Radiogenic Neutron Background in Antineutrino Experiments

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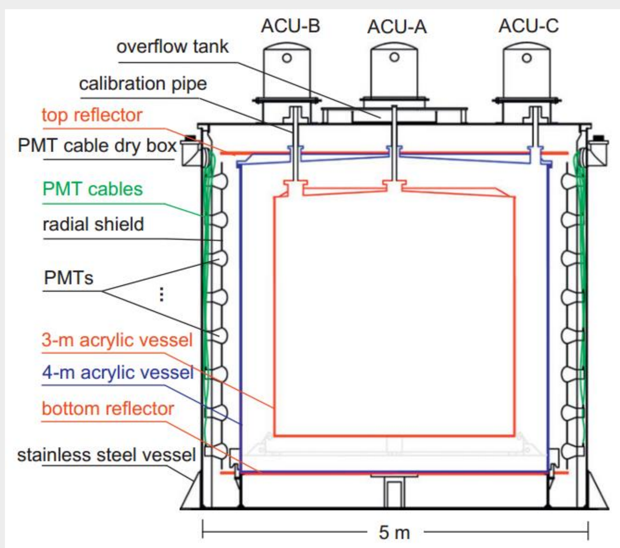
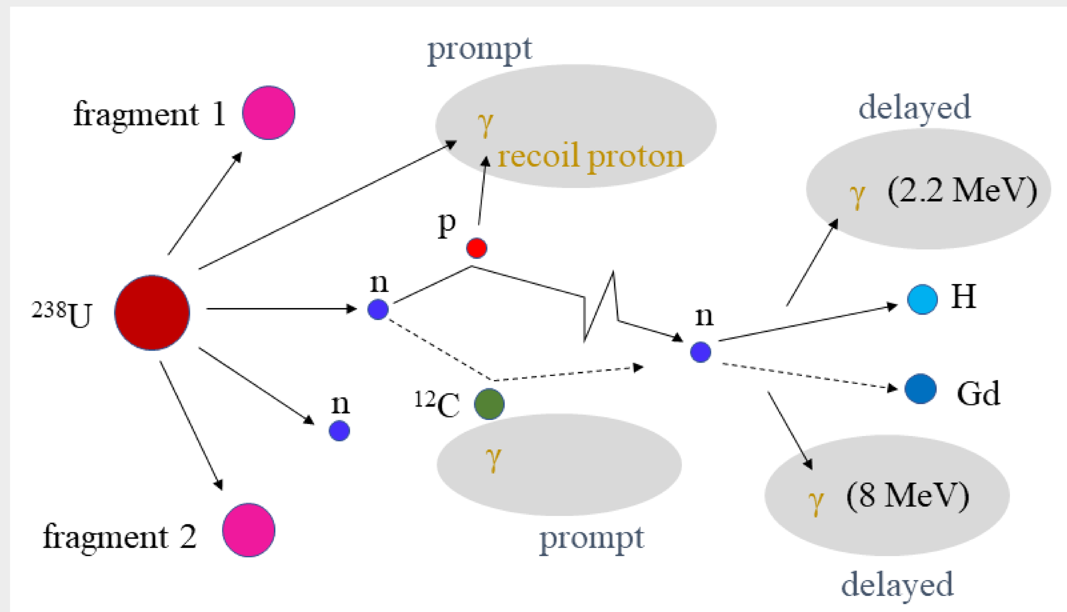
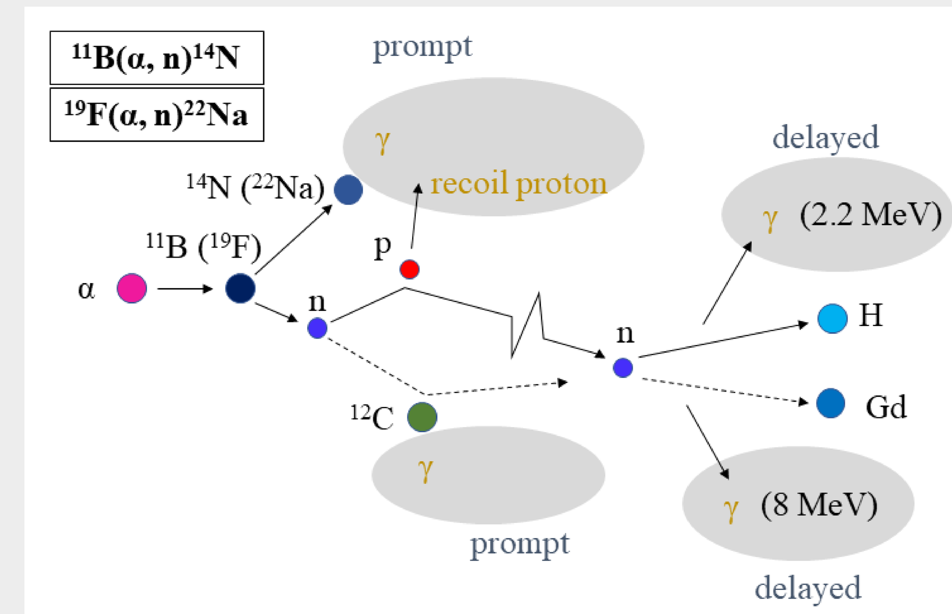
Take Daya Bay detector[1] as an example



