Nuclear Data for Science and Technology (1988 MITO), 415- 418, Copyright © 1988 JAERI.

FISSION FRAGMENT TRANSFER EFFICIENCY FOR HELIUM JET SYSTEM

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Abstract: A study has been made of the fission fragment transfer efficiency of the helium jet system used in our measurements of delayed neutron energy spectra from fission. X-ray spectra from radioactive progeny of the fission fragments were measured using the helium jet and compared with those using a pneumatic rabbit system. With certain exceptions, a high degree of uniformity of the helium jet transfer efficiency is observed.

(fission products, He-jet transfer efficiency, characteristic x rays)

Introduction

A helium jet system is employed in the University of Lowell measurements of composite delayed neutron (DN) spectra/1,2/ to rapidly transfer fission fragments from the fission chamber to the low background environment of a neutron time-of-flight spectrometer. In order to measure undistorted delayed neutron spectra, the mass distribution of fission fragments must be preserved in their transfer to the spectrometer. To test the uniformity of the helium-jet transfer efficiency over the mass distribution of fission fragments, characteristic x-ray spectra of the fission products were measured at the exit of the helium jet. These were then compared with characteristic spectra obtained using a rabbit shuttle transfer system for which the transfer efficiency was assumed known.

Helium Jet System

Our helium jet system was designed to meet specific requirements in the measurements of delayed neutron spectra following fission. Since approximately 30% of these delayed neutrons are emitted within one second after fission, a rapid transfer time and fission chamber flush time are required for the fission fragments. Using a 4.6-m long two-stage capillary tube and a hemispherical fission chamber of only 17-mm radius, a mean transfer time of 0.16s and a time spread of 0.15s are obtained (Fig. 1a). With this arrangement, the major contributors to the delayed neutron spectra measured in our shortest delay interval (0.17 - 0.37s) are from Keepin groups 5 and 6 /2/. A second, 14-m long capillary providing a mean transfer time of 0.83s and a time spread of 0.43s (Fig. 1b) is used in measurements for longer delay-time intervals. Details of the time profile measurements shown in Fig. 1 have already been reported/1/.

The small dimensions of the fission chamber were also chosen to provide uniform stopping of the fission fragments in the helium atmosphere of the chamber. The fission foils lining the surfaces of the hemisphere have a thickness greater than the range of the most energetic fission fragment. This would ordinarily produce a distortion of the fission fragment mass distribution because lighter, more energetic fragments escape the foil from a greater depth. For the two masses at the peaks of the bimodal distribution resulting from the thermal fission of U-235, the light/heavy escape ratio is about 4/3. This is compensated for in the small

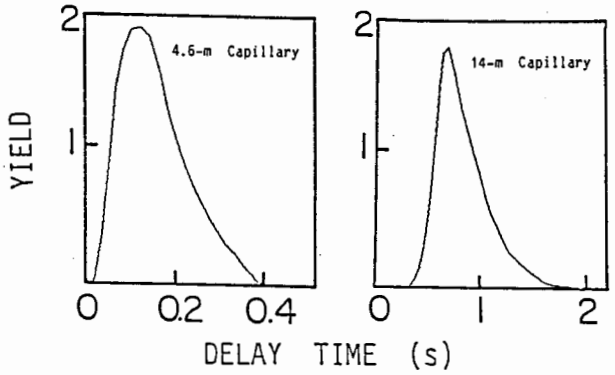

Fig. 1 He-jet transfer time responses.

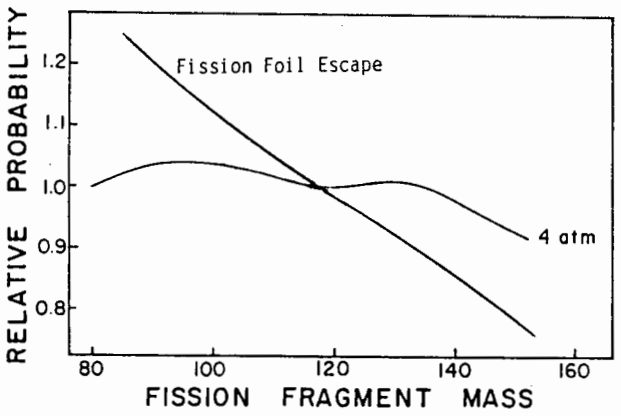

Fig. 2 Fission fragment stopping probabilities.

fission chamber, however, since the lighter fragment has a greater probabality of not being stopped in the helium and becoming imbedded instead in the chamber wall. The present chamber dimensions were chosen/1,3/ to yield nearly uniform stopping probability for all fission fragments, as demonstrated in Fig. 2. The normalized fission-foil escape probability is also plotted in the figure for comparison.

