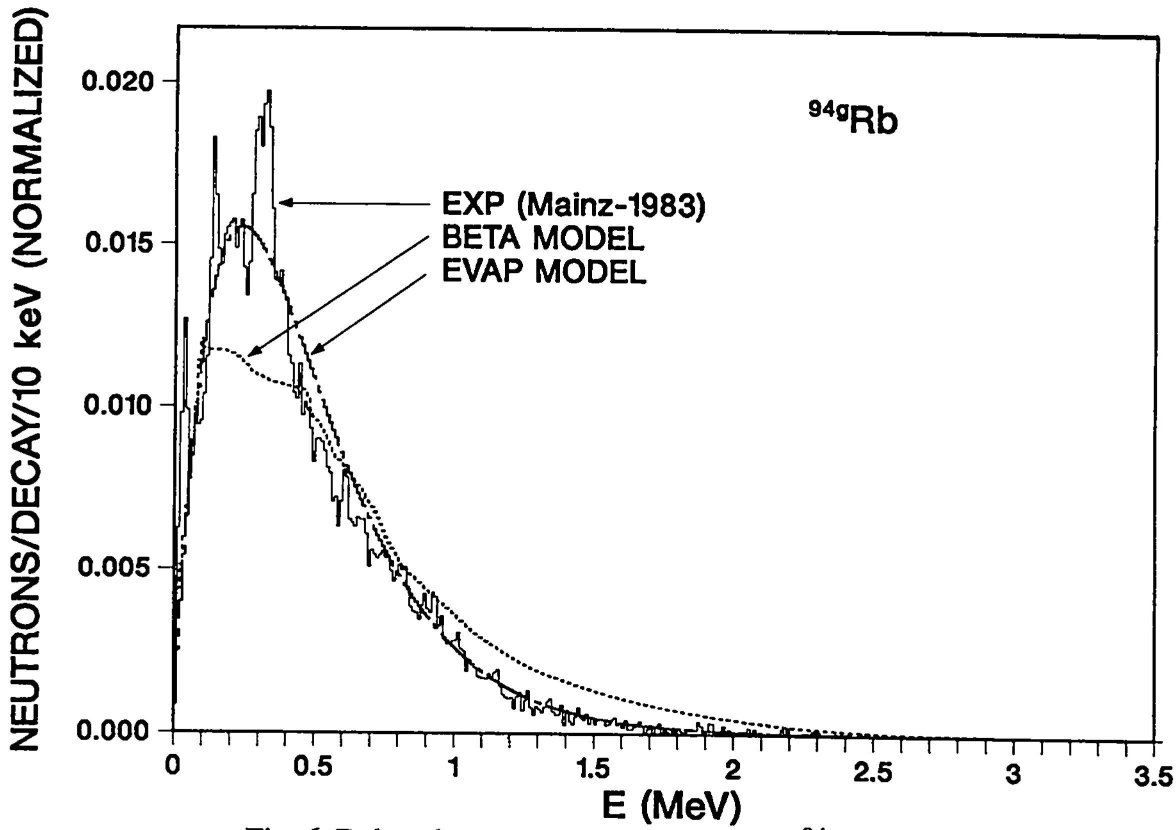

Fig. 6. Delayed neutron spectra for nuclide ^{94g}Rb.

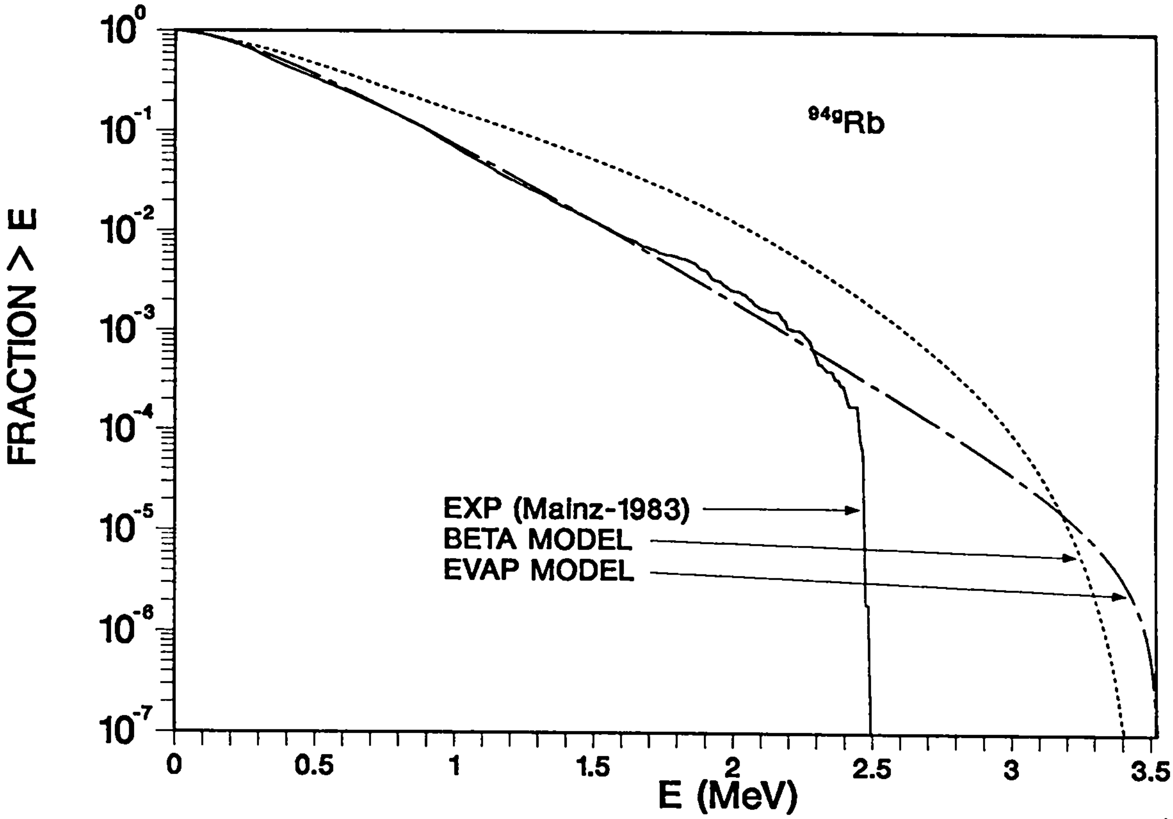

Fig. 7. Spectra as a fraction > E for nuclide ^{94g}Rb.

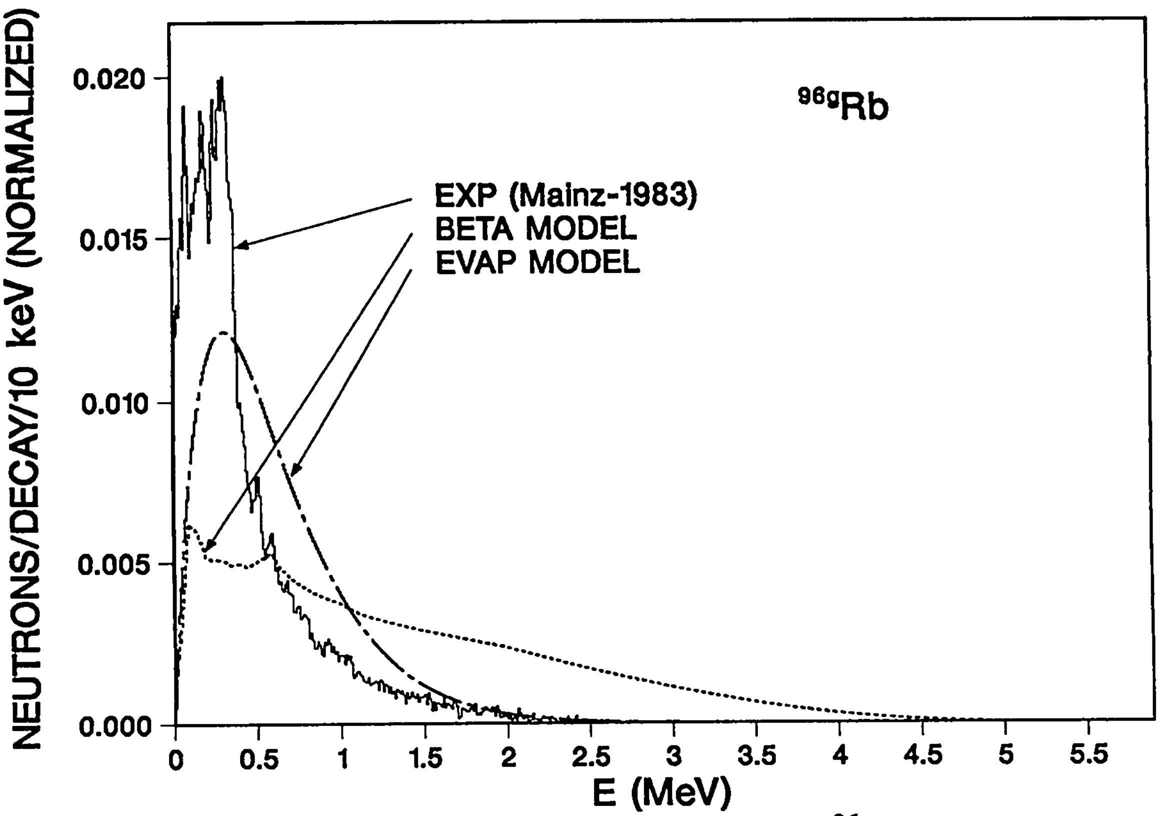

Fig. 8. Delayed neutron spectra for nuclide ^{96g}Rb.

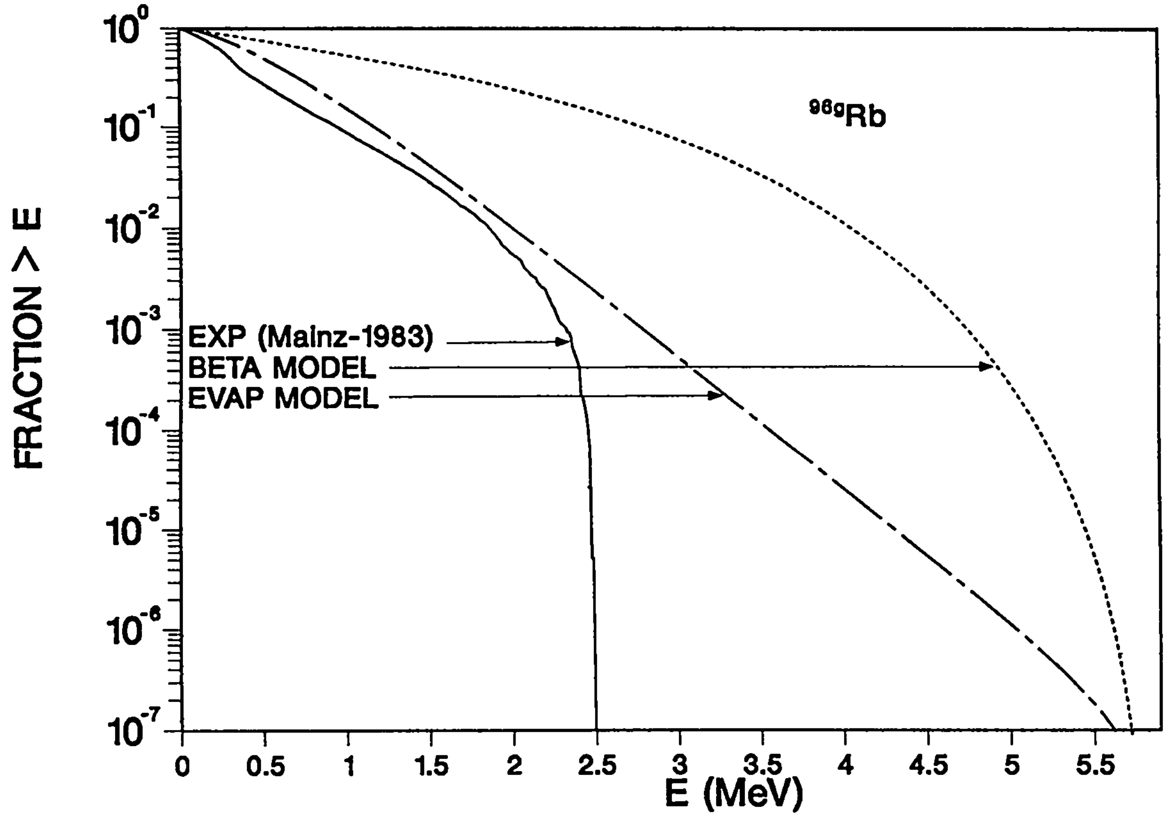

Fig. 9. Spectra as a fraction > E for nuclide ^{96g}Rb.

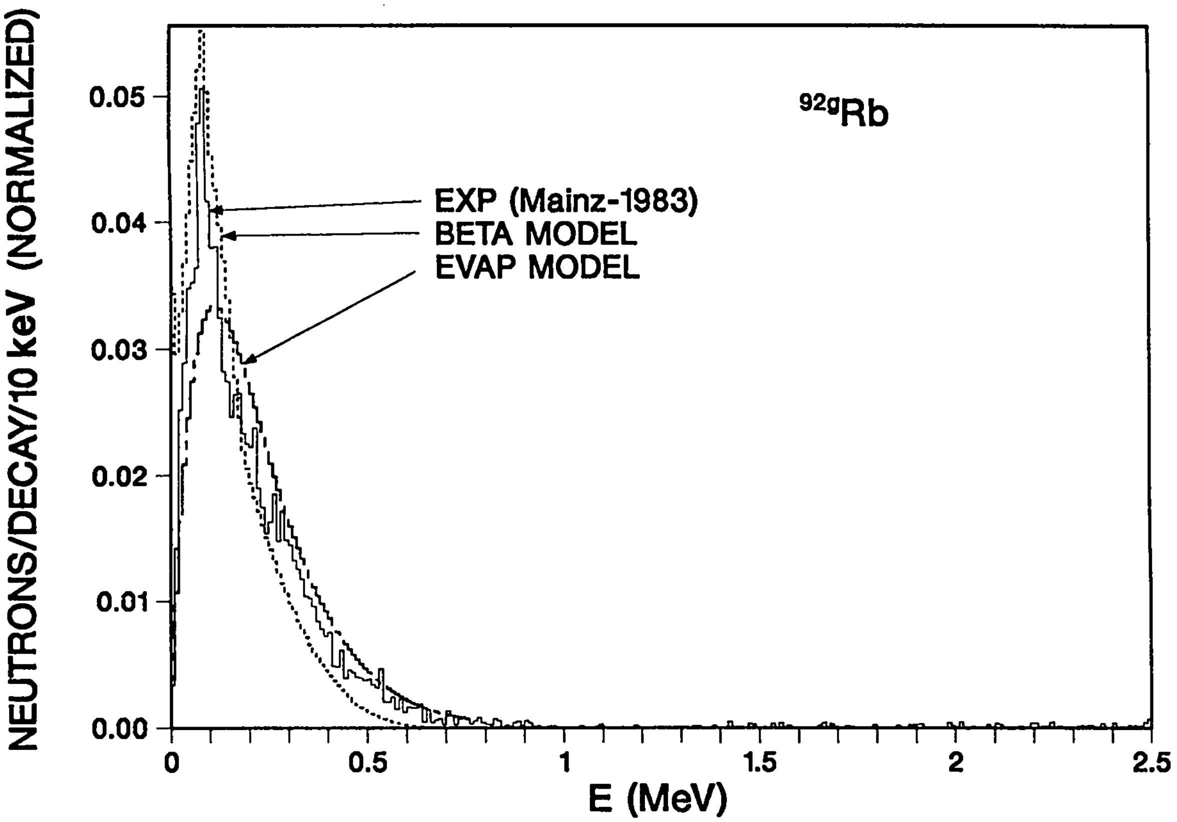

Fig. 10. Delayed neutron spectra for nuclide ^{92g}Rb.

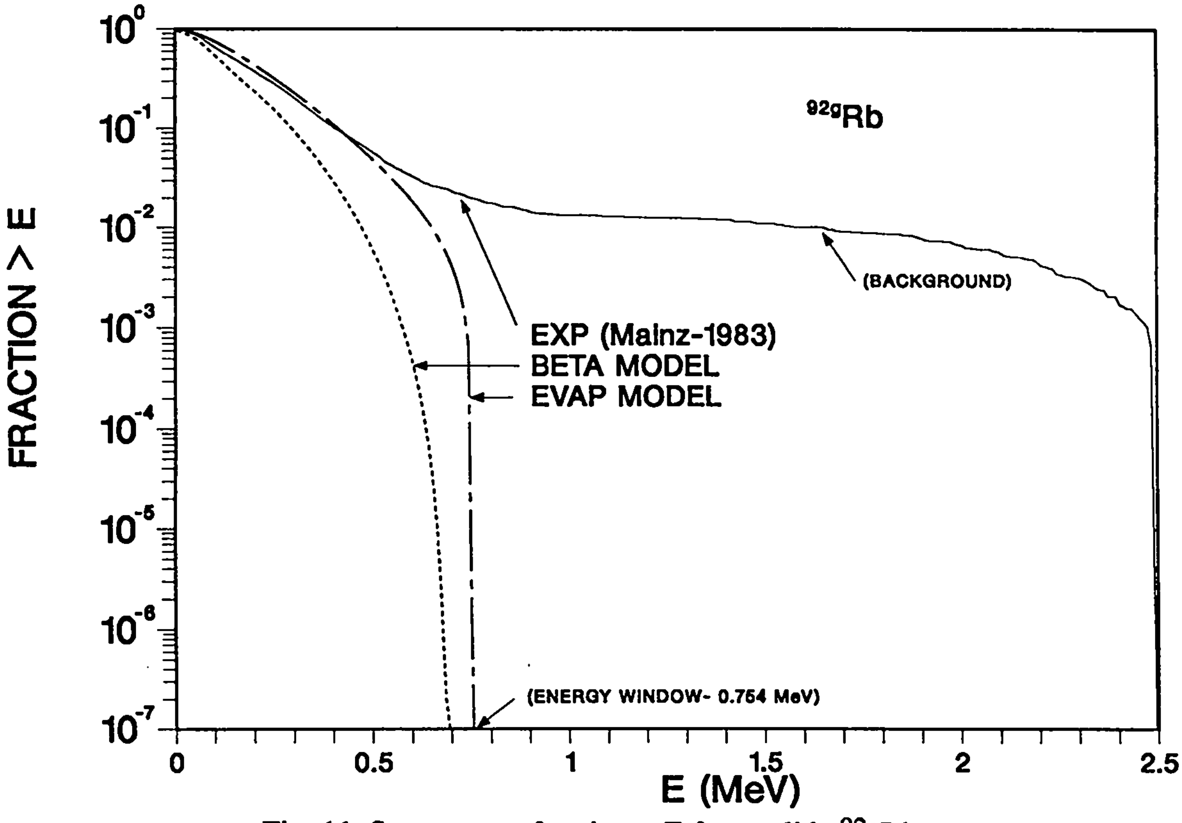

Fig. 11. Spectra as a fraction > E for nuclide ^{92g}Rb.

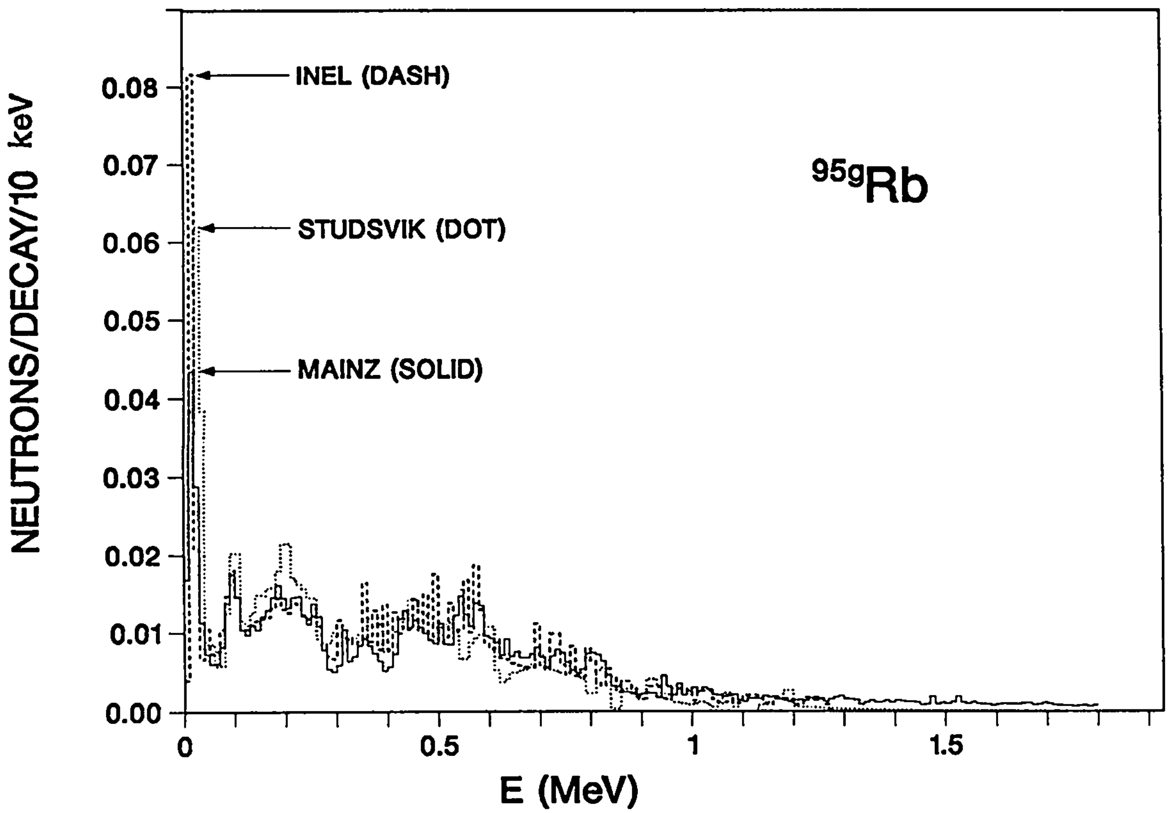

Fig. 12. Normalized delayed neutron spectra for ^{95g}Rb.

In Fig. 8 a primary problem occurring with existing measured spectra and our models is more evident. Measured spectra extend to only ~ 2.5 MeV and are normalized over this range; yet the energy window is ~ 5.9 MeV. Here, the model spectra are clearly incorrect at low energies and the measured spectral range is probably inadequate. This is the case with at least 20 of the 34 measured spectra. Essentially all single measurements are likely to be incomplete in the sense of covering the total energy range. Thus, some are also inadequate at low energies (≤ 100 keV), important in reactors. Attempts here to combine spectra suffer from the problem of normalizations, although this is less severe than suggested by Figs. 8 and 9. As noted earlier, measured spectra do include most of the neutrons but their energy range is usually inadequate.

Figures 10 and 11 illustrate a different, less common problem. The measured spectrum decidedly has a background that must be removed. This appears to be evident from the figures and must be so if the 0.754-MeV energy window is correct.

Figure 12 compares three measured spectra. In this case, normalization affects the comparison of even the measured spectra, especially because of the very large differences in the low-energy peak, although there are real differences that are more evident when comparing ratios of various peaks; ratios are unaffected by normalization.

Our first objective in the current work has been to obtain a complete, fiducial set of precursor data, including data for all probable precursors and a complete energy range for the spectra. This has required some decisions that are in part subjective in the choice of spectral models, measured data to be combined, and the specific method of combination. Table III defines precisely what was combined or used for each precursor. In the case of more than one measurement being available, of the 34 precursors having measurements, we generally used the one covering the largest energy range. There are exceptions based on a comparison of uncertainties. The measurement was assumed to contain essentially all of the neutrons, and any model spectra were first renormalized to this dominant measurement, based on a small energy range defined in Table III. Results were then joined and the total spectrum was renormalized. The available hydrogen recoil measurements (8 precursors) made at Idaho National Engineering Laboratory (INEL)[17] were assumed to be more correct at small energies than the data using ^{3}He spectrometry.[19,20] These were similarly joined below 200 keV, as were the model results (below approximately 100 keV) in 12 cases.

The combined spectra from models generally had little effect on the initial experimental data, as is evident in Fig. 13 where the dashed and solid plots are essentially the same. The range of results from various other combinations is illustrated by Figs. 13-16.

The BETA code[18] was combined only with the 34 measured spectra where it could be normalized to a small range of measured data. This code is described in Ref. 18, as well as in Ref. 13, where it was used extensively. From the previous comparisons, the code clearly needs improvement before using it where no measured data exist to replace its low-energy predictions. Rather, most spectra have a general shape that can be approximated by a simple evaporation model.

The following evaporation model was employed for the 231 precursors having unmeasured spectra:

$$n_d(E) = C\,\{E e^{-E/T} - (Q_\beta - S(n)) e^{-aT}\} \ , \qquad (2)$$

where

$$(Q_\beta - S(n)) = aT^2 \ . \qquad (3)$$

From Eq. (2), the average energy is $\overline{E} \cong 2T$. We used the known spectra to derive an average energy and to then find a value of "a" in Eq. (3), based on the Q_β and S(n) values. The results were used to find a general correlation between "a" and the nuclide mass number:

$$a \cong 2/3\ A. \qquad (4)$$

Based on this and on Eq. (3), the temperature we derived is listed in Table III for each precursor in which the spectra are noted as being "EVAP," i.e., derived from Eq. (2).

