Strong one-neutron emission from two-neutron unbound states in β decays of r-process nuclei ^{86,87}Ga[†]

R. Yokoyama,[*1] R. Grzywacz,[*1,*2] B. C. Rasco,[*1,*2] N. T. Brewer,[*1,*2] K. P. Rykaczewski,[*2] I. Dillmann,[*3] J. L. Tain,[*4] and S. Nishimura[*5] for the BRIKEN collaboration

Delayed neutron emission after β decays is found in neutron-rich nuclei in which the energy window of β^- decay (Q_β) is high enough to populate excited states of the daughter nucleus above the neutron separation energy (S_n). All of the neutron-rich nuclei on the r-process path are either one or multi-n β-delayed precursors. Delayed neutron emission shapes the final abundance pattern owing to the modification of the isotopic population through the modification of the decay path back to stability and by contributing significantly to the neutron flux after freeze-out. However, experimental data that enable the evaluation of the role of multi-n emission for the r-process nuclei are almost non-existent. Often, predictions for neutron emission probabilities are based on a simplified *cut-off* model that neglects γ-decay competition and assumes that only the higher-multiplicity neutron emission prevails in the energy regions open to multiple neutron-emission channels.

We studied neutron-rich Ga isotopes by means of β-neutron-γ spectroscopy at RIBF using the in-flight fission of a 345 MeV/nucleon $^{238}U^{86+}$ beam on a 4-mm-thick ^{9}Be production target. For decay measurement, 7×10^4 and 6×10^3 ions of ^{86}Ga and ^{87}Ga, respectively, were transported to the final focal plane. Double-sided silicon-strip detectors (DSSSDs), AIDA,[1)] WAS3ABi,[2)] and a YSO scintillator[3)] were employed for ion and β correlation measurements. The ^{3}He neutron counter array, BRIKEN,[4)] was used for neutron measurement.

The half-lives and P_{xn} values were obtained through the analysis described in Ref. 6). The P_{1n} and P_{2n} values obtained in this work for ^{86}Ga are consistent with the data reported by Miernik *et al.*[7)] We discovered new β-delayed two-neutron emitters, ^{84,85,87}Ga, and measured their two-neutron branching ratio for the first time. Figure 1 shows a comparison of the experimental neutron branching ratio with shell-model calculations based on the cut-off model reported by Madurga *et al.*[5)] and shell-model calculations based on the Hauser-Feshbach statistical model.[8)] When comparing the new experimental results with the predictions from the shell-model calculations, we notice a discrepancy between the cut-off model and experimental data for all investigated $\beta 2n$ gallium precursors,

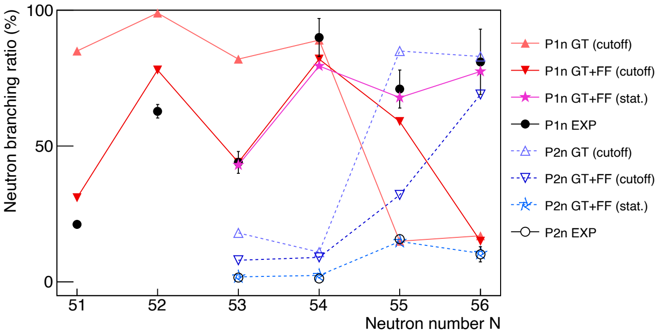

Fig. 1. Comparison of the experimental data and the predictions from the shell-model calculations by Madurga *et al.*[5)] "GT" and "GT+FF" in the legend denote shell-model calculations with pure Gamow-Teller and GT + first forbidden transitions, respectively. The GT+FF predictions, when coupled with the statistical model (stat.), provide a much better agreement with the data than the cutoff model.

which is most dramatically manifested in ^{87}Ga.

In contrast to the cut-off model, the inclusion of the statistical model correctly reproduces the dominating role of one-neutron emission from two-neutron unbound states. This result is the first clear case in medium/heavy nuclei where the effects of statistical emission must be considered to model β-delayed multi-neutron emission, which is of particular importance for r-process modeling. The strong 1n emission from 2n unbound states will require more detailed studies of neutron and γ-ray spectra to establish the details of the emission process. The detection of neutron energies and γ-ray energies is required to better constrain both the strength-distribution models and statistical model parameters.

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*1 University of Tennessee, Knoxville
*2 Oak Ridge National Laboratory
*3 TRIUMF
*4 IFIC (CSIC, Universitat de Valencia)
*5 RIKEN Nishina Center