In our system the helium is recycled by venting the forepump to a compressor. Forepump oil vapor is consequently also present in the helium and this serves to promote fission fragment transfer. The paths of ionization through the gas act as nucleation sites for the oil vapor. The fission fragments imbedded in these microscopic oil droplets are essentially unaffected by collisions with the gas atoms and

move instead with the macroscopic flow of the helium. Whereas the transfer efficiency of the fission fragments for the 14-m capillary is quite uniform as a function of time, the efficiency for the 4.6-m capillary varies considerably with the compressor cycle. This may be related to the rapid chamber flush time and near breakdown of laminar flow conditions at the chamber end of the capillary tube. It was deemed important, therefore, to study the transfer characteristics separately for the 4.6-m and 14-m capillaries.

X-Ray Measurements

The fission fragments are neutron rich and decay by beta emission. Their progeny are often left in excited states and may give rise to characteristic x-ray emission through internal conversion. A particular x-ray line can arise from several different isotopes having various halflives. Furthermore, an isotope may be several beta decays removed from the fission fragment, and so not follow a simple exponential decay rule.

A thin-window, high purity germanium detector was employed to measure the characteristic x-ray spectra. With the detector viewing a catcher at the exit of the capillary, the helium-jet time sensitivity function is simply a constant after a very short threshold time (0.13s for the 4.6-m capillary, 0.65s for the 14-m capillary). To determine the transfer efficiency of the helium jet, it was necessary for comparison to devise an alternative transfer method with known transfer efficiency and a time sensitivity function approximating that of the helium jet. The method chosen utilized a small cylindrical nylon rabbit (7mm diam. x 25mm) which was pneumatically shuttled (through a shield wall) between the x-ray detector at one end and a neutron irradiated U-235 fission foil which surrounded the rabbit at the other end. The transfer time was about 0.5s and the dwell time of the rabbit at both the detector and the foil was 4.5s. This cycle repeated continuously. Figure 3 compares the relative time sensitivity of the two methods for the first 20s after fission. Although the differences in the time sensitivities seem pronounced, Fig. 4 shows the relative detection sensitivity for the two methods to be nearly constant for beta halflives greater than 2s.

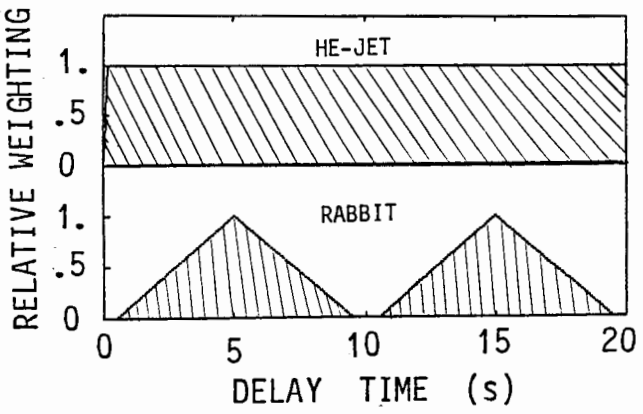

Fig. 3 Relative time sensitivities for helium jet and rabbit transfer systems.

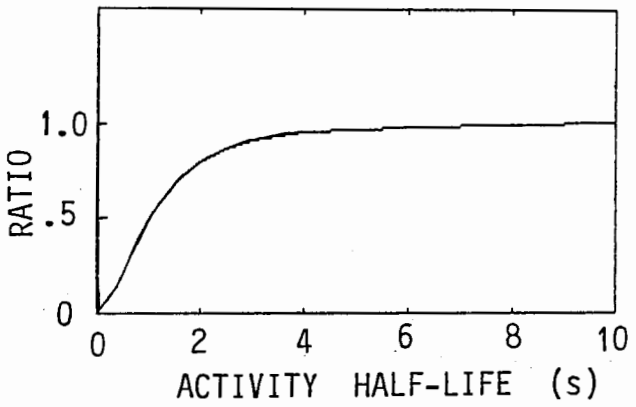

Fig. 4 Rabbit/helium jet x-ray intensity ratio as a function of precursor halflife.