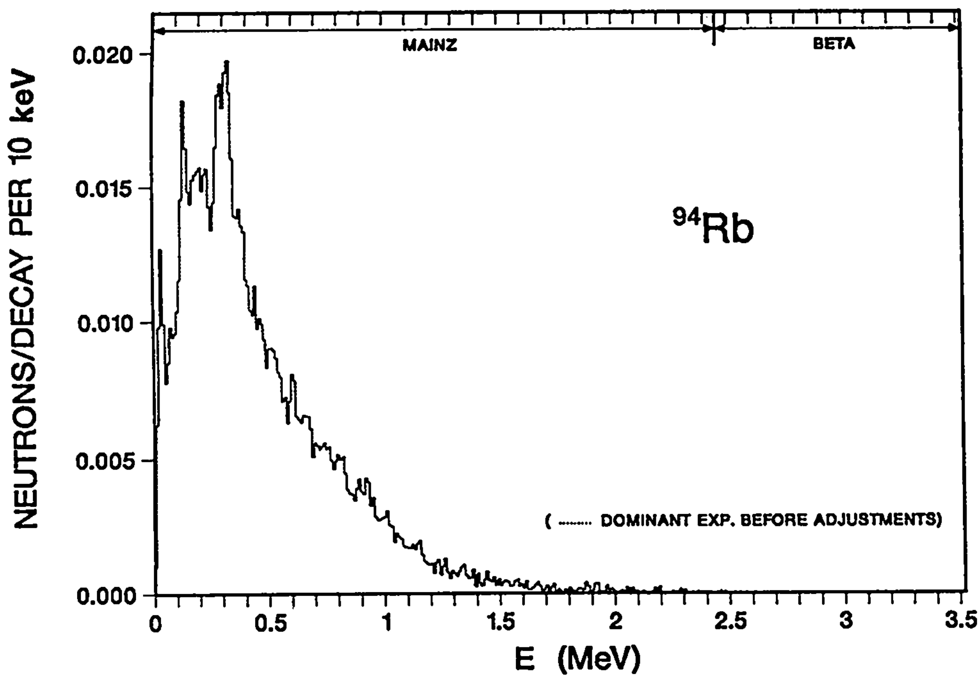

Fig. 13. Normalized delayed neutron spectra for ^{94}Rb.

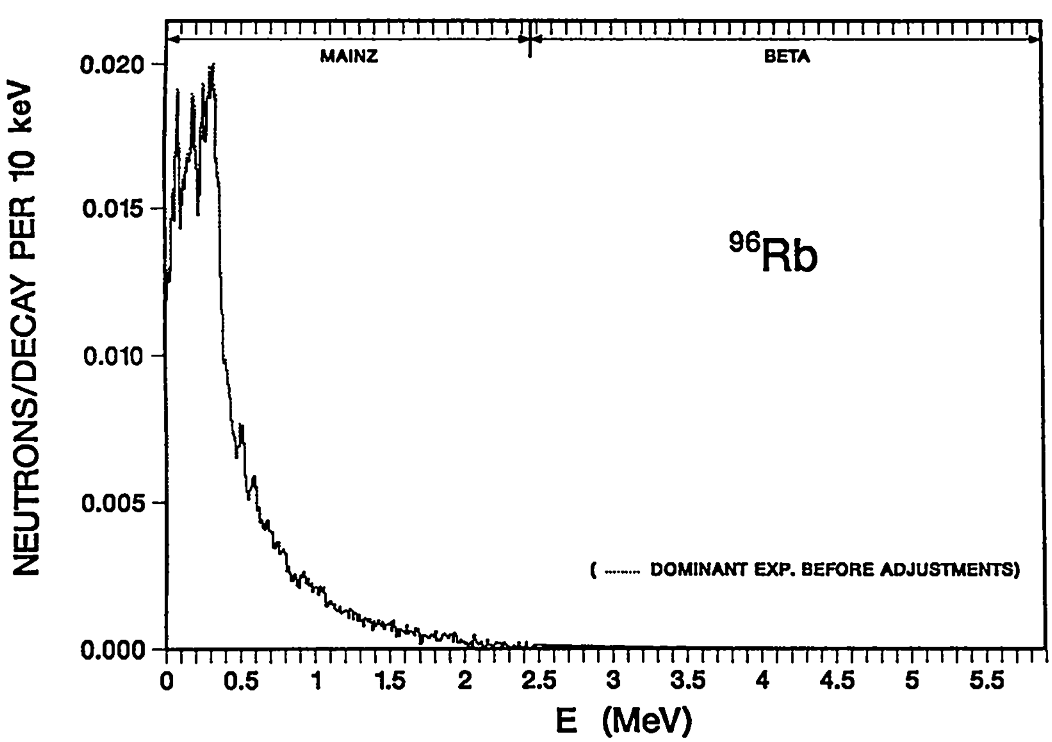

Fig. 14. Normalized delayed neutron spectra for ^{96}Rb.

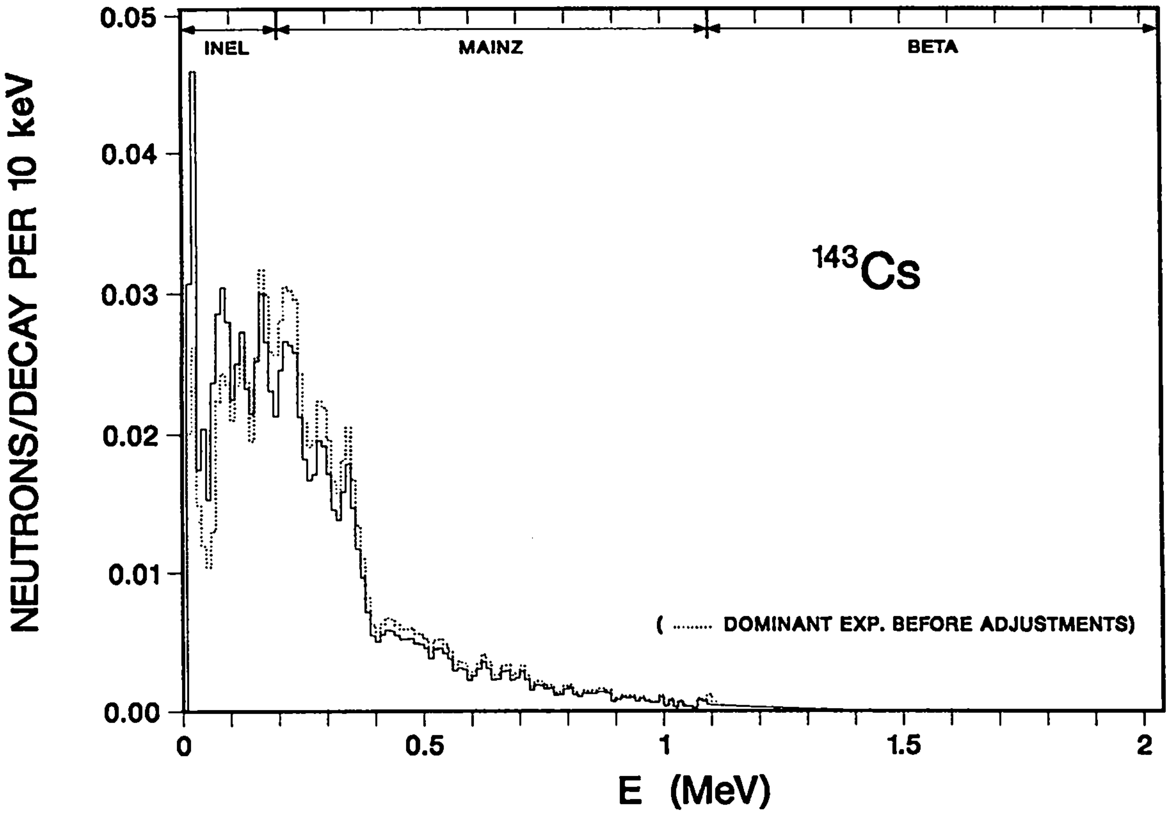

Fig. 15. Normalized delayed neutron spectra for ^{143}Cs.

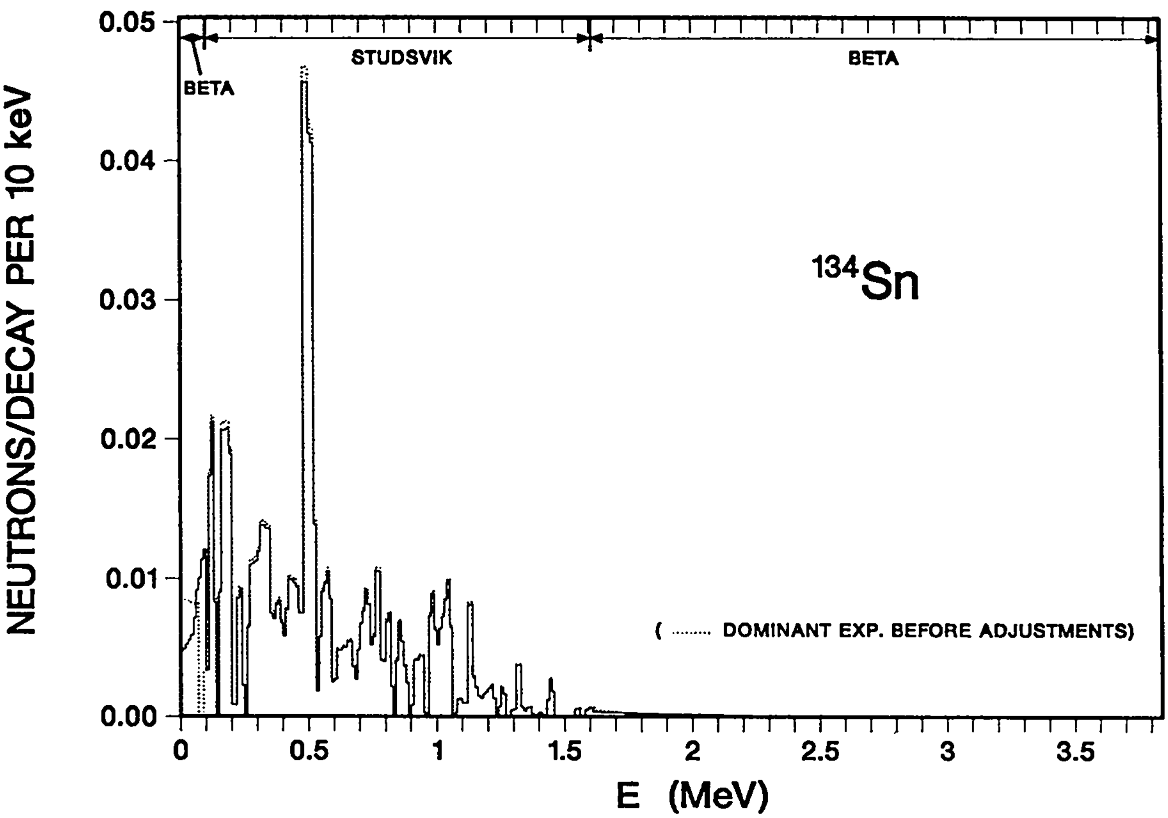

Fig. 16. Normalized delayed neutron spectra for ^{134}Sn.

In an attempt to verify the general validity of the extended spectra, a measurement was made of ^{96}Rb and ^{97}Rb. Results from Ref. 16 show a preliminary comparison with our spectra converted to counts/channel in Figs. 17-18. More recently, we compared the ^{96}Rb as an energy plot with the measured spectra extended by both the BETA code and evaporation models, as shown in Fig. 19. The measured spectra fall between the two extensions. (Here, the measured spectra were normalized to earlier and more detailed measurements of Kratz[19] over their common energy range.) From Figs. 17-19, the higher energy neutrons are obviously present, but there is a large uncertainty in any particular spectrum. The aggregate spectra could be significantly larger or smaller than values shown in Section IV.

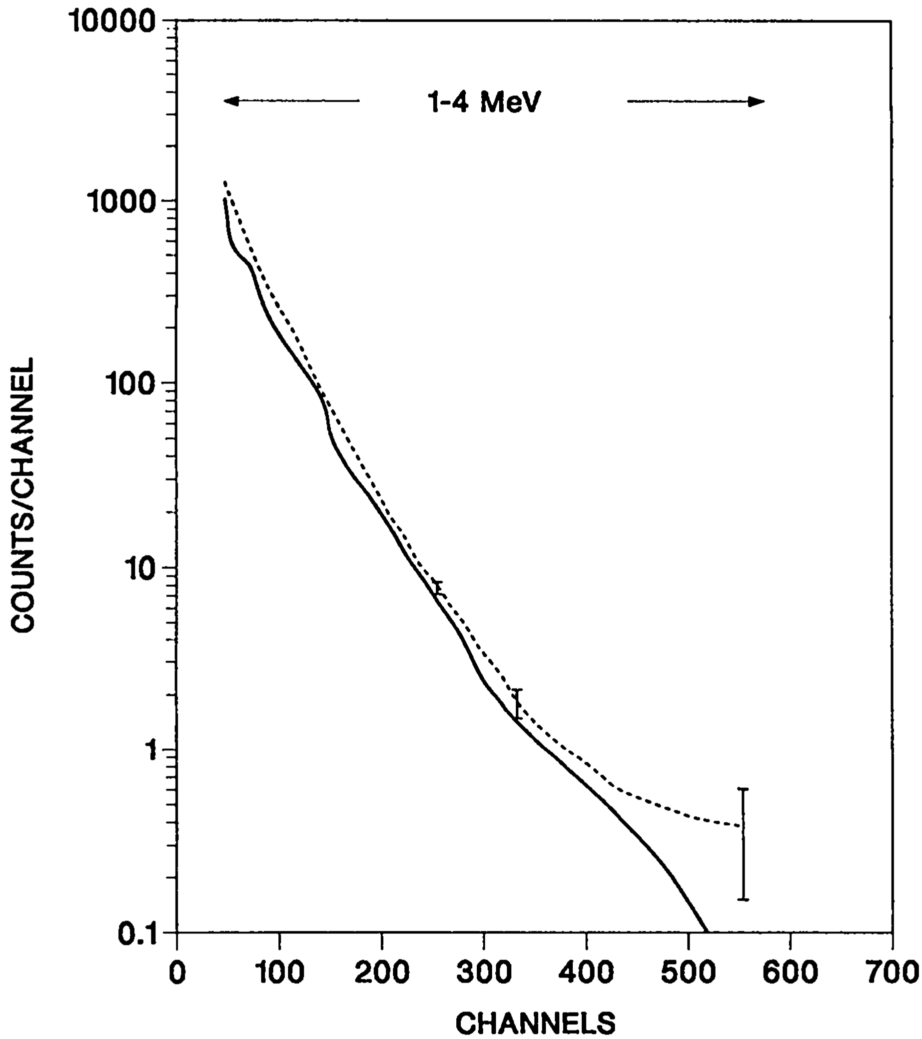

Fig. 17. ^{96}Rb Delayed neutron spectrum.

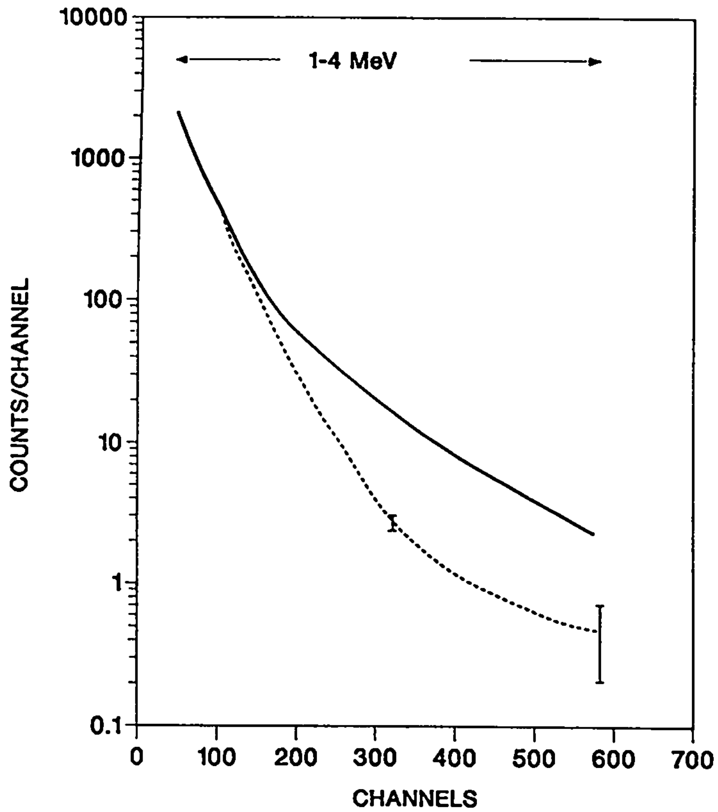

Fig. 18. ^{97}Rb delayed neutron spectrum.

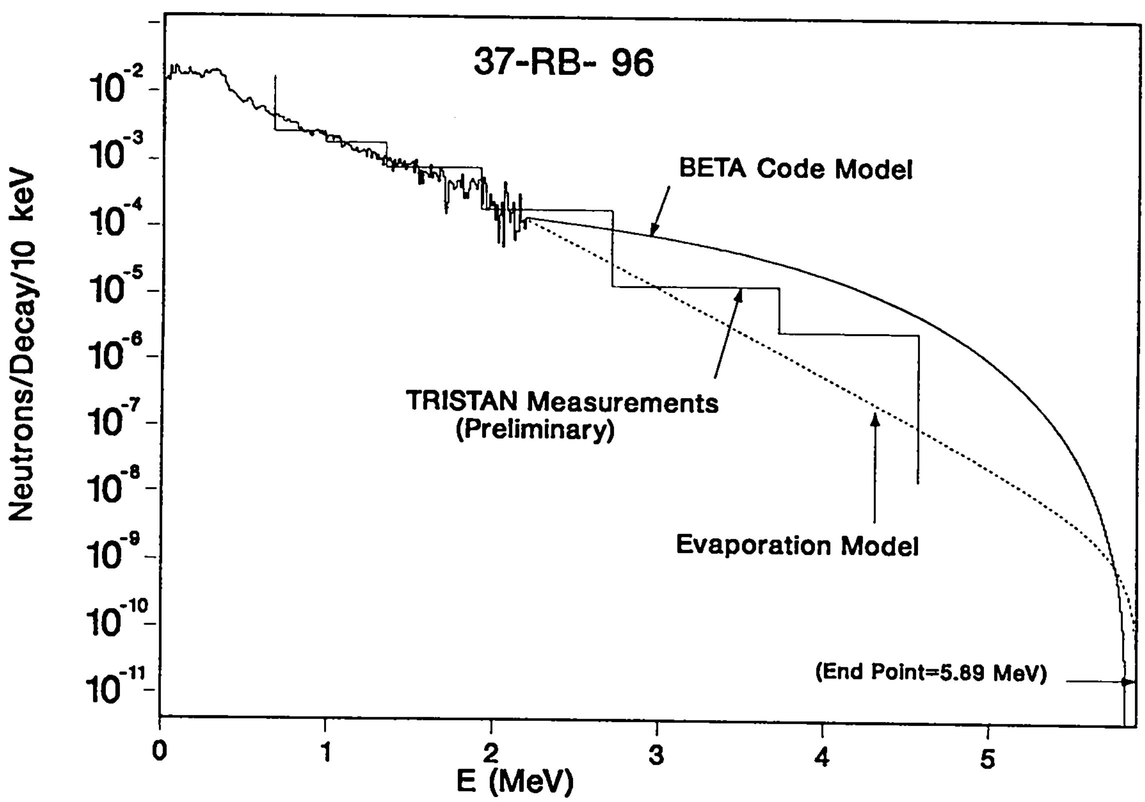

Fig. 19. Comparison of delayed neutron spectra for ^{96}Rb.

Prior to 1986 there were no aggregate measurements ≥ 1.6 MeV. Very preliminary measurements were made at Los Alamos for ^{235}U samples irradiated by bursts from the Godiva reactor. Results reported in Ref. 16 are shown in Figs. 20-22, where the histograms are the measured spectra and the solid lines are our calculated results in 1986. Again, results are very uncertain at high energies but demonstrate the existence of the high-energy delayed neutrons.

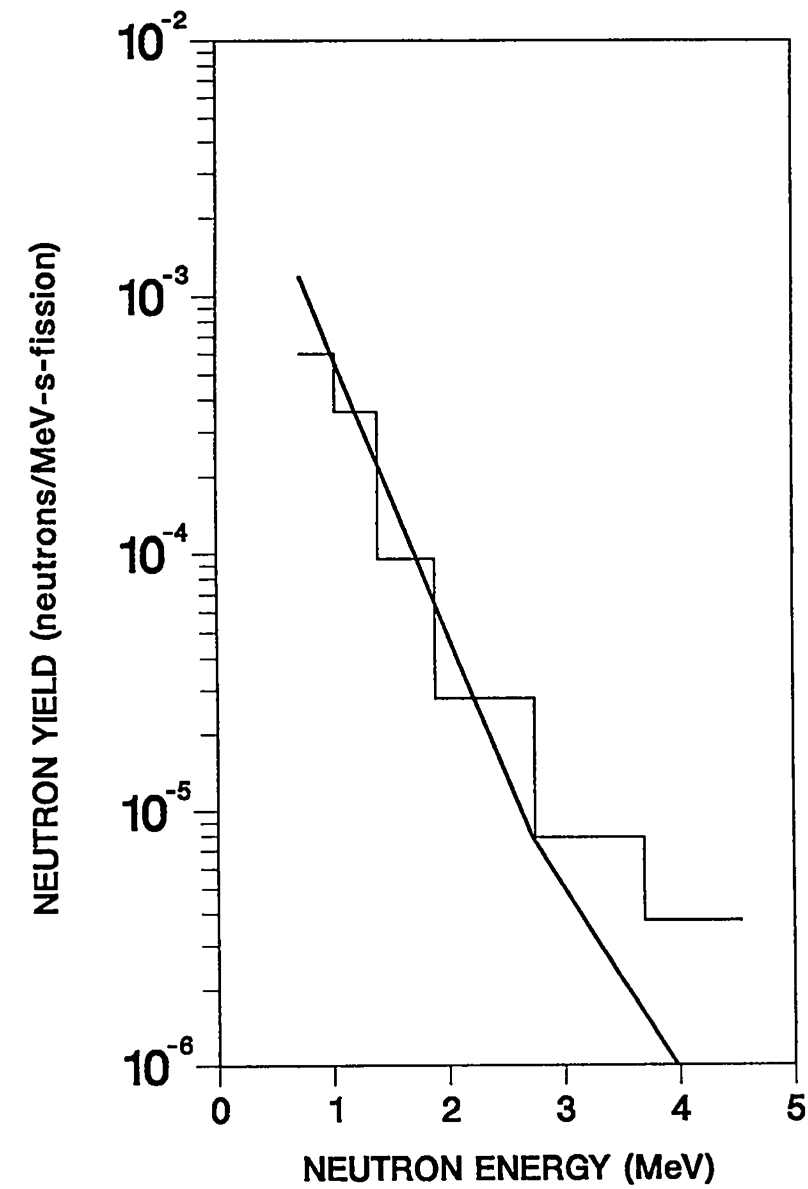

Fig. 20. Neutron spectrum, 1-5 s after Godiva burst.

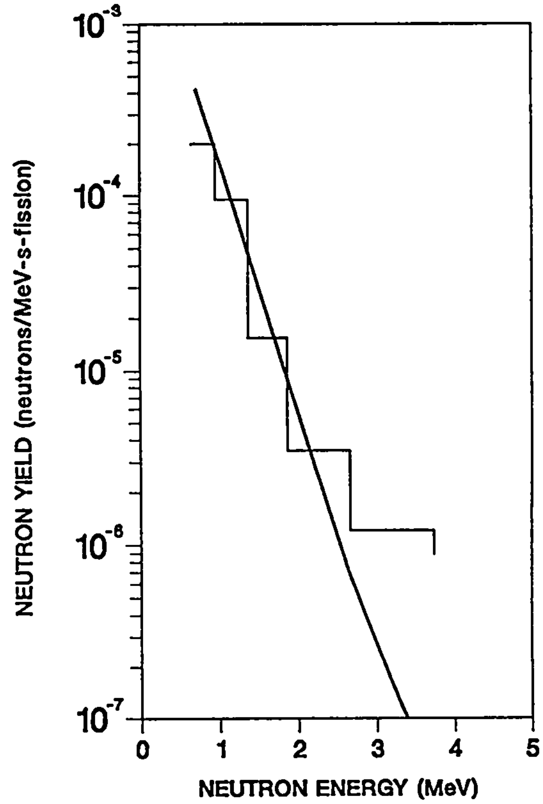

Fig. 21. Neutron spectrum, 5-10 s after Godiva burst.

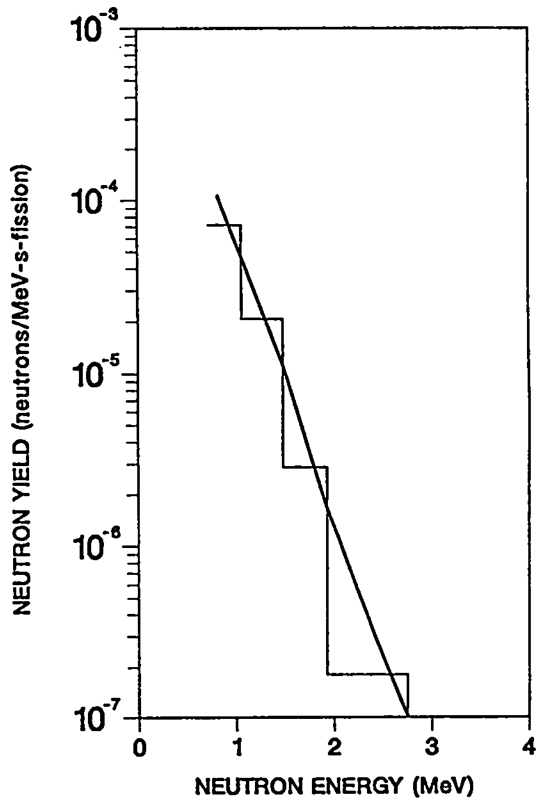

Fig. 22. Neutron spectrum, 10-20 s after Godiva burst.

