

Measurements of high energy excited states and γ -rays of fission products with 4π clover detector

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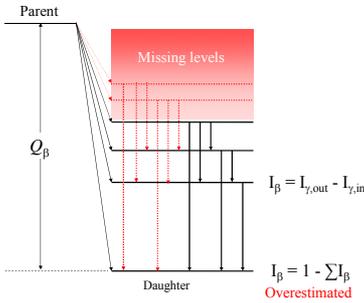
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Introduction

Identification of high energy levels and γ -rays and determination of γ -ray intensities are important to determine precise β -branching ratios. We measured γ -rays following the decay of fission products ^{147}La and ^{145}Ba and identified high energy levels and γ -rays in daughter nuclides ^{147}Ce and ^{145}La using a 4π clover detector. In order to determine γ -ray intensities, detection efficiencies of the detector were deduced, applying coincidence summing corrections.

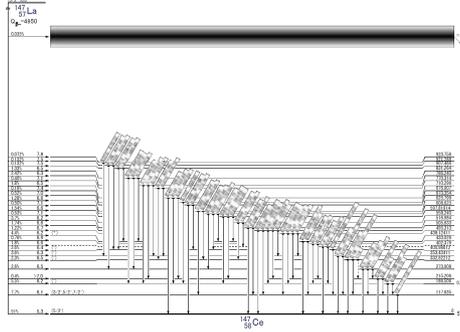


A schematic decay scheme and calculation of β -branching ratios.

Decay data of ^{147}La and ^{145}Ba taken from ENSDF[1]

nuclide	half-life	β -decay energy (keV)	previously reported level
^{147}La	4.06 s	5366 [2]	≤ 924.3
^{145}Ba	4.31 s	4923	≤ 973.6

High energy levels and γ -rays are not observed in the decay of ^{147}Ce and ^{145}La .



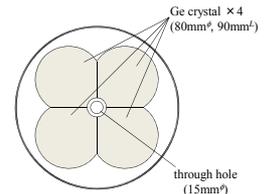
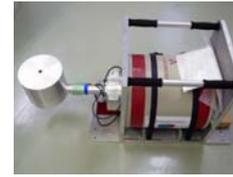
A decay scheme of ^{147}La .

Purpose

- Identification of high-energy levels and γ -rays in ^{147}Ce and ^{145}La .
- Determination of peak efficiencies of the clover detector, applying coincidence summing corrections.

4π clover detector

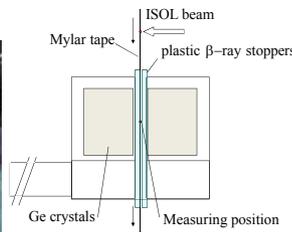
A 4π clover detector is composed of four Ge crystals and has a through hole along the central axis. Radioactive sources are placed at the center of the hole, where a solid angle subtended by the four Ge crystals is 98%. An energy signal from each Ge crystal is recorded in list mode together with the corresponding time information. The list data were converted to various spectra through off-line sorting.



A photograph of the total absorption clover detector (left) and a schematic drawing of the detector (right).

Measurements of ^{147}La and ^{145}Ba

The 4π clover detector was installed at the Kyoto University Research Reactor (KUR). The ^{147}La and ^{145}Ba isotope was produced with thermal neutron induced fission reaction of ^{235}U and mass-separated by on-line isotope separator (ISOL).

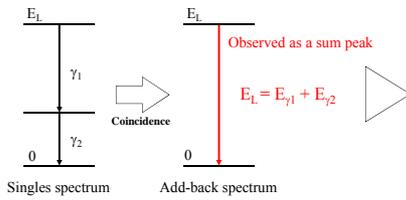


Photographs (left and center) and a schematic drawing (right) of experimental setup at KUR-ISOL.

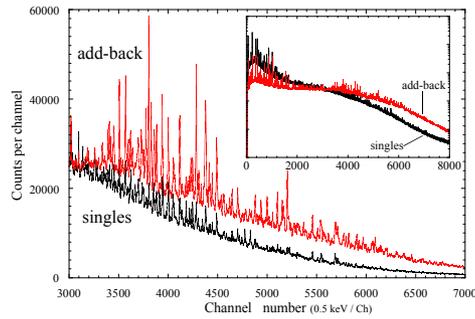
- Target: 50mg UF_4 (93% enriched)
- Thermal neutron flux: $6 \times 10^{11} \text{ n/cm}^2/\text{s}$ (1MW)
- Tape cycle: (8.0 s collection) – (8.0 s measurement)
- Measuring time: 24 (^{147}La) and 36 hours (^{145}Ba)

Analysis and Results

We identified excited levels by sum peaks in a singles and an add-back spectrum. Cascade relations were deduced from two-step cascade spectra.



