Gamma-ray spectroscopy of ^{141}Ba β^{-}decay into ^{141}La for antineutrino spectrum

Javier Rufino, SULI intern, Department of Physics and Astronomy, University of Texas at San Antonio, San Antonio, TX, 78249
Elizabeth Ricard-McCutchan, mentor, Department of Nuclear Science and Technology, Brookhaven National Lab, Upton, NY, 11973-5000

U.S. Department of Energy, Office of Science · Brookhaven National Laboratory · NSF · UTSA, The University of Texas at San Antonio, Department of Physics and Astronomy

Abstract

The focus of this study is to re-evaluate the gamma-rays that are produced from the β^- decay of ^{141}Ba into ^{141}La, for its applications in nuclear reactor physics, and to better understand nuclear data. The experiment was conducted in the ATLAS facility at Argonne National Lab and recorded with the world class high purity germanium detector, Gammasphere. After analyzing the energies and intensities of the gamma-rays, a summation method was applied to obtain the antineutrino spectrum. The resulting antineutrino spectrum of ^{141}La will be used in the ongoing research for antineutrino emissions of strongly populating fission yields.

Motivation

When fissile materials like ^{235}U, ^{238}U or ^{239}Pu are irradiated with thermal neutrons over 800 fission fragments can be created[1]. The fission yields of those nuclear reactions can be seen in Figure 1, and it is important to note that these fragments lie on the neutron side of the valley of stability. As a result, those unstable nuclei, ^{141}Ba in this particular experiment, will reach stable isotopes through the β^-decay process:

$$ {}^{141}_{56}Ba \rightarrow {}^{141}_{57}La + e + \bar{\nu}_e . $$

Measuring the gamma-ray energies and the respective intensities of the strongly populating fission yields during the β^- decay process allows us to further study their antineutrino spectrum as well (seen in Figure 2). The importance of studying the antineutrino emissions from these fission yields corresponds to research in the field of nuclear reactor physics, as well as our understanding of nuclear data. The nuclei focused in this study, ^{141}La, is merely a tree in the forest of our investigation as it is one of over 800 possible fission fragments.

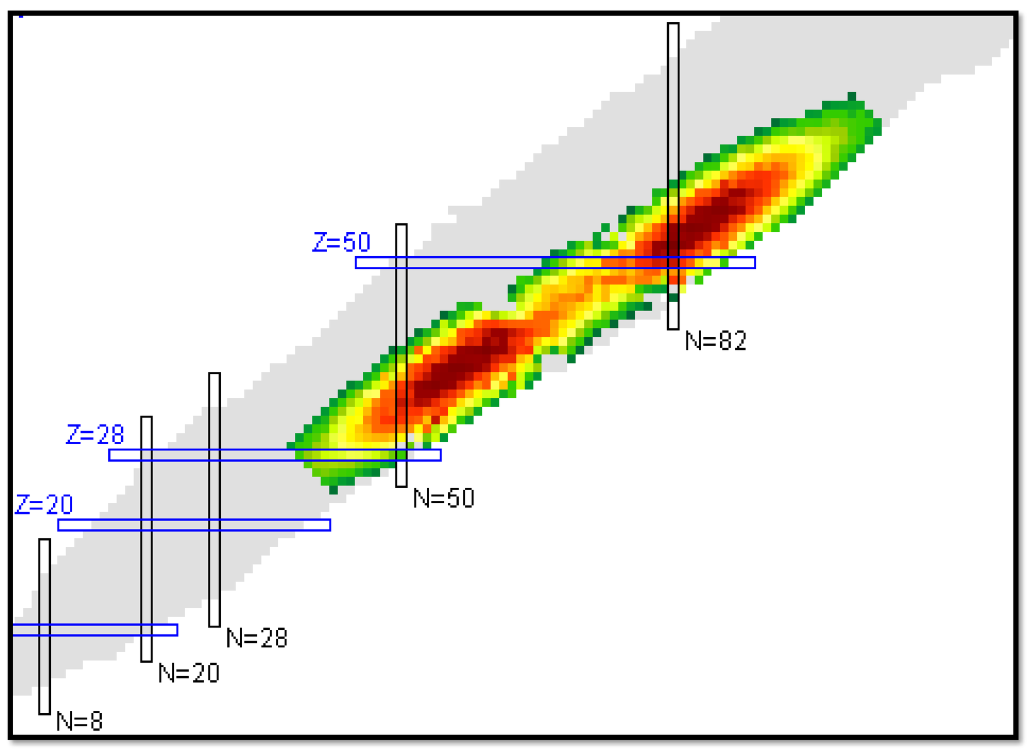

Figure 1: The chart of nuclides from NuDat illustrating the possible 800 fission fragments of ^{235}U