IV. CALCULATED $\bar{\nu}_d$ SPECTRA FROM FISSION PULSES

All of the data discussed in Section III were used in the CINDER-10 code to calculate the 271 precursor activities vs time following a fission pulse. The code includes all known fission products coupled together by all known decay branching. There is no approximation in the calculation other than the accuracy of the input data.

Normalized spectra and Pn values are folded into the precursor activities at various times to produce aggregate spectra and integrated delayed neutron rates for several fissioning species.

The fission pulse consists of 1.3 x 10^{26} fissions over 10^{-4} s. Table IV is an exception. Here, total $\bar{\nu}_d$ values at time zero are based on 100 fissions for each of 42 fissioning species. This table was actually produced using the Pn values, direct fission yields, and precursor halflives. Such calculations are relatively simple, but cannot describe the subsequent temporal variations in totals or in aggregate spectra. Table IV does show the importance of various fissioning systems except for hardness of the spectrum; and we have used these results to verify the CINDER-10 calculations at time ~ 0 (calculated results labelled as time = 0 are actually values that apply at 10^{-4} s).

The temporal variation of each of these 42 cases has been calculated. In this report we primarily include the results for four fuels: ^{235}U, ^{238}U, ^{239}Pu, and ^{232}Th--all at fast or fission neutron energies. These bracket the range of calculated spectra. Figure 23 does show the total $\bar{\nu}_d$ rate vs time for eight of the fuels.

Figure 24 shows a comparison of the ^{235}U spectra at 5 s cooling before and after spectral expansions. Also included is an independent calculation made by A. Sierk[14] using a totally statistical approach to both spectra and fission yields as a check on the general validity of results in this report.

Figures 25-28 show the spectrum for each of four fuels as a fraction of the delayed neutron rate remaining above the abscissa energy. Values at nine decay times are plotted. Total values and average energies are included on the plots. Figures 29-31 compare these fractions for each fuel at 1, 5, and 10 s and Figs. 32 and 33 show the same data in more detail above 4 MeV.

The inclusion of ^{232}Th is based on its total $\bar{\nu}_d$ rate. When the total spectrum is compared with ^{238}U, ^{232}Th is the larger value at most times. This is shown at three times in the comparisons of Figs. 34-36. ^{239}Pu is smaller at all times and energies. The range of spectra above 4 MeV found for the eight fuels plotted in Fig. 23 is shown in Fig. 37 at 5-s decay.

TABLE IV

DELAYED NEUTRON YIELD RATE PER 100 FISSIONS AT $t = 10^{-4}$ s

Fissionable Nuclide [a]	Current Calculated Values per 100 Fissions
Th-227(t)	0.37e+00
Th-229(t)	0.51e+00
Th-232(f)	0.31e+01
Th-232(h)	0.25e+01
Pa-231(f)	0.48e+00
U-232(t)	0.12e+00
U-233(t)	0.68e+00
U-233(f)	0.29e+00
U-233(h)	0.24e+00
U-234(f)	0.49e+00
U-234(h)	0.28e+00
U-235(t)	0.10e+01
U-235(f)	0.98e+00
U-235(h)	0.47e+00
U-236(f)	0.12e+01
U-236(h)	0.77e+00
U-237(f)	0.22e+01
U-238(f)	0.29e+01
U-238(h)	0.19e+01
Np-237(f)	0.51e+00
Np-237(h)	0.52e+00
Np-238(f)	0.12e+01
Pu-238(f)	0.32e+00
Pu-239(t)	0.29e+00
Pu-239(f)	0.29e+00
Pu-239(h)	0.16e+00
Pu-240(f)	0.36e+00
Pu-240(h)	0.23e+00
Pu-241(t)	0.70e+00
Pu-241(f)	0.74e+00
Pu-242(f)	0.79e+00
Am-241(t)	0.22e+00
Am-241(f)	0.20e+00
Am-241(h)	0.11e+00
Am-242m(t)	0.33e+00
Am-243(f)	0.32e+00
Cm-242(f)	0.47e-01
Cm-245(t)	0.30e+00
Cf-249(t)	0.51e-01
Cf-251(t)	0.25e+00
Es-254(t)	0.19e+00
Fm-255(t)	0.67e-01

[a] (t), (f), and (h) refer to thermal, fast (fission spectrum), and 14-MeV neutron fission energies.

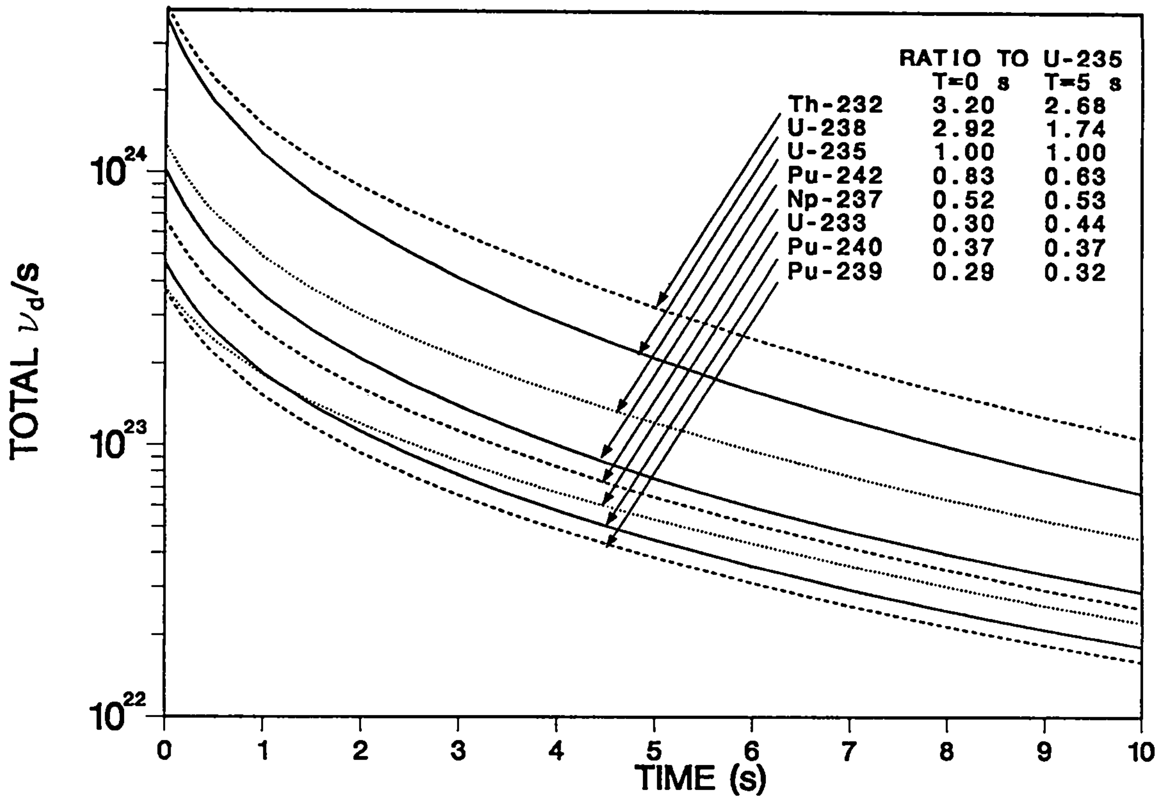

Fig. 23. Total ν_d/s for eight fuels vs time (pulse).

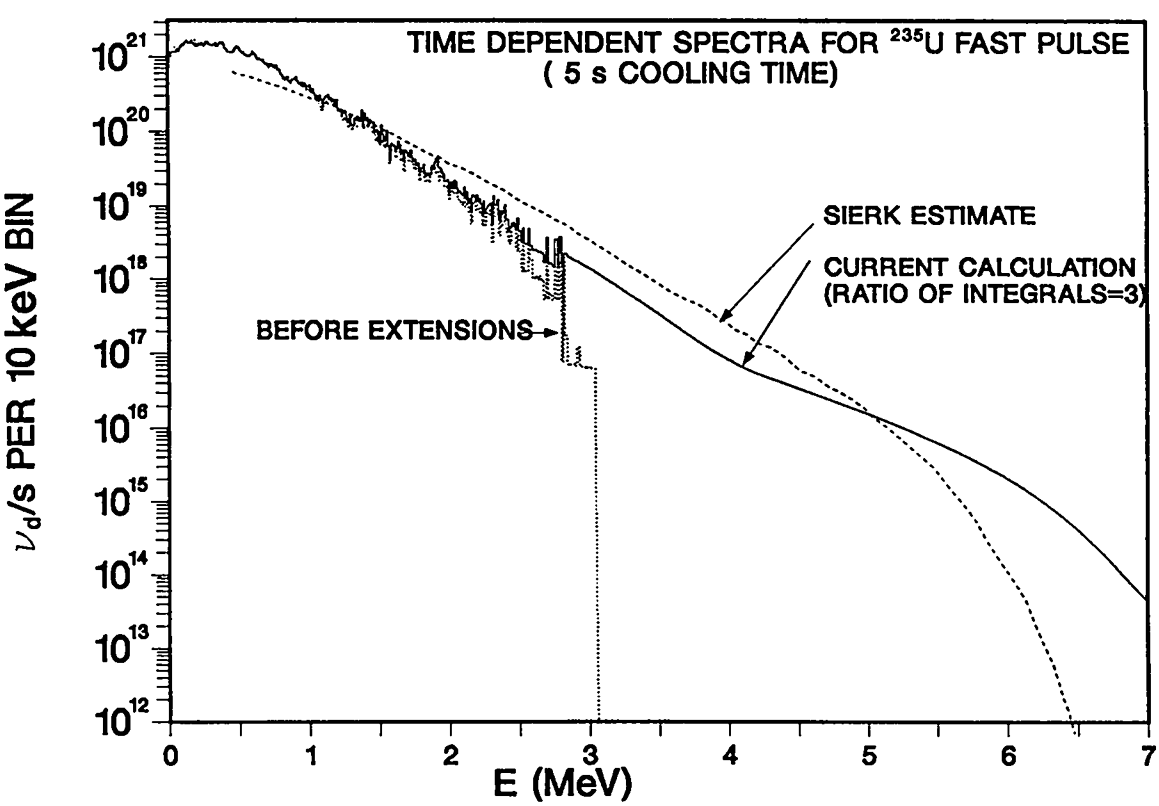

Fig. 24. ^{235}U ν_d spectra comparisons at 5 s.

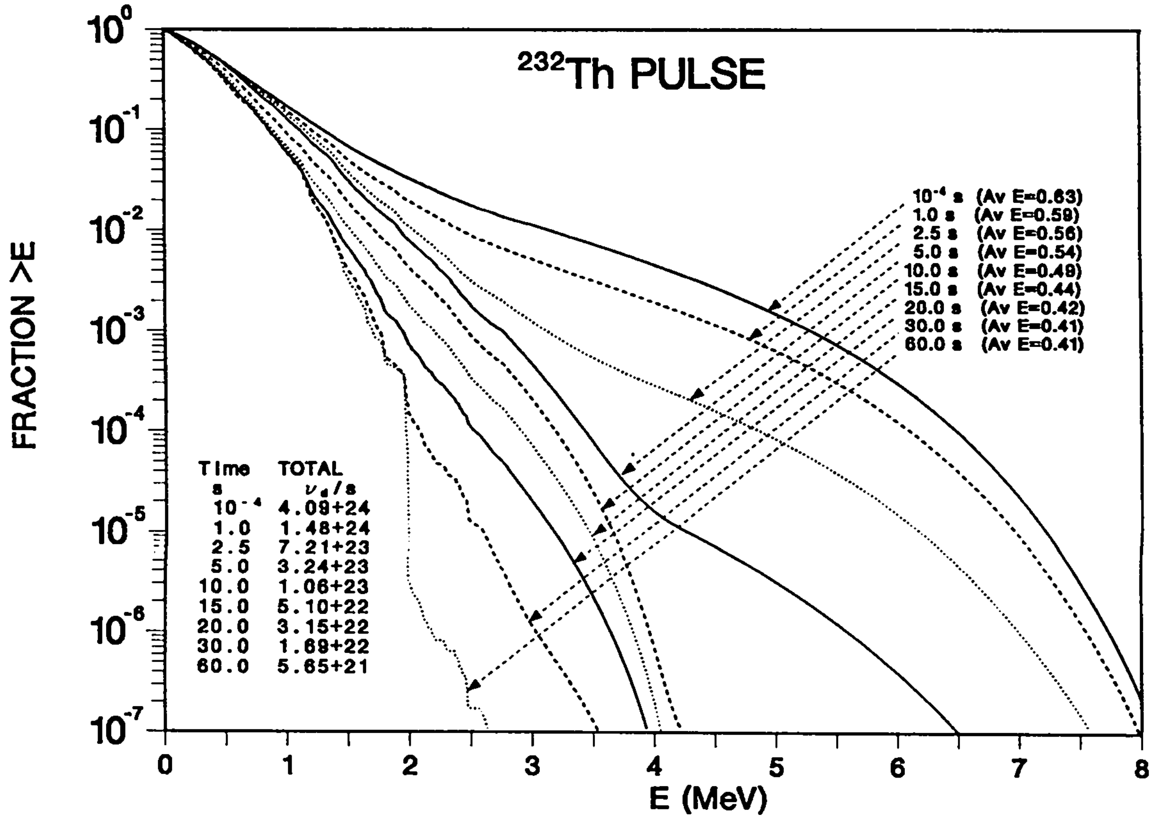

Fig. 25.^{232}Th fraction of total delayed neutrons > E.

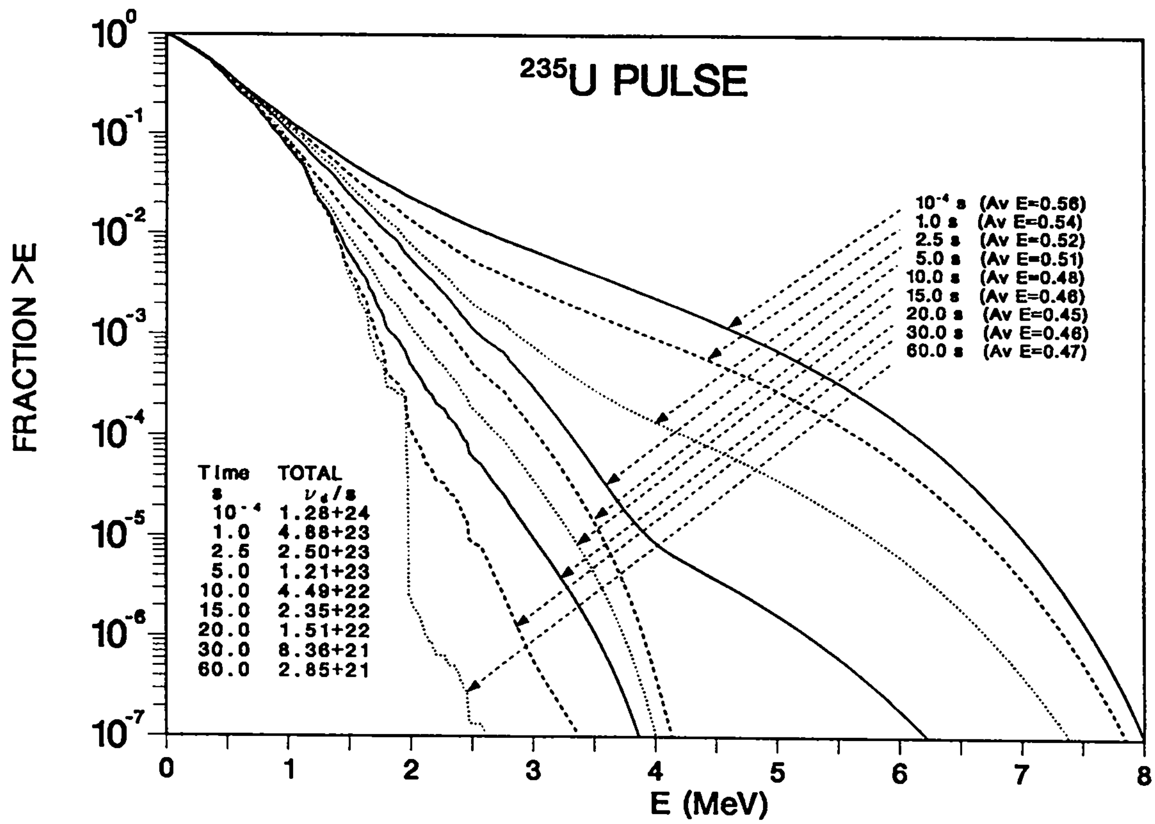

Fig. 26. ^{235}U fraction of total delayed neutrons > E.

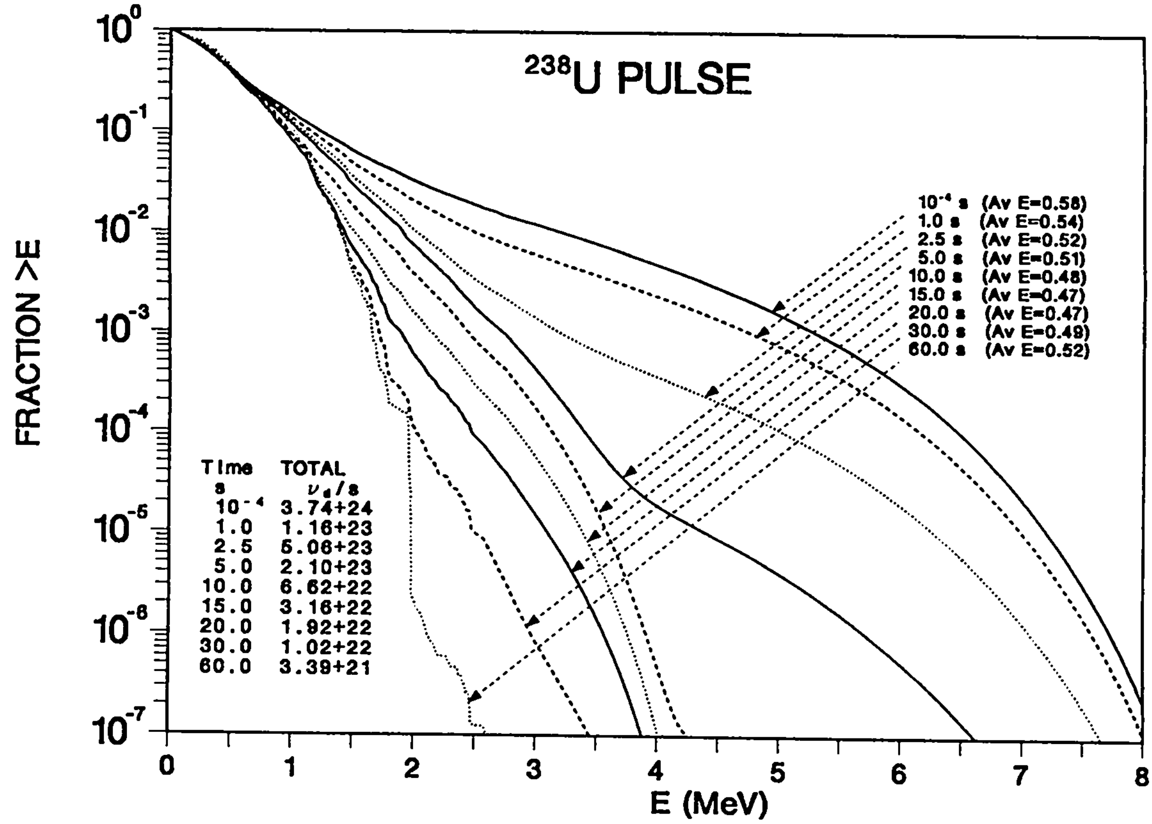

Fig. 27. ^{238}U fraction of total delayed neutrons > E.

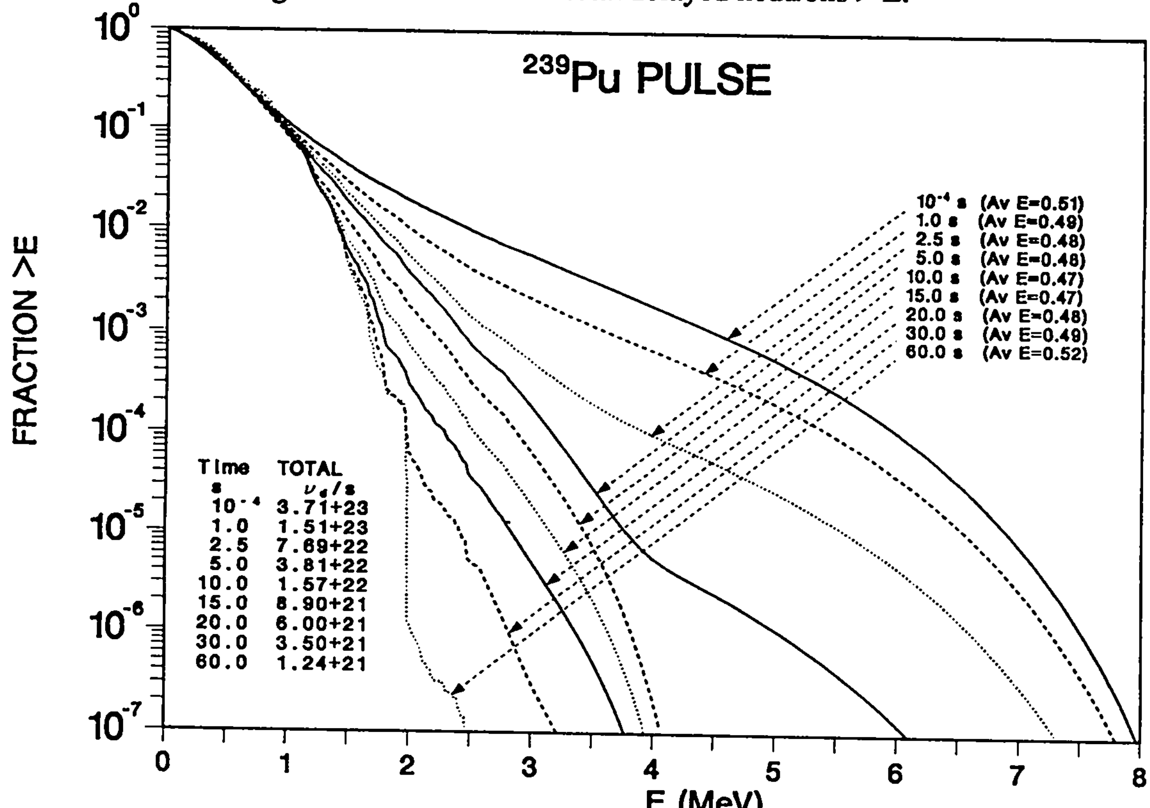

Fig. 28. ^{239}Pu fraction of total delayed neutrons > E.

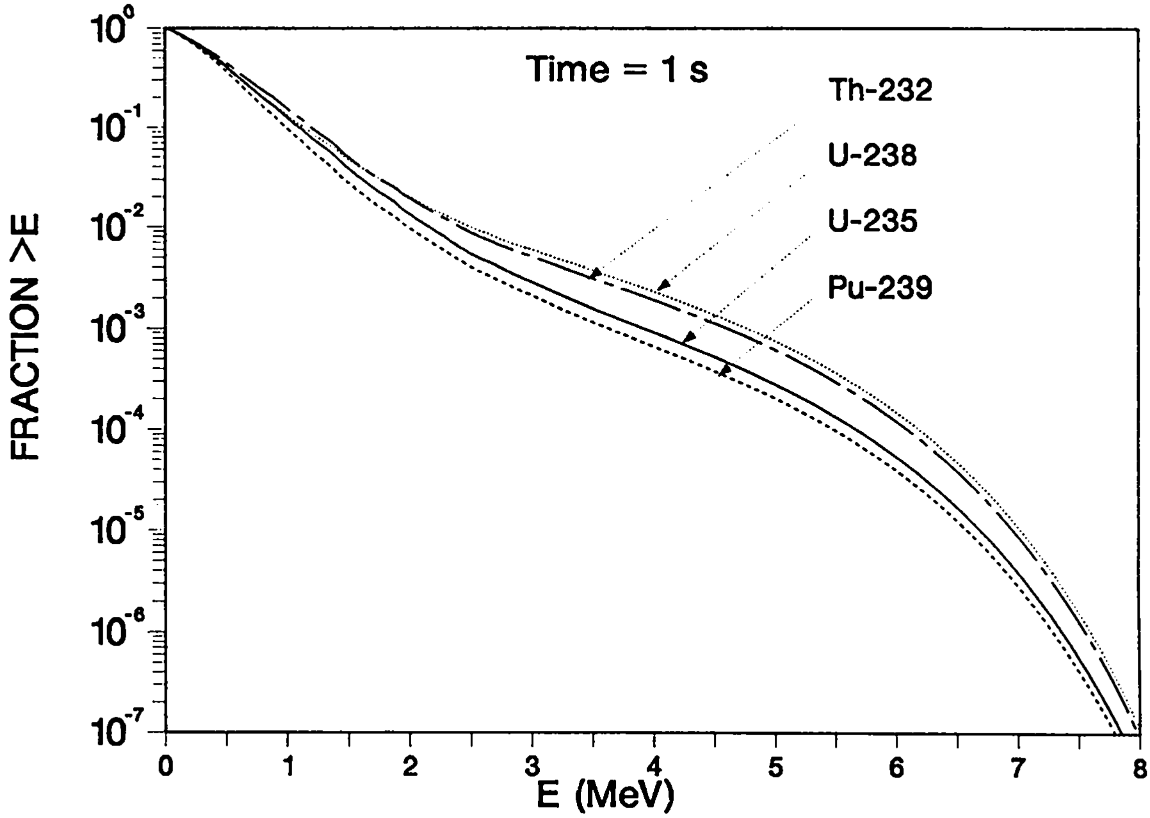

Fig. 29. Comparison of spectra fractions at 1 s.