- Fast neutrons could be generated in **peripheral detector materials** via spontaneous fissions and (α, n) reactions.
- May form correlated background in antineutrino experiments.

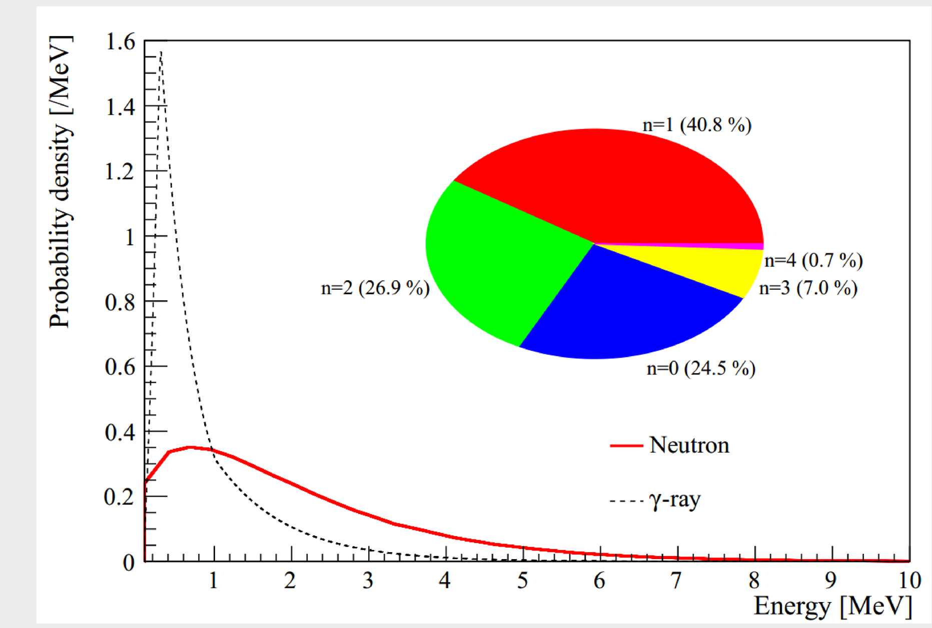
Background sources: Boron and Fluorine





- Borosilicate glass of PMTs is the main contributor for fission and ^{11}B(α,n)^{14}N neutrons.
- Materials rich in fluorine, like Teflon and Viton, are sources of ^{19}F(α,n)^{22}Na neutrons.

Spontaneous fission



- Gamma spectrum

$$N(E) = \begin{cases} 38.13(E-0.085)e^{1.648E} & E < 0.3 \text{ MeV} \\ 26.8e^{-2.30E} & 0.3 < E < 1.0 \text{ MeV} \\ 8.0e^{-1.10E} & 1.0 < E < 8.0 \text{ MeV} \end{cases}$$