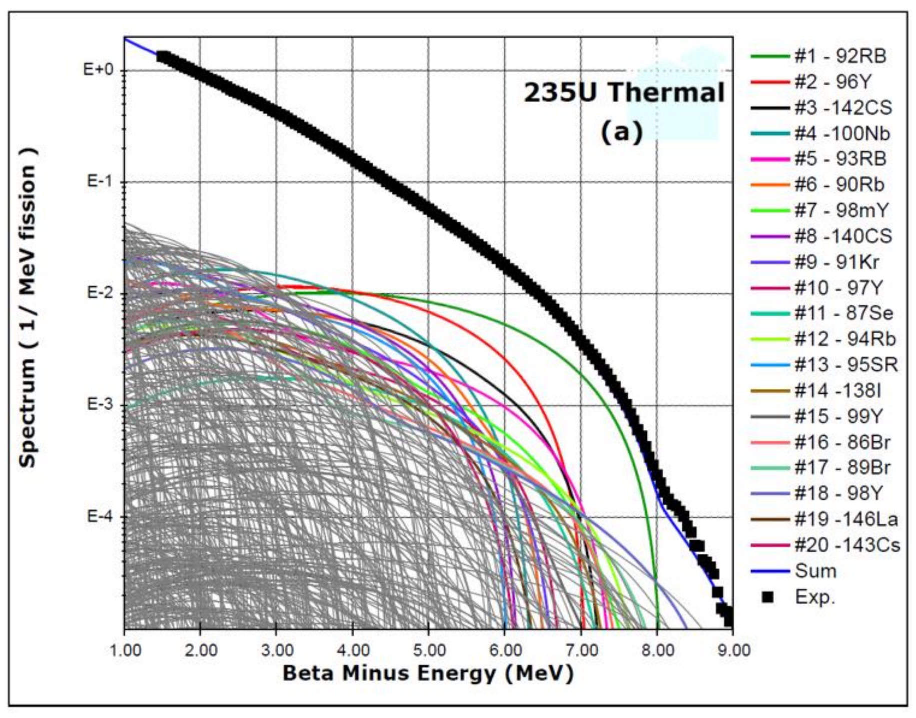

Figure 2: Antineutrino spectrum of strongly populating fission yields using the summation method[1].

Methodology

- Becoming familiarized with Radware software run on National Nuclear Data Center's (NNDC) gamma2 Linux machines, is how we are able to evaluate the single γ- spectra and γ-γ matrix from the ^{141}Ba β^- decay experiment. The experiment was conducted at Argonne National Lab and detected with high resolution gamma-ray detector, Gammasphere.
- Using γ-γ coincidences in the matrix we confirmed, appended to and corrected the gamma-ray's belonging to excited states of ^{141}La from the previous published ^{141}Ba β^- decay studies[2]. For example Figure 3 illustrates how γ-1713keV is misplaced in current ENSDF file level scheme transitioning from 2293keV to 580keV when it is transition from 2180keV to 467keV, as it is γ-γ coincidence gating from below on 276keV and not 304keV.
- Single energy transitions were fitted from either the single γ- spectrum seen in Figure 4, or by slicing or gating the γ-γ matrix from above.
- Gamma-rays with energy transitions that did not depopulate or "feed" directly into the ground state were fitted by slicing or gating the gamma-rays in the matrix coming from below and from above.