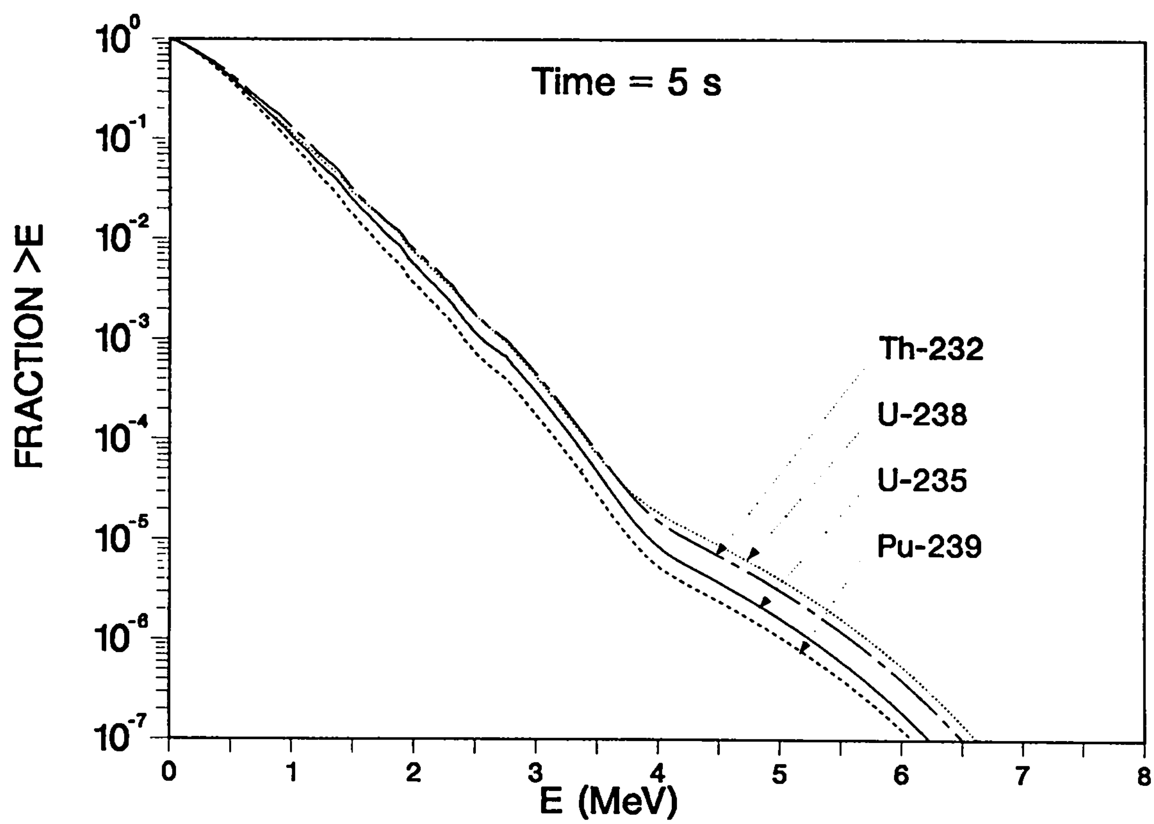

Fig. 30. Comparison of spectra fractions at 5 s.

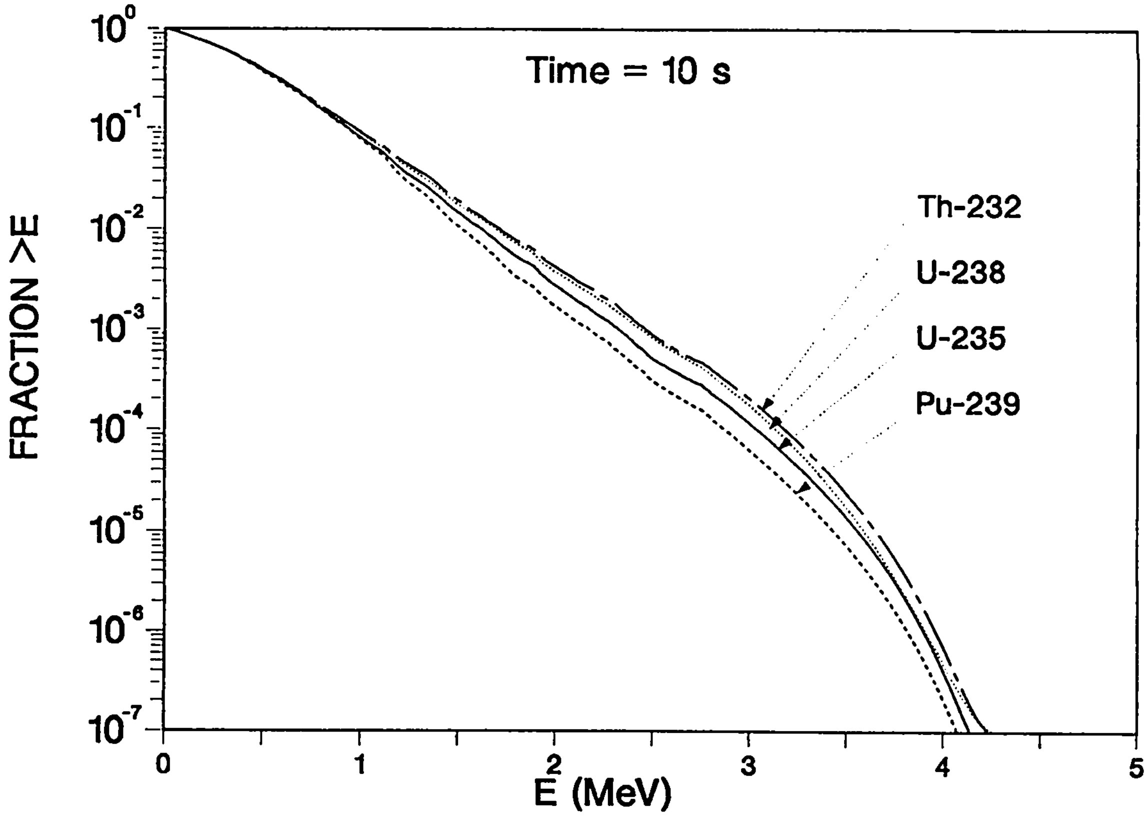

Fig. 31. Comparison of spectra fractions at 10 s.

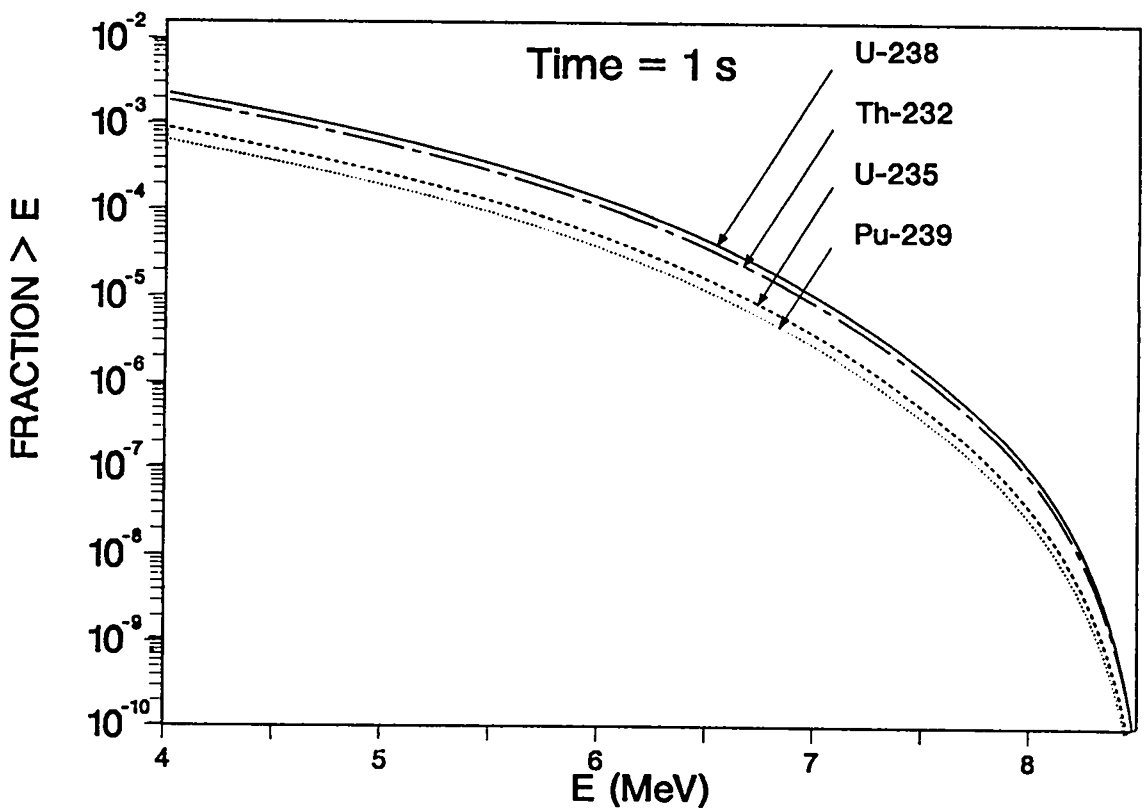

Fig. 32. Comparison: fraction of neutrons > E above 4 MeV at 1 s.

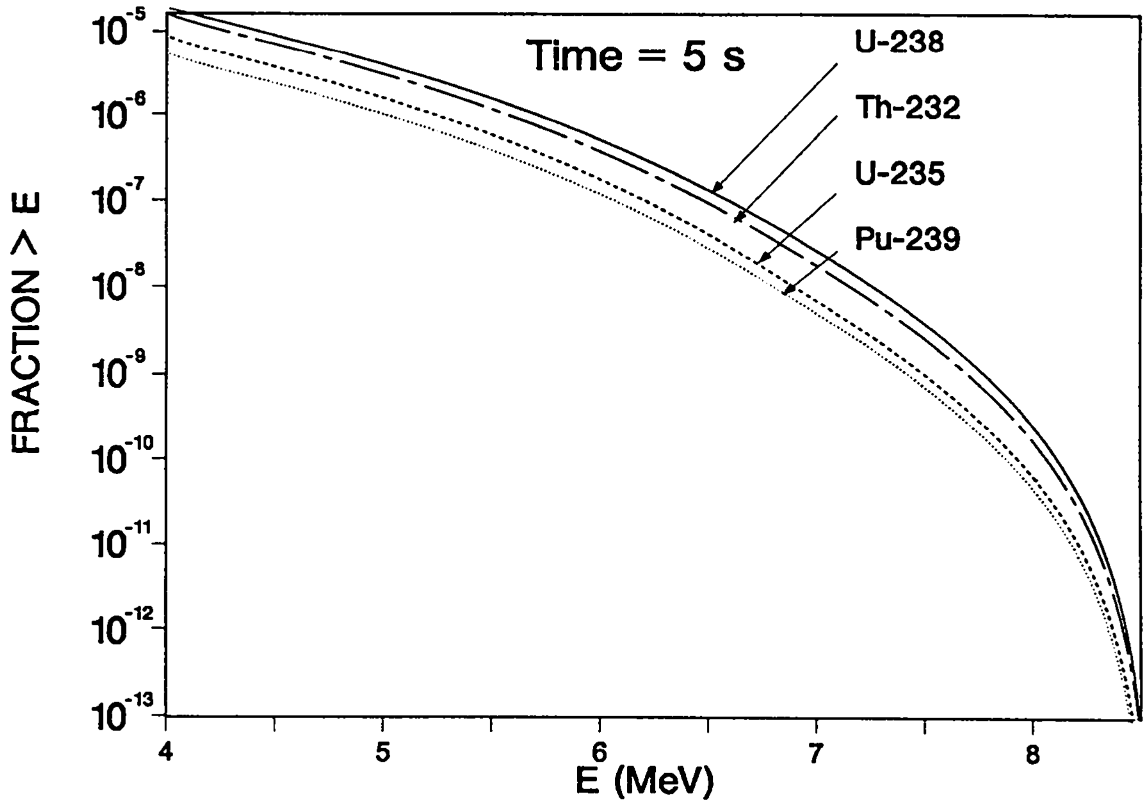

Fig. 33. Comparison: fraction of neutrons > E above 4 MeV at 5 s.

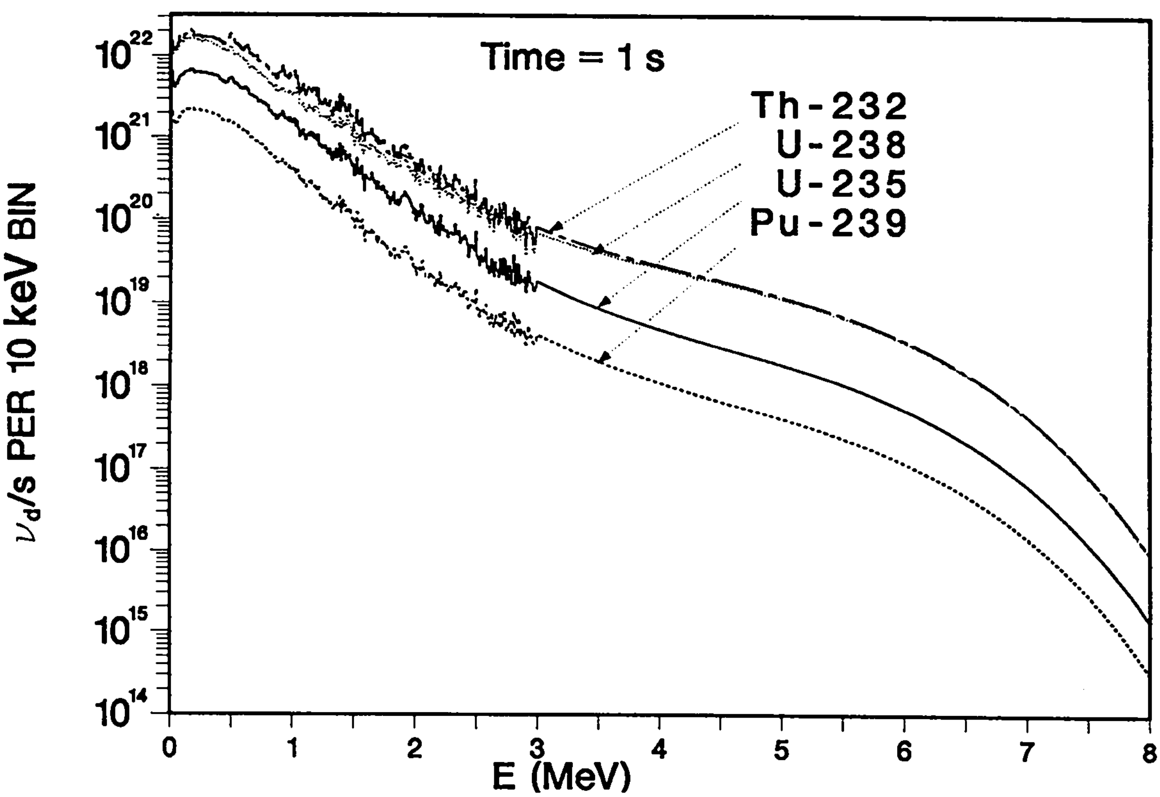

Fig. 34. ν_d spectra comparisons at 1 s.

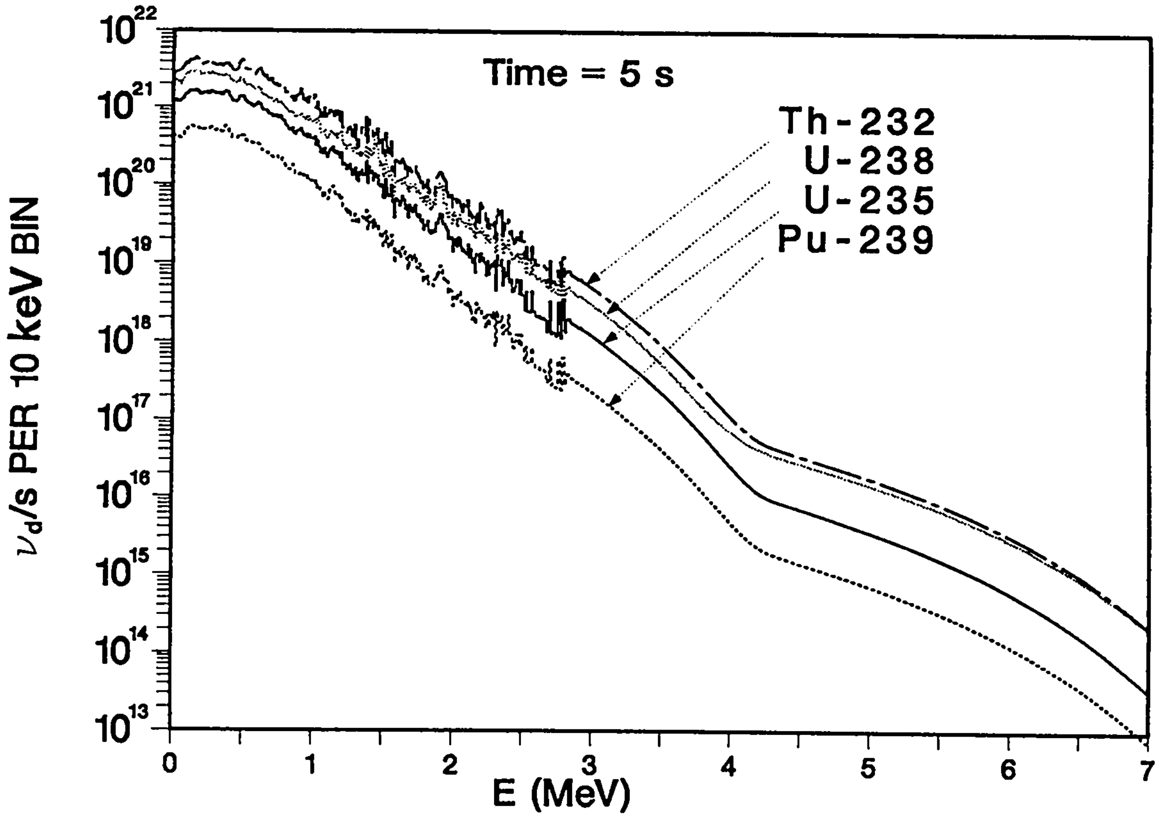

Fig. 35. ν_d spectra comparisons at 5 s.

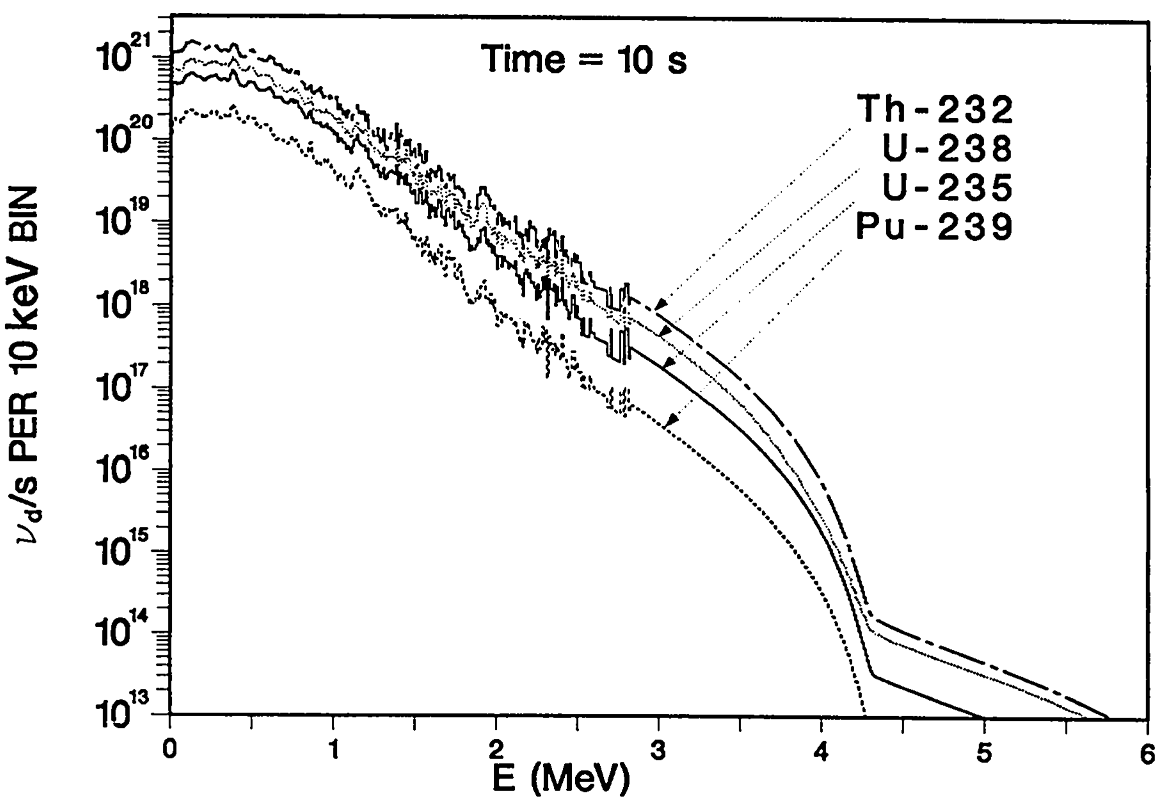

Fig. 36. ν_d spectra comparisons at 10 s.

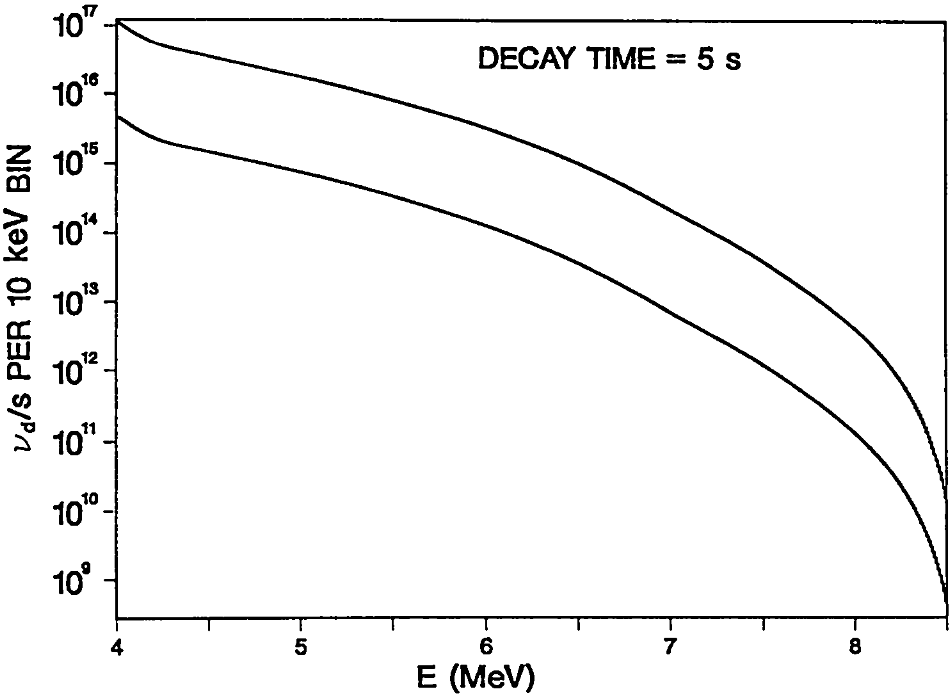

Fig. 37. Absolute delayed neutron spectra per fission for E > 4 MeV.

There is a dependence of the spectra on the incident energy. Figure 38 shows this for ^{235}U at 1 and 14 MeV at 5-s decay, the value at 1 MeV being significantly larger at all energies. This is generally true for all fuels.

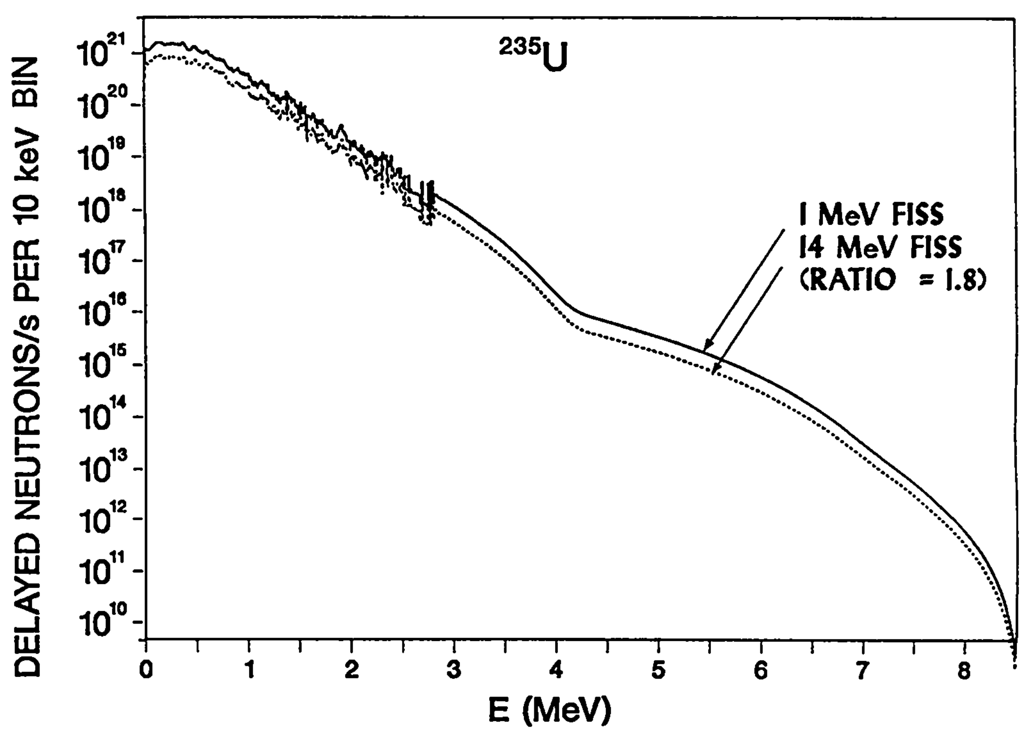

Fig. 38. ^{235}U delayed neutron spectra at 5 s.