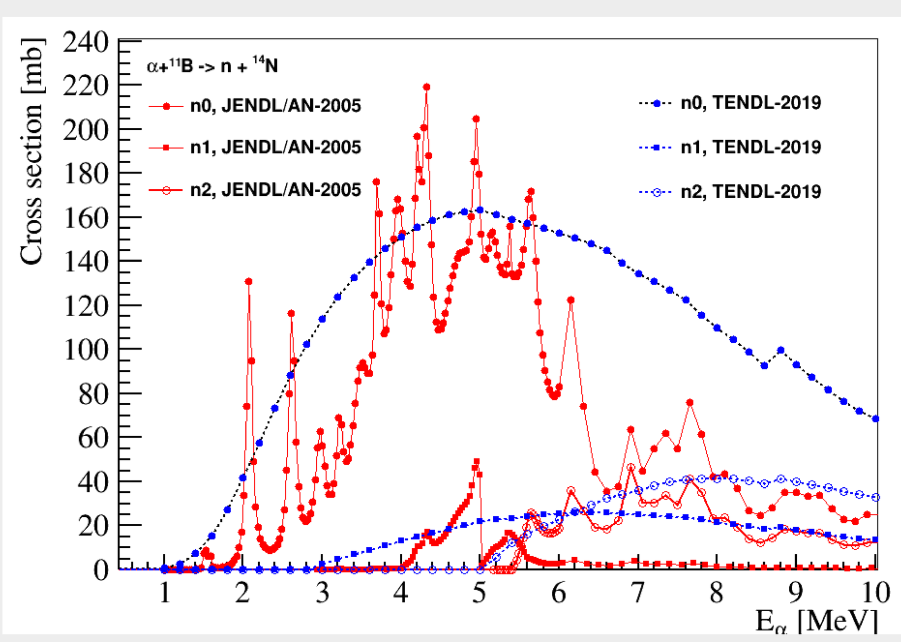
- Neutron spectrum

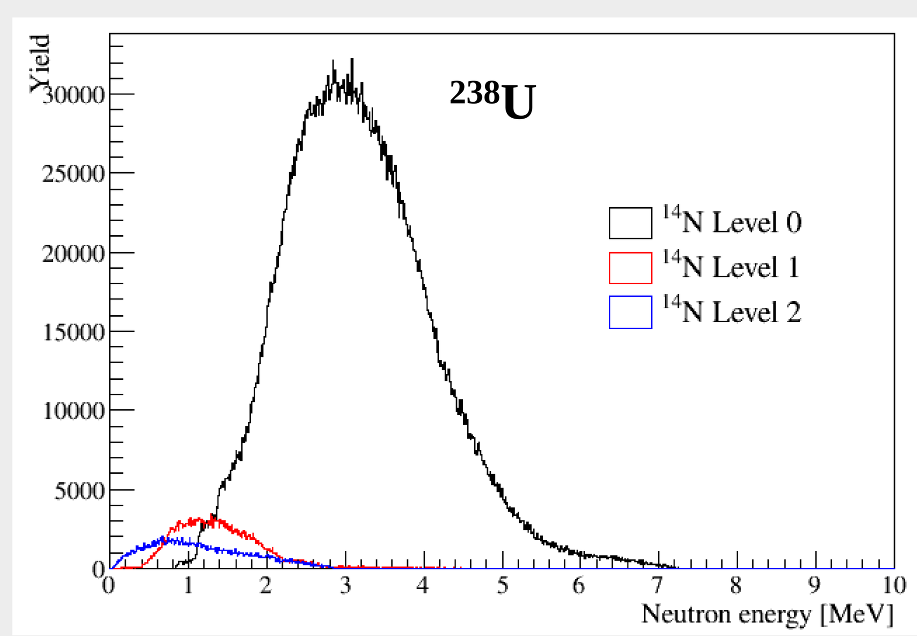
$$W(a,b,E') = Ce^{-aE'} sinh(\sqrt{bE'})$$

