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Beyond-neutron-threshold structure investigations in the N=20 & 28 regions via beta-delayed spectroscopy techniques

Abstract:

The discovery of β-delayed neutron emission is almost as old as that of nuclear fission itself. In 1939, Roberts et al. [1] reported neutron emission persisting for more than a minute after the end of irradiation of a bottle containing roughly 100 g of uranium nitride. It was later recognized that this process plays a pivotal role both in nucleosynthesis, in particular the r-process, and in reactor kinetics, where controllability relies crucially on the presence of a delayed neutron population [2]. Yet, nearly nine decades after its discovery, no fully microscopic theory exists that can describe this key phenomenon end-to-end, from the β decay of the precursor to the complete energy spectra of all emitted products. Indeed, β-delayed neutron emission was incorporated almost immediately by Bohr and Wheeler into their liquid-drop description, and since that early era the process has remained, to a large extent, walled within the same paradigm. It is commonly framed as a two-step mechanism: first, β decay populates a "compound-nucleus"configuration in the Bohr sense; second, the subsequent de-excitation is governed by purely statistical laws [3]. Within this viewpoint, it is widely assumed that the system rapidly loses the structural memory of the β-decaying state, so that the final emissions do not depend on it.

Over the past few years, however, a growing body of observations has revealed strongly non-statistical behavior in radioactive decay, placing this picture under severe strain. Several of these findings were initiated at ALTO in the N=50 region, through (i) the pronounced oscillations of Pn values along the gallium chain for N>50 [4], (ii) γ/neutron competition persisting at spectacular "altitudes", far more than 1 MeV above the neutron separation threshold [5], and more recently (iii) in the N=82 region, through the wholly unexpected observation of delayed-neutron emission within one of the narrowest Qβn windows in the nuclear chart (the decay of 126Cd, with Qβn=85±3 keV) [6]. These breakthroughs were achieved in an ISOL-production mode context, using sources collected on a movable tape and specialized instrumentation such as the TETRA 3He neutron counter, essentially free of an intrinsic detection-energy threshold, and the PARIS γ-ray spectrometer for very-high-energy γ radiation.

Through this LoI, we express our interest in extending these studies to the A=40–50 region, close to the magic numbers N=20 and N=28, by exploiting the beams of 36,37,38,39,40P, 42,43,44,45Cl, and 48,49,50K that are indicated as potentially available from SPIRAL1 via fragmentation of a 48Ca primary beam. These beams have already been used at ISOLDE, with pioneering work by a Strasbourg group on Cl and K beams in the early 1980s [7], and by a GANIL/Dubna collaboration at LISE for P isotopes in the late 1980s [8]. It is precisely in the potassium chain beyond N=28 that the striking oscillatory behavior of Pn values was first noted ; this observation directly inspired the subsequent work in the N=50 region reported in Ref. [4]. However, most of these early studies were not conceived with the search for non-statistical decay phenomena in mind, and they did not have access to the dedicated tools required to reveal them, such as TETRA or PARIS. Moreover, and rather surprisingly, a recent re-investigation of the decay of 51,52,53K at ISOLDE [9] did not report any non-statistical signatures. The authors themselves underline the unexpected nature of this outcome, but it is plausible that an energy-threshold effect in their neutron detector, underestimated in their analysis, may have masked the relevant features. This tends to demonstrate that a dedicated revisit of this case is worthwhile.

The forthcoming development of a sufficiently versatile and modular decay station at DESIR, able, like the BEDO station at ALTO, to host multiple detector types, including bulky devices, in a compact geometry, is essential to carry out this program successfully.

[1] Roberts, Meyer and Wang Phys. Rev. 55, 510 (1939)
[2] see Dimitriou et al Nuclear Data Sheets 173, 144 (2021) and refs therein
[3] Kawano et al. Phys. Rev. C 78 054601 (2008)
[4] Verney et al. Phys. Rev. C 95 054320 (2017)
[5] Gottardo et al Phys. Let. B772 359 (2017)
[6] Testov et al, submitted to EPJA (2026)
[7] Huck et al. Proc 4th Int Conf on nuclei far from stability, Helsingor, p. 378 (1981)
[8] Lewitowicz et al. Nucl. Phys. A496, 477 (1989)
[9] Xu et al. Phys. Rev. Let. 133 042501 (2024)

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