Skobeltsyn institute
НИИЯФ МГУ
Moscow State University

iDREAM: Industrial Detector of REactor Antineutrinos for Monitoring at Kalinin nuclear power plant

Andrei Konstantinov on behalf of the iDREAM collaboration

Conference NUCLEUS–2022

NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

Introduction.
iDREAM detector had been specifically intended as a commercial detector prototype for using at nuclear power plants (NPP) in order to demonstrate the feasibility of antineutrino detectors for remote reactor monitoring and safeguard purposes. The detector concept was to use a simple design and employ well-established technologies, therefore providing easy producing and high-maintainability of such a detector. iDREAM had been installed at Unit 3 of Kalinin NPP (Russia) in 2021, in a ground level hall, 20 m from the 3GW reactor core. The detector commissioning was completed and data collection has started in the antineutrino flux. Antineutrinos are detected with a 1 ton liquid scintillator via inverse beta decay (IBD) process on protons.

The goals.
The detector was made as an industrial prototype for monitoring:
- the thermal power of the reactor;
- the reactor shutdown/start-up (reactor on/off);
- the composition of the burning fuel in order to estimate the plutonium production for nonproliferation.

Antineutrino detection method.
The basic registration principle is based on the inverse beta-decay process: $p + \tilde{\nu}_e \rightarrow e^+ + n$
The reactor antineutrino interacts with a proton (the reaction threshold is 1.8 MeV), then a neutron and a positron appear. Positron losses its kinetic energy and annihilates with an electron, giving the prompt signal. Neutron is thermalized and captured on gadolinium (E ~ 8 MeV) or hydrogen (E = 2.22 MeV), forming the delayed signal.
Even though the IBD signature is very special, there are several types of background events, which should be subtracted. Two main types of background events are distinguished: Accidental coincidence, when two random triggers somehow meet the selection cuts. Both signals are usually due to gamma rays from natural radioactivity and cosmic muons. The main source of random background is natural radioactivity (the energy region of natural radioactivity extends up to about 5 MeV). It is determined by means of the off-time window method. Correlated background events. They can be divided into two categories: correlated events associated with the muons passed through or near the detector (for example, stopping muons or fast neutrons), and long-lived cosmogenic isotopes (9Li, 8He). It is determined on the base of the reactor off measurements.

Detector discription.
iDREAM detector has 1m^3 target and consists of 3 inner volumes(figure 1,2):
- the target(1.1 m3) contains Gd-loaded LAB-based liquid scintillator: LAB + PPO(2.7g/l) + bis-MSB(0.02g/l)+Gd(1g/l);
- the gamma-catcher(1.7 m^3): LAB