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Short note

Fragment yields from the fission of ^{238}U by fast neutrons

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Abstract. Independent yields of post-neutron emission, secondary fragments from the fission of ^{238}U induced by fast neutrons have been measured using γ-γ coincidence data. The yields of these products are found to be centred on more neutron-rich isotopes than the yields from fission processes previously used for spectroscopic studies on neutron-rich nuclei. The average angular momentum in the fragments is found to be similar to that in fragments formed in other low-energy fission processes.

PACS. 24.75.+i General properties of fission – 21.10.Gv Mass and neutron distributions – 21.10.Hw Spin, parity, and isobaric spin

Fission of ^{238}U by neutrons with energies of a few MeV is expected to allow spectroscopic studies to be made on fragments with a higher neutron to proton ratio than possible with other available fission sources. The average neutron to proton ratio in post-neutron emission, secondary fission-fragments is close to $(N_f - \nu)/Z_f$, where N_f is the neutron number of the fissioning system, Z_f its proton number and ν the average number of neutrons emitted before γ decay in secondary fragments. This ratio is higher for fission of ^{238}U by neutrons with energies of a few MeV than for the low-energy fission sources used in previous spectroscopic studies on neutron-rich nuclei. Up to now detailed spectroscopic studies have been made solely on products of the spontaneous fission of ^{252}Cf and ^{248}Cm [1,2], and on products from the fission of ^{235}U induced by slow neutrons [3]. This note presents results for independent yields of secondary fragments resulting from the fission of ^{238}U induced by neutrons of average energy 2.5 MeV and compares them with the predictions of a phenomenological model. The average angular momentum at which secondary fragments are formed in the fission of ^{238}U is also measured and compared with that observed in the above fission processes.

A beam of ^{7}Li of energy 25.5 MeV from the ANU 14 UD Pelletron bombarded a hydrogen gas target of thickness 0.62 mg cm^{-2} through a tantalum entrance window 27 mg cm^{-2} thick. The beam energy on entering the gas was 15.5 MeV, and the energy loss in the hydrogen was 1.7 MeV. This arrangement produced a beam of neutrons confined within a forward cone of half angle 23° and with energies between 1.5 and 3.5 MeV. The average neutron energy was about 2.5 MeV. The fission cross-section increases significantly above 1.5 MeV, and at 2.5 MeV is about 600 mbarns. The neutron beam interacted with a ^{238}U foil of thickness 0.5 mm situated in the centre of the CAESAR array of six Compton-suppressed Ge detectors. The beam was pulsed with bursts of width approximately 1 ns ocurring every 856 ns. Timing of the detector signals against the beam pulse enabled almost complete discrimination against γ–γ coincidences from beta decays. Only those coincidence events in which two detectors gave signals within a time interval of 35 ns which overlapped the beam pulse were selected for the analysis of prompt γ-ray decays.

In order to measure and compare the enhanced production of neutron-rich nuclides, relative independent yields of even-even isotopes for the strongly produced even-Z nuclei were determined from the coincidence data. Figure 1 shows the sum of spectra of γ rays in coincidence with the lowest three transitions in the nucleus ^{142}Xe and in the nucleus ^{102}Zr. The observed intensities in spectra similar to these were used, after correction for detector efficiencies, to calculate the relative yields of secondary fragments. Figure 2 shows the relative yields obtained for the isotopes of Zr, Xe and Ba in this experiment, together with the relative yields observed [4–6] in the spontaneous fission of ^{248}Cm. The ^{238}U yields follow the usual gaussian-like profile and the mean mass of a given isotopic series is

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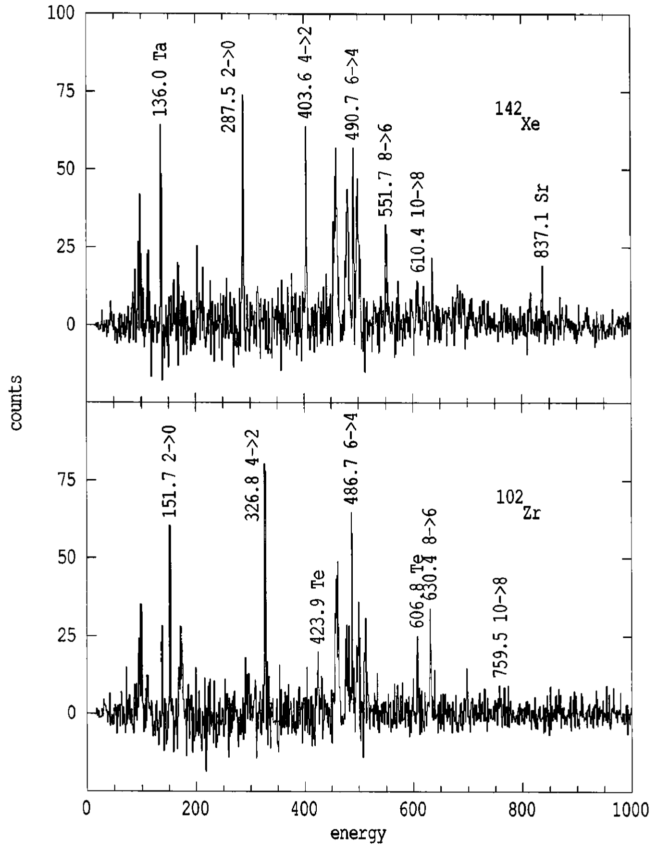