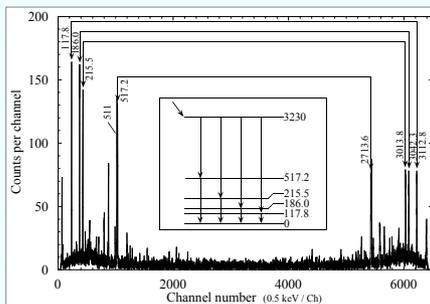
Gate on sum peak



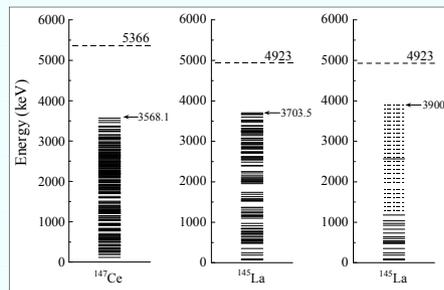
A singles and an add-back spectra of ^{147}La .

About 1000 γ -rays following the decay of ^{147}La and 300 γ -rays following the decay of ^{145}Ba were identified.

More than 200 levels in ^{147}Ce and 90 levels in ^{145}La were identified.



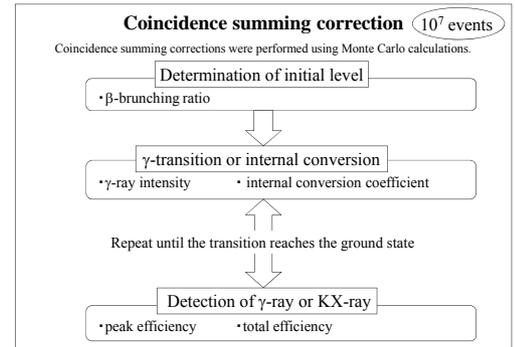
A typical two-step cascade spectrum of the 3230 keV sum peak and a partial decay scheme depopulating the level.



Beta-decay energy of ^{147}La and ^{145}Ba , and excited levels in ^{147}Ce and ^{145}La . The previous result of ^{145}La [3] is shown in the right figure.

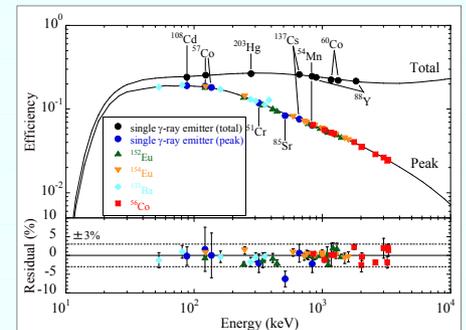
Efficiency determination

- Determination peak and total efficiencies using single γ -ray emitters.
- Calculation the efficiencies using the Monte Carlo simulation code GEANT4.
- Determination peak efficiencies using multiple γ -ray emitters, combined with coincidence summing corrections.



A flowchart of coincidence summing corrections and input data

The peak efficiencies from 50 to 3200 keV were determined with 3% accuracy.



Peak and total efficiencies for single Ge crystal.

Conclusions

- About 1000 γ -rays following the decay of ^{147}La and more than 200 levels in ^{147}Ce were identified.
- About 300 γ -rays following the decay of ^{145}Ba and more than 90 levels in ^{145}La were preliminary identified.
- Corrected peak efficiencies from 50 to 3200 keV were determined with 3% accuracy.
- Determination of observed γ -ray intensities is now in progress.

Acknowledgements

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References

- [1] Evaluated Nuclear Structure Data File (ENSDF), <http://nndc.bnl.gov/ensdf>.
- [2] H. Hayashi *et al.*, Nucl. Instrum. Meth. A **606** (2009) 484.
- [3] R.C. Greenwood *et al.*, Nucl. Instrum. Meth. A **390** (1997) 95.