Member of the US Nuclear Data Program

Novel Approach for Improving Nuclear Data for Antineutrino Spectra Predictions

FOA-LAB17-1763

Nuclear Physics  NA-22

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Introduction

compelling physics
- physics beyond the Standard Model
- astrophysics - supernovae core collapse & big bang nucleosynthesis
- neutrinoless double beta decay
- reactor anomaly & ν oscillations

applications
- detection of fissile materials from peaceful & military program
- remote safeguards and monitoring of operation status and power levels of reactors
- remote fission inventories in operating reactors

The New York Times
How to Spot a Nuclear Bomb Program? Look for Ghostly Particles
By Kenneth Chang
March 27, 2018
Nuclear Data Needs

INDC International Nuclear Data Committee

~30 priority I and II nuclides

How to improve the needed ND?

- unique capabilities of CARIBU@ANL (DOE/SC/NP National User Facility) to produce high-purity beams of essentially all fission products
- state-of-the-art detector equipment - Gammasphere
Gammasphere decay station

Advantages

- discrete & calorimetry $\gamma$-ray spectroscopy techniques within a single device
- high granularity & resolving power ($\Delta\varepsilon_{\gamma}=2$ keV, $P/T\sim60\%$ and $\varepsilon_{\gamma}\sim85\%$) - ability to resolve week $\gamma$-ray cascades ($10^{-5}-10^{-6}\%$)
- complete decay schemes - angular correlations for transition multipolarities & $J\pi$ assignments - end game in nuclear spectroscopy

HEART - HExagonal ARray for Triggering
- 6 EJ-204 plastic scint. & 12 SiPM
- $\varepsilon_{\beta}\sim75\%$ from $\beta-\gamma$ singles & coin.
- powerful $\gamma-\gamma-\beta-t$ coincidence device
Current status

• Completed two experimental campaigns:
  ✓ **December 2018** – aimed at transitional (weakly-deformed) $^{144}\text{La}$, $^{146}\text{g,mLa}$, $^{146}\text{Ba}$, $^{146}\text{Ba}$, $^{146}\text{Ce}$ nuclei
  ✓ **December 2019** – aimed at well-deformed $^{102}\text{g,mNb}$, $^{104}\text{g,mNb}$, $^{102}\text{Zr}$, $^{104}\text{Zr}$, $^{102}\text{Mo}$, $^{104}\text{Mo}$ nuclei
• Additional nuclear data were obtained by implementing the Canadian Penning Trap (CPT) & X array (5 Ge CLOVER detectors)

• A new campaign was approved by the ATLAS Program Advisory Committee - delayed to later this year due to COVID-19

$^{144}\text{La}$

(3$^-$) 0.0

40.8 (4) s

$^{144}\text{La}$

$T_{1/2}=44.0 (7)$ s

202 levels & 249 gamma rays

sum gates on 398, 541, 585 and 845-keV

10% difference - purity of the source in previous experiments

$^{144}\text{Ba}(11.7 \text{ s}) \rightarrow ^{144}\text{La}(44 \text{ s}) \rightarrow ^{144}\text{Ce}(285 \text{ d})$
Deformed nuclei & isomers

\[ ^{102}\text{Nb} \]

\[ \begin{array}{c|c}
1^+ & 94 \\
4^+ & 0 \\
\hline
& 1.3 (2) s \\
& 4.3 (4) s \\
\end{array} \]

spin-traps isomers resulting from the residual \( \pi-\nu \) interactions

- very complex decay schemes with overlapping decay paths between the ground state and isomer
- unambiguously resolved the isomer from the ground state
- for the first time a comprehensive decay schemes for the ground state and the isomer were established
Recent publications

- Data on $^{144}$La are being prepared for publication in PHYSICAL REVIEW C.
Conclusions & Outlook

• **Gammasphere** was converted into a powerful spectrometer for beta-decay studies of nuclei in the fission product region - state-of-the-art decay spectroscopy with **CARIBU** beams

✓ **compelling physics** - structure of neutron-rich nuclei in the FP region - great discovery potential & detailed spectroscopy studies (resolving isomer decays)

✓ **valuable data for applications** - antineutrino spectra, fission product yields (presentations by K. Kolos & G. Savard), decay heat, safeguards and others

• first results on $^{144}$La & $^{146,146m}$La ($^{144,146}$Ba & $^{146}$Ce) & deformed $^{102,102m,104,104m}$Nb ($^{102,104}$Zr & $^{102,104}$Mo) – resolved differences between previous studies & existing ND evaluations

• targeted experiments will continue during FY21-FY22 for other nuclei on the IAEA priority list
Collaborators

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