Fig. 1. Summed coincidence spectra of γ rays for ^{102}Zr and ^{142}Xe. γ rays at energies of 136 and 301 keV are random events arising from Coulomb excitation of Ta. γ rays in the interval 400 to 500 keV are randoms arising from the ^{7}Li(p,p$'$) reaction

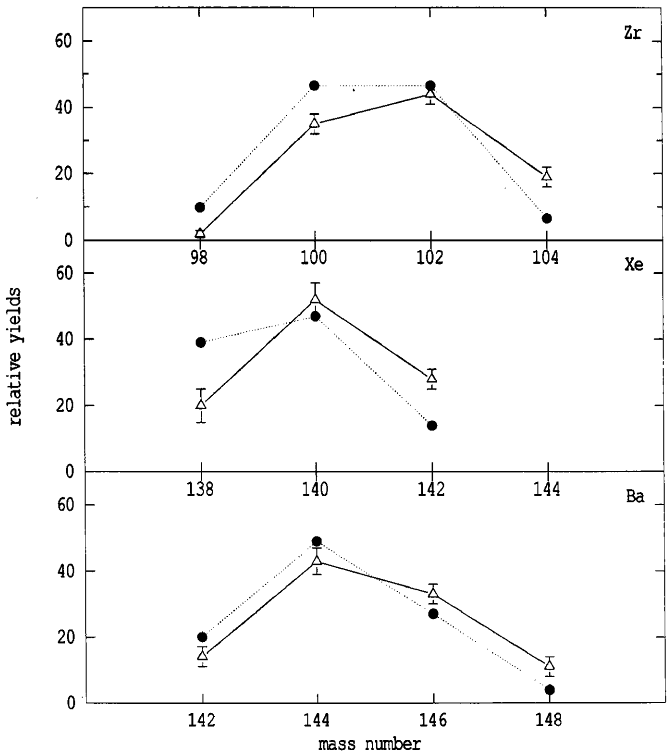

Fig. 2. Relative yields of istopes of Zr, Xe and Ba. Solid circles are yields from ^{248}Cm; triangles from fission of ^{238}U. Errors on the Cm points are comparable with the symbol size

Table 1. Mean mass numbers of secondary fragments. Columns 2 and 3 refer to ^{248}Cm; 4 and 5 to ^{238}U

Element	Predicted	Experiment	Predicted	Experiment
Zr	100.65	100.91(4)	101.27	101.60(9)
Te	134.49		134.98	135.41(9)
Xe	139.16	139.53(7)	139.78	140.16(16)
Ba	143.84	144.30(4)	144.64	144.81(14)

Table 2. γ-ray intensity ratios; column 2 for ^{248}Cm; 3 for ^{238}U

Nucleus	$8-6/6-4$	$8-6/6-4$
^{102}Zr	0.48(5)	0.32(9)
^{142}Xe	0.48(5)	0.44(9)
^{144}Ba	0.53(7)	0.43(9)

higher than for the SF of ^{248}Cm. The dispersion is similar to that observed in the SF of ^{248}Cm and ^{252}Cf, and corresponds to a half-width at full height of ~ 5 mass units.

The increased yields of nuclei with high neutron to proton ratio compared with yields from other fission sources may be quantified for a given Z using a phenomenological model [7] with the mean mass number obtained in the present experiment. The mean mass numbers for Zr, Te, Xe and Ba are shown in table 1 and compared with experimental values for ^{248}Cm SF decay [4–6] and with model predictions [7,8] obtained using the model estimates of the mean mass numbers.

The average angular momenta at which the secondary fragments from ^{238}U are formed are roughly the same as for fragments from the SF of ^{248}Cm and ^{252}Cf and from the fission of ^{235}U induced by slow neutrons. Table 2 shows the ratios of the intensities of successive γ rays in the yrast sequences of ^{102}Zr, ^{142}Xe and ^{144}Ba observed in this experiment and compares them with the corresponding ratios observed in the SF of ^{248}Cm. The ratios suggest rather similar average angular momenta, which in ^{248}Cm are $\sim 7\hbar$.

In summary, the present experiment shows that the secondary fragments from fast-neutron induced fission of ^{238}U are more neutron-rich than fragments from low-energy fission processes so far used for spectroscopic studies. The ^{238}U fragments are also formed at much the same average angular momenta. The fission of ^{238}U should thus allow spectroscopic studies of yrast and near-yrast decays to be extended to nuclei which are more neutron-rich than those examined up to now.

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