EPJ Web of Conferences **109**, 08003 (2016)
DOI: 10.1051/epjconf/201610908003

β-decay half-lives of neutron-rich nuclei around ^{158}Nd, relevant to the formation of the A≈165 rare-earth element peak

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Abstract. A β-decay spectroscopy experiment around ^{158}Nd was performed at RI Beam Factory (RIBF), RIKEN Nishina Center, in order to understand the production mechanism of the A≈165 rare-earth element (REE) peak in the *r*-process mass abundance pattern. In this experiment, 53 half-lives are measured including 34 new results, which could be employed in a fully dynamic *r*-process network calculation.

1 Introduction

Approximately half of elements in the universe heavier than iron are produced by the rapid neutron-capture (*r*-) process, which remains a challenge to scientists for decades of years. In the solar-system *r*-process mass abundance pattern, two prominent peaks around A=130 and A=195 are

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produced along the *r*-process path as the nuclear flow pass through neutron-closed-shells at N=82 and N=126, which have long β-decay lifetimes acting as bottlenecks to build up abundance [1]. Between these two peaks, the production mechanism of one smaller peak around A=165 with a broader shape, which is known as the rare-earth element (REE) peak, is still a controversial topic.

In the presence of available nuclear properties data, variety of dynamic *r*-process network calculations have been performed during the past decades of years trying to understand the production mechanism of the REE peak. The study of Surman et al [2] suggests that the REE peak is formed during the freeze-out of a $(n,\gamma)\rightleftharpoons(\gamma,n)$ equilibrium due to the subtle interplay between nuclear deformation and β decay, which emphasize that the peak is formed in the "Hot *r*-process" condition. However, S. Goriely et al [3] think that the fission cycling around mass number A=278 plays a significant role, which introduces that neutron star merger as the main site of *r*-process. Due to the absence of nuclear properties for more exotic region, the REE peak cannot be properly reproduced. A reliable system of nuclear properties is needed to perform the *r*-process calculation.

Not only can newly-measured β-decay half-lives provide nuclear physical inputs to the *r*-process network calculation, but also they can provide a first test to the theoretical models that is essential to calculate other physical properties which cannot be accessed by experiment in the current condition.

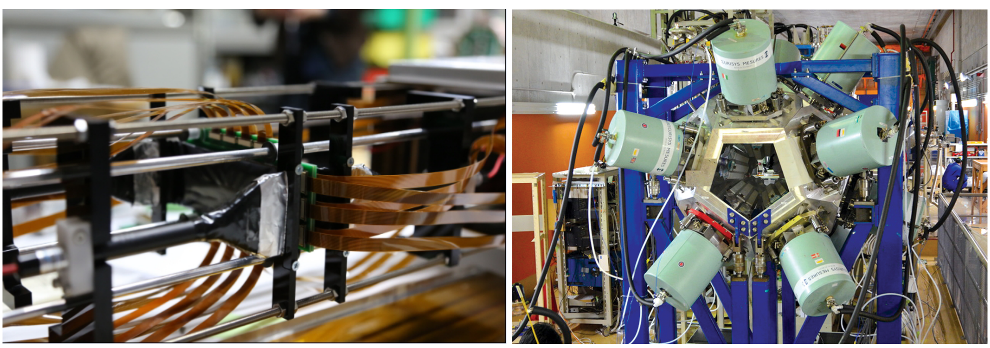

Figure 1. (Color online) The beta counting system WAS3ABi (left figure) and High-purity Germanium Cluster detectors EUROBALL (right figure).

2 Experimental setup

One β-decay spectroscopy experiment around neutron-rich nuclei ^{158}Nd was performed at RI Beam Factory (RIBF), RIKEN Nishina Center. With the help of the large-acceptance isotope separator (BigRIPS), very neutron-rich nuclei of interest are implanted to the beta counting system (WAS3ABi) constructed by five highly-segmented DSSSDs with 60 strips in the horizontal direction and 40 strips in the vertical direction combined with two plastic scintillators located in the upstream and downstream. Each DSSSD has a thickness of 1mm and the width of each strip is 1mm [4–8]. In conjunction with High-purity Germanium Cluster detectors (EUROBALL) [9], not only beta-decay events but also the prompt and β-delayed γ-rays emitted from implanted particle can be measured with relative high efficiency (see Fig. 1). Considering the position correlation between implantations and beta-decay events, the beta-decay curve was constructed by the difference of their time information, which was fitted by several components to extract β-decay half-life (see Fig. 2).

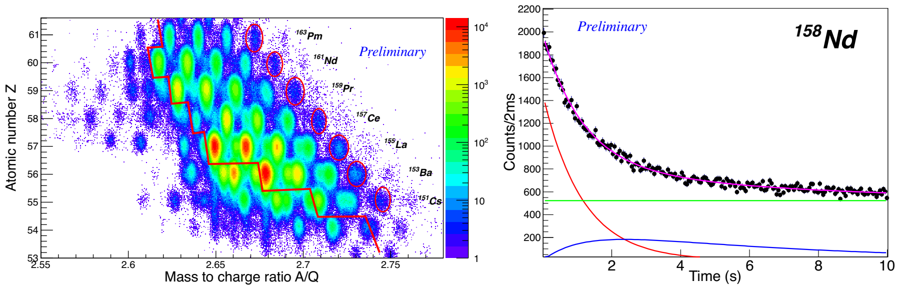

Figure 2. (Color online) Left figure shows the particle identification (Atomic number Z vs the ratio of Mass to charge A/Q) constructed by TOF-Bρ-ΔE method [10]. The nuclei in the right side of the red line stands for the nuclei with newly-measured β-decay half-lives. The β-decay curve (pink) of nuclei ^{158}Nd fitted with several components (parent nuclei (red), daughter nuclei (blue), background (green)) is displayed in the right figure.

3 Discussion

In this experiment, totally 53 nuclei with 34 newly-measured β-decay half-lives are obtained, which will play a significant role in the production of the REE peak according to the calculation of Mumpower (see Fig. 2). Table 1 shows some preliminary results compared with previous measurement. The mainly effect is the rising slope of the rare-earth elements peak. In future, A fully dynamic r-process network calculation will be performed employing newly-measured half-live, which could provide a deeper understanding of the production mechanism of the REE peak.

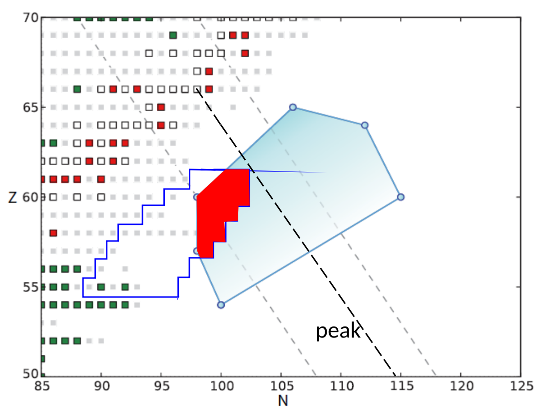

Figure 3. (Color online) The shadow area is the region of nuclei which is essential to the formation of the REE peak according to the calculation of Mumpower et al [11]. The area inside the blue line stands for the nuclei measured in this experiment overlapping with the predicted area (red region).

Table 1. $T_{1/2}$ measured in this experiment.

Nuclide	$T_{1/2}^{exp}$(Preliminary)	$T_{1/2}^{lit}$	Nuclide	$T_{1/2}^{exp}$(Preliminary)	$T_{1/2}^{lit}$
^{144}Cs	0.932(76)s	0.994(6)s [12]	^{151}Ce	1.71(9)s	1.76(6)s [12]
^{146}Ba	2.56(29)s	2.22(7)s [12]	^{153}Pr	4.68(70)s	4.28(11)s [12]
^{148}La	1.27^{+10}_{-9}s	1.26(8)s [12]	^{156}Nd	5.2(14)s	5.06(13)s [12]

4 Summary

In order to understand the formation of the REE peak in the solar system mass abundance pattern, one β-decay spectroscopy experiment around ^{158}Nd was performed at RIBF, RIKEN Nishina Center. In future, newly-measured β-decay half-lives will be employed to perform the dynamic network *r*-process calculation. It is possible to judge the notion that the rare-earth abundance peak around A=165 is formed during the freeze-out of a $(n,\gamma)\rightleftharpoons(\gamma,n)$ equilibrium.

Acknowledgement

This work was carried out at the RIBF operated by RIKEN Nishina Center, RIKEN and CNS, University of Tokyo. We acknowledge the EUROBALL Owners Committee for the loan of germanium detectors and the PreSpec Collaboration for the readout electronics of the cluster detectors. Part of the WAS3ABi was supported by the Rare Isotope Science Project which is funded by the Ministry of Education, Science and Technology (MEST) and National Research Foundation (NRF) of Korea. This work was partially supported by US DOE Grant No.DEFG02-91ER-40609, Kakenki Grant No.25247045, and the Japan Society for the Promotion of Science (JSPS) Kakenhi Grant No.2301752.

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