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MEASURED COMPOSITE DELAYED NEUTRON SPECTRA FROM FISSION OF U-235, U-238 AND Pu-239 AND DERIVED SIX-GROUP SPECTRA

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Abstract: Delayed neutron (DN) energy spectra have been measured as a function of delay time after fission for U-235, U-238 and Pu-239 using a helium jet transfer system for fission product transfer. Beta-neutron correlations were used for background suppression and for energy determination by the neutron time-of-flight method. Each spectrum spans a DN energy range of 0.01 - 4.00 MeV. The U-235 and Pu-239 spectra show marked similarity, while those from the fast fission of U-238 are considerably more energetic. DN six-group spectra for U-235, U-238 and Pu-239 have been deduced from these measurements using a constrained least-squares iterative method.

(fission delayed neutrons; ^{235}U, ^{238}U, ^{239}Pu; time-dependent spectra; derived six-group spectra)

Introduction

Composite (aggregate) delayed neutron (DN) energy spectra have been measured as a function of delay time following thermal fission of U-235 and Pu-239 and fast fission of U-238. A major objective of this program was to contribute to the DN data base relevant to nuclear reactor kinetics. Our studies of U-235 DN energy spectra from both thermal and fast fission have been previously reported/1,2/. In the present paper we present final results of our investigation of DN spectra of Pu-239 and compare these with the corresponding ones from U-235. We also present results from our nearly completed study of U-238 which displays considerably harder DN energy spectra for most delay-time intervals. Consideration of the contributors of delayed neutrons to the core of fast breeder reactor prototypes/3/ indicates that U-238 and Pu-239 each contribute about 40% of the DN total.

For reactor kinetics calculations it is useful to approximate the time evolution of the measured spectra using the Keepin six-group approach/4/. To deduce six-group energy spectra from the measurements, we have developed a constrained least-squares iterative analysis procedure that results in solutions that are well behaved and essentially unique.

Features of Experimental System

The University of Lowell DN system/5/, shown schematically in Fig. 1, combines a helium-jet and tape transport system with an isolated neutron time-of-flight (TOF) spectrometer. Two sets of scintillators (Li-6 glass and BC501 liquid) span the neutron energy range of 10 keV to 4 MeV. Measurements at very short delay times, e.g. 0.17 - 0.37s, give excellent sensitivity to group 5 and 6 neutrons. The method gives essentially equal sensitivity to all delay times falling within a time interval. Measurements can be made in nearly successive delay time intervals over the time range 0.17 - 85s, which includes >90% of all delayed neutrons emitted. The TOF method separates beta-gamma correlated events from the desired beta-neutron events and n-γ pulse shape discrimination on both sets of detectors greatly reduces the sensitivity to the gamma-ray background.

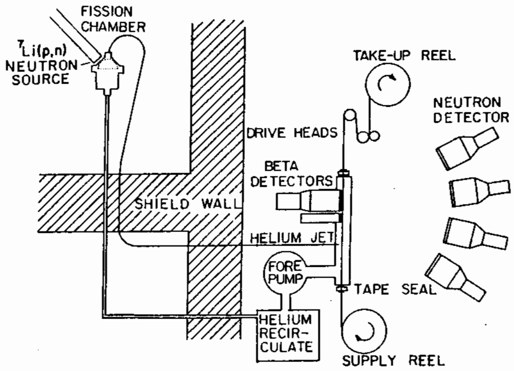

Fig. 1. Schematic of the experimental arrangement.

Typical DN TOF spectra with BC501 scintillators are shown in Fig. 2. Improved time (energy) resolution is achieved by dividing the spectrum into two parts, according to the pulse amplitude of the neutron detector signal. Each TOF spectrum is analyzed by 1) subtracting the random background and gamma peak, 2) subtracting the neutron detector time-response tails/6/, and 3) converting the result into an efficiency-corrected energy spectrum. For each delay-time interval the BC501 and Li-6 glass spectra are normalized to give the same area in the 150 - 400 keV region and then combined using linear-ramp weighting functions over the 150 - 250-keV energy region.

Composite Delayed Neutron Spectra

The delay time intervals chosen for the measurements are given in Table 1, which also shows the contributions of the six DN groups to each interval for Pu-239 thermal fission. The U-235 and U-238 6-group contributions are very similar. Composite DN energy spectra have been measured at delay time intervals 1 - 8 for U-235, 1 - 7 for Pu-239 and at 1 - 6 for U-238.

The spectra from Pu-239 are compared with our earlier measurements for U-235/1/ in Fig. 3. The two sets are remarkably similar, as has also been indicated in the U-235 and Pu-239 composite measurements of Kratz and Gabelmann/7/.

