

STUDY OF THE STRUCTURE OF COLD, HIGH-SPIN NUCLEI USING NEUTRON-MULTIPLICITY FILTER

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Much of the current interest in the structure of nuclei at high spin stems from the expectation of significant shape changes with the addition of angular momentum. At the simplest level, the evolution in shape can be predicted on the basis of the classical rotating-liquid-drop model (RLDM). The macroscopic RLDM predictions for high-spin structure are expected to be significantly modified in a real nucleus by the inclusion of shell and pairing corrections to the potential energy surface, which themselves depend on deformation and spin.

Nuclei at high spins are produced in fusion reactions induced by heavy ions, in which a large amount of excitation energy and angular momentum are brought into the compound system. The nucleus then cools mainly by the emission of low-L neutrons (and, with much smaller probability, charged particles), thus leading to the formation of high-spin evaporation residues. Fission decay provides an alternative mode of de-excitation which is particularly important for nuclei with $A > 200$. From observations which are integrated over the decay chain one may extract information about barrier height $B_{fiss}(J)$ and the s-wave particle separation energies $B_v(J)$ only by a statistical model unfolding of the competition among many open decay channels.

The competition, described to the first approximation by the ratio of fission and neutron emission widths Γ_f/Γ_n , is sensitive to many aspects of the structure of rotating nucleus which cannot be

obtained by any other method, including γ -spectroscopy.

In recent years we have investigated the decay of compound nuclei formed at high excitation and angular momentum in ${}^6\text{Li}$ -bombardment of ${}^{181}\text{Ta}$, ${}^{194,198}\text{Pt}$, ${}^{197}\text{Au}$ and ${}^{208}\text{Pb}$ in a coherent program of experiments and statistical model analyses, which have been carried out using the code MBEGAT. The most important conclusion from this work¹ is that the measurements of gross decay properties can be understood quite well using statistical model calculations in which all nuclear structure parameters are fixed to values consistent with the RLDM and non-interacting Fermi gas (NIFG) models.

The success in this earlier work of the statistical model analysis based on RLDM-NIFG models indicates that the overall decay properties of hot fusion products are not very sensitive to microscopic structure corrections, but at the same time seems to provide a credible signature for shell and pairing effects in more selective second-generation experiments. If one develops experimental techniques for enhancing the decay contributions from cold nuclei, one would then expect microscopic structure corrections to introduce significant deviations of measured target dependences from those predicted by the statistical-model-RLDM-NIFG calculations, which succeeded so well at high temperatures.

We therefore proposed a method to investigate the decay of cold, high-spin nuclei, which stresses measurements with enhanced sensitivity to high-chance

contributions to σ_{fiss} in the decay of compound systems formed initially at high temperature. The instrument which helps to provide this direct experimental information on the fission of cold high-spin nuclei is a prefission "neutron multiplicity filter." This device allows us to emphasize fission from progressively lower temperatures by gating on higher-fold neutron coincidences, just as in a γ -multiplicity experiment one can emphasize cascades from progressively higher spin by gating on higher-fold γ -events.

The neutron multiplicity filter makes use of the fact that neutrons emitted after fission come almost entirely from fully accelerated, rapidly moving fragments and are therefore directionally correlated with these fragments. The prefission neutrons, on the other hand, should show no such correlation and are approximately isotropic in the lab system. They will have, on the average, smaller lab energies than post-fission neutrons, decreasing sharply with the temperature of the emitting nucleus.

The experimental set-up consists of the neutron multiplicity filter (NMF) and large solid angle wire chambers for detecting fission fragments. The NMF includes two arrays of 9 large-volume liquid scintillator neutron detectors placed in and out of the reaction plane. Each neutron detector is a rectangular cell of 265 cm³ volume, filled with NE-213 scintillator. Neutrons are separated from abundant γ -rays with the help of home-built pulse shape discrimination boxes, and additional separation is obtained from the time-of-flight measurements. The fission fragments are detected in two x-y position sensitive wire-chambers, each of 15 x 15 cm² active area, one covering 71.5°-116.5° angular bite and the second one covering 165°-175° region.