Table V lists the total delayed neutron rates for ^{235}U, ^{238}U, ^{239}Pu, and ^{232}Th at 39 times out to 5 minutes of decay. Tables VI-IX show fractional values of the totals at 8 cooling times remaining above each 1/2-MeV energy.

TABLE V

TOTAL DELAYED NEUTRON RATE vs COOLING TIME

time	u-235	u-238	pu-239	th-232
0.0	1.28e+24	3.73e+24	3.70e+23	4.09e+24
0.1	1.10e+24	3.12e+24	3.25e+23	3.51e+24
0.2	9.67e+23	2.67e+24	2.89e+23	3.06e+24
0.3	8.60e+23	2.31e+24	2.59e+23	2.71e+24
0.4	7.74e+23	2.04e+24	2.36e+23	2.42e+24
0.5	7.04e+23	1.82e+24	2.16e+23	2.20e+24
1.0	4.88e+23	1.16e+24	1.51e+23	1.48e+24
1.5	3.74e+23	8.35e+23	1.16e+23	1.11e+24
2.0	3.01e+23	6.38e+23	9.29e+22	8.83e+23
2.5	2.50e+23	5.06e+23	7.69e+22	7.21e+23
3.0	2.11e+23	4.12e+23	6.50e+22	6.01e+23
3.5	1.81e+23	3.41e+23	5.59e+22	5.08e+23
4.0	1.56e+23	2.87e+23	4.87e+22	4.34e+23
4.5	1.37e+23	2.44e+23	4.29e+22	3.74e+23
5.0	1.21e+23	2.10e+23	3.81e+22	3.24e+23
6.0	9.54e+22	1.59e+23	3.07e+22	2.49e+23
7.0	7.70e+22	1.24e+23	2.53e+22	1.95e+23
8.0	6.33e+22	9.86e+22	2.12e+22	1.57e+23
9.0	5.29e+22	8.01e+22	1.81e+22	1.28e+23
10.0	4.49e+22	6.62e+22	1.57e+22	1.06e+23
15.0	2.35e+22	3.16e+22	8.90e+21	5.10e+22
20.0	1.51e+22	1.92e+22	6.00e+21	3.15e+22
25.0	1.09e+22	1.35e+22	4.46e+21	2.22e+22
30.0	8.36e+21	1.02e+22	3.50e+21	1.69e+22
35.0	6.71e+21	8.11e+21	2.84e+21	1.34e+22
40.0	5.52e+21	6.63e+21	2.36e+21	1.10e+22
45.0	4.62e+21	5.52e+21	1.99e+21	9.17e+21
50.0	3.91e+21	4.65e+21	1.69e+21	7.74e+21
55.0	3.33e+21	3.96e+21	1.45e+21	6.59e+21
60.0	2.85e+21	3.39e+21	1.24e+21	5.65e+21
70.0	2.12e+21	2.51e+21	9.31e+20	4.22e+21
80.0	1.60e+21	1.88e+21	7.05e+20	3.21e+21
90.0	1.22e+21	1.42e+21	5.38e+20	2.47e+21
100.0	9.38e+20	1.08e+21	4.13e+20	1.93e+21
110.0	7.28e+20	8.29e+20	3.20e+20	1.53e+21
120.0	5.71e+20	6.40e+20	2.49e+20	1.22e+21
180.0	1.59e+20	1.55e+20	6.52e+19	3.95e+20
240.0	5.74e+19	4.86e+19	2.18e+19	1.59e+20
300.0	2.40e+19	1.86e+19	8.80e+18	7.08e+19

TABLE VI

^{235}U

FRACTION OF DELAYED NEUTRONS ABOVE ENERGIES IN 1/2 MeV INCREMENTS

E	0 s	1 s	2.5 s	5 s	10 s	15 s	30 s	60 s
0.5	4.1-01	4.1-01	4.1-01	4.1-01	3.8-01	3.6-01	3.5-01	3.7-01
1.0	1.3-01	1.2-01	1.2-01	1.0-01	8.1-02	7.0-02	7.5-02	8.5-02
1.5	5.1-02	3.9-02	3.0-02	2.4-02	1.5-02	8.8-03	4.1-03	3.4-03
2.0	2.3-02	1.4-02	7.8-03	5.5-03	2.7-03	1.2-03	1.1-04	2.3-06
2.5	1.2-02	5.4-03	2.0-03	1.1-03	5.1-04	1.8-04	8.8-06	1.3-07
3.0	6.8-03	2.9-03	7.5-04	3.0-04	1.2-04	3.6-05	5.7-07	7.9-10
3.5	4.0-03	1.6-03	2.8-04	4.8-05	1.4-05	4.2-06	5.4-08	4.1-12
4.0	2.3-03	9.2-04	1.4-04	8.7-06	3.9-07	1.0-07	1.3-09	4.1-14
4.5	1.3-03	5.3-04	7.4-05	3.8-06	2.8-08	2.8-10	~0	~0
5.0	7.1-04	2.8-04	3.8-05	1.6-06	1.1-08	9.4-11	~0	~0
5.5	3.4-04	1.3-04	1.7-05	6.2-07	3.5-09	2.8-11	~0	~0
6.0	1.4-04	5.4-05	6.4-06	1.9-07	8.3-10	6.4-12	~0	~0
6.5	4.4-05	1.7-05	1.9-06	4.3-08	1.1-10	7.7-13	~0	~0
7.0	1.0-05	3.9-06	4.2-07	7.3-09	2.8-12	~0	~0	~0
7.5	1.5-06	5.6-07	6.1-08	1.0-09	4.8-14	~0	~0	~0
8.0	9.7-08	3.7-08	4.0-09	6.8-11	~0	~0	~0	~0
8.5	4.2-11	8.7-12	8.5-13	4.4-15	~0	~0	~0	~0
9.0	3.7-12	~0	~0	~0	~0	~0	~0	~0
9.5	6.3-13	~0	~0	~0	~0	~0	~0	~0

TABLE VII

^{238}U

FRACTION OF DELAYED NEUTRONS ABOVE ENERGIES IN 1/2-MeV INCREMENTS

E	0 s	1 s	2.5 s	5 s	10 s	15 s	30 s	60 s
0.5	4.0-01	3.9-01	4.0-01	4.0-01	3.8-01	3.7-01	3.9-01	4.2-01
1.0	1.5-01	1.3-01	1.2-01	1.1-01	8.9-02	7.7-02	8.6-02	9.9-02
1.5	6.3-02	4.7-02	3.4-02	2.9-02	1.8-02	1.0-02	4.5-03	3.6-03
2.0	3.2-02	2.0-02	1.0-02	7.3-03	3.8-03	1.5-03	1.1-04	2.1-06
2.5	1.9-02	9.9-03	3.3-03	1.7-03	8.1-04	2.9-04	1.0-05	1.2-07
3.0	1.2-02	6.0-03	1.4-03	4.2-04	1.7-04	5.7-05	8.4-07	7.9-10
3.5	7.7-03	3.7-03	6.5-04	7.1-05	1.7-05	5.5-06	7.3-08	5.2-12
4.0	4.8-03	2.3-03	3.6-04	1.9-05	4.7-07	1.1-07	1.4-09	6.4-14
4.5	2.8-03	1.4-03	2.1-04	9.0-06	6.2-08	6.0-10	~0	~0
5.0	1.6-03	7.6-04	1.1-04	4.1-06	2.4-08	2.0-10	~0	~0
5.5	7.5-04	3.7-04	5.1-05	1.6-06	8.0-09	6.3-11	~0	~0
6.0	3.1-04	1.5-04	2.0-05	5.5-07	1.9-09	1.5-11	~0	~0
6.5	1.0-04	4.8-05	6.2-06	1.4-07	2.6-10	1.9-12	~0	~0
7.0	2.3-05	1.1-05	1.4-06	2.8-08	9.5-12	1.7-14	~0	~0
7.5	3.3-06	1.6-06	2.0-07	4.0-09	6.8-13	~0	~0	~0
8.0	2.2-07	1.1-07	1.3-08	2.6-10	~0	~0	~0	~0
8.5	1.3-10	2.4-11	2.9-12	5.1-14	~0	~0	~0	~0
9.0	1.6-11	~0	~0	~0	~0	~0	~0	~0
9.5	3.4-12	~0	~0	~0	~0	~0	~0	~0

TABLE VIII

^{232}Th

FRACTION OF DELAYED NEUTRONS ABOVE ENERGIES IN 1/2-MeV INCREMENTS

E	0 s	1 s	2.5 s	5 s	10 s	15 s	30 s	60 s
0.5	4.6-01	4.5-01	4.5-01	4.4-01	3.9-01	3.5-01	3.0-01	2.9-01
1.0	1.7-01	1.5-01	1.4-01	1.3-01	9.1-02	6.7-02	5.8-02	6.3-02
1.5	6.8-02	5.0-02	3.7-02	3.1-02	1.9-02	1.1-02	3.9-03	3.1-03
2.0	3.2-02	1.9-02	1.1-02	7.8-03	4.2-03	1.8-03	1.4-04	2.9-06
2.5	1.8-02	8.8-03	3.1-03	1.8-03	8.7-04	3.3-04	1.2-05	1.7-07
3.0	1.1-02	5.1-03	1.2-03	4.5-04	2.0-04	7.0-05	1.1-06	1.0-09
3.5	7.2-03	3.1-03	5.3-04	7.5-05	2.4-05	8.1-06	1.2-07	1.1-11
4.0	4.5-03	1.9-03	2.8-04	1.6-05	6.8-07	1.9-07	2.8-09	2.0-13
4.5	2.7-03	1.1-03	1.6-04	7.0-06	5.6-08	7.3-10	~0	~0
5.0	1.5-03	6.2-04	8.2-05	3.2-06	2.1-08	2.3-10	~0	~0
5.5	7.1-04	3.0-04	3.8-05	1.2-06	6.8-09	6.8-11	~0	~0
6.0	2.9-04	1.2-04	1.5-05	4.0-07	1.6-09	1.6-11	~0	~0
6.5	9.4-05	3.9-05	4.6-06	9.9-08	2.2-10	2.1-12	~0	~0
7.0	2.2-05	8.9-06	1.0-06	1.9-08	7.2-12	2.6-14	~0	~0
7.5	3.1-06	1.3-06	1.5-07	2.7-09	3.7-13	~0	~0	~0
8.0	2.1-07	8.5-08	9.8-09	1.8-10	~0	~0	~0	~0
8.5	2.2-10	2.4-11	2.4-12	2.6-14	~0	~0	~0	~0
9.0	3.9-11	~0	~0	~0	~0	~0	~0	~0
9.5	9.0-12	~0	~0	~0	~0	~0	~0	~0

TABLE IX

^{239}Pu

FRACTION OF DELAYED NEUTRONS ABOVE ENERGIES IN 1/2-MeV INCREMENTS

E	0 s	1 s	2.5 s	5 s	10 s	15 s	30 s	60 s
0.5	3.7-01	3.7-01	3.7-01	3.7-01	3.7-01	3.7-01	4.0-01	4.2-01
1.0	1.1-01	9.7-02	9.2-02	8.7-02	7.7-02	7.7-02	9.0-02	1.0-01
1.5	4.1-02	2.8-02	2.1-02	1.7-02	1.1-02	7.0-03	4.1-03	3.7-03
2.0	1.9-02	9.8-03	5.2-03	3.6-03	1.7-03	6.9-04	5.9-05	1.1-06
2.5	9.7-03	4.0-03	1.4-03	7.3-04	3.1-04	1.1-04	4.9-06	6.3-08
3.0	5.6-03	2.1-03	5.0-04	1.8-04	6.3-05	1.9-05	3.0-07	4.2-10
3.5	3.2-03	1.2-03	2.0-04	2.8-05	7.2-06	2.0-06	2.4-08	1.7-12
4.0	1.8-03	6.7-04	9.7-05	5.5-06	2.0-07	4.8-08	5.6-10	~0
4.5	1.0-03	3.8-04	5.3-05	2.4-06	1.5-08	1.3-10	~0	~0
5.0	5.5-04	2.1-04	2.7-05	1.1-06	6.0-09	4.4-11	~0	~0
5.5	2.7-04	9.8-05	1.2-05	4.1-07	2.0-09	1.3-11	~0	~0
6.0	1.1-04	4.0-05	4.7-06	1.3-07	4.7-10	3.0-12	~0	~0
6.5	3.5-05	1.3-05	1.4-06	3.0-08	6.2-11	3.4-13	~0	~0
7.0	8.0-06	2.9-06	3.1-07	5.3-09	1.6-12	~0	~0	~0
7.5	1.2-06	4.1-07	4.5-08	7.4-10	2.1-14	~0	~0	~0
8.0	7.7-08	2.7-08	3.0-09	4.9-11	~0	~0	~0	~0
8.5	2.1-11	5.9-12	6.1-13	~0	~0	~0	~0	~0
9.0	5.0-13	~0	~0	~0	~0	~0	~0	~0
9.5	~0	~0	~0	~0	~0	~0	~0	~0

Appendix B tabulates precursors with contributions greater than 0.01% at various times above 0 and 4 MeV. The more important high-energy emitters are also identified in Fig. 4; specifically isotopes of As, Br, I, and Rb are important at energies above 4 MeV for decay times between 1 and 10 s. Measurements of a few of these at energies > 3 MeV could greatly improve calculations for the various fuels and provide tests for the nuclear models that must be used for most of the precursors.

The reader is reminded that measured data exist for a small fraction of the number of probable precursors and their energy range, as illustrated in Fig. 39.

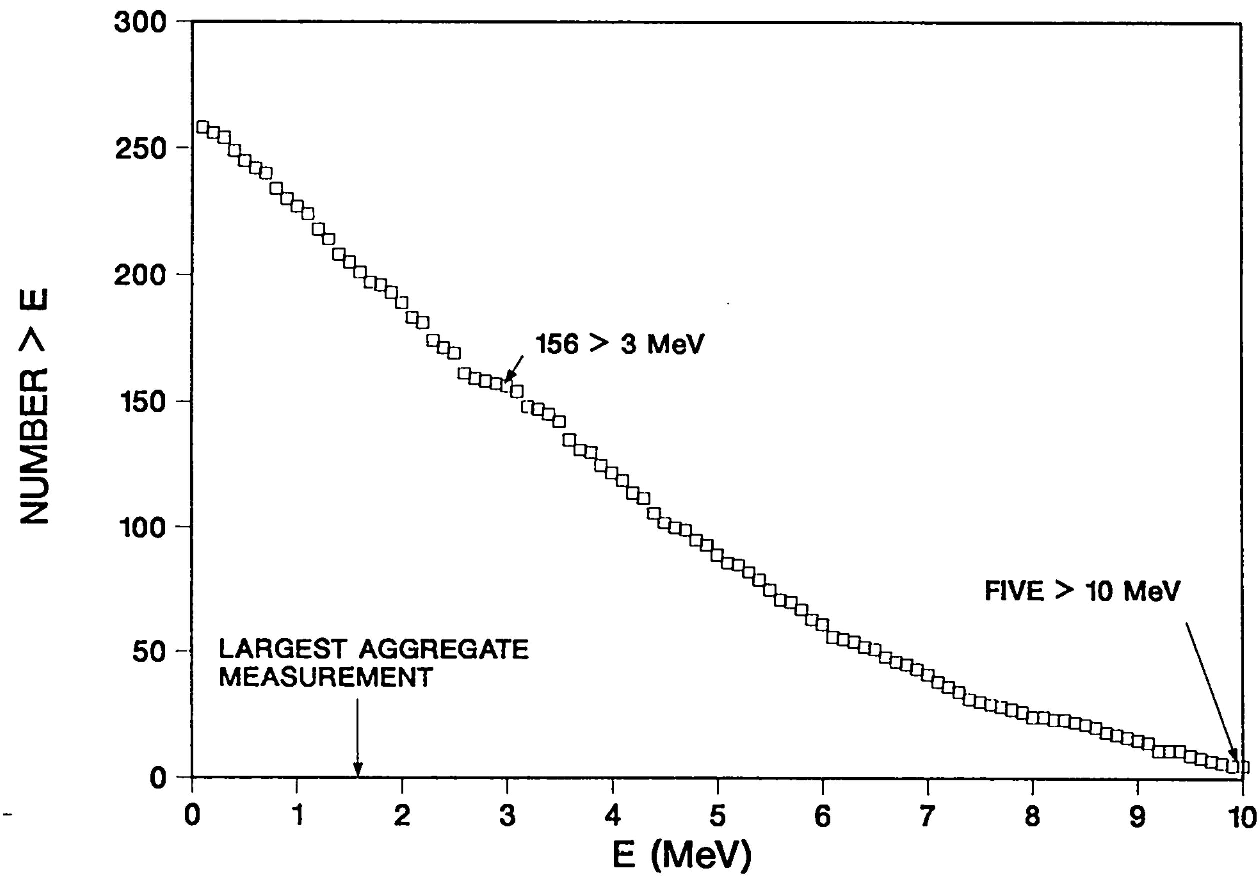

Fig. 39. Number of precursors having energies > E.

Finally, some readers will be interested in the conventional six-time group approximations to these results. This has been made for most fuels and will be of most interest to reactor designers. Results for some fuels have been published in Refs. 26 and 27 and will be discussed in detail in the aforementioned dissertation (Ref. 15).

V. DELAYED β^- AND γ RADIATION FROM FISSION PRODUCTS

Delayed radiations are considered to be occurring later than 10^{-4} s after the fission pulse. The fields coming from approximately 800 different radioactive products coupled by decay produce β^- and γ rays as well as delayed neutrons. The ensemble varies with fissioning species, fission neutron energy, and with time.

To evaluate the nuclear background following a nuclear explosion, we explicitly include all nuclides in several hundred chains that typically consist of 6 to 20 nuclides each (isotopes and isomers). For this, we need to know the initial yield of each nuclide, nuclide halflives, branching fractions per decay, and the detailed β^- and γ energy distributions, as discussed in Secs. I and II, and in Ref. 4.

While the method of calculating the aggregate radiation fields from this plexus is exact, the data are not. Measured and evaluated data per nuclide are used if known; otherwise we necessarily resort to systematics and nuclear models. There are measured spectra for 300 of the approximately 800 radioactive products, and spectra based on systematics were constructed for the remaining, less important, unmeasured products. For three fissioning nuclides, namely, ^{235}U, ^{239}Pu, and ^{241}Pu at thermal neutron fission energies, there are high quality aggregate spectra measurements to 7.5 MeV to use in validations. Investigations based on these experiments have revealed that at least 50 of the most important individual products are missing high energy gamma transitions. The resulting aggregate calculations show a gamma energy that is too small and a spectrum that is skewed towards low energy emission. (The opposite is true for beta spectra.) The number of important products having a deficiency is too large to be corrected with a few selected measurements, so the data base must be augmented with nuclear model calculations.

We have improved aggregate spectra for ^{235}U and ^{239}Pu using the recent ORNL measurements of Refs. 10 and 11. With the exception of ^{241}Pu, this cannot be done for other fuels.

By plotting the spectra as a fraction of the energy remaining above the abscissa energy, as in Sec. IV for ν_d, we can compare the temporal variations of β^-, γ, and delayed neutrons. This is done in Figs. 40-43 at four cooling times. Here one can see the relatively rapid drop in high-energy neutrons vs time compared with β^- and γ energies. As noted on these plots, the average and total β^- and γ energies are larger at all times than values for delayed neutrons.

New decay heat measurements are currently being made in Japan[8,9] and we are in the process of including these data in our files as they become available. Figures 44-47 show comparisons of Japanese measurements of β^- and γ decay heat for ^{238}U and ^{232}Th with our calculations using data from ENDF/B-IV and ENDF/B-V. These figures clearly illustrate the need for updating our files. We anticipate that the Japanese will soon make available new spectral measurements that would be useful in additional file improvements. Thus, considering the promise of new measurements, along with development and application of nuclear model codes, we expect to be able to greatly improve our data base, and, consequently, improve our predictive capabilities during the next year.

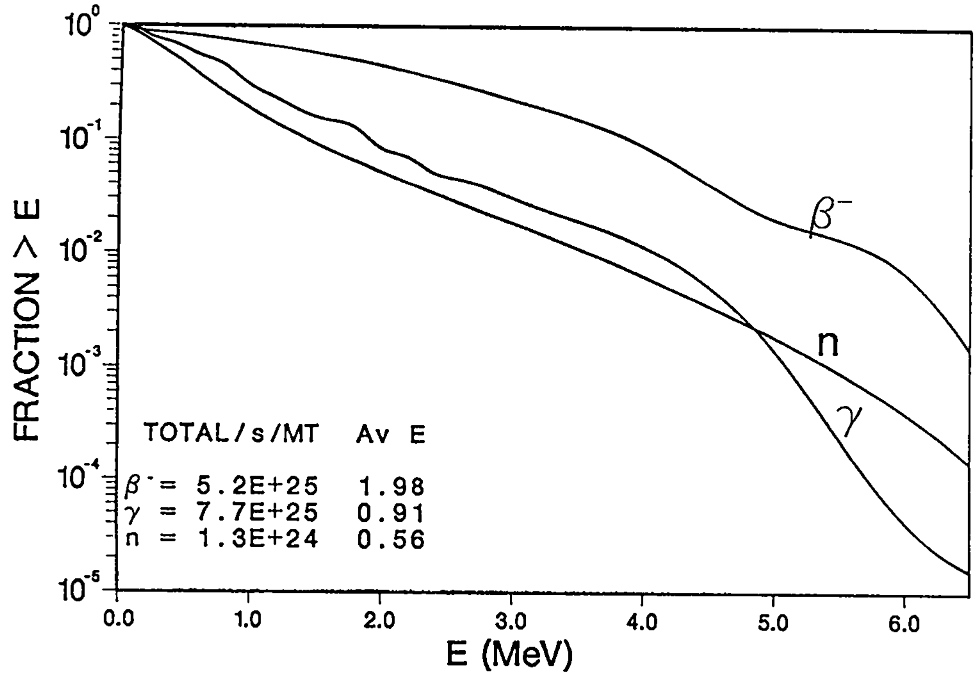

Fig. 40. ^{235}U Fission: Background at $T = 10^{-4}$ s.

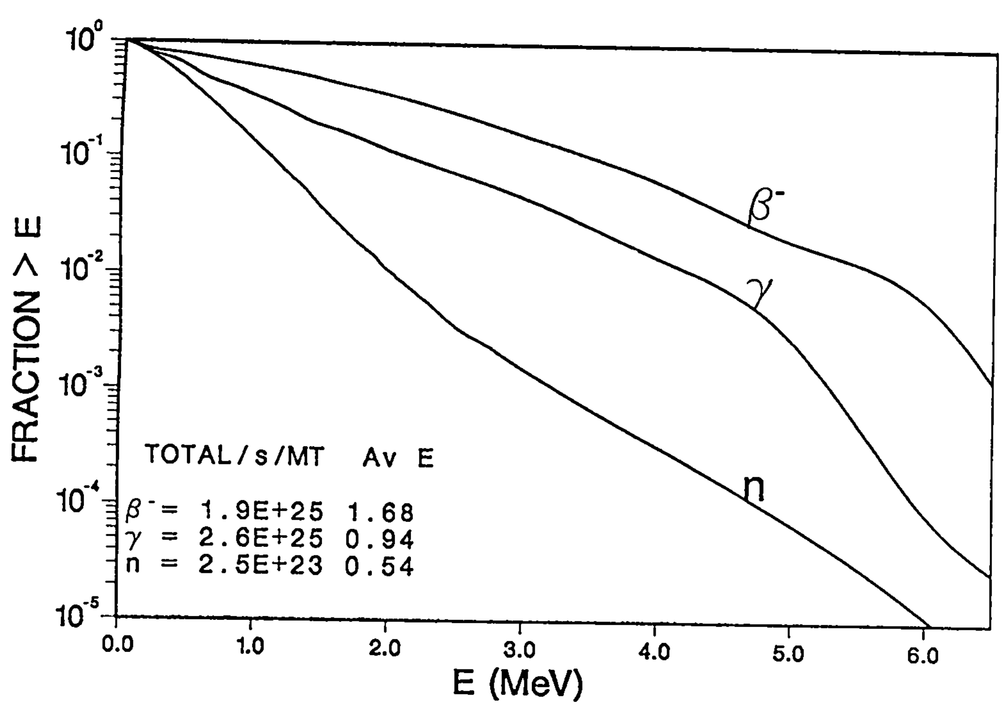

Fig. 41. ^{235}U Fission: Background at $T = 2.5$ s.

