LIFETIMES IN NEUTRON–RICH MASS 100 NUCLEI MEASURED BY A DOPPLER PROFILE METHOD*

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The Eurogam–1 array has been used to study γ rays emitted following the spontaneous fission of a ^{248}Cm source. The stopping of the fission fragments in the source material leads to Doppler–broadened γ–ray lineshapes for those states that have lifetimes comparable to the stopping time. From the analysis of these lineshapes the transition quadrupole moments for the Yrast states in the neutron–rich nuclei ^{100,102}Zr and ^{104,106}Mo in the spin range 6-12 $\hbar$ have been deduced.

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There is at present considerable interest in the extension of experimental data to cover new regions of the nuclear chart far from stability. Such data will determine whether existing approaches to nuclear structure at low

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excitation energy remain valid as isospin varies significantly from that of the stable species. The determination of level energies and spins is often insufficient to differentiate between competing models, and additional information on the lifetimes of the states provides a more stringent test of theoretical approaches.

Lifetime measurements of medium to high spin nuclear states (with spin quantum number, $I \geq 6$) have, in the past, been confined to neutron–deficient nuclei produced in fusion evaporation reactions, and to stable species excited by Coulomb excitation. In these neutron–deficient nuclei, states with lifetimes of less than 2 picoseconds have been measured using the Doppler Shift Attenuation Method (DSAM). This involves stopping the recoiling nuclei in a target backing, thereby attenuating the Doppler shift of the emitted radiation with time and producing asymmetric lineshapes in the γ–ray energy spectra observed in a fixed detector. Knowledge of the stopping powers and initial recoil velocity enables lifetimes to be extracted by fitting the lineshapes. DSAM is normally performed in cases where there is a well defined recoil cone and therefore a well defined angle between the initial recoil velocity and the detector–target axis. In this paper we describe a modified DSAM that has enabled the measurement of lifetimes of states ($6 \leq I \leq 12$) in the fragments from spontaneous fission.

In this work the spontaneously fissioning isotope ^{248}Cm was used as a source of neutron–rich fragments whose electromagnetic decay properties were to be studied. The source consisted of about 5 mg of curium oxide (giving a fission rate of about 7×10^4 nuclei per second) embedded uniformly in a pellet of potassium chloride. The Eurogam phase 1 array [1] of Compton–suppressed Germanium detectors was used to detect the emitted γ–radiation. Events for which three or more detectors fired were used to construct a cubic data array whose axes represented the energies of the detected γ rays, and the contents of each channel the number of events with that particular combination of γ–ray energies. This data structure enabled the fast creation of one–dimensional spectra of γ rays that occur in coincidence with any two supplied gating energies, thus providing the selectivity needed to separate the decays of the fragments of interest from those of the many other products of the fission process.

At spins above $I = 6$ symmetrically broadened γ–ray lineshapes were observed. This broadening is due to the variable Doppler shifts of the radiation emitted from the randomly directed fission fragments as they stop in the source pellet and is associated with γ rays emitted from states with lifetimes in the range 1–2 ps, *i.e.* comparable to the stopping time of the fission fragments in the pellet. Such lifetimes are amenable to modified DSAM measurements in which the initial energy distribution and random velocity direction of the fragments are taken into account (Doppler Profile Method).

To determine the state lifetimes from the Doppler broadened lineshapes the velocity history of the fragments as they stop in the source pellet was simulated using electronic and nuclear stopping powers given by the computer code ZBL [2]. The initial fragment kinetic energy distribution was assumed to be Gaussian with its centroid and width taken from Ref. [3] and Ref. [4]. The simulation produced a two-dimensional data matrix (Fractional Doppler Shift, or FDS matrix) whose contents gave the probability of observing a particular fractional Doppler shift ($\beta \cos\theta$, where β is the velocity of the fragment and θ is the angle between the fragment velocity and the γ-ray detection axis) in the emitted radiation at any given time. Anisotropic angular distributions of the γ radiation relative to the fragment velocity direction can, in principle, affect the form of the FDS matrix but these effects are small in fission and have been neglected in the present analysis. The FDS matrix was used in conjunction with a simulation of the decay process to generate lineshapes that were compared with the experimental data.

The decay process was simulated in a model for which the lifetimes were parameterized in terms of the transition quadrupole moment Q. The procedure allowed both slow and fast components in the sidefeeding to those levels whose lifetimes were to be measured. The fraction of the sidefeeding that was prompt, as well as the feeding time of the slow component were varied in the fits. The lineshape from the highest-initial-spin transition that could be observed in each band was difficult to fit independently due to the absence of the feeding information that would have been contained in the lineshape of a preceeding transition. For this reason, it was necessary to fit the first two lineshapes in each band with a common quadrupole moment. The results of the fits are shown in Fig. 1 where the deduced quadrupole moments are plotted against the excitation energy of the first 2^+ state. Where it has been possible to obtain more than one independent fit to the lineshapes there are multiple results shown for the same excitation energy.