Comparison of Characteristic Spectra

In Fig. 5, x-ray spectra for the rabbit system and the 4.6-m and 14-m helium-jet capillary systems are compared. The element designations indicate the positions of their K_α lines. The two groupings of x-ray lines arise from the bimodal mass distribution from the fission of U-235. The figure clearly shows a strong similarity among the three spectra. Table 1 lists the rabbit/helium-jet system ratio (arbitrarily normalized) of the x-ray intensities for each identified element. In determining these, account was taken of those K_β lines superimposed on the K_α lines of neighboring elements. These are particularly bothersome for weak K_α lines to the right of strong peaks. In correcting for such superpositions, use was made of the published/4/ K_β/K_α intensity ratios. Two corrections were also applied to the rabbit spectrum. One accounted for the self absorption of the x rays in the nylon rabbit (an 11% effect between 15-keV and 30-keV x rays). The other correction concerned the distortion of the mass distribution owing to the varying probability of fragment escape from the thick U-235 foil (Fig. 2) and their subsequent embedment in the nylon cylinder. These two corrections somewhat compensated each other. Listed also in the table are possible sources of the x rays and the halflives of their precursors in parentheses.

A rabbit/helium-jet ratio significantly less than 1.0 suggests that the precursor prior to internal conversion has a lifetime shorter than 2 seconds. A ratio considerably greater than 1.0 suggests a loss of helium-jet transfer efficiency for that precursor. The majority of peaks are seen to have rabbit/helium jet ratios near unity, indicating that the helium jet transfers the fission fragments to the spectrometer with little distortion in the mass distribution.

The uncertainty in the rabbit/helium-jet ratio is about 5% for the strongest lines, 10% for the transitions of medium intensity and 20% or greater for the weak lines. The ratios for Br (40-50% uncertainty), I (50% uncertainty) and Xe (60% uncertainty) suggest a reduced helium-jet transfer efficiency for these precursors. No meaningful yields could be extracted for the Xe and Cs K_α lines in the 14-m helium-jet spectrum.

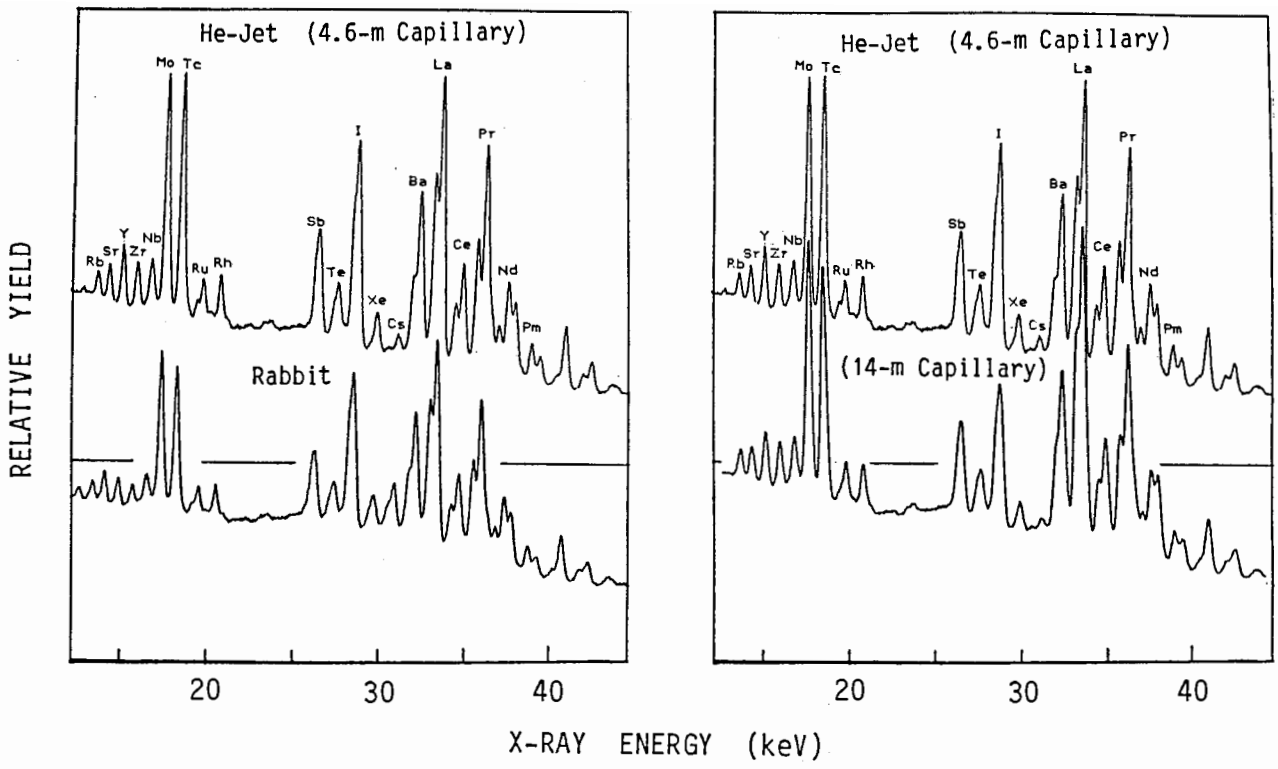

Fig. 5 X-ray energy spectra measured with the helium-jet and rabbit transfer systems.

