Ac-227 as a Calibration Source in PROSPECT

Danielle Berish
Temple University

on behalf of the PROSPECT collaboration

October 26, 2017
Introduction

PROSPECT - The Precision Reactor Oscillation and Spectrum Experiment

• Probe short baseline oscillations of antineutrinos in search of an eV-scale sterile neutrino

• Make a precise measurement of the U-235 spectrum from the High Flux Isotope Reactor at Oak Ridge National Lab

For greatest sensitivity to oscillation signature, must verify that segment-to-segment volume variation is understood to better than 1%
Measuring the Relative Volumes of 154 Cells

Want to

• Dissolve a source in the Li-6 loaded liquid scintillator (LiLS)
• Measure the rate of the source in each cell over the lifetime of the detector
• Using measured rates, define the relative cell-to-cell volume to 1% or better over a year

Need a source that

• Will be uniformly distributed - no adsorption or sinking
• Not degrade the scintillator
• Will not introduce significant background to our IBD (inverse beta decay) signal
Why Ac-227?

- $\alpha$, $\alpha$ coincidence in the decay chain: $^{219}\text{Rn} \rightarrow ^{215}\text{Po} \rightarrow ^{211}\text{Pb}$
- Half-life of Po-215 is small - 1.78 ms -> low accidental rate
- Decay of Po-215 is mono-energetic with quenched energy, ~0.85 MeVee, distinct from neutron capture peak, 0.5 - 0.6 MeVee
- Alpha mean free path is a few microns, creating a highly localized signal contained in a single cell

Therefore we can

- Use a low activity - 1.8 Bq in AD
- Use alpha coincidence (RnPo’s) to calculate the rate per cell

Note: not full U-235 decay chain

Fig. 2.4 Alpha spectrum of $^{227}\text{Ac}$ in equilibrium with its decay products (Kirby, 1970).
Testing for Adsorption

2/27/17: Dispensed Ac-227 into 12 mL vials of LiLS at BNL at ~94 Bq per vial

S2 - Reference
S3 - UVT acrylic
S4 - FEP (fluorinated ethylene propylene)
S5 - PLA (polylactide)
S6 - PEEK nut (polyether ether ketone)
S7 - RG188 cable
S8 - Viton o-ring

Dark Box

~27 cm
~42 cm

2” PMT
12 mL vial
Results of Tests for Adsorption

Material - Reference Rate

No significant signs of adsorption

Shift in energy creating threshold effects - losing some alphas. At present not believed to be adsorption.
Prototype Test

2 cell prototype detector at Yale University
Loaded the Li-6 scintillator with Ac-227

Cuts on:
- Energy
- PSD
- Position
- Time

Prompt
Delay

Rn
Po
Prototype Test

- Useful for energy and position calibration
- See no degradation of the LiLS from Ac-227 spiking
- See no significant increase in background near neutron capture signal
- Initial calculations for AD estimate background from (alpha, n) to be < 7.5/day compared to 900/day IBD events

Preliminary
Summary

• Placing Ac-227 in the PROSPECT detector will allow us to measure the relative cell-to-cell volume to 1% or better
• Can use Ac-227 to calibrate energy and position
• See no significant signs of adsorption
• Have mitigated risks to the liquid scintillator
• Proof of concept through adsorption and prototype tests
• Use of Ac-227 in AD still being evaluated

Placing Ac-227 in the PROSPECT AD is a low risk way to measure relative volume variation throughout the detector
Backup
U-235 Decay Chain
Materials Tested for Adsorption

S2 - Reference
S3 - UVT acrylic
S4 - FEP
S5 - PLA
S6 - PEEK nut
cable
S7 - RG188
cable
S8 - Viton o-ring
Adsorption Testing - Calculating Rate

- **Alpha Rate**
  - Fit PSD distribution with four gaussians

  \[ f(x) = \left\{ C_1 e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + C_2 e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \right\} \]

  \[ \text{Number of alphas} = N \]

  \[ \text{Alpha rate} = \frac{N}{\text{livetime}\times5} \]

- **Coincidence Rate**
  - Find \( dt \) between prompt-delay and prompt-fake delay events
  - Subtract and fit with exponential \( N(t) = Ne^{t/\tau} \)

  \[ \text{Coincidence rate} = \frac{N}{\text{livetime}\times\text{efficiency}} \]

  from energy & PSD cuts
Adsorption Tests - Energy Shift

Reference

Acrylic

PEEK

Viton
Ac-227 in P50X

- **May 26, 2017** - spiked LiLS prepared for P50X at BNL
  - Concentration: $1.77 \pm 0.09$ mBq/g
  - Origin vial, LiLS#9, left at BNL for observation
    - Measured activity: $3.395 \pm 0.010$ Bq
- **June 20, 2017** - spiked LiLS shipped to Yale
- **July 21, 2017** - spiked LiLS added to barrel of LiLS and P50X filled
  - Expected activity per cell: $90.66 \pm 4.48$ mBq

- See [docdb-1897](docdb-1897) for David’s calculations
Ac-227 in P50X - Coincidence $\Delta t$

$$f(t) = Ne^{-t/T} \frac{binwidth}{T}$$

$$rate = \frac{N}{livetime*efficiency}$$

$T = 2.57 \text{ ms}$, lifetime of Po-215

Coincident $\Delta t$ - Cell 0

Coincident $\Delta t$ - Cell 1

Series 030
339 hours
Efficiencies: PSD cut on prompt and delay, energy cut on delay, and position cut.