The deduced quadrupole moments decrease with increasing 2^+ excitation energy, qualitatively consistent with the expectation for deformed rotating nuclei. Also plotted in Fig.1 are quadrupole moments deduced from the results of previous measurements of lifetimes of the first 2^+ states. These show a similar trend with 2^+ excitation energy although the results of the Doppler profile method are lower. This may reflect a decrease in the quadrupole moment of these nuclei with increasing spin.

This paper has reported the first measurements of state lifetimes at medium spin in the fragments of spontaneous fission around $A = 100$. The measurements have been made possible by the quality of the data from the Eurogam array, which has enabled the observation of Doppler-broadened lineshapes of γ-rays decaying from states with $I > 6$ in fission fragments.

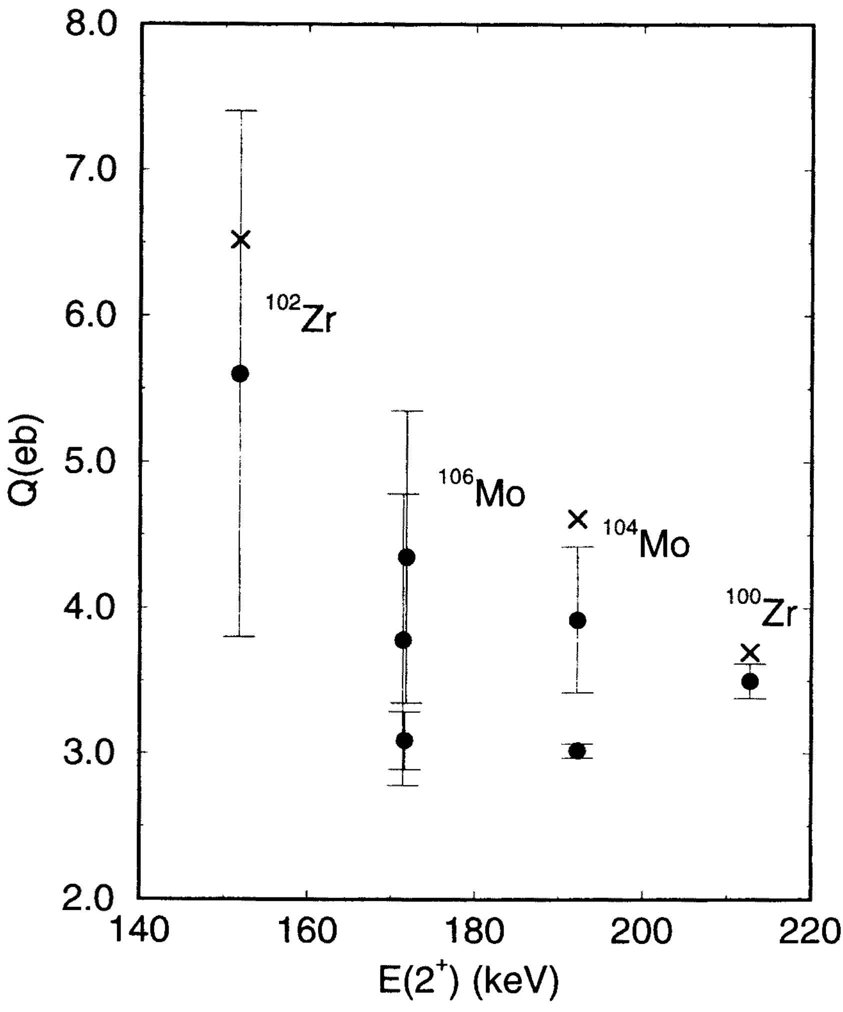

Fig. 1. Quadrupole moments (Q) (deduced from the measured state lifetimes) plotted against the excitation energy of the first 2^+ level. The crosses indicate quadrupole moments deduced from lifetime measurements of the first 2^+ states (^{100}Zr Refs [5, 6], ^{102}Zr Ref. [7] and ^{104}Mo Ref. [8]).

Since many different products are formed in spontaneous fission, the Doppler profile method may be used to survey the quadrupole moments of rotational nuclei over a large range of the neutron-rich side of the nuclear chart, and should thereby prove a useful tool in the exploration of low energy nuclear structure far from stability.

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