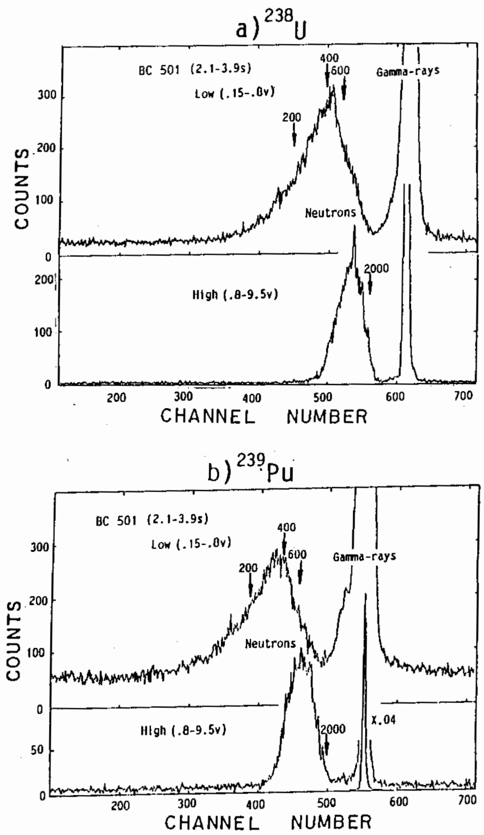

Fig. 2. Delayed Neutron TOF spectrum measured in the 2.1 - 3.9s delay-time interval for a) U-238, and b) Pu-239. Each spectrum is divided into two pulse height ranges, 0.15 - 0.80 and 0.8 - 9.5 volts.

Spectra have been obtained with BC501 (0.25 - 4.00 MeV) following fast fission of U-238. Li-6 glass measurements (0.01-0.25 MeV) are currently in progress, with intervals 3 and 4 (Table 1) so far completed. In Fig. 4 the two completed spectra for U-238 are compared with the corresponding ones for Pu-239. Although some of the same structure persists in the two sets, the U-238 spectra are noticeably more energetic. In order to perform a preliminary 6-group analysis of the U-238 measurements, the missing Li-6 glass spectra for delay times 1,2,5 and 6 have been replaced by the corresponding ones for U-235. The substitution allows the completed 0.25 - 4.00 MeV region of each spectrum to be normalized such that the overall yield over 0 - 4 MeV is 10^4 counts.

Six-group Spectra

Stable six-group solutions were obtained by applying a constrained least-squares fitting method/8,9/ to composite DN spectra measured at six or more of the delay-time intervals shown in Table 1. The group spectra deduced for U-235, U-238 and Pu-239 are all physically reasonable and give excellent fits to the measured spectra. Because the sensitivity of the measurements is low for the delay group 1 (see Table 1), its spectrum was treated as known/10/ and the spectra for the groups 2 - 6 were determined using our computer code SIXGD.

Table 1. Contributions (%) of six groups to delay-time intervals for Pu-239 thermal fission.

Delay Interval (s)	Group					
	1	2	3	4	5	6
	$T_{1/2}$ (s)					
	52.1	23.0	6.11	2.35	0.81	0.26
0.17 - 0.37	0.1	2.8	7.2	31.9	35.8	22.3
0.41 - 0.85	0.2	3.7	9.3	38.8	35.8	12.3
0.79 - 1.25	0.3	4.8	11.5	44.6	33.1	5.7
1.2 - 1.9	0.3	6.1	14.1	49.8	27.7	2.0
2.1 - 3.9	0.5	9.8	20.1	54.9	14.6	0.2
4.7 - 10.2	1.3	22.4	32.1	42.5	1.7	0.0
12.5 - 29.0	4.2	58.2	30.9	6.7	0.0	0.0
35.8 - 85.5	11.3	84.9	3.8	0.0	0.0	0.0

Spectra for groups 2 - 6 deduced for the thermal fission of Pu-239 are compared with corresponding group spectra from the compilation of T.R. England/10/ in Fig. 5. There is remarkable similarity in the two sets with the exception of group 2. However, the group 2 Pu-239 spectrum is subject to particularly large uncertainties.

In Fig. 6, preliminary group spectra deduced for the fast fission of U-238 are compared with those from thermal fission of Pu-239. Although the region 0.25 - 4.0 MeV has been completed for all six spectra, determination of some of the missing low-energy regions could modify the overall normalization, causing minor adjustments in the 0.25 - 4.0-MeV region of the group spectra as well. The relative hardness of U-238 DN spectra is again evident from the group solutions.