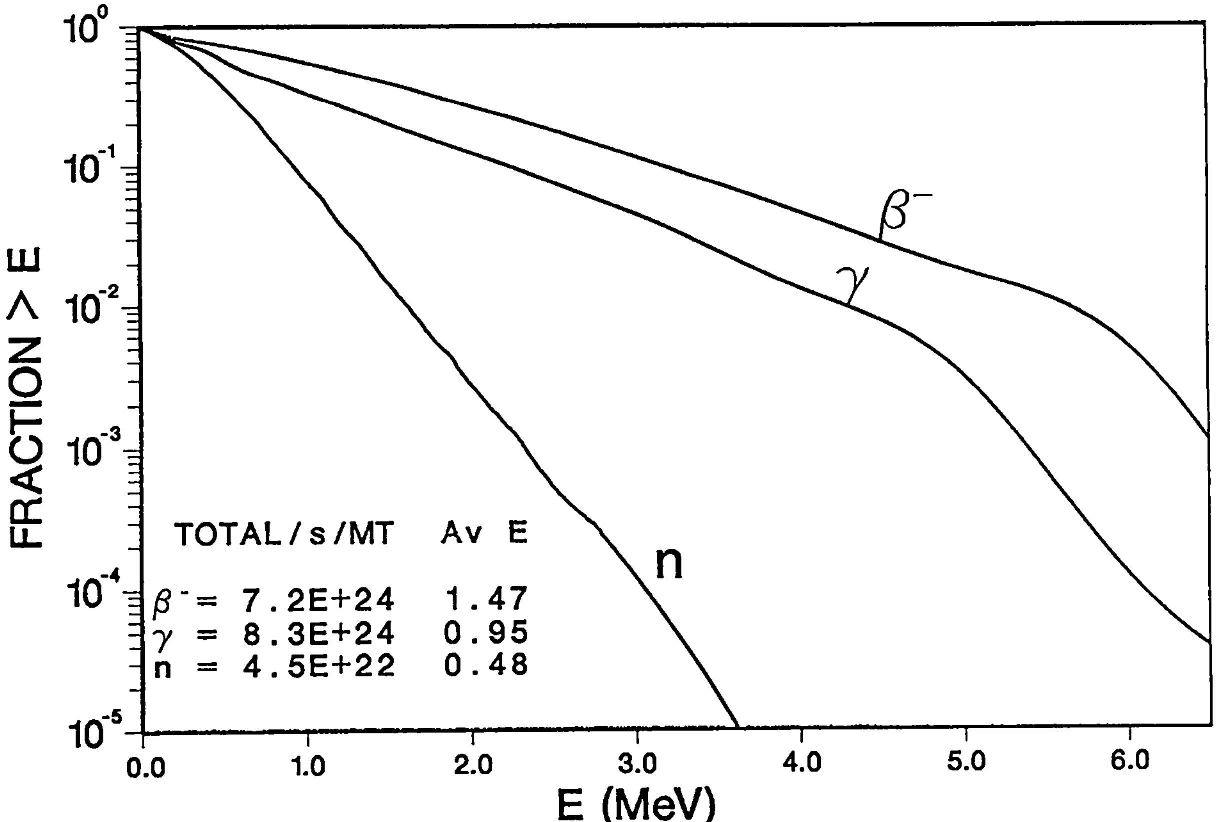

Fig. 42. ^{235}U Fission: Background at T = 10 s.

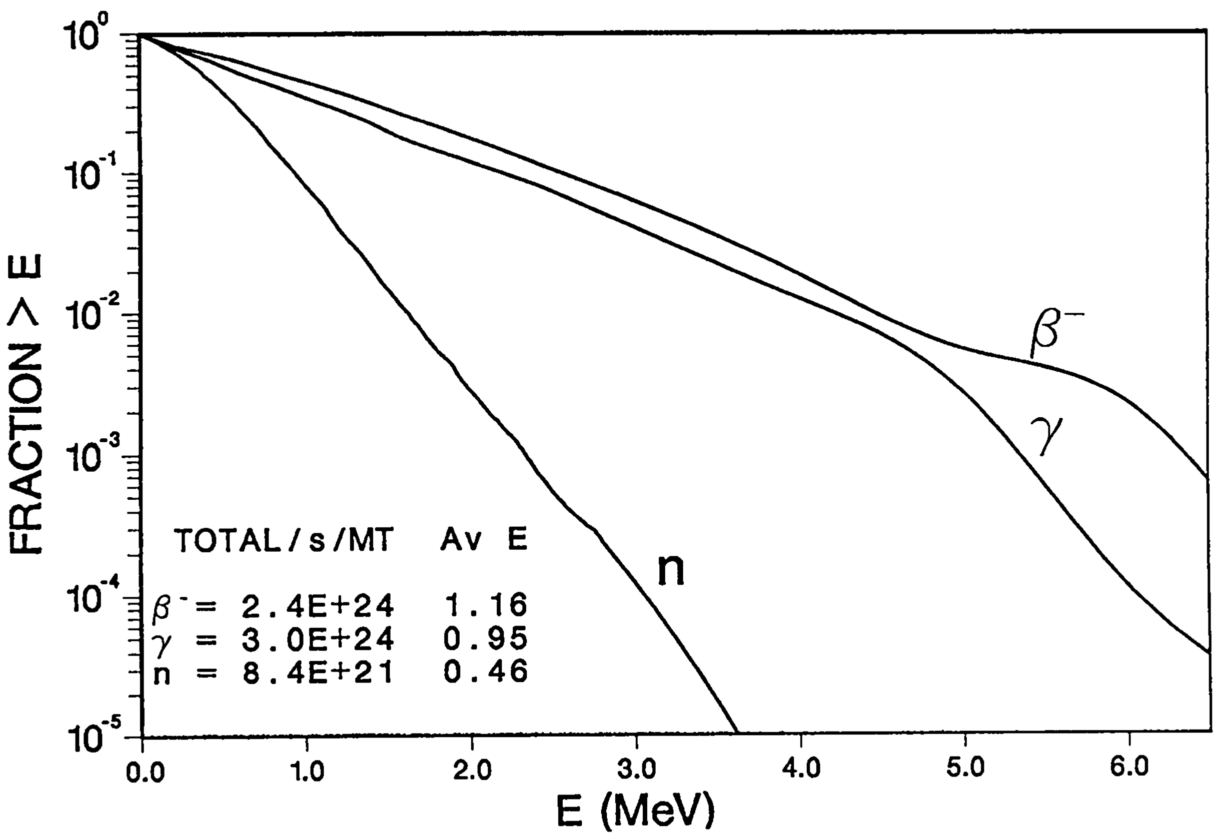

Fig. 43 ^{235}U Fission: Background at T = 30 s.

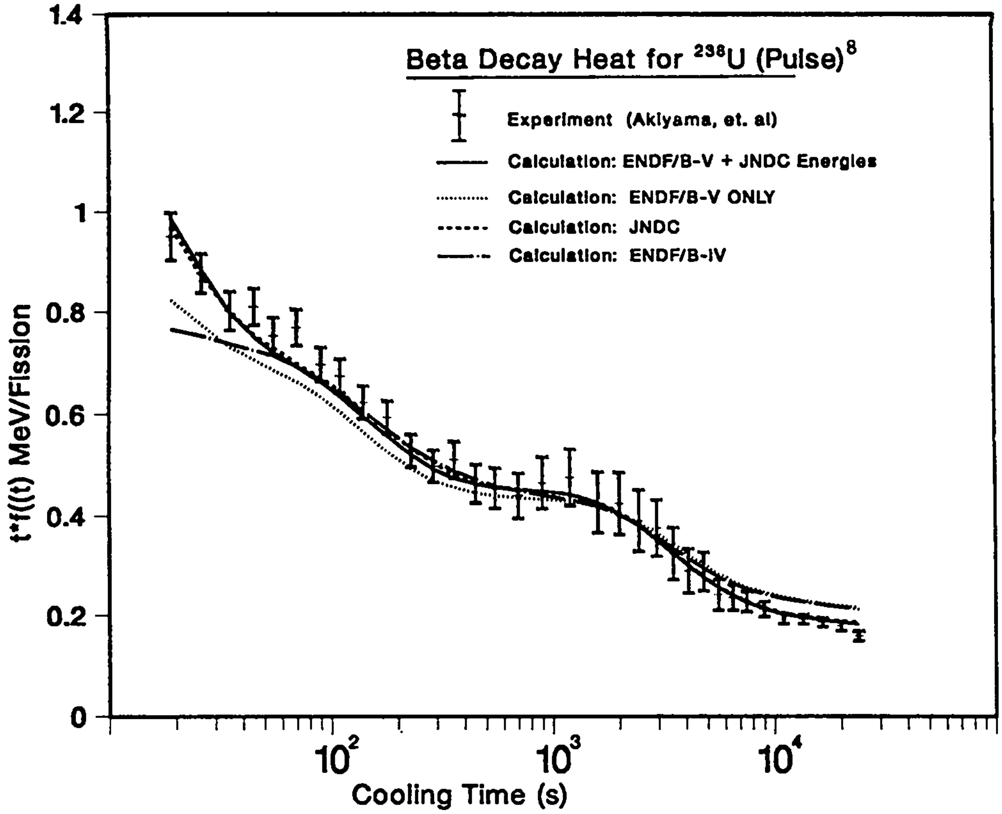

Fig. 44. Beta decay heat for ^{238}U (Pulse).

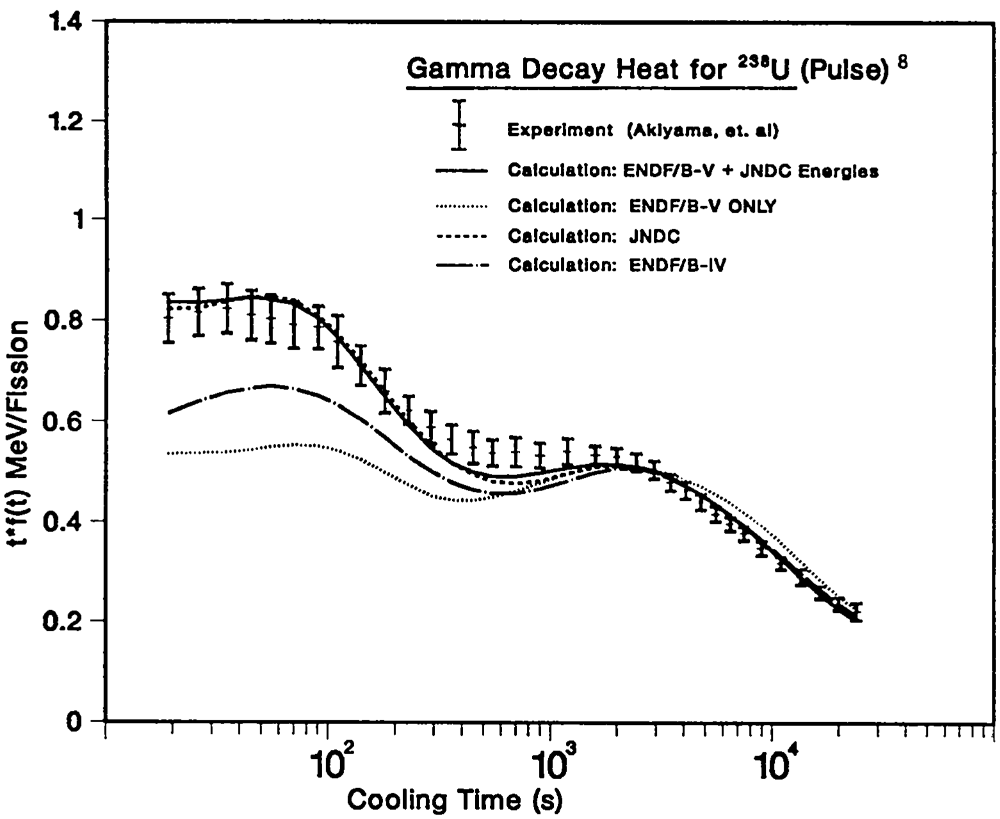

Fig. 45. Gamma decay heat for ^{238}U (Pulse).

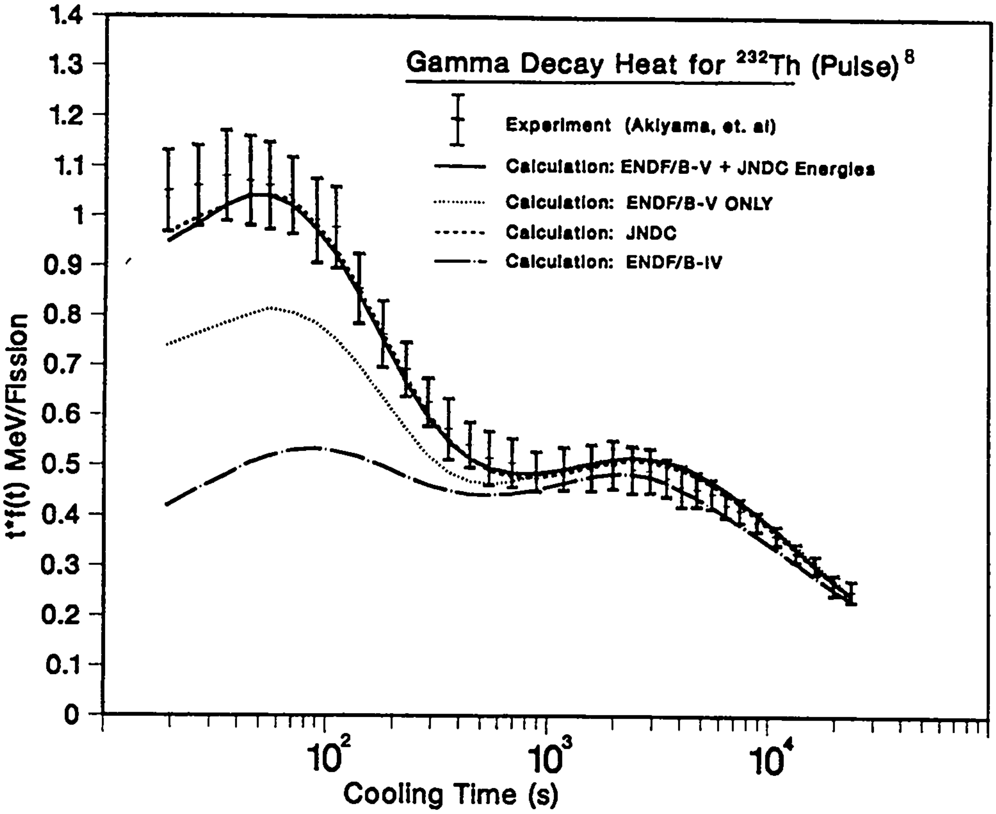

Fig. 46. Gamma decay heat for ^{232}Th (Pulse).

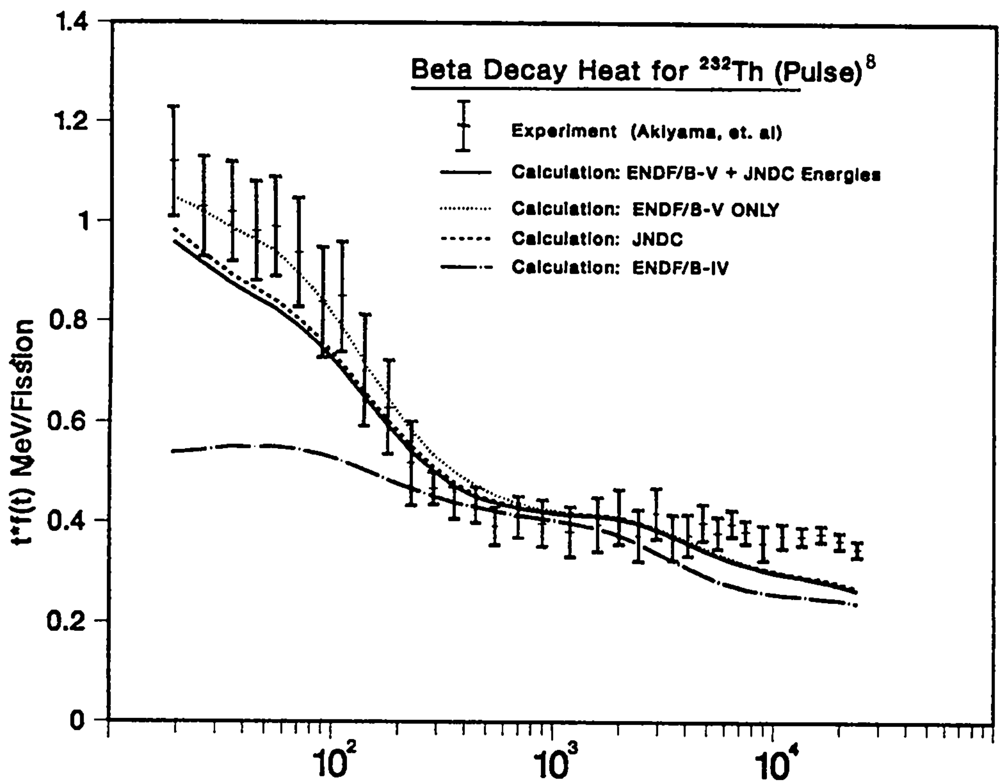

Fig. 47. Beta decay heat for ^{232}Th (Pulse).

VI. SUMMARY

The dominant radiation fields produced by nuclear devices are neutron, electromagnetic (x-ray and gamma), and electron, each being prompt and delayed, and all being device dependent. In this report we have focussed on the delayed radiation fields that come from about 800 different radioactive products, 270 of which are delayed neutron emitters and all of which produce spectra of β^- and γ energies. The initial content of this ensemble is characterized by a fission-product yield that varies with the type of device.

To predict this radiation background, we require a complete data base for each product and various application codes. These now exist, but the data bases require improvement because of the emphasis on high radiation energies, the need to examine different fissioning species and devices, and the need to predict fission-product yields from a fission pulse. Some improvements can be made with selected measurements, but many will require nuclear model calculations because of the large number of difficult measurements needed. With sufficient support, progress can be made in updating the necessary data bases during the next year by incorporating US, Japanese, and other measurements, and by developing and applying the necessary model codes.

ACKNOWLEDGMENTS

Drs. F. M. Mann (Hanford Engineering Development Laboratory), P. L. Reeder (Pacific Northwest Laboratory), C. Goulding (Los Alamos National Laboratory), T. Yoshida (Nippon Atomic Industry Group), K. -L. Kratz (University of Mainz), and G. Rudstam (Swedish Research Councils Laboratory, Studsvik) contributed portions of data used in this report, as did others noted in the references. Several people, in addition to C. Goulding, were involved in the Los Alamos measurements (see Ref. 16). Most of the recent calculations were encouraged and supported by a Los Alamos program directed by G. F. Auchampaugh and earlier calculations were promoted by O. P. Judd. The basic data development was supported primarily by the US Department of Energy (Basic Energy Sciences).

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APPENDIX A.

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APPENDIX B

INDIVIDUAL PRECURSOR CONTRIBUTIONS

In Section I we identified the major contributors at high energies (Figs. 4a and 4b, where arsenic, bromine, rubidium, and iodine isotopes are explicitly noted). In this appendix more detail is provided; specifically, for ^{235}U, ^{238}U, ^{232}Th, and ^{239}Pu fast fission, the per cent contribution of each precursor to the total overall energy and to the total value above 4 MeV is listed for ~ 0, 1.0, 5.0, 10.0, and 30.0 s. Only contributions > 0.01% are included. (Table B-I lists precursors having energies greater than 2, 3, 4, 5, 6, 7, and 8 MeV, but not their actual contribution to delayed neutrons.) Aggregate totals were included in Section IV.

Tables B-II through B-IX are intended to serve as a guide in the determination of the probable importance to calculations of future precursor experiments. It is important for the user to realize that the listed contributions above 4 MeV are based entirely on fission-product yields, emission probabilities, and delayed neutron spectrum models. Any single value could easily be in error by an order of magnitude; and, if so, all other relative contributions would change. Thus, a listed small contribution above 4 MeV should not discourage a possible measurement.

TABLE B-I

PRECURSORS HAVING PROBABLE DELAYED NEUTRON ENERGIES ABOVE NOTED VALUES

2.0 MeV Nuclide	3.0 MeV Nuclide	4.0 MeV Nuclide	5.0 MeV Nuclide	6.0 MeV Nuclide	7.0 MeV Nuclide	8.0 MeV Nuclide
Co- 72g	Co- 72g	Co- 72g	Co- 72g	Co- 72g	Co- 72g	Co- 73g
Co- 73g	Co- 73g	Co- 73g	Co- 73g	Co- 73g	Co- 73g	Co- 74g
Co- 74g	Co- 74g	Co- 74g	Co- 74g	Co- 74g	Co- 74g	Co- 75g
Co- 75g	Co- 75g	Co- 75g	Co- 75g	Co- 75g	Co- 75g	Cu- 80g
Ni- 75g	Cu- 75g	Ni- 77g	Cu- 77g	Cu- 78g	Cu- 79g	Cu- 81g
Cu- 75g	Ni- 76g	Cu- 77g	Ni- 78g	Cu- 79g	Cu- 80g	Zn- 83g
Ni- 76g	Cu- 76g	Ni- 78g	Cu- 78g	Cu- 80g	Cu- 81g	Ga- 83g
Cu- 76g	Ni- 77g	Cu- 78g	Cu- 79g	Cu- 81g	Zn- 82g	Ga- 84g
Ni- 77g	Cu- 77g	Cu- 79g	Cu- 80g	Zn- 82g	Zn- 83g	Ga- 85g
Cu- 77g	Ni- 78g	Cu- 80g	Cu- 81g	Zn- 83g	Ga- 83g	As- 87g
Ni- 78g	Cu- 78g	Cu- 81g	Zn- 81g	Ga- 83g	Ga- 84g	Ge- 88g
Cu- 78g	Cu- 79g	Zn- 81g	Zn- 82g	Ga- 84g	Ga- 85g	As- 88g
Cu- 79g	Cu- 80g	Zn- 82g	Ga- 82g	Ga- 85g	As- 86g	As- 89g
Zn- 79g	Cu- 81g	Ga- 82g	Zn- 83g	Ge- 85g	Ge- 87g	As- 90g
Cu- 80g	Zn- 81g	Zn- 83g	Ga- 83g	Ge- 86g	As- 87g	Br- 92g
Zn- 80g	Ga- 81g	Ga- 83g	Ga- 84g	As- 86g	Ge- 88g	Br- 93g
Ga- 80g	Zn- 82g	Ga- 84g	Ga- 85g	Ge- 87g	As- 88g	Br- 94g
Cu- 81g	Ga- 82g	Ge- 84g	Ge- 85g	As- 87g	As- 89g	Br- 95g
Zn- 81g	Zn- 83g	Ga- 85g	Ge- 86g	Ge- 88g	As- 90g	Br- 96g
Ga- 81g	Ga- 83g	Ge- 85g	As- 86g	As- 88g	Se- 91g	Rb-101g
Zn- 82g	Ga- 84g	As- 85g	Ge- 87g	As- 89g	Br- 91g	Y -107g
Ga- 82g	Ge- 84g	Ge- 86g	As- 87g	As- 90g	Br- 92g	Cd-132g
Zn- 83g	Ga- 85g	As- 86g	Ge- 88g	Se- 90g	Se- 93g	In-133g
Ga- 83g	Ge- 85g	Ge- 87g	As- 88g	Se- 91g	Br- 93g	In-134g
Ga- 84g	As- 85g	As- 87g	As- 89g	Br- 91g	Br- 94g	---
Ge- 84g	Ge- 86g	Ge- 88g	Se- 89g	Se- 92g	Br- 95g	---
Ga- 85g	As- 86g	As- 88g	As- 90g	Br- 92g	Br- 96g	---
Ge- 85g	Ge- 87g	As- 89g	Se- 90g	Se- 93g	Rb- 99g	---
As- 85g	As- 87g	Se- 89g	Se- 91g	Br- 93g	Rb-100g	---
Ge- 86g	Ge- 88g	As- 90g	Br- 91g	Br- 94g	Rb-101g	---
As- 86g	As- 88g	Se- 90g	Se- 92g	Br- 95g	Y -106g	---
Ge- 87g	Se- 88g	Br- 90g	Br- 92g	Br- 96g	Y -107g	---
As- 87g	As- 89g	Se- 91g	Se- 93g	Rb- 97g	Tc-117g	---
Ge- 88g	Se- 89g	Br- 91g	Br- 93g	Rb- 98g	Rh-123g	---
As- 88g	Br- 89g	Se- 92g	Br- 94g	Rb- 99g	Cd-132g	---
Se- 88g	As- 90g	Br- 92g	Br- 95g	Rb-100g	In-133g	---
As- 89g	Se- 90g	Se- 93g	Br- 96g	Rb-101g	In-134g	---
Se- 89g	Br- 90g	Br- 93g	Rb- 96g	Sr-103g	Sb-138g	---
Br- 89g	Se- 91g	Br- 94g	Kr- 97g	Sr-104g	Sb-139g	---
As- 90g	Br- 91g	Kr- 94g	Rb- 97g	Y -105g	I -143g	---
Se- 90g	Se- 92g	Br- 95g	Kr- 98g	Y -106g	Cs-149g	---
Br- 90g	Br- 92g	Kr- 95g	Rb- 98g	Y -107g	---	---
Se- 91g	Se- 93g	Rb- 95g	Rb- 99g	Nb-111g	---	---
Br- 91g	Br- 93g	Br- 96g	Rb-100g	Tc-116g	---	---
Se- 92g	Br- 94g	Kr- 96g	Rb-101g	Tc-117g	---	---
Br- 92g	Kr- 94g	Rb- 96g	Sr-103g	Rh-121g	---	---
Se- 93g	Rb- 94g	Kr- 97g	Sr-104g	Rh-122g	---	---
Br- 93g	Br- 95g	Rb- 97g	Y -104g	Rh-123g	---	---

Continued

Table B-I (Cont.)

