Two years of iDREAM antineutrino data-taking at Kalinin NPP.

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30 of October 2023 г.
Historic reference

• First observation of the antineutrino has occurred 60 years ago;
• For the first time the antineutrino method for reactor monitoring has been suggested 40 years ago. The fuel isotopic evolution of the active zone leads to:
  • Changes in antineutrino flux;
  • Changes in antineutrino spectrum.
• Many proof-of-principle experiments were carried out. The first one was the ROVNO experiment more than 30 years ago.
• The quantitative studies are necessary within nuclear safeguards framework.
The iDREAMs aims

• Key goal:
  • Build the industrial neutrino detector for the applied researches based on the proven technologies with the simple design for replicating;
  • Implement complementary non-intrusive neutrino-based tool for the monitoring of the reactor state and the estimation of the accumulated fissile materials;
  
➢ Gain experience, studying new materials and solutions for future industrial neutrino detectors, and provide them to Russian power units, including floating power plants;

➢ Move towards precision measurements of the nuclear fuel burn-up.
Experimental cite

1 (orange) – cast iron (14 cm)
2 (yellow) – lead (5 cm)
3 (brown) – pure p/e (10 cm)
4 (blue) – borated p/e (16 cm)
5 – detector

3 GW$_{th}$ VVER type power reactor core (KNPP 3$^{rd}$ unit, Russia)

- Target (TG) – Gd-LS (1 g/l) in an inner SS tank, 1 m$^3$
- G-catcher (GC) – LS w/o Gd in an external SS tank, 1.8 m$^3$
- Buffer – pure LAB, 0.5 m$^3$
- 16 R5912 PMTs in the TG, 12 in the GC
- Two muon veto plates on top
Background in the laboratory

**Neutrons inside shielding**

**Neutrons in the hall**

Factor of 100 suppression of neutron flux achieved (measured by $^3$He counters)

**Muons & cosmogenic neutrons rate**

Structure of $\gamma$ background in the experimental hall understood (measured by NaI)
Detection methods and selection cuts

\[ \bar{\nu}_e + p \rightarrow e^+ + n \] – the inverse beta decay reaction

- \( E_{th} = 1.8 \text{ MeV} \) – threshold
- \( E_{prompt} = E_{\nu} - 0.78 \text{ MeV} \) – the positron energy dependence of the neutrino energy

Selection cuts:
- \( E_{prompt} \in [2; 10] \text{ MeV} \)
- \( E_{delayed} \in [5;10] \text{ MeV} \)
- \( \Delta T < 100 \mu s \)
- absence of any triggers 100 \( \mu s \) before prompt and after delayed events

Accidental selection cuts (the “off-time” method):
- \( \text{GAP} = 500 \mu s; \)
- \( \text{WINDOW} = 100 \mu s; \)
- 100 consecutive windows.
Selected events

The data of more than two months of R-OFF period between reactor campaigns has been obtained.

The distribution of $\Delta T$- time difference between prompt and delayed events
The prompt energy spectrum
The delayed energy spectrum
Response stability

The response stability has been monitored via regular calibration with radioactive sources 60 Co and 252 Cf.

The quenching function has been measured using various sources: 207Bi, 137Cs, 54Mn, 65Zn, 22Na и 60Co.

The gadolinium fraction has been calculated following way:

\[ R_{Gd-H} = \frac{N_{Gd}}{N_{Gd} + N_H} \]
Antineutrino signal

\[ N_{\text{det}} = \frac{\varepsilon}{4\pi L^2} \cdot N_p \cdot \frac{P_{\text{th}}}{E_f} \cdot \langle \sigma \rangle - \text{расчетная скорость счета} \]

\( \langle \sigma \rangle \) from V. Kopeikin et al, Phys. Rev. D 104 (2021) L071301

Blue curve – the reported power of the reactor by the NPP services
Empty points – the IBD rate in the iDREAM detector
Black line with the red band – the theoretical rate prediction

The positron spectrum in comparison with a MC prediction based on the reported fissile fractions from KNPP service.

<table>
<thead>
<tr>
<th>Period</th>
<th>R-ON</th>
<th>R-OFF</th>
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<tbody>
<tr>
<td>Number of live-days</td>
<td>248.6</td>
<td>39.5</td>
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The Rate analysis

\[ \frac{dN_{det}}{dt} = k \cdot \frac{P_{th}}{\langle E_f \rangle(t)} \cdot \langle \sigma \rangle, \]

where \( k = \frac{\epsilon N_p}{4\pi L_r^2} \) - detector-related parameters,
\( \epsilon \) – detection efficiency,
\( N_p \) - number of protons,
\( L_r \) - distance between the reactor and the detector.
The iDREAM experiment at Kalinin NPP is supported by the Russian Science Foundation (project No. 22-12-00219).