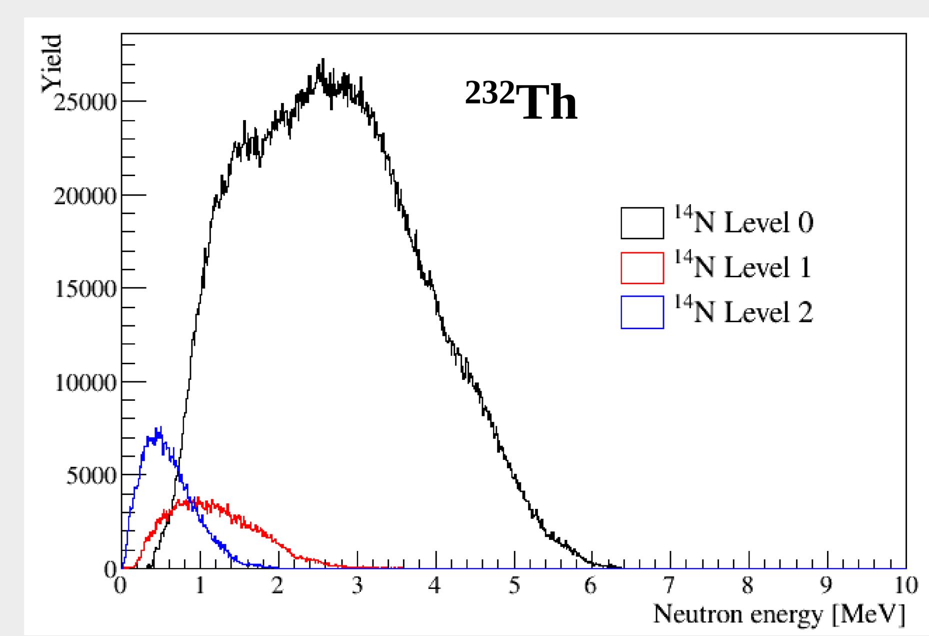
- Fission neutrons are mostly from spontaneous fission of ^{238}U.
- Open source software package, FREYA2.0.2 [2], is used as a generator.