Table 1. Measured Rabbit/He-jet Ratio of X-ray Intensities

Precursor Element	X-ray Element	Rabbit / He-jet 4.6m	Rabbit / He-jet 14m	Possible Precursor Isotope ($T_{1/2}$)
Br	Kr	3.31	6.49	Br -87(56s) -88(16s) -91(4.4s)
Kr	Rb	1.04	0.78	Kr -85*(4.5h) -89(3.2m) -90(32s) -91(9s) -92(1.8s)
Rb	Sr	1.13	1.11	Rb -91(59s) -92(4.5s) -94(2.8s)
Sr	Y	0.47	0.57	Sr -93(7.5m) -94(1.3m) -95(26s) -96(4s) -97(0.4s)
Y	Zr	0.55	0.62	Y -96(10s) -97(3.7s) -98(2s) -98*(0.7s) -99(1.4s)
Zr	Nb	0.88	0.91	Zr -99(2.4s) -100(7.1s) -101(2s) -102(2.9s)
Nb	Mo	0.93	0.83	Nb -101(7s) -102(3s) -103(1.5s)
Mo	Tc	0.80	0.86	Mo -103(60s) -104(60s) -105(40s)
Sn	Sb	1.09	1.11	Sn -130(3.7m) -131(63s) -132(40s)
Sb	Te	1.14	1.25	Sb -131(23m) -132(4.2m) -133(2.4m)
Te	I	1.07	1.55	Te -133*(55m) -134(42m) -135(19s) -136(6.5s)
I	Xe	1.73	-	I -135(6.6h) -136(85s) -137(25s) -138(6.5s)
Xe	Cs	14.3	-	Xe -135*(15m) -137(3.8m) -138(14m) -139(40s) -140(14s)
Cs	Ba	1.12	1.02	Cs -140(64s) -141(25s) -142(1.7s) -143(1.8s)
Ba	La	1.06	0.96	Ba -142(11m) -143(14s) -144(11s) -145(4.8s)
La	Ce	0.95	0.95	La -145(29s) -146(8.3s) -148(5s)
Ce	Pr	0.88	0.99	Ce -147(56s) -148(43s) -149(5s)
Pr	Nd	0.96	1.77	Pr -149(2.5m) -150(12s) -151(4s)

The possible reduced efficiency of Br and I requires further study because of their relative importance in DN production. In all three cases the present analysis has larger uncertainties than desirable due to the weakness of the x-ray lines, competition from K_β transitions of neighboring elements and other possible interpretations for their diminished contribution in the helium-jet spectra. In the present analysis it was assumed they the Kr and Xe x-ray lines result from internal conversion following the beta decay of $_*$Br and I$_*$ respectively. However, both Kr-85 and Xe-135 are possible fission products. These isomeric states can decay to the ground state by internal conversion, producing their own characteristic x rays. Thus, a reduced intensity for these x rays may be due to loss of Kr and Xe gases rather than due to reduced transfer of Br and I. This alternative explanation is more favorable for DN measurements as neither Kr nor Xe are major DN contributors. The resolution of this question will require further analysis and perhaps further measurements.

Acknowledgement

This work was supported by the U.S. Department of Energy.

REFERENCES

1. W.A. Schier, G.P. Couchell, D.J. Pullen, N.M. Sampas, C.A. Ciarcia, M.H. Haghighi, Q. Sharfuddin and R.S. Tanczyn: Nucl. Instr. Meth. in Phys. Res. 227, 549(1984)

2. R.S. Tanczyn, Q. Sharfuddin, W.A. Schier, D.J. Pullen, M.H. Haghighi, L. Fisteag and G.P. Couchell: Nucl. Sci. Eng. 94, 353 (1986)

3. R.S. Tanczyn, G.P. Couchell and W.A. Schier: Comp. Phys. Comm. 38, 61(1985)

4. G.C. Nelson, B.G. Saunders and S.I. Salem: in Atomic Data 1, 337(1970); ed. K. Way, publ. Academic Press, N.Y.