2.0 MeV Nuclide	3.0 MeV Nuclide	4.0 MeV Nuclide	5.0 MeV Nuclide	6.0 MeV Nuclide	7.0 MeV Nuclide	8.0 MeV Nuclide
Kr- 93g	Kr- 95g	Kr- 98g	Y -105g	Cd-132g	---	---
Rb- 93g	Rb- 95g	Rb- 98g	Y -106g	In-133g	---	---
Br- 94g	Br- 96g	Rb- 99g	Y -107g	In-134g	---	---
Kr- 94g	Kr- 96g	Rb-100g	Zr-109g	Sb-138g	---	---
Rb- 94g	Rb- 96g	Rb-101g	Nb-109g	Sb-139g	---	---
Br- 95g	Kr- 97g	Y -101g	Nb-110g	I -142g	---	---
Kr- 95g	Rb- 97g	Sr-103g	Nb-111g	I -143g	---	---
Rb- 95g	Kr- 98g	Y -103g	Tc-115g	I -144g	---	---
Br- 96g	Rb- 98g	Sr-104g	Tc-116g	I -145g	---	---
Kr- 96g	Rb- 99g	Y -104g	Tc-117g	Cs-148g	---	---
Rb- 96g	Y - 99g	Y -105g	Ru-120g	Cs-149g	---	---
Kr- 97g	Rb-100g	Y -106g	Rh-121g	Cs-150g	---	---
Rb- 97g	Rb-101g	Y -107g	Rh-122g	La-155g	---	---
Kr- 98g	Sr-101g	Nb-107g	Rh-123g	---	---	---
Rb- 98g	Y -101g	Zr-108g	Ag-127g	---	---	---
Y - 98g	Sr-102g	Nb-108g	Ag-128g	---	---	---
Rb- 99g	Y -102g	Zr-109g	Cd-131g	---	---	---
Sr- 99g	Sr-103g	Nb-109g	Cd-132g	---	---	---
Y - 99g	Y -103g	Nb-110g	In-132g	---	---	---
Rb-100g	Sr-104g	Nb-111g	In-133g	---	---	---
Sr-100g	Y -104g	Mo-113g	In-134g	---	---	---
Y -100g	Y -105g	Tc-113g	Sn-135g	---	---	---
Rb-101g	Y -106g	Tc-114g	Sn-136g	---	---	---
Sr-101g	Y -107g	Tc-115g	Sb-137g	---	---	---
Y -101g	Zr-107g	Tc-116g	Sb-138g	---	---	---
Sr-102g	Nb-107g	Tc-117g	Sb-139g	---	---	---
Y -102g	Zr-108g	Ru-119g	Te-140g	---	---	---
Sr-103g	Nb-108g	Rh-119g	Te-141g	---	---	---
Y -103g	Zr-109g	Ru-120g	I -141g	---	---	---
Sr-104g	Nb-109g	Rh-120g	Te-142g	---	---	---
Y -104g	Nb-110g	Rh-121g	I -142g	---	---	---
Y -105g	Nb-111g	Rh-122g	I -143g	---	---	---
Zr-105g	Tc-111g	Rh-123g	I -144g	---	---	---
Nb-105g	Tc-112g	Ag-125g	I -145g	---	---	---
Y -106g	Mo-113g	Pd-126g	Xe-147g	---	---	---
Zr-106g	Tc-113g	Ag-126g	Cs-148g	---	---	---
Nb-106g	Tc-114g	Ag-127g	Cs-149g	---	---	---
Y -107g	Tc-115g	Ag-128g	Cs-150g	---	---	---
Zr-107g	Tc-116g	Cd-131g	La-154g	---	---	---
Nb-107g	Tc-117g	Cd-132g	La-155g	---	---	---
Zr-108g	Ru-117g	In-132g	Pr-159g	---	---	---
Nb-108g	Rh-117g	In-133g	---	---	---	---
Zr-109g	Ru-118g	In-134g	---	---	---	---
Nb-109g	Rh-118g	Sn-135g	---	---	---	---
Nb-110g	Ru-119g	Sb-135g	---	---	---	---
Mo-110g	Rh-119g	Sn-136g	---	---	---	---
Nb-111g	Ru-120g	Sb-136g	---	---	---	---
Mo-111g	Rh-120g	Sb-137g	---	---	---	---

Continued

Table B-I (Cont.)

2.0 MeV Nuclide	3.0 MeV Nuclide	4.0 MeV Nuclide	5.0 MeV Nuclide	6.0 MeV Nuclide	7.0 MeV Nuclide	8.0 MeV Nuclide
Tc-111g	Rh-121g	Sb-138g	---	---	---	---
Mo-112g	Rh-122g	Sb-139g	---	---	---	---
Tc-112g	Rh-123g	Te-139g	---	---	---	---
Mo-113g	Pd-124g	Te-140g	---	---	---	---
Tc-113g	Ag-124g	I -140g	---	---	---	---
Tc-114g	Pd-125g	Te-141g	---	---	---	---
Tc-115g	Ag-125g	I -141g	---	---	---	---
Tc-116g	Pd-126g	Te-142g	---	---	---	---
Ru-116g	Ag-126g	I -142g	---	---	---	---
Tc-117g	Ag-127g	I -143g	---	---	---	---
Ru-117g	Ag-128g	I -144g	---	---	---	---
Rh-117g	Cd-131g	I -145g	---	---	---	---
Ru-118g	In-131g	Xe-145g	---	---	---	---
Rh-118g	Cd-132g	Xe-146g	---	---	---	---
Ru-119g	In-132g	Cs-146g	---	---	---	---
Rh-119g	In-133g	Xe-147g	---	---	---	---
Ru-120g	In-134g	Cs-147g	---	---	---	---
Rh-120g	Sn-134g	Cs-148g	---	---	---	---
Rh-121g	Sn-135g	Cs-149g	---	---	---	---
Rh-122g	Sb-135g	Cs-150g	---	---	---	---
Rh-123g	Sn-136g	Ba-150g	---	---	---	---
Pd-123g	Sb-136g	La-153g	---	---	---	---
Ag-123g	Sb-137g	La-154g	---	---	---	---
Pd-124g	Sb-138g	La-155g	---	---	---	---
Ag-124g	Sb-139g	Pr-158g	---	---	---	---
Pd-125g	Te-139g	Pr-159g	---	---	---	---
Ag-125g	I -139g	---	---	---	---	---
Pd-126g	Te-140g	---	---	---	---	---
Ag-126g	I -140g	---	---	---	---	---
Ag-127g	Te-141g	---	---	---	---	---
Ag-128g	I -141g	---	---	---	---	---
In-129g	Te-142g	---	---	---	---	---
Cd-130g	I -142g	---	---	---	---	---
In-130g	I -143g	---	---	---	---	---
Cd-131g	Xe-143g	---	---	---	---	---
In-131g	I -144g	---	---	---	---	---
Cd-132g	Xe-144g	---	---	---	---	---
In-132g	I -145g	---	---	---	---	---
In-133g	Xe-145g	---	---	---	---	---
In-134g	Cs-145g	---	---	---	---	---
Sn-134g	Xe-146g	---	---	---	---	---
Sn-135g	Cs-146g	---	---	---	---	---
Sb-135g	Xe-147g	---	---	---	---	---
Sn-136g	Cs-147g	---	---	---	---	---
Sb-136g	Cs-148g	---	---	---	---	---
Sb-137g	Cs-149g	---	---	---	---	---
Sb-138g	Cs-150g	---	---	---	---	---
Te-138g	Ba-150g	---	---	---	---	---
I -138g	Ba-151g	---	---	---	---	---

Continued

TABLE B-I (Cont.)

2.0 MeV Nuclide	3.0 MeV Nuclide	4.0 MeV Nuclide	5.0 MeV Nuclide	6.0 MeV Nuclide	7.0 MeV Nuclide	8.0 MeV Nuclide
Sb-139g	La-151g	---	---	---	---	---
Te-139g	Ba-152g	---	---	---	---	---
I -139g	La-152g	---	---	---	---	---
Te-140g	La-153g	---	---	---	---	---
I -140g	La-154g	---	---	---	---	---
Te-141g	La-155g	---	---	---	---	---
I -141g	Ce-156g	---	---	---	---	---
Te-142g	Ce-157g	---	---	---	---	---
I -142g	Pr-157g	---	---	---	---	---
I -143g	Pr-158g	---	---	---	---	---
Xe-143g	Pr-159g	---	---	---	---	---
Cs-143g	---	---	---	---	---	---
I -144g	---	---	---	---	---	---
Xe-144g	---	---	---	---	---	---
Cs-144g	---	---	---	---	---	---
I -145g	---	---	---	---	---	---
Xe-145g	---	---	---	---	---	---
Cs-145g	---	---	---	---	---	---
Xe-146g	---	---	---	---	---	---
Cs-146g	---	---	---	---	---	---
Xe-147g	---	---	---	---	---	---
Cs-147g	---	---	---	---	---	---
Cs-148g	---	---	---	---	---	---
Cs-149g	---	---	---	---	---	---
Ba-149g	---	---	---	---	---	---
Cs-150g	---	---	---	---	---	---
Ba-150g	---	---	---	---	---	---
Ba-151g	---	---	---	---	---	---
La-151g	---	---	---	---	---	---
Ba-152g	---	---	---	---	---	---
La-152g	---	---	---	---	---	---
La-153g	---	---	---	---	---	---
La-154g	---	---	---	---	---	---
La-155g	---	---	---	---	---	---
Ce-155g	---	---	---	---	---	---
Pr-155g	---	---	---	---	---	---
Ce-156g	---	---	---	---	---	---
Pr-156g	---	---	---	---	---	---
Ce-157g	---	---	---	---	---	---
Pr-157g	---	---	---	---	---	---
Pr-158g	---	---	---	---	---	---
Pr-159g	---	---	---	---	---	---
Nd-161g	---	---	---	---	---	---
Pm-162g	---	---	---	---	---	---

TABLE B-II

^{235}U FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01%
FOR ENERGIES ABOVE 0.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Cu- 77g	0.01	Ga- 80g	0.01	Ga- 80g	0.01	Ge- 84g	0.01	As- 85g	0.04
Ga- 81g	0.09	Ga- 81g	0.14	Ga- 81g	0.06	As- 85g	6.19	Se- 87g	0.08
Ga- 82g	0.11	Ga- 82g	0.09	Ge- 84g	0.07	Se- 87g	0.17	Br- 87g	7.49
Ga- 83g	0.13	Ga- 83g	0.04	As- 85g	12.70	Br- 87g	1.56	Br- 88g	26.69
Ga- 84g	0.03	Ge- 84g	0.18	As- 86g	0.15	Se- 88g	0.06	Br- 89g	5.27
Ge- 84g	0.12	As- 84g	0.01	Se- 87g	0.12	Br- 88g	11.79	Br- 90g	0.01
As- 84g	0.04	Ge- 85g	0.06	Br- 87g	0.54	Br- 89g	23.24	Rb- 92g	0.01
Ge- 85g	0.38	As- 85g	12.28	Se- 88g	0.22	Br- 90g	4.85	Rb- 93g	3.09
As- 85g	6.42	As- 86g	0.80	Br- 88g	5.31	Rb- 92g	0.05	Rb- 94g	0.45
Ge- 86g	0.05	As- 87g	0.70	Br- 89g	19.07	Kr- 93g	0.03	Y- 97g	0.02
As- 86g	0.66	Se- 87g	0.05	Br- 90g	12.38	Rb- 93g	6.12	Nb-105g	0.01
As- 87g	2.67	Br- 87g	0.12	Br- 91g	0.13	Rb- 94g	12.79	Sb-134g	0.07
Se- 87g	0.02	Se- 88g	0.35	Kr- 92g	0.02	Y- 97g	0.16	Te-136g	3.30
Br- 87g	0.04	Br- 88g	1.37	Rb- 92g	0.03	Y- 98g	0.11	Te-137g	0.10
As- 88g	0.40	Se- 89g	0.82	Kr- 93g	0.15	Y- 98m	0.02	I-137g	46.52
Se- 88g	0.21	Br- 89g	8.74	Rb- 93g	4.09	Y- 99g	0.48	I-138g	6.36
Br- 88g	0.50	Se- 90g	0.18	Rb- 94g	16.70	Zr-104g	0.01	I-139g	0.05
As- 89g	0.07	Br- 90g	14.16	Kr- 95g	0.02	Nb-104g	0.02	Cs-141g	0.40
Se- 89g	1.68	Se- 91g	0.02	Rb- 95g	0.06	Nb-105g	0.36	La-146g	0.01
Br- 89g	3.67	Br- 91g	3.33	Y- 97g	0.16	In-127g	0.05	La-147g	0.01
Se- 90g	0.35	Br- 92g	0.82	Y- 97m	0.07	Sb-134g	0.04		
Br- 90g	7.76	Kr- 92g	0.02	Sr- 98g	0.01	Sb-135g	0.78		
Se- 91g	0.10	Rb- 92g	0.01	Y- 98g	0.23	Te-136g	1.27		
Br- 91g	4.00	Kr- 93g	0.31	Y- 98m	1.06	Te-137g	0.94		
Br- 92g	2.13	Rb- 93g	1.58	Y- 99g	2.12	I-137g	14.88		
Kr- 92g	0.01	Kr- 94g	0.34	Y-100g	0.12	Te-138g	0.10		
Br- 93g	0.16	Rb- 94g	11.24	Y-101g	0.03	I-138g	9.97		
Kr- 93g	0.20	Kr- 95g	0.17	Y-102g	0.07	I-139g	2.89		
Rb- 93g	0.66	Rb- 95g	6.71	Nb-103g	0.02	Cs-141g	0.13		
Br- 94g	0.08	Kr- 96g	0.01	Zr-104g	0.02	Cs-142g	0.07		
Kr- 94g	3.51	Rb- 96g	1.15	Nb-104g	0.02	Cs-143g	0.58		
Rb- 94g	5.09	Rb- 97g	0.26	Nb-105g	0.47	Cs-144g	0.04		
Kr- 95g	0.16	Y- 97g	0.07	In-127g	0.05	La-147g	0.04		
Rb- 95g	15.31	Y- 97m	0.18	Sn-133g	0.02	La-149g	0.04		
Kr- 96g	0.04	Sr- 98g	0.25	Sn-134g	0.08				
Rb- 96g	12.68	Y- 98g	0.23	Sb-134g	0.02				
Rb- 97g	5.81	Y- 98m	7.79	Sb-135g	1.94				
Sr- 97g	0.02	Sr- 99g	0.02	Sb-136g	0.09				
Y- 97g	0.02	Y- 99g	3.58	Te-136g	0.57				
Y- 97m	0.11	Sr-100g	0.02	Te-137g	0.94				
Rb- 98g	0.52	Y-100g	0.87	I-137g	6.15				
Sr- 98g	0.27	Y-101g	0.66	Te-138g	0.34				
Y- 98g	0.12	Y-102g	0.35	I-138g	6.25				
Y- 98m	5.61	Y-103g	0.05	I-139g	4.62				
Rb- 99g	0.01	Zr-103g	0.01	I-140g	0.20				

Continued

Table B-II (Cont.)

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Sr- 99g	0.03	Nb-103g	0.02	Xe-141g	0.02				
Y- 99g	2.10	Zr-104g	0.01	Cs-141g	0.05				
Sr-100g	0.03	Zr-105g	0.01	Xe-142g	0.06				
Y-100g	0.76	Nb-105g	0.31	Cs-142g	0.18				
Sr-101g	0.03	Nb-106g	0.03	Xe-143g	0.02				
Y-101g	0.78	Nb-107g	0.04	Cs-143g	1.50				
Y-102g	0.29	In-127g	0.02	Xe-144g	0.01				
Y-103g	0.28	In-130g	0.09	Cs-144g	0.42				
Nb-103g	0.01	In-130m	0.06	Cs-145g	0.06				
Y-104g	0.02	In-131g	0.04	La-147g	0.03				
Zr-105g	0.02	Sn-133g	0.03	La-148g	0.02				
Nb-105g	0.15	Sn-134g	0.30	La-149g	0.06				
Nb-106g	0.03	Sb-135g	2.19						
Nb-107g	0.04	Sb-136g	0.67						
Ag-124g	0.01	Te-136g	0.16						
In-130g	0.05	Sb-137g	0.04						
In-130m	0.08	Te-137g	0.51						
In-131g	0.07	I-137g	1.60						
In-131m	0.16	Te-138g	0.47						
In-132g	0.14	I-138g	2.29						
In-133g	0.07	Te-139g	0.08						
Sn-133g	0.02	I-139g	3.63						
Sn-134g	0.22	Te-140g	0.01						
Sn-135g	0.01	I-140g	1.22						
Sb-135g	1.22	I-141g	0.33						
Sb-136g	0.59	Xe-141g	0.02						
Te-136g	0.06	Cs-141g	0.01						
Sb-137g	0.06	Xe-142g	0.15						
Te-137g	0.24	Cs-142g	0.19						
I-137g	0.61	Xe-143g	0.09						
Sb-138g	0.01	Cs-143g	1.71						
Te-138g	0.28	Xe-144g	0.04						
I-138g	0.95	Cs-144g	1.55						
Te-139g	0.10	Cs-145g	1.45						
I-139g	1.83	Cs-146g	0.11						
I-140g	1.04	Cs-147g	0.05						
I-141g	0.56	La-147g	0.01						
Xe-141g	0.01	La-148g	0.04						
I-142g	0.11	La-149g	0.05						
Xe-142g	0.10								
Cs-142g	0.10								
Xe-143g	0.07								
Cs-143g	0.93								
Xe-144g	0.03								
Cs-144g	1.17								
Cs-145g	1.79								
Cs-146g	0.32								
Cs-147g	0.07								
La-148g	0.03								
La-149g	0.02								

Continued

TABLE B-III

^{235}U FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 4.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Ga- 83g	0.03	Ga- 83g	0.02	Ga- 82g	0.03	As- 85g	39.14	As- 85g	67.92
Ge- 85g	0.02	As- 85g	0.04	As- 85g	3.94	As- 86g	2.93	Br- 90g	32.08
As- 86g	0.04	As- 86g	0.13	As- 86g	2.52	Br- 90g	44.25		
As- 87g	0.38	As- 87g	0.25	As- 87g	0.01	Br- 91g	11.82		
As- 88g	0.05	Se- 89g	0.03	Se- 89g	0.02	Br- 92g	0.05		
As- 89g	0.01	Br- 90g	0.06	Br- 90g	5.55	Kr- 95g	0.02		
Se- 89g	0.03	Br- 91g	16.83	Br- 91g	69.67	Rb- 95g	1.06		
Br- 90g	0.01	Br- 92g	78.66	Br- 92g	14.93	I-140g	0.71		
Br- 91g	7.99	Rb- 95g	2.40	Kr- 95g	0.03				
Br- 92g	81.03	Rb- 96g	0.90	Rb- 95g	2.29				
Br- 93g	0.02	Rb- 97g	0.30	I-140g	0.71				
Br- 94g	0.01	Rb- 98g	0.02	I-141g	0.29				
Rb- 95g	2.16	I-140g	0.04	Cs-147g	0.02				
Rb- 96g	3.91	I-141g	0.28						
Rb- 97g	2.61								
Rb- 98g	1.43								
I-140g	0.01								
I-141g	0.19								

TABLE B-IV

^{238}U FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 0.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Ga- 81g	0.05	Ga- 81g	0.10	Ga- 81g	0.06	Ga- 81g	0.01	As- 85g	0.04
Ga- 82g	0.11	Ga- 82g	0.11	Ge- 84g	0.14	Ge- 84g	0.02	Se- 87g	0.07
Ga- 83g	0.22	Ga- 83g	0.08	As- 85g	9.96	As- 85g	5.72	Br- 87g	4.39
Ga- 84g	0.09	Ge- 84g	0.26	As- 86g	0.18	As- 86g	0.01	Br- 88g	13.96
Ge- 84g	0.14	Ge- 85g	0.10	Se- 87g	0.07	Se- 87g	0.12	Br- 89g	4.72
As- 84g	0.01	As- 85g	7.00	Br- 87g	0.19	Br- 87g	0.70	Br- 90g	0.01
Ga- 85g	0.01	Ge- 86g	0.02	Se- 88g	0.17	Se- 88g	0.05	Rb- 92g	0.01
Ge- 85g	0.48	As- 86g	0.72	Br- 88g	1.90	Br- 88g	5.09	Rb- 93g	2.59
As- 85g	2.83	As- 87g	0.61	Br- 89g	12.02	Br- 89g	17.25	Rb- 94g	0.54
Ge- 86g	0.11	Se- 87g	0.02	Br- 90g	10.27	Br- 90g	4.74	Y- 97g	0.02
As- 86g	0.47	Br- 87g	0.02	Br- 91g	0.26	Kr- 92g	0.02	Nb-104g	0.04

Continued

Table B-IV (Cont.)

(0.0s) Nuclide	%	(1.0s) Nuclide	%	(5.0s) Nuclide	%	(10.0s) Nuclide	%	(30.0s) Nuclide	%
Ge- 87g	0.01	Se- 88g	0.19	Kr- 92g	0.03	Rb- 92g	0.03	Nb-105g	0.09
As- 87g	1.89	Br- 88g	0.30	Rb- 92g	0.02	Kr- 93g	0.13	Rh-115g	0.02
As- 88g	0.50	Se- 89g	0.90	Kr- 93g	0.60	Rb- 93g	4.24	Sb-134g	0.20
Se- 88g	0.09	Br- 89g	3.92	Rb- 93g	2.32	Rb- 94g	12.64	Sb-135g	0.01
Br- 88g	0.08	Se- 90g	0.33	Rb- 94g	14.01	Y- 97g	0.13	Te-136g	7.84
As- 89g	0.21	Br- 90g	8.41	Kr- 95g	0.06	Y- 98g	0.07	Te-137g	0.31
Se- 89g	1.49	Se- 91g	0.08	Rb- 95g	0.15	Y- 98m	0.04	I-137g	53.29
Br- 89g	1.21	Br- 91g	4.75	Y- 97g	0.10	Y- 99g	0.65	I-138g	11.24
Se- 90g	0.53	Br- 92g	2.31	Y- 97m	0.03	Y-102g	0.02	I-139g	0.13
Br- 90g	3.56	Kr- 92g	0.03	Sr- 98g	0.02	Nb-103g	0.02	Cs-141g	0.40
Se- 91g	0.33	Br- 93g	0.08	Y- 98g	0.13	Zr-104g	0.08	La-146g	0.02
Br- 91g	4.57	Kr- 93g	0.93	Y- 98m	1.42	Nb-104g	0.08	La-147g	0.02
Se- 92g	0.03	Rb- 93g	0.53	Y- 99g	2.43	Nb-105g	1.98		
Br- 92g	4.84	Kr- 94g	0.53	Y-100g	0.18	Tc-111g	0.02		
Kr- 92g	0.01	Rb- 94g	6.84	Y-101g	0.06	Rh-115g	0.02		
Br- 93g	1.29	Kr- 95g	0.38	Y-102g	0.24	In-127g	0.02		
Kr- 93g	0.49	Rb- 95g	5.60	Zr-103g	0.02	In-129m	0.03		
Rb- 93g	0.15	Kr- 96g	0.05	Nb-103g	0.04	Sn-133g	0.03		
Br- 94g	0.29	Rb- 96g	1.63	Zr-104g	0.09	Sn-134g	0.10		
Kr- 94g	4.37	Rb- 97g	0.22	Nb-104g	0.04	Sb-134g	0.12		
Rb- 94g	2.20	Y- 97g	0.03	Nb-105g	2.15	Sb-135g	3.79		
Kr- 95g	0.29	Y- 97m	0.07	Nb-106g	0.08	Sb-136g	0.03		
Rb- 95g	9.79	Sr- 98g	0.29	Nb-107g	0.05	Te-136g	2.51		
Kr- 96g	0.16	Y- 98g	0.09	Tc-111g	0.03	Te-137g	2.52		
Rb- 96g	13.46	Y- 98m	5.25	In-127g	0.02	I-137g	13.44		
Kr- 97g	0.02	Sr- 99g	0.04	In-129g	0.06	Te-138g	0.58		
Rb- 97g	3.92	Y- 99g	2.77	In-129m	0.04	I-138g	14.48		
Y- 97m	0.03	Sr-100g	0.08	In-130g	0.03	I-139g	6.86		
Rb- 98g	1.44	Y-100g	0.88	Sn-133g	0.08	I-140g	0.05		
Sr- 98g	0.26	Sr-101g	0.01	Sn-134g	0.85	Xe-141g	0.01		
Y- 98g	0.04	Y-101g	1.10	Sb-134g	0.05	Cs-141g	0.11		
Y- 98m	1.81	Y-102g	0.95	Sb-135g	8.04	Xe-142g	0.02		
Rb- 99g	0.33	Y-103g	0.30	Sb-136g	0.67	Cs-142g	0.09		
Sr- 99g	0.04	Zr-103g	0.02	Te-136g	0.95	Cs-143g	0.86		
Y- 99g	1.20	Nb-103g	0.02	Te-137g	2.14	Xe-144g	0.01		
Sr-100g	0.07	Zr-104g	0.05	I-137g	4.37	Cs-144g	0.10		
Y-100g	0.59	Zr-105g	0.09	Te-138g	1.60	La-147g	0.06		
Sr-101g	0.12	Nb-105g	1.01	I-138g	7.48	La-148g	0.02		
Y-101g	1.03	Zr-106g	0.02	Te-139g	0.02	La-149g	0.19		
Sr-102g	0.02	Nb-106g	0.19	I-139g	9.28				
Y-102g	0.63	Nb-107g	0.35	Te-140g	0.04				
Y-103g	1.33	Tc-110g	0.01	I-140g	0.76				
Zr-103g	0.01	Tc-111g	0.02	I-141g	0.03				
Y-104g	0.24	Rh-117g	0.02	Xe-141g	0.03				
Zr-104g	0.02	In-129g	0.16	Cs-141g	0.04				
Y-105g	0.11	In-129m	0.02	Xe-142g	0.12				
Zr-105g	0.12	In-130g	0.20	Cs-142g	0.17				
Nb-105g	0.37	In-130m	0.14	Xe-143g	0.08				

Continued

Table B-IV (Cont.)