In the first run last summer we tested all the components of hardware and measured the neutron background in the target room using 100 MeV ⁶Li beam. Figure 1 shows the picture of experimental set-up. Only one neutron array (9 cells) was used since the run was not meant as a production run. We collected neutron multiplicity-fission fragment coincidences with ¹⁹⁷Au and ²³²Th target at two positions of neutron array relative to the forward wire chamber. Position one, called the 90° position, has a relative angle between fission fragments and registered neutrons in the vicinity of 90°, position 2, called the 0° position, has a relative angle between fragment registered in the forward wire chamber and detected neutron in the vicinity of 0°. We also collected off-line coincidence data with ²⁵²Cf source in both positions of neutron detector. ¹⁹⁷Au is the first target we intend to investigate in the experiment, attempting to sort out post-fission neutrons emitted from fully accelerated fission fragments using the principle of kinematic focusing of post-fission neutrons. Data with ²³²Th target provide us with numerical estimate of the kinematic focusing effect, since there are virtually no pre-fission neutrons emitted in the reaction of ⁶Li with thorium. Off-line coincidence data with ²⁵²Cf source allow us to calibrate our equipment, due to the fact that we are able to reproduce angular distributions of neutrons with respect to the fission fragment (ff) direction what can be compared with existing data² on ff-neutron angular correlations in ²⁵²Cf decay.

Data analysis is still in the very preliminary stage. Figure 2 shows angular correlations between fission fragments and neutrons in ²⁵²Cf decay deduced from our off-line data. Crosses present our measurements from all the neutron cells, while circles

