# Identification of a new $\mu$s-isomer in the REP region

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The solar $r$-process abundance distribution has two characteristic maxima at $A \approx 130$ and $A \approx 195$, which can be explained by neutron shell closures at $N = 82$ and $N = 126$, respectively. A smaller peak also exists between these two maxima at $A \approx 160$, which is known as the rare-earth peak (REP). The formation of the REP is sensitive to parameters that control the neutron density and neutron-to-seed ratio $Y_e$ in the late stages of the $r$-process, such as the timescale for the expansion of the material. However, these astrophysical conditions are entangled with nuclear physics processes that provide additional neutrons, of which $\beta$-delayed neutron emissions can be a main contributor.[1)] The mass region responsible for the formation of the REP has previously been inferred.[2)]

During the NP1612-RIBF148 experiment's heavier setting, exotic neutron-rich $^{159\text{–}166}$Pm, $^{161\text{–}168}$Sm, $^{165\text{–}170}$Eu, and $^{167\text{–}172}$Gd isotopes were produced (among others) at RIKEN Nishina Center by the fragmentation of a $^{238}$U primary beam with an intensity of approximately 60 particle nA to produce isotopes as close to the aforementioned region of nuclei as possible. The fission fragments were selected and identified using the standard $\Delta E$-$B\rho$-ToF method by BigRIPS. The radioactive ions were implanted in the AIDA implantation detector[3,4)] after adjusting their kinetic energy with aluminum degraders placed at the F11 focal point. The AIDA implantation detector was centered in the BRIKEN neutron counter,[5)] which consisted of 140 $^3$He-filled proportional counters embedded in a large polyethylene moderator matrix. Moreover, two CLARION-type clover detectors[6)] were inserted horizontally from the left and right sides into holes in the matrix that allowed facing the center of the stack of double-sided silicon strip detectors (DSSSD).

Half-lives and $P_{1n}$ values were deduced from implantation–$\beta$ correlations and implantation–$\beta$–neutron correlations for the produced isotopes. These results were used for variance-based sensitivity analysis to reveal the influence of nuclear physics inputs on the calculated abundance pattern for the case of REP.[7)] Beta-delayed $\gamma$-spectroscopy was also performed using the CLARION-type clover detectors. In most of the studied nuclei, there was a significant number of newly identified $\gamma$-ray transitions. In order to build decay-schemes, $\gamma$–$\gamma$ coincidence analysis was performed as well.

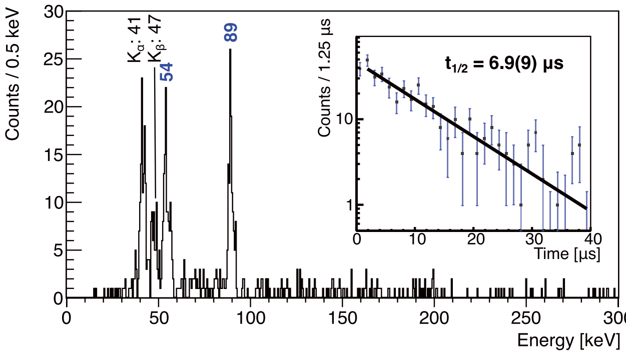


Fig. 1. Energy spectrum of isomer-delayed $\gamma$-rays from $^{164}$Eu*. Inset: exponential function fit to the isomeric decay curve.

A $\mu$s-isomer candidate of $^{164}$Eu was identified earlier using implantation–$\gamma$ correlations; however, no half-life nor exact energy level was reported.[8)] We found that the $^{164}\text{Sm} \rightarrow {}^{164}\text{Eu}^*$ $\beta$-decay populates a low-lying isomeric state located at $E_{exc.} = 143.7(3)$ keV, which de-excites through $E_\gamma = 54$ keV and $E_\gamma = 89$ keV $\gamma$-transitions. The half-life of this isomeric state was found to be 6.9(9) $\mu$s. Figure 1 shows the measured gamma spectra and the isomeric decay curve.

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