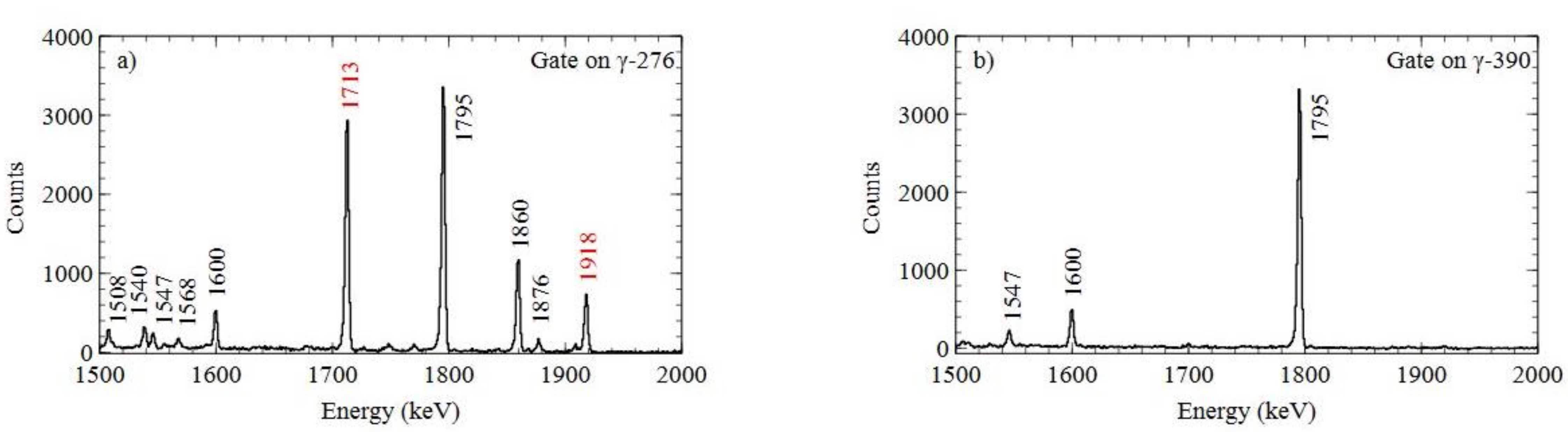

Figure 3: a) Doubles γ-γ matrix by gating from below on γ-276keV. b) Doubles γ-γ matrix by gating from below on γ-390keV.

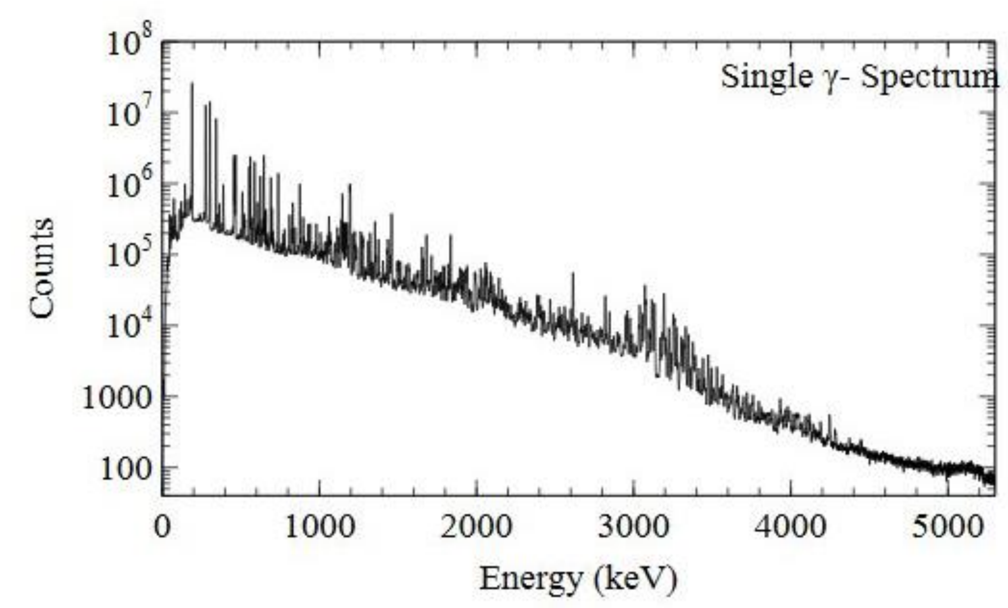

Figure 4: Single γ spectrum from ^{141}Cs β^- decay experiment. Excited states of ^{141}La.

Results

- A series of new gamma-ray's and energy levels were discovered within the level scheme, some outlined in blue in Figure 5. In addition, 7 gamma-ray's were relocated and 3 energy levels were deemed necessarily removed from the current level scheme.
- Using an internal energy calibration technique we fit the spectrum's channel to the energy and achieved a $\pm$0.2(keV) calibration error.