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Zr-106g	0.01	In-131g	0.17	Cs-143g	1.86				
Nb-106g	0.12	In-132g	0.01	Xe-144g	0.10				
Nb-107g	0.26	Sn-133g	0.10	Cs-144g	0.78				
Nb-108g	0.03	Sn-134g	2.21	Xe-145g	0.01				
Tc-112g	0.01	Sb-134g	0.01	Cs-145g	0.27				
Ag-124g	0.02	Sn-135g	0.11	La-147g	0.03				
Ag-125g	0.02	Sb-135g	6.60	La-148g	0.04				
Ag-126g	0.01	Sn-136g	0.02	La-149g	0.25				
Ag-127g	0.02	Sb-136g	3.45						
Ag-128g	0.01	Te-136g	0.19						
In-129g	0.08	Sb-137g	0.35						
Cd-130g	0.01	Te-137g	0.85						
In-130g	0.09	I-137g	0.70						
In-130m	0.14	Sb-138g	0.01						
Cd-131g	0.04	Te-138g	1.64						
In-131g	0.24	I-138g	1.78						
In-131m	0.56	Te-139g	0.49						
Cd-132g	0.02	I-139g	5.18						
In-132g	1.02	Te-140g	0.16						
In-133g	1.16	I-140g	3.12						
Sn-133g	0.05	Te-141g	0.01						
In-134g	0.09	I-141g	1.85						
Sn-134g	1.33	Xe-141g	0.03						
Sn-135g	0.17	I-142g	0.06						
Sb-135g	2.94	Xe-142g	0.21						
Sn-136g	0.02	Cs-142g	0.10						
Sb-136g	2.47	I-143g	0.08						
Te-136g	0.06	Xe-143g	0.24						
Sb-137g	0.46	Cs-143g	1.47						
Te-137g	0.32	Xe-144g	0.22						
I-137g	0.20	Cs-144g	1.78						
Sb-138g	0.17	Xe-145g	0.05						
Te-138g	0.78	Cs-145g	4.19						
I-138g	0.56	Cs-146g	0.66						
Sb-139g	0.02	Cs-147g	0.11						
Te-139g	0.50	La-148g	0.05						
I-139g	2.04	La-149g	0.14						
Te-140g	0.11	Ba-150g	0.01						
I-140g	2.12	La-150g	0.02						
Te-141g	0.05	La-151g	0.07						
I-141g	2.49	Pr-155g	0.01						
Xe-141g	0.01								
I-142g	0.55								
Xe-142g	0.11								
Cs-142g	0.04								
I-143g	0.14								
Xe-143g	0.15								
Cs-143g	0.61								

Continued

Table B-IV (Cont.)

(0.0s) Nuclide	%	(1.0s) Nuclide	%	(5.0s) Nuclide	%	(10.0s) Nuclide	%	(30.0s) Nuclide	%
Xe-144g	0.13								
Cs-144g	1.04								
Xe-145g	0.03								
Cs-145g	4.12								
Cs-146g	1.54								
Cs-147g	0.13								
Cs-148g	0.04								
La-148g	0.02								
La-149g	0.06								
La-150g	0.02								
La-151g	0.06								

TABLE V

^{238}U FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 4.0 MeV

(0.0s) Nuclide	%	(1.0s) Nuclide	%	(5.0s) Nuclide	%	(10.0s) Nuclide	%	(30.0s) Nuclide	%
Ga- 83g	0.02	Ga- 83g	0.02	Ga- 82g	0.02	As- 85g	30.47	As- 85g	66.69
Ga- 84g	0.02	As- 86g	0.05	As- 85g	1.43	As- 86g	3.58	Br- 90g	33.30
Ge- 85g	0.01	As- 87g	0.09	As- 86g	1.43	Br- 90g	36.41		
As- 86g	0.01	Se- 89g	0.01	Se- 89g	0.01	Br- 91g	23.04		
As- 87g	0.13	Br- 90g	0.01	Br- 90g	2.12	Br- 92g	0.21		
As- 88g	0.03	Br- 91g	9.52	Br- 91g	63.24	Kr- 95g	0.06		
As- 89g	0.02	Br- 92g	88.15	Br- 92g	26.74	Rb- 95g	3.20		
Se- 89g	0.01	Rb- 95g	0.79	Kr- 95g	0.04	I-140g	2.97		
Se- 91g	0.01	Rb- 96g	0.51	Rb- 95g	2.62	I-141g	0.07		
Br- 91g	4.42	Rb- 97g	0.10	I-140g	1.25				
Br- 92g	89.28	Rb- 98g	0.02	I-141g	1.05				
Br- 93g	0.07	I-140g	0.04	Cs-147g	0.03				
Br- 94g	0.02	I-141g	0.64						
Rb- 95g	0.67								
Rb- 96g	2.01								
Rb- 97g	0.86								
Rb- 98g	1.92								
In-133g	0.02								
I-140g	0.01								
I-141g	0.41								

TABLE B-VI

^{239}Pu FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01%
FOR ENERGIES ABOVE 0.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Ga- 80g	0.01	Ga- 80g	0.02	Ga- 80g	0.01	As- 85g	3.54	As- 85g	0.02
Ga- 81g	0.08	Ga- 81g	0.11	Ga- 81g	0.04	Se- 87g	0.10	Se- 87g	0.04
Ga- 82g	0.06	Ga- 82g	0.05	Ge- 84g	0.03	Br- 87g	1.66	Br- 87g	6.28
Ga- 83g	0.04	Ga- 83g	0.01	As- 85g	8.05	Se- 88g	0.02	Br- 88g	16.74
Ge- 84g	0.06	Ge- 84g	0.08	As- 86g	0.07	Br- 88g	8.87	Br- 89g	2.55
As- 84g	0.04	As- 84g	0.01	Se- 87g	0.08	Br- 89g	13.48	Rb- 92g	0.01
Ge- 85g	0.11	Ge- 85g	0.02	Br- 87g	0.68	Br- 90g	2.25	Rb- 93g	2.82
As- 85g	4.50	As- 85g	7.93	Se- 88g	0.09	Kr- 92g	0.01	Rb- 94g	0.39
As- 86g	0.33	As- 86g	0.37	Br- 88g	4.48	Rb- 92g	0.07	Y- 97g	0.03
As- 87g	0.92	As- 87g	0.22	Br- 89g	12.24	Kr- 93g	0.06	Nb-104g	0.04
Se- 87g	0.01	Se- 87g	0.03	Br- 90g	6.34	Rb- 93g	6.69	Nb-105g	0.08
Br- 87g	0.06	Br- 87g	0.16	Br- 91g	0.08	Rb- 94g	13.28	Rh-115g	0.02
As- 88g	0.08	Se- 88g	0.15	Kr- 92g	0.03	Y- 97g	0.31	In-127g	0.02
Se- 88g	0.10	Br- 88g	1.26	Rb- 92g	0.05	Y- 97m	0.02	Sb-134g	0.04
Br- 88g	0.52	Se- 89g	0.24	Kr- 93g	0.36	Y- 98g	0.23	Te-136g	2.74
Se- 89g	0.52	Br- 89g	5.76	Rb- 93g	4.92	Y- 98m	0.03	Te-137g	0.05
Br- 89g	2.68	Se- 90g	0.04	Rb- 94g	19.20	Y- 99g	0.80	I-137g	58.24
Se- 90g	0.08	Br- 90g	7.42	Rb- 95g	0.04	Nb-103g	0.03	I-138g	9.19
Br- 90g	4.41	Br- 91g	2.13	Y- 97g	0.33	Zr-104g	0.03	I-139g	0.03
Se- 91g	0.03	Br- 92g	0.60	Y- 97m	0.17	Nb-104g	0.14	Cs-141g	0.64
Br- 91g	2.75	Kr- 92g	0.04	Sr- 98g	0.01	Nb-105g	2.50	La-146g	0.02
Br- 92g	1.68	Rb- 92g	0.02	Y- 98g	0.54	Tc-111g	0.03	La-147g	0.01
Kr- 92g	0.02	Kr- 93g	0.77	Y- 98m	1.50	Rh-115g	0.03		
Br- 93g	0.19	Rb- 93g	1.87	Y- 99g	3.90	In-127g	0.13		
Kr- 93g	0.54	Kr- 94g	0.17	Y-100g	0.17	In-129m	0.04		
Rb- 93g	0.83	Rb- 94g	13.18	Y-101g	0.04	Sb-134g	0.04		
Br- 94g	0.02	Kr- 95g	0.07	Y-102g	0.08	Sb-135g	0.47		
Kr- 94g	1.92	Rb- 95g	6.86	Zr-103g	0.02	Te-136g	1.27		
Rb- 94g	6.68	Rb- 96g	0.96	Nb-103g	0.10	Te-137g	0.54		
Kr- 95g	0.07	Rb- 97g	0.17	Zr-104g	0.05	I-137g	22.67		
Rb- 95g	17.11	Sr- 97g	0.01	Nb-104g	0.11	Te-138g	0.06		
Kr- 96g	0.02	Y- 97g	0.16	Nb-105g	3.55	I-138g	17.30		
Rb- 96g	11.51	Y- 97m	0.51	Nb-106g	0.09	I-139g	2.18		
Rb- 97g	4.14	Sr- 98g	0.26	Nb-107g	0.04	Cs-141g	0.25		
Sr- 97g	0.03	Y- 98g	0.55	Tc-109g	0.03	Cs-142g	0.08		
Y- 97g	0.05	Y- 98m	15.14	Tc-111g	0.06	Cs-143g	0.57		
Y- 97m	0.37	Sr- 99g	0.02	Rh-115g	0.02	Cs-144g	0.02		
Rb- 98g	0.28	Y- 99g	6.92	In-127g	0.14	La-146g	0.01		
Sr- 98g	0.31	Sr-100g	0.02	In-129g	0.08	La-147g	0.05		
Y- 98g	0.32	Y-100g	1.37	In-129m	0.06	La-149g	0.04		
Y- 98m	14.50	Y-101g	0.88	Sn-134g	0.02				
Rb- 99g	0.01	Y-102g	0.44	Sb-134g	0.02				

Continued

Table B-VI (Cont.)

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Sr- 99g	0.02	Y-103g	0.06	Sb-135g	1.31				
Y- 99g	4.50	Zr-103g	0.03	Sb-136g	0.04				
Sr-100g	0.02	Nb-103g	0.13	Te-136g	0.63				
Y-100g	1.31	Zr-104g	0.04	Te-137g	0.60				
Sr-101g	0.02	Nb-104g	0.05	I-137g	10.61				
Y-101g	1.12	Zr-105g	0.04	Te-138g	0.22				
Y-102g	0.38	Nb-105g	2.39	I-138g	12.10				
Y-103g	0.36	Nb-106g	0.35	I-139g	3.85				
Zr-103g	0.02	Nb-107g	0.34	I-140g	0.12				
Nb-103g	0.08	Tc-109g	0.06	Xe-141g	0.03				
Y-104g	0.04	Tc-110g	0.06	Cs-141g	0.12				
Zr-104g	0.02	Tc-111g	0.06	Xe-142g	0.04				
Nb-104g	0.02	Rh-117g	0.01	Cs-142g	0.25				
Zr-105g	0.06	In-127g	0.07	Cs-143g	1.63				
Nb-105g	1.23	In-128g	0.01	Cs-144g	0.27				
Nb-106g	0.29	In-129g	0.32	Cs-145g	0.03				
Nb-107g	0.34	In-129m	0.05	La-147g	0.04				
Nb-108g	0.01	In-130g	0.09	La-148g	0.02				
Tc-109g	0.04	In-130m	0.06	La-149g	0.07				
Tc-110g	0.06	In-131g	0.02						
Tc-111g	0.04	Sn-133g	0.02						
Tc-112g	0.02	Sn-134g	0.08						
Rh-117g	0.01	Sb-135g	1.51						
Ag-124g	0.03	Sb-136g	0.27						
Ag-125g	0.01	Te-136g	0.18						
In-127g	0.03	Te-137g	0.33						
In-128g	0.01	I-137g	2.92						
In-129g	0.26	Te-138g	0.32						
In-129m	0.03	I-138g	4.61						
In-130g	0.05	Te-139g	0.02						
In-130m	0.08	I-139g	3.10						
In-131g	0.04	I-140g	0.74						
In-131m	0.10	I-141g	0.16						
In-132g	0.05	Xe-141g	0.03						
In-133g	0.01	Cs-141g	0.03						
Sn-133g	0.01	Xe-142g	0.09						
Sn-134g	0.07	Cs-142g	0.31						
Sb-135g	0.90	Xe-143g	0.04						
Sb-136g	0.25	Cs-143g	1.92						
Te-136g	0.08	Cs-144g	1.07						
Sb-137g	0.02	Cs-145g	0.69						
Te-137g	0.17	Cs-146g	0.04						
I-137g	1.22	La-147g	0.02						
Te-138g	0.20	La-148g	0.05						
I-138g	2.08	La-149g	0.05						

Continued

Table B-VI (Cont.)

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Te-139g	0.03								
I-139g	1.69								
I-140g	0.68								
I-141g	0.29								
Xe-141g	0.02								
Cs-141g	0.01								
I-142g	0.02								
Xe-142g	0.06								
Cs-142g	0.18								
Xe-143g	0.04								
Cs-143g	1.14								
Cs-144g	0.87								
Cs-145g	0.91								
Cs-146g	0.11								
La-148g	0.03								
La-149g	0.03								

TABLE B-VII

^{239}Pu FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 4.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Ga- 83g	0.01	As- 85g	0.03	Ga- 82g	0.02	As- 85g	43.42	As- 85g	72.37
As- 86g	0.03	As- 86g	0.08	As- 85g	3.97	As- 86g	2.32	Br- 90g	27.62
As- 87g	0.17	As- 87g	0.11	As- 86g	1.81	Br- 90g	39.66		
As- 88g	0.01	Se- 89g	0.01	Br- 90g	4.51	Br- 91g	12.99		
Se- 89g	0.01	Br- 90g	0.04	Br- 91g	69.44	Br- 92g	0.07		
Br- 91g	7.00	Br- 91g	14.84	Br- 92g	17.16	kr- 95g	0.01		
Br- 92g	81.60	Br- 92g	79.93	kr- 95g	0.02	Rb- 95g	0.79		
Br- 93g	0.03	Rb- 95g	3.38	Rb- 95g	2.16	I-140g	0.72		
Rb- 95g	3.08	Rb- 96g	1.03	I-140g	0.67				
Rb- 96g	4.53	Rb- 97g	0.27	I-141g	0.22				
Rb- 97g	2.37	Rb- 98g	0.01						
Rb- 98g	0.98	I-140g	0.04						
I-140g	0.01	I-141g	0.19						
I-141g	0.13								

TABLE B-VIII

^{232}Th FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 0.0 MeV

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Zn- 79g	0.01	Ga- 80g	0.01	Ga- 80g	0.01	Ga- 81g	0.02	As- 85g	0.10
Zn- 81g	0.03	Ga- 81g	0.24	Ga- 81g	0.12	Ge- 84g	0.08	Se- 87g	0.19
Ga- 81g	0.15	Ga- 82g	0.28	Ga- 82g	0.01	As- 85g	14.60	Br- 87g	11.29
Zn- 82g	0.03	Ga- 83g	0.24	Ge- 84g	0.45	As- 86g	0.02	Br- 88g	34.84
Ga- 82g	0.32	Ge- 84g	0.99	As- 85g	26.22	Se- 87g	0.36	Br- 89g	6.65
Ga- 83g	0.80	As- 84g	0.03	As- 86g	0.38	Br- 87g	1.83	Br- 90g	0.01
Ga- 84g	0.23	Ge- 85g	0.37	Se- 87g	0.22	Se- 88g	0.15	Rb- 92g	0.01
Ge- 84g	0.64	As- 85g	22.26	Br- 87g	0.49	Br- 88g	13.15	Rb- 93g	2.14
As- 84g	0.05	Ge- 86g	0.07	Se- 88g	0.51	Br- 89g	25.19	Rb- 94g	0.31
Ga- 85g	0.04	As- 86g	1.80	Br- 88g	5.02	Br- 90g	5.23	Rh-115g	0.02
Ge- 85g	2.14	As- 87g	2.18	Se- 89g	0.01	Kr- 92g	0.02	Sb-134g	0.10
As- 85g	10.38	Se- 87g	0.08	Br- 89g	18.10	Rb- 92g	0.04	Te-136g	3.98
Ge- 86g	0.40	Br- 87g	0.07	Br- 90g	11.69	Kr- 93g	0.14	Te-137g	0.21
As- 86g	1.35	As- 88g	0.02	Br- 91g	0.22	Rb- 93g	3.62	I-137g	32.88
Ge- 87g	0.06	Se- 88g	0.70	Kr- 92g	0.04	Rb- 94g	7.50	I-138g	6.81
As- 87g	7.86	Br- 88g	0.92	Rb- 92g	0.02	Y- 97g	0.07	I-139g	0.07
Se- 87g	0.03	Se- 89g	1.91	Kr- 93g	0.66	Y- 98g	0.02	Cs-141g	0.33
Br- 87g	0.02	Br- 89g	7.10	Rb- 93g	2.03	Y- 98m	0.02	La-146g	0.01
As- 88g	1.23	Se- 90g	0.56	Rb- 94g	8.57	Y- 99g	0.17	La-147g	0.02
Se- 88g	0.40	Br- 90g	11.51	Kr- 95g	0.04	Nb-105g	0.01		
Br- 88g	0.25	Se- 91g	0.10	Rb- 95g	0.09	Rh-115g	0.01		
As- 89g	0.30	Br- 91g	4.78	Y- 97g	0.06	Sn-134g	0.06		
Se- 89g	3.72	Br- 92g	1.87	Y- 97m	0.02	Sb-134g	0.06		
Br- 89g	2.48	Kr- 92g	0.04	Y- 98g	0.04	Sb-135g	1.31		
Se- 90g	1.03	Br- 93g	0.06	Y- 98m	0.60	Te-136g	1.32		
Br- 90g	5.60	Kr- 93g	1.23	Y- 99g	0.65	Te-137g	1.80		
Se- 91g	0.47	Rb- 93g	0.52	Y-100g	0.02	I-137g	8.52		
Br- 91g	5.35	Kr- 94g	0.49	Nb-105g	0.01	Te-138g	0.43		
Se- 92g	0.04	Rb- 94g	5.05	Tc-111g	0.02	I-138g	9.09		
Br- 92g	4.55	Kr- 95g	0.29	In-129g	0.02	I-139g	3.96		
Kr- 92g	0.02	Rb- 95g	3.63	Sn-133g	0.03	I-140g	0.03		
Br- 93g	1.16	Kr- 96g	0.02	Sn-134g	0.50	Xe-141g	0.01		
Kr- 93g	0.76	Rb- 96g	0.60	Sb-134g	0.02	Cs-141g	0.09		
Rb- 93g	0.16	Rb- 97g	0.22	Sb-135g	2.86	Xe-142g	0.02		
Br- 94g	0.18	Y- 97g	0.02	Sb-136g	0.21	Cs-142g	0.08		
Kr- 94g	4.74	Y- 97m	0.03	Te-136g	0.52	Cs-143g	0.68		
Rb- 94g	1.79	Sr- 98g	0.15	Te-137g	1.58	Xe-144g	0.01		
Kr- 95g	0.26	Y- 98g	0.04	I-137g	2.81	Cs-144g	0.09		
Rb- 95g	7.28	Y- 98m	2.52	Te-138g	1.22	La-147g	0.04		
Kr- 96g	0.08	Sr- 99g	0.01	I-138g	4.81	La-148g	0.01		
Rb- 96g	5.64	Y- 99g	0.87	Te-139g	0.02	La-149g	0.05		
Kr- 97g	0.02	Sr-100g	0.01	I-139g	5.52				
Rb- 97g	4.70	Y-100g	0.10	Te-140g	0.03				
Y- 97m	0.02	Y-101g	0.07	I-140g	0.41				

Continued

Table B-VIII (Cont.)

(0.0s)		(1.0s)		(5.0s)		(10.0s)		(30.0s)	
Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%	Nuclide	%
Rb- 98g	0.50	Y-102g	0.03	I-141g	0.02				
Sr- 98g	0.16	Tc-111g	0.02	Xe-141g	0.04				
Y- 98g	0.02	Rh-117g	0.02	Cs-141g	0.03				
Y- 98m	0.88	In-129g	0.05	Xe-142g	0.14				
Rb- 99g	0.11	In-130g	0.04	Cs-142g	0.15				
Sr- 99g	0.02	In-130m	0.03	Xe-143g	0.10				
Y- 99g	0.43	In-131g	0.04	Cs-143g	1.50				
Sr-100g	0.01	Sn-133g	0.05	Xe-144g	0.10				
Y-100g	0.08	Sn-134g	1.58	Cs-144g	0.68				
Y-101g	0.07	Sn-135g	0.06	Cs-145g	0.14				
Y-102g	0.02	Sb-135g	2.84	La-147g	0.02				
Y-103g	0.02	Sb-136g	1.32	La-148g	0.02				
Tc-112g	0.01	Te-136g	0.13	La-149g	0.07				
Ag-125g	0.01	Sb-137g	0.18						
In-129g	0.03	Te-137g	0.76						
In-130g	0.02	I-137g	0.53						
In-130m	0.03	Te-138g	1.51						
Cd-131g	0.01	I-138g	1.34						
In-131g	0.07	Te-139g	0.41						
In-131m	0.16	I-139g	3.71						
In-132g	0.33	Te-140g	0.12						
In-133g	0.37	I-140g	2.00						
Sn-133g	0.03	Te-141g	0.01						
In-134g	0.04	I-141g	1.46						
Sn-134g	1.11	Xe-141g	0.04						
Sn-135g	0.11	I-142g	0.04						
Sb-135g	1.47	Xe-142g	0.29						
Sb-136g	1.11	Cs-142g	0.09						
Te-136g	0.05	I-143g	0.10						
Sb-137g	0.28	Xe-143g	0.38						
Te-137g	0.33	Cs-143g	1.36						
I-137g	0.17	Xe-144g	0.28						
Sb-138g	0.11	Cs-144g	1.76						
Te-138g	0.84	Xe-145g	0.03						
I-138g	0.48	Cs-145g	2.59						
Sb-139g	0.01	Cs-146g	0.36						
Te-139g	0.50	Cs-147g	0.08						
I-139g	1.69	La-148g	0.03						
Te-140g	0.10	La-149g	0.05						
I-140g	1.58	La-151g	0.02						
Te-141g	0.07								
I-141g	2.27								
Xe-141g	0.02								
I-142g	0.50								
Xe-142g	0.18								
Cs-142g	0.03								
I-143g	0.20								

Continued

Table B-VIII (Cont.)

(0.0s) Nuclide	%	(1.0s) Nuclide	%	(5.0s) Nuclide	%	(10.0s) Nuclide	%	(30.0s) Nuclide	%
Xe-143g	0.28								
Cs-143g	0.60								
Xe-144g	0.19								
Cs-144g	1.19								
Xe-145g	0.03								
Cs-145g	2.96								
Cs-146g	0.97								
Cs-147g	0.10								
Cs-148g	0.02								
La-148g	0.02								
La-149g	0.02								
La-151g	0.02								

TABLE B-IX

^{232}Th FISSION PULSE

PER CENT CONTRIBUTION PER PRECURSOR GREATER THAN 0.01% FOR ENERGIES ABOVE 4.0 MeV

(0.0s) Nuclide	%	(1.0s) Nuclide	%	(5.0s) Nuclide	%	(10.0s) Nuclide	%	(30.0s) Nuclide	%
Ga- 83g	0.09	Ga- 83g	0.06	Ga- 82g	0.05	Ga- 82g	0.01	As- 85g	82.24
Ga- 84g	0.04	Ge- 85g	0.02	As- 85g	4.54	As- 85g	52.71	Br- 90g	17.76
Ga- 85g	0.01	As- 85g	0.03	As- 86g	3.58	As- 86g	4.86		
Ge- 85g	0.06	As- 86g	0.14	As- 87g	0.02	Br- 90g	27.25		
As- 86g	0.04	As- 87g	0.38	Se- 89g	0.02	Br- 91g	12.61		
As- 87g	0.58	Se- 89g	0.04	Se- 90g	0.01	Br- 92g	0.09		
As- 88g	0.07	Se- 90g	0.01	Br- 90g	2.92	Kr- 95g	0.02		
As- 89g	0.03	Br- 90g	0.02	Br- 91g	63.60	Rb- 95g	1.33		
Se- 89g	0.03	Br- 91g	11.57	Br- 92g	21.58	I-140g	1.08		
Se- 91g	0.02	Br- 92g	86.06	Kr- 95g	0.03	I-141g	0.03		
Br- 91g	5.52	Rb- 95g	0.62	Rb- 95g	1.96				
Br- 92g	89.71	Rb- 96g	0.22	I-140g	0.82				
Br- 93g	0.07	Rb- 97g	0.12	I-141g	0.83				
Br- 94g	0.01	I-140g	0.03	Cs-147g	0.02				
Rb- 95g	0.53	I-141g	0.61						
Rb- 96g	0.90								
Rb- 97g	1.09								
Rb- 98g	0.71								
I-140g	0.01								
I-141g	0.40								

Printed in the United States of America
Available from
National Technical Information Service
US Department of Commerce
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