Background Characterization at HFIR for PROSPECT

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Outline

• Motivation for PROSPECT
• Details of the PROSPECT experiment at HFIR
• Background radiation sources at HFIR
• Study of variations in background radiation fields
• Other environmental factors explored
• Summary and future work
Reactor Anti-neutrino Anomalies – A Motivation for PROSPECT

- ~6% absolute flux deficit from predicted values
- Excess of events in 4-6 MeV region
- Need to characterize isolated $^{235}$U fission spectrum
- Local efforts eg MTAS are being made to understand these anomalies

See CN.01: “Reactor Antineutrinos and Nuclear Physics” by Akif Baha Balantekin for more information.
PROSPECT – The Precision Oscillation and Spectrum Experiment

- A short baseline neutrino oscillation experiment 7-12 m from HFIR reactor core
- Detector is a highly segmented array filled with $^6$Li-doped liquid scintillator
- Uses the $\bar{\nu}_e(p,n)e^+$ signature to detect antineutrinos
- Each cell has two PMTs, enabling event reconstruction along the cells
- Experiment aims:
  - Define the world’s most precise $^{235}$U antineutrino energy spectrum
  - Resolve anomalous neutrino flux
  - Provide evidence about the existence of sterile neutrinos

See CN.02: “Towards a Precise Measurement of the $^{235}$U Antineutrino Spectrum with PROSPECT” by Karsten Heeger for more information
PROSPECT at the High Flux Isotope Reactor (HFIR)

- Compact, highly enriched (93% $^{235}$U core) research reactor
- Opportunity to isolate neutrino spectrum to $^{235}$U fission fragments
- Duty factor of 46% with ~3 week on/off cycles
- Large flux of anti-neutrinos with detector <10m from source

- Active facility, hence environmental factors that to be considered:
  - Background radiation
  - Temperature variations
  - Magnetic fields
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Background Radiation Sources at HFIR

- Sources of background radiation
  - Cosmic induced backgrounds
  - Neutron activation experiments
  - Radioactive building structure
  - Neutron beamlines
  - Reactor core

- Variations in the temporal and spatial radiation fields were studied to provide information for:
  - Detector simulations
  - Design of shielding package

See LA.01: “Short-baseline reactor anti-neutrino results from PROSPECT” by Michael Mendenhall for more information
DANG – Detector Array to measure Neutrons and Gamma-rays

- Detectors, electronics and DAQ mounted on mobile structure
- Carefully scan volume that PROSPECT detector occupies
- Detects range of radiation:
  - Neutrons – Thermal, Epithermal and Fast energy scales
  - Gamma-rays – 0.01-10 MeV
Spatial Variation Studies – NaI 1-3 MeV Singles Rates $z=33”$

- Mapped singles rates to PROSPECT detector locations
- Significant rates during reactor on, consistent through volume
- Rates reduced by order of magnitude during reactor off
- Highlights hotspot in upper left corner

Note, $z =$ vertical distance from floor
Spatial Variation Studies – NaI 1-3 MeV Singles Rates z=33”

Reactor on

\[ \text{Reactor on} \]

\[ { }^{41}\text{Ar} \quad \text{(from MIF)} \]

\[ \text{e}^+/\text{e}^- \quad \text{annihilation} \]

Reactor off

\[ \text{Reactor off} \]

\[ { }^{60}\text{Co} \]

\[ { }^{208}\text{TI} \]

Note, \( z \) = vertical distance from floor
Temporal Variation Studies – NaI Singles Rates

- Events seen in NaI detectors correspond to HFIR operations:
  - 1. Reactor powers off
  - 2. Outer and inner fuel core removed
  - 3. Venting of reactor room

- DANG also sensitive to neutron beamline experiments and operations
Additional Environmental Factors Considered: Temperature

- Temperature fluctuations of a few degrees seen inside PROSPECT detector
- EJ-309 is the commercial benchmark to PROSPECT’s liquid scintillator
- Study to measure how temperature fluctuations change EJ-309 and PROSPECT liquid scintillator properties:
  - Light yield
  - PSD
  - Viscosity
Additional Environmental Factors Considered: Magnetic Fields

- Neutron scattering experiments use high magnetic field environments
- Magnetic fields around the PROSPECT detector fluctuate as a result
- Magnetometers have been incorporated into slow controls to monitor magnetic field fluctuations
Conclusions

• PROSPECT detector successfully commissioned and has released their first antineutrino energy spectrum

• DANG completed background radiation studies to support PROSPECT measurements

• Very little spatial variation over PROSPECT fiducial volume (rates within a factor of ~3)

• Temporal studies show DANG is sensitive to both reactor operations and neutron beamline experiments

• Careful monitoring confirms that environmental factors have negligible impact on PROSPECT data

• Further study into temperature dependence of EJ 309 and PROSPECT’s $^6$Li-doped scintillator to be completed
Thank you to all collaborators
MTAS – Modular Total Absorption Spectrometer

- 19 NaI(Tl) modules with total weight of 1 ton with auxiliary silicon detectors
- Shielded from background radiation by about 5 tons of mostly lead layers
- Measures nearly 100% of radiation emitted from the studied samples
- Provide detail to beta-decay properties of very neutron-rich nuclei (like fission products)
Temporal Variation Studies – NaI Singles Rates

- Correlated events seen
  - 1. Reactor turns on
  - 2. Exp. 556 scan 16 on HB-3
  - 3. HB-3 scan aborted

- DANG is sensitive to reactor operations and experiments
EJ-309 Data with Cs-137 source

- Start at 25°C, run for ~3 hrs at -10°C per hr
- Preliminary results suggest PSD increases with temperature decrease
EJ-309 Data with Cf-252 source

- Start at 30°C, run for ~3 hrs at -10°C per hr, ramp up to 20°C
- Preliminary results suggest PSD increases with temperature decrease