Development of the neutrino control method for nuclear reactors within the iDREAM project.

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NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

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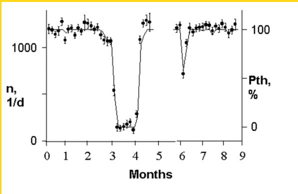
industrial Detector for Reactor Antineutrino Monitoring

RONS Detector



1970—L.Mikaelyan and A.Borovoi proposed a new method of the reactor diagnotics by the neutrino irraviation

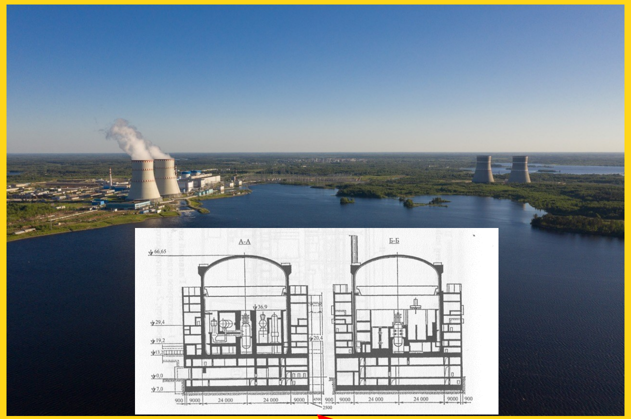
At the Neutrino-77 method was presented..

1985-1992— NPP ROVNO first on-site experiment and method approbation.

iDREAM project is aiming to develop an industrial detector, which can provide information about a reactor power and an isotope content of the active zone independently from the reactor services.

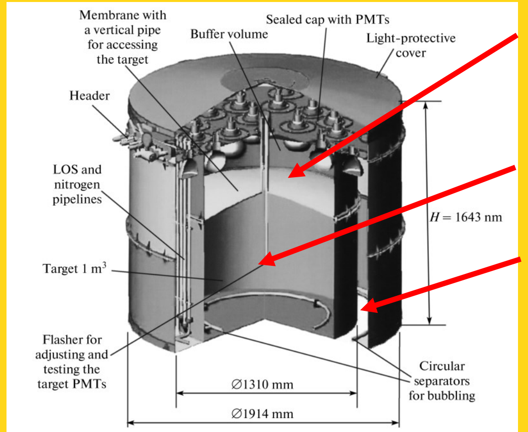
Unlike a research detector an industrial detector must meet strict requirements such as long-term stability and full independence.

Experimental site and detector design.



Kalinin NPP is located within 400 km from Moscow in a picturesque area near the city Udomlya. The detector site is located under the 3rd nuclear unit. Overall overburden is ≈ 20-25 m.w.e..

3rd nuclear unit began operating in 2004. It is PWR-1000.

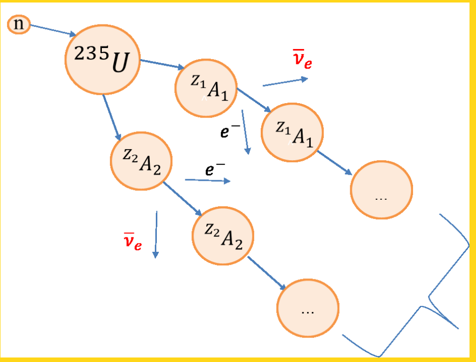


Buffer: ~0.5 m^3 Organic oil (LAB)

Gd-target: ~ 1 m^3 Gd-doped scintillator

Gamma-catcher: ~1.7 m^3 Gd-free scintillator

Monitoring method

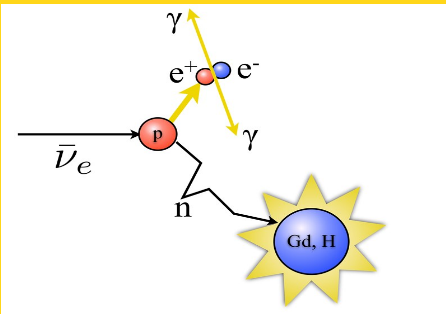


For the PWR-1000 with a thermal power P_{th}= 3000 MWt the total flux: Φ_ν~10^{21} ν/s

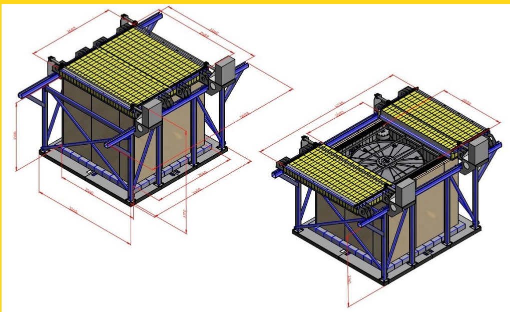
>99.8% ν_e from 4 main isotopes ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu.

~6 ν_e per one fission, thus number of fissions N ~ Φ.

Inverse Beta Decay



The active and passive shielding design



IBD reaction has special signature which helps to distinguish it from background events.

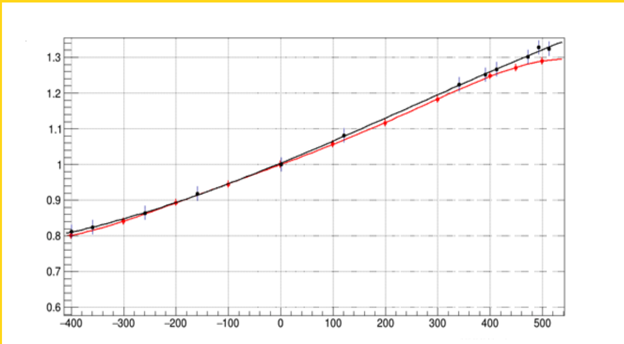
There are two signals: the prompt and the delayed.

