Nuclear Data Needs (and/or Wants) for Near-Surface $\overline{\nu}_{\mathrm{e}}$ Detectors

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Current-generation nearfield $\overline{\nu}_e$ detectors

- Reactor $\overline{\nu}_e$ detectors for **fundamental physics** (spectrum, short-baseline oscillation) measurements
- Near-reactor implies **near-surface** — no heavy shielding overburden
- Typically few-to-one signal-to-background ratios: **accuracy of background** determination critical to measurement
- Selectively sited at advantageous locations: research reactor user facilities with substantial scheduled reactor-off periods
- **Backgrounds directly measured** for subtraction during prolonged reactor-off periods (minimal dependence on modeling)
- Some small "wants" but no big "needs" for backgrounds-related nuclear data.

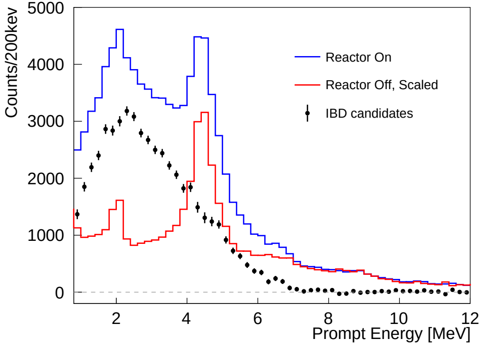
Next-generation projects: need nuclear data

- **Applications-focused**
- Non-invasive, construction-details-independent fission power and fuel composition monitoring
- Much less flexibility in choosing site and reactor operations conditions
- Commercial power reactors **minimize powered-off (background measurement) time**
- Heavily dependent on (nuclear-data-driven) **modeling to "transfer" backgrounds** from off-site characterizations to on-site conditions

"$\overline{\nu}_e$" detectors: mostly just neutron detectors

- Inverse Beta Decay (IBD) detectors look for $\overline{\nu}_e$+ p $\rightarrow$ n + e^+ coincidence between prompt positron ionization and delayed thermalized neutron capture
- **Neutron capture timescale** (tens of μs) is highly distinctive ($\gg$ ns-scale electromagnetic interactions, $\ll$ ms-scale accidentals)
- Nuclear physics relevant to IBD detectors is all about **neutron production and interactions**

$\overline{\nu}_e$ backgrounds



◁ A "typical" surface detector signal and background spectrum from PROSPECT (Phys. Rev. D 103, 032001)

- Background mechanisms generally **require** production/presence of **neutrons** (unique capture timescale)
- Typical background features:
  - Continuum spectrum from elastic and inelastic **fast neutron recoils**
  - 4.4 MeV ^{12}C resonance de-excitation gamma
  - Thermal neutron capture n+H 2.23 MeV gammas (from **multi-neutron showers**)

Data needs: ambient backgrounds model

- **Ambient fast neutrons** from cosmic ray showers are dominant background source in surface (minimal overburden)
- Fast neutron production in **GeV-to-TeV-scale hadronic interactions** and subsequent atmospheric propagation helps model fast neutron background source term
- **Muon-induced neutrons** in local hadronic showers are next-to-leading background source (increasingly dominant with

Data needs: backgrounds detector response

- **Precision neutron transport physics** from fast to thermalized (sensitive to molecular binding of nuclei) to capture in/near detector is critical for modeling background response
- **Quenching** (nonlinear response) of detection media to fast-neutron-induced recoils influences detector sensitivity to fast neutron backgrounds

How Nuclear Data gets used by experimentalists

- **Montecarlo** physics simulation packages are used to model complex whole-detector response
- While nuclear-engineering-oriented physicists are most likely familiar with `MCNP` (optimized for integral flux calculations), $\overline{\nu}_{\mathrm{e}}$-detection experimentalists are more likely to use `Geant4` (good for highly-granular individual particle interactions in complex detector geometries)

Making Nuclear Data useful to experimentalists

- Nuclear data needs to be **integrated into MC frameworks** to impact experimental efforts — perhaps more work to do here than new measurements
- **Curated tables** of best-presently-available data, possibly ahead of more "conservatively" updated individual database projects, need to be **continuously** pushed to MC frameworks
- Nuclear data **uncertainty propagation** integrated into MC simulations is a major **missing component** that would greatly increase the utility of simulations
  - Accurate (or at least pessimistic) uncertainties are as important as central values!

Summary

- $\overline{\nu}_{\mathrm{e}}$ detection physics is mostly **neutron production and interaction** physics
- Next-generation applications require accurate **background simulations**, based on
  - **fast neutron source term** from cosmic ray interactions and local muon spallation (**high energy nuclear/hadronic interactions**),
  - neutron **transport and thermalization** in/near detector,
  - recoil proton **quenching** response of detection medium
- Best-available evaluations need to be **incorporated into MC packages**, especially `Geant4`
- Integrated **uncertainty propagation** would be a major milestone
  - Only as useful as quality of reported uncertainties — prefer pessimism to underestimation