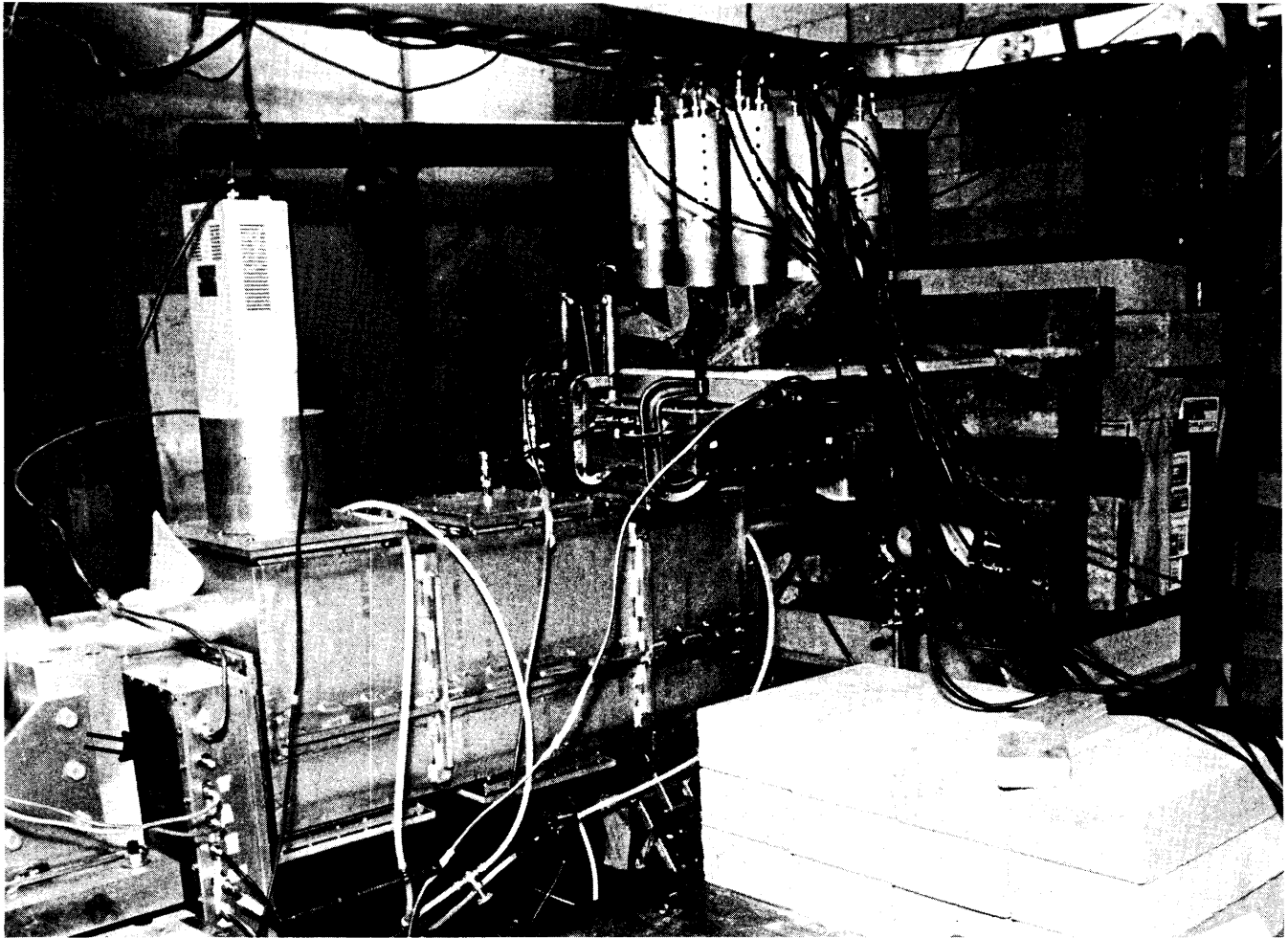


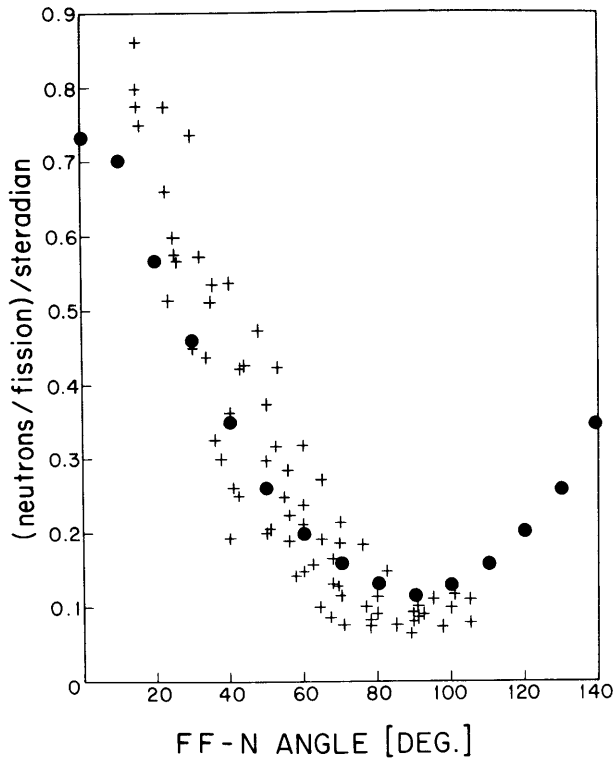
Figure 1. Picture of experimental set-up. Single arrow points to neutron array in the 0° position, double arrows point to wire chambers.

show the data of Bowman et al.² The improvement in efficiency corrections to the neutron spectra should further improve the agreement between both sets of data.