Acknowledgements

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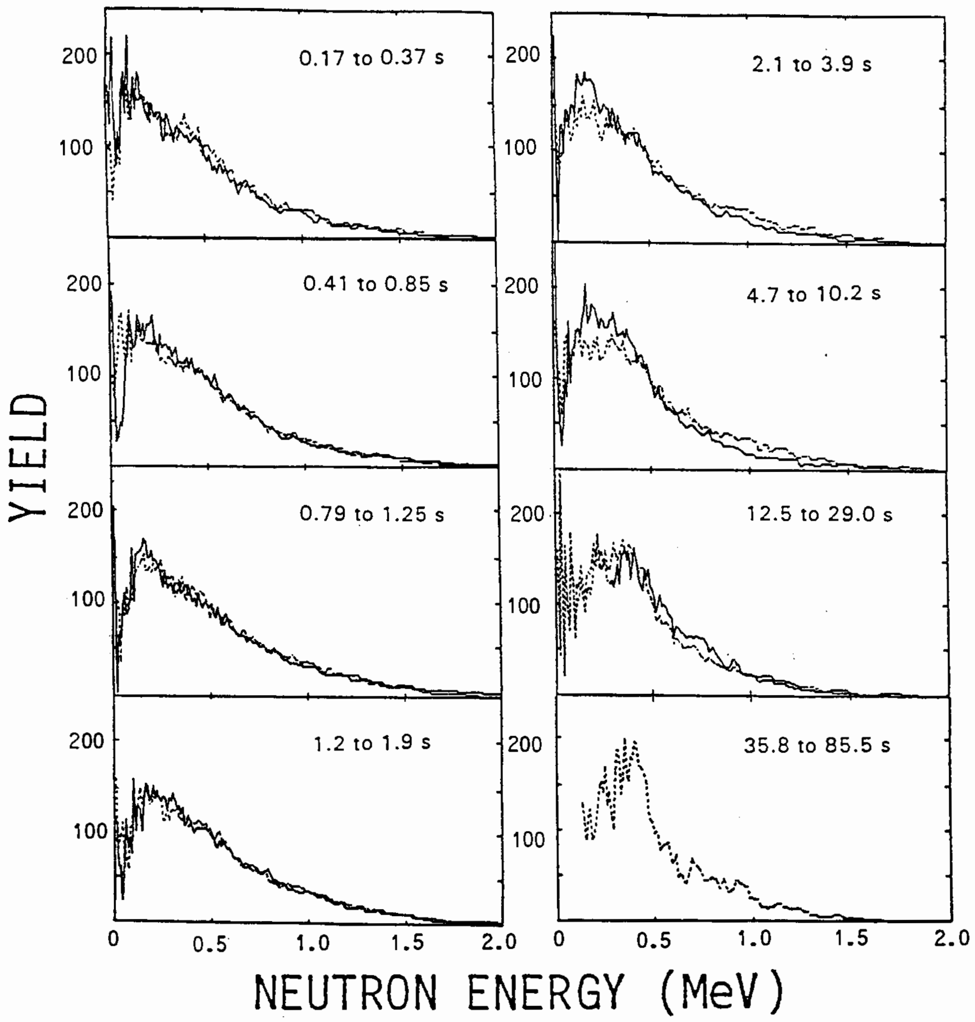

Fig. 3. Composite DN energy spectra from the thermal fission of Pu-239 (solid curves) compared with those from U-235.