(α, n) reaction

^{11}B(α, n)^{14}N



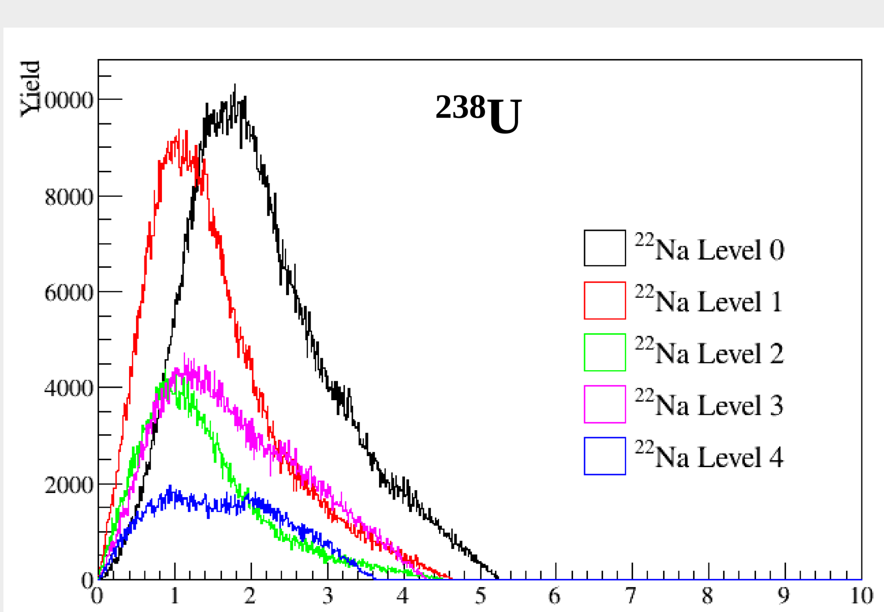


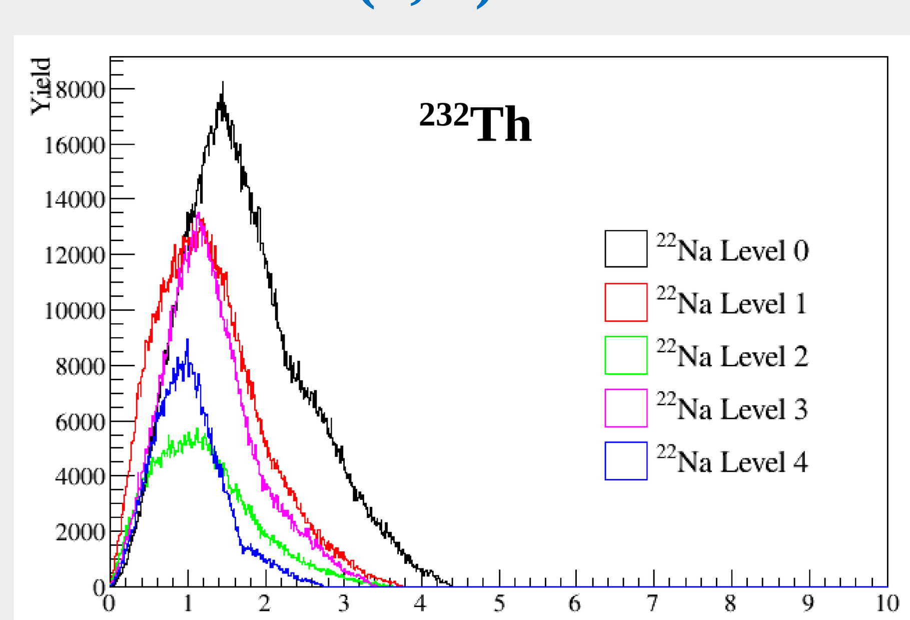


- Cross sections in JENDL[3] and TENDL[4] are used to calculate the neutron spectrum.
- Systematic uncertainty is estimated by the difference between these two datasets.
- ^{238}U and ^{232}Th decay chains are set to secular equilibrium.

^{14}N level	Branching ratio (%) ^{238}U	Branching ratio (%) ^{232}Th	γ-rays energy [MeV]
0	91.4	88.4	0
1	5.1	5.5	2.2
2	3.5	6.1	2.2 + 1.6

^{19}F(α, n)^{22}Na





- There are 14 excited states for ^{22}Na in ^{19}F(α,n)^{22}Na. De-excitation information obtained from NNDC [5].
- 8.87×10^{-5} neutron per decay of ^{238}U chain.
- Should be careful about Teflon, Viton, and other materials rich in fluorine.

^{22}Na level	Branching ratio (%) ^{238}U	Branching ratio (%) ^{232}Th	γ-rays energy [MeV]
0	26.885	22.946	0
1	20.101	15.892	0.58
2	8.280	6.494	0.58 + 0.074
3	12.044	12.706	0.89
4	5.323	6.501	1.53
5	4.567	5.301	1.28 + 0.58 + 0.074
6	6.208	7.407	1.37 + 0.58
7	5.847	7.296	1.4 + 0.58
8	3.739	4.744	1.55 + 0.58 + 0.074
9	2.859	3.899	2.57
10	1.667	2.313	1.01 + 1.37
11	1.317	1.790	1.1 + 1.37 + 0.58
12	0.894	1.641	1.59 + 1.37 + 0.58
13	0.171	0.647	2.81 + 0.89
14	0.098	0.424	3.28 + 0.58 + 0.074

Background in antineutrino experiments

- Take Daya Bay an example:
  - 192 Hamamatsu R-5912 8" PMTs, assuming 0.7 kg glass per PMT and 18% mass fraction of B_2O_3 in glass
  - 1.9 Bq/kg ^{238}U and 1.4 Bq/kg ^{232}Th, taken from [1]
  - 700 neutrons generated in PMT glass per day
- We have built a simple geometry for DYB detector using a standalone Geant 4.10.1 package:
  - No optical simulation, only energy deposit is simulated.
  - Use IBD section criteria similar to Daya Bay nH analysis
  - Time interval 1 to 400 μs, prompt (delayed) energy > 1.5 (1.9) MeV
- Our simulation suggests a background rate of 0.2 per day per AD in Daya Bay IBD sample using neutron capture on hydrogen.
  - Could affect the θ_{13} measurement since this is a common background for all ADs.
- Negligible in the IBD sample using neutron capture on gadolinium.
- For RENO and Double Chooz, the neutron background from PMT glass is negligible, because lower radioactivity contaminations in glass and larger distance between PMTs and LS.
- We also recommend the three experiments to examine how many materials rich in fluorine are used in the detector.

Reference

1. F. P. An et al. (Daya Bay Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A 811, 133 (2016)
2. UCRL-AR-228518-REV-1

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