Separation of neutrons and γ -rays emitted in the reaction is absolutely crucial for the success of the experiment. Hence, a lot of experimental effort was put into achieving the best separation possible. We used NE213 liquid scintillator in our neutron cells, with Pulse Shape Discrimination (PSD) boxes built at

IUCF specifically for this experiment. Figure 3 presents a typical off-line PSD vs Pulse Height spectrum taken with the radioactive source. The off-line separation between neutrons and γ 's at low pulse heights is not very good, but in the actual run it is greatly enhanced by the time of flight (TOF) information. Good background conditions in the target room allow us to obtain quite clean TOF spectra (Fig. 4). We are also able to obtain valuable time-of-flight information in the off-line ^{252}Cf data by measuring

difference between TOF of neutrons or γ 's and TOF of fission fragments. Figure 4 shows on-line TOF with ^{232}Th target and off-line TOF with ^{252}Cf .



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Figure 2. Angular correlations of neutrons with respect to fission fragment direction. Full points show data of Bowman et al.,² while crosses show our data. Our data were normalized to the data of Ref. 2 at one point for one cell only.

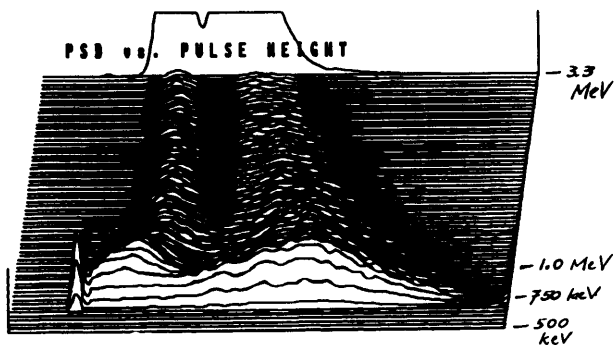


Figure 3. The spectrum of pulse shape discrimination signal vs. pulse height.

Finally, we compared rates of neutron-fission fragments coincidences at 0° and 90° positions of neutron array. We calculated the ratio of two-fold coincidences at 0° and 90° , obtaining 3.7 as a result. This indicates relatively strong influence of kinematic focusing on observed yields.

Data analyzed so far indicate that the experiment is feasible in the present experimental arrangement. More data analysis is necessary, before the experiment can be continued.

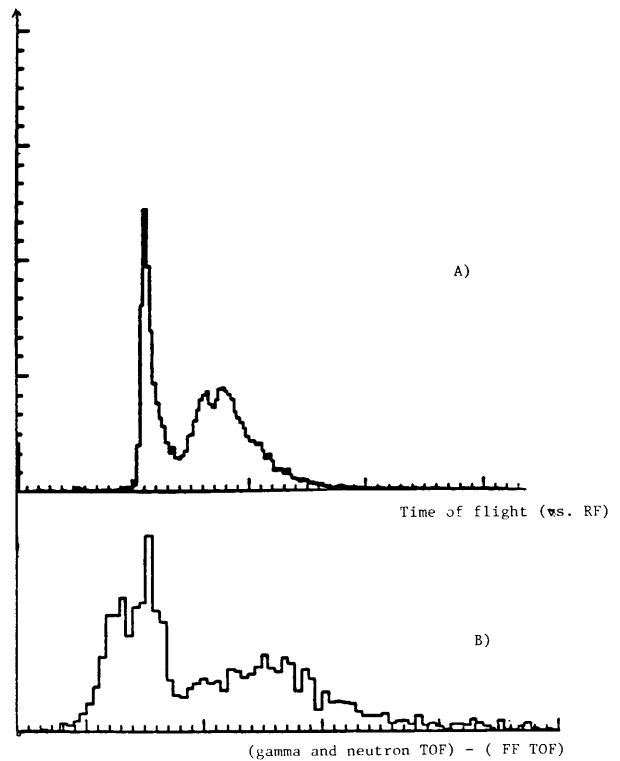


Figure 4. Typical time-of-flight spectra
a) On line spectrum with gold target
b) Off line spectrum taken with ^{252}Cf source. The difference between time-of-flight of detected γ or neutron and time-of-flight of the coincident fission fragment.

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- 1) S.E. Vigdor et al., Phys. Rev. C 26, 1035 (1982).
- 2) H.R. Bowmann et al., Phys. Rev. 126 G, 2120 (1962).