Prompt: The positron simultaneously loses its energy and annihilates with electron giving two gammas with energy ~0.511 keV each.

Delayed: Due to the presence of the Gd in the Target the neutron live time in the Gd-LOS is reduced to ~30 μs. Firstly the neutron loses its energy on thermalisation. Afterwards it captures on Gd, which irradiates several gammas with total energy of ~8 MeV.

Background: Unfortunately , some BG events can mimic IBD , such as BG induced by cosmic muons, fast neutrons and also neutron and gamma irradiation from reactor. To conquer these BG iDREAM will be equipped with passive and active shielding systems.

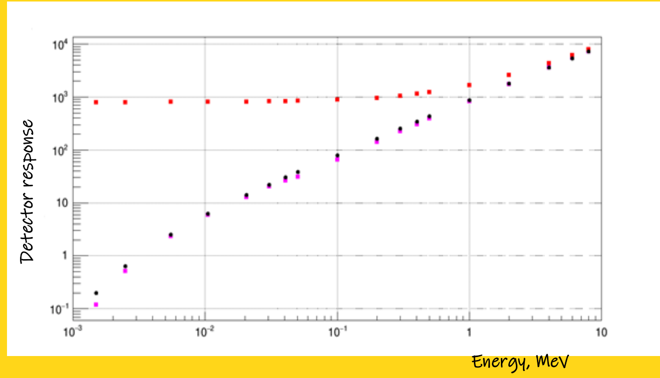
Monte-Carlo



Source placement,

The plot on the left: the calibration data (^{137}cs—red curve) has been used in order to test the robustness of the MC detector model (black curve). For culindrical part of the target (-400, +400 mm) along z-axis MC mode agrees with the calibration within 1%.

The plot on the right: the detector response for $E_{kin.}$ of positrons (red points), electrons (black points) and gammas (violet points).



Modeling detector response for the reactor spectra

$N = N_f \times N_p \times (4\pi L^2) \times T \times \int \sigma(E) \times \rho(E) \times dE$ — Number of events

$N_f = P_{th} / E_f$ - Number of fissions

N_p - Proton number

σ(E) - IBD cross-section

ρ(E)- - antineutrino spectrum

Fission fractions used for calculations

Isotope	^{235}U	^{239}Pu	^{238}U	^{241}Pu
α_i	0,591	0,287	0,068	0,054

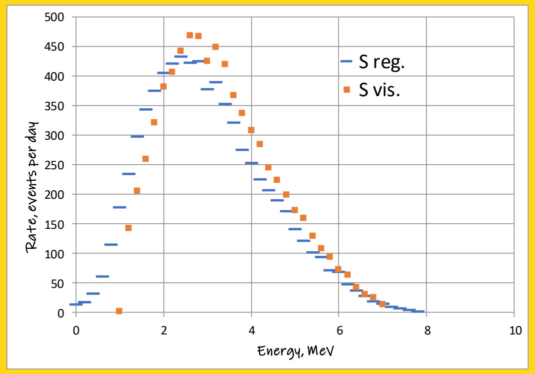
Model inputs:

- antineutrino spectrum based on the Huber-Muller model,
- detector baseline 19 m,.

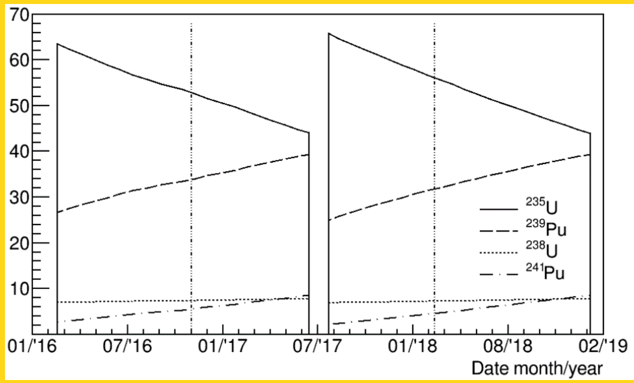
A toy model:

$N(t) = N(t=0) - dN/d\alpha_9 [\alpha_9(t) - \alpha_9(t=0)]$

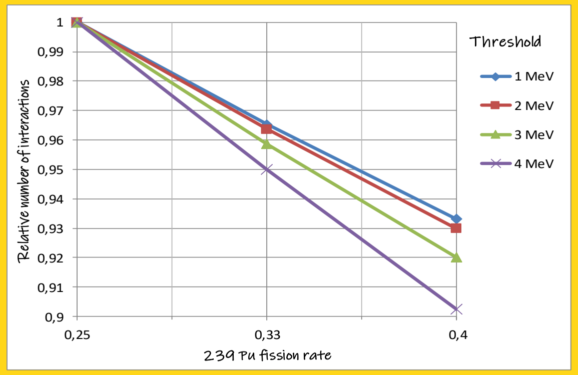
α_9—^{239}Pu fission rate



The prompt E spectrum ($S_{vis.}$) and the registered E spectrum ($S_{reg.}$)



The fission rate evolution during Kalinin NPP reactor campaign



The relative number of interaction in the detector target center for different ^{239} Pu fission rates