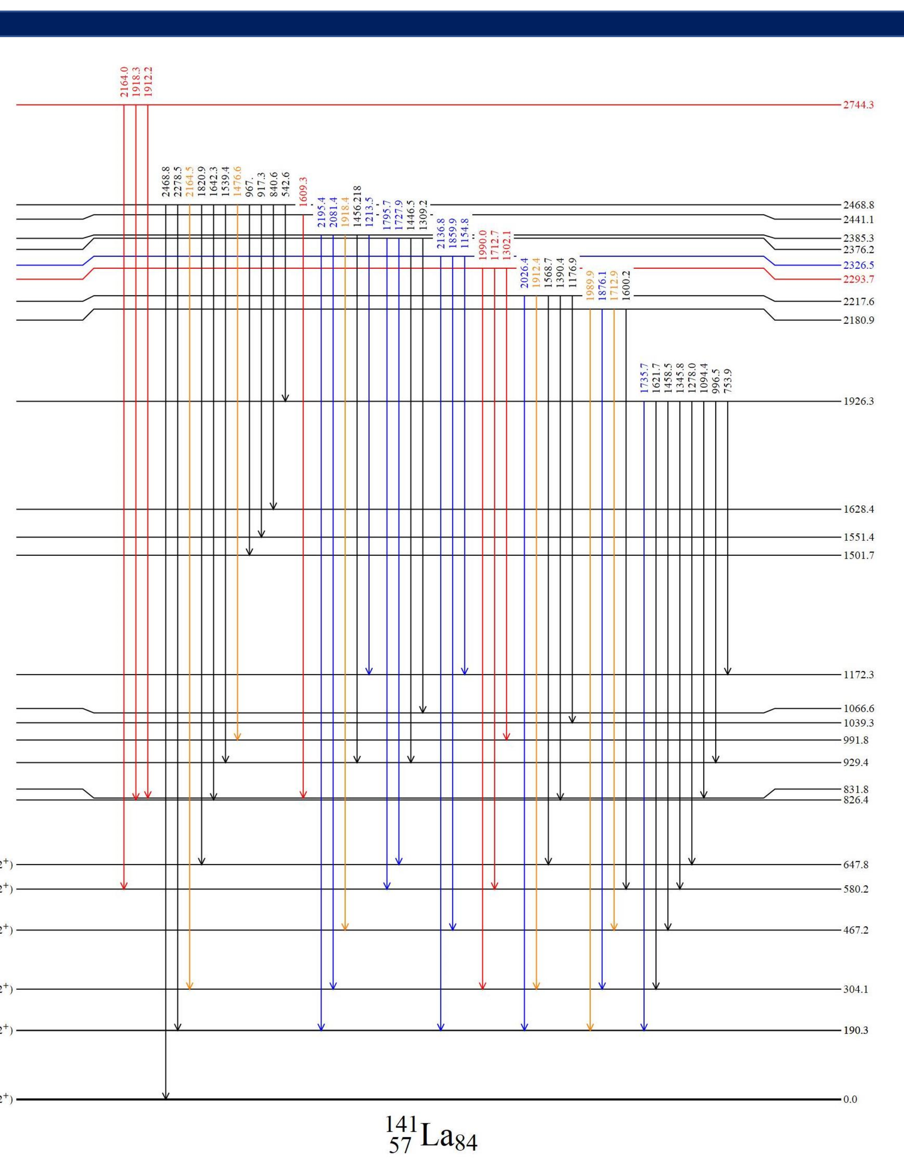

Figure 5: One page of five of the β^- decay level scheme of ^{141}Ba into ^{141}La. Gamma-ray transitions that are outlined in red are transitions that do not belong to that energy level, and have either been relocated to transitions outlined in orange, or removed altogether. Energy levels that are outlined in red have been removed from current level scheme. Blue gamma-ray transitions and blue energy levels are new energy transitions.

Conclusion

The technological advancements made by Gammasphere at ANL allowed us to revise previously published data that is currently in the NNDC. Figure 5 is only one of five pages where updates and refined measurements were made for these gamma-ray transitions. Now that all the gamma-ray's are measured and intensities are calculated, future works will include applying the summation method to calculate the antineutrino spectrum seen in the works done by Alejandro Sonzogni et al.[1].

Literature

1. Sonzogni, A. A., Johnson, T. D., & Mccutchan, E. A. (2015). Nuclear structure insights into reactor antineutrino spectra. *Physical Review C, 91*(1). doi:10.1103/physrevc.91.011301
2. Scott H. Faller, et al. (1986). Decay of 83-min ^{139}Ba to levels of ^{139}La and the decay of 18-min ^{141}Ba to the levels of ^{141}La. *Physical Review C, 34(2).* https://doi.org/10.1103/PhysRevC.34.654

Acknowledgement

- I would like to express my very great appreciation to my mentor Libby, for all the information, guidance and support she provided throughout this project.
- I wish to acknowledge the office of educational program team (OEP), and my OEP team leader Karl, for providing us help and resources to be successful interns this Fall.
- This project was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

Rufino, Javier