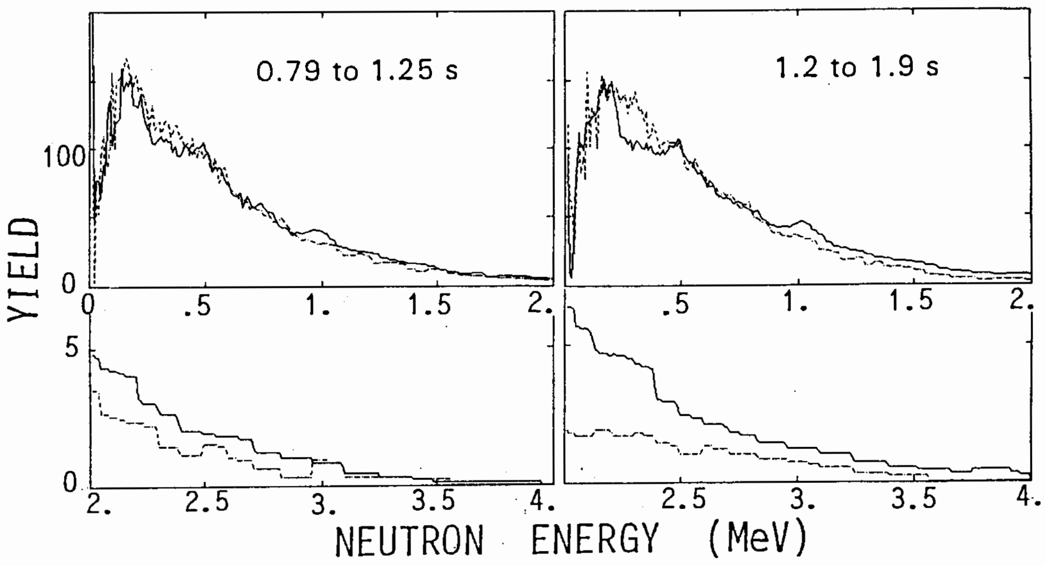

Fig. 4. Composite DN energy spectra from fast fission of U-238 (solid curves) compared with those from thermal fission of Pu-239.

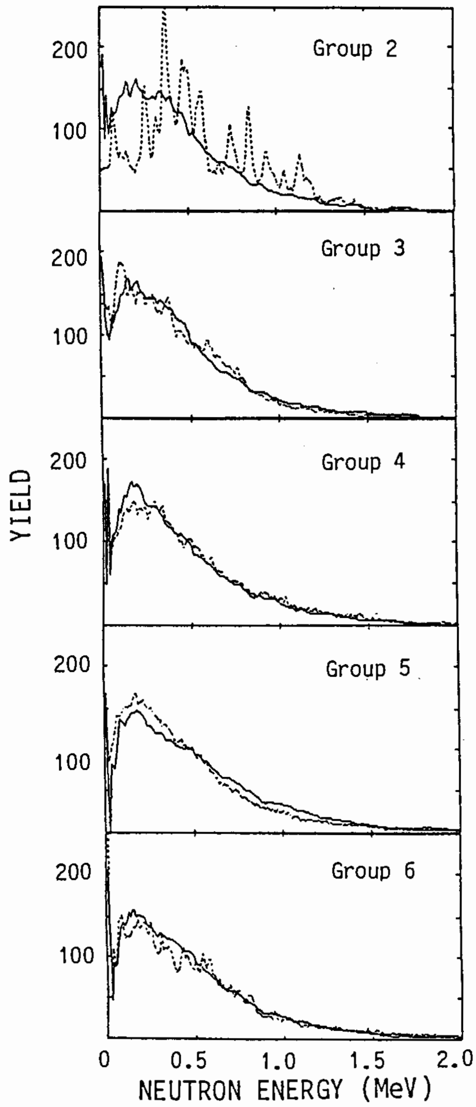

Fig. 5. A comparison of group 2 - 6 spectra deduced from Pu-239 (solid curve) with corresponding groups from the evaluation by T.R. England.

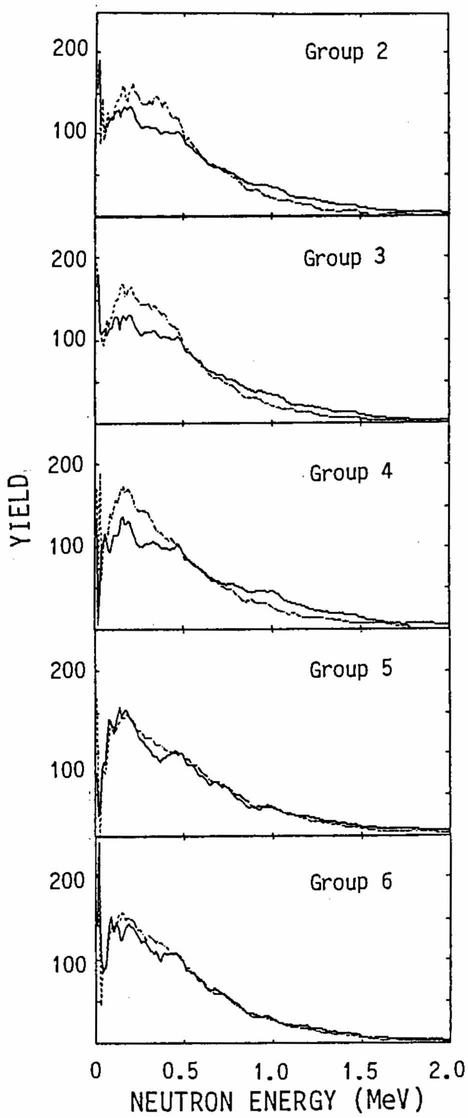

Fig. 6. A comparison of group 2 - 6 spectra deduced from U-238 (solid curve, preliminary) and Pu-239 composite measurements.

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