\(\beta\)-decay half-lives of neutron-rich nuclei around \(^{158}\text{Nd}\), relevant to the formation of the A\(\approx\)165 rare-earth element peak

J. Wu\(^{1,2,a}\), S. Nishimura\(^{2}\), G. Lorusso\(^{3}\), Z.Y. Xu\(^{4}\), E. Ideguchi\(^{5}\), G.S. Simpson\(^{6}\), H. Baba\(^{2}\), F. Browne\(^{7,2}\), R. Daido\(^{8}\), P. Doornebal\(^{2}\), Y.F. Fang\(^{8}\), T. Isobe\(^{2}\), Z. Li\(^{1}\), Z. Patel\(^{9,2}\), S. Rice\(^{9,2}\), L. Sinclair\(^{10,2}\), P.-A. Söderström\(^{2}\), T. Sumikama\(^{11}\), H. Watanabe\(^{12}\), A. Yagi\(^{8}\), R. Yokoyama\(^{13}\), N. Aoi\(^{5}\), F.L. Bello Garrote\(^{14}\), G. Benzoni\(^{15}\), G. Gey\(^{6,16}\), A. Gottardo\(^{17}\), H. Nishibata\(^{8}\), A. Odahara\(^{8}\), H. Sakurai\(^{2}\), M. Tanaka\(^{5}\), J. Taprogge\(^{18,19,2}\), T. Yamamoto\(^{8}\), and the EURICA collaboration

\(^{1}\)School of Physics, Peking University, Beijing 100871, China
\(^{2}\)RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan
\(^{3}\)National Physical Laboratory, Teddington, Middlesex, TW11 0LW, U.K.
\(^{4}\)Department of Physics, University of Hong Kong
\(^{5}\)Research Center for Nuclear Physics, Osaka University, Japan
\(^{6}\)LPSC, UJF/INPG, CNRS/IN2P3, F-38026, Grenoble Cedex, France
\(^{7}\)School of Computing, Engineering and Mathematics, University of Brighton, U.K.
\(^{8}\)Department of Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan
\(^{9}\)Department of Physics, University of Surrey, U.K.
\(^{10}\)Department of Physics, University of York, Heslington, York, YO10 5DD, U.K.
\(^{11}\)Department of Physics, Tohoku University, Sendai 980-8578, Japan
\(^{12}\)Department of Physics, Beihang University, China
\(^{13}\)Center for Nuclear Study, University of Tokyo, Japan
\(^{14}\)University of Oslo, P.O. Box 1072 Blindern, 0316 Oslo, Norway
\(^{15}\)INFN, Sezione di Milano, via Celoria 16, I-20133 Milano, Italy
\(^{16}\)ILL, 28042 Grenoble Cedex, France
\(^{17}\)INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy
\(^{18}\)Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
\(^{19}\)Instituto, de Estructura de la Materia, CSIC, E-28006 Madrid, Spain

Abstract. A \(\beta\)-decay spectroscopy experiment around \(^{158}\text{Nd}\) was performed at RI Beam Factory (RIBF), RIKEN Nishina Center, in order to understand the production mechanism of the A\(\approx\)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

\(\text{a-mail: wujin@ribf.riken.jp}\)

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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 $\beta$-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 $(n, \gamma) \leftrightarrow (\gamma, n)$ equilibrium due to the subtle interplay between nuclear deformation and $\beta$ 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 $\beta$-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 $\beta$-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 $\beta$-delayed $\gamma$-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 $\beta$-decay half-life (see Fig. 2).
3 Discussion

In this experiment, totally 53 nuclei with 34 newly-measured $\beta$-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.
Table 1. \( T_{1/2} \) measured in this experiment.

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

4 Summary

In order to understand the formation of the REE peak in the solar system mass abundance pattern, one \( \beta \)-decay spectroscopy experiment around \(^{158}\text{Nd}\) was performed at RIBF, RIKEN Nishina Center. In future, newly-measured \( \beta \)-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 \((n,\gamma)\equiv(\gamma,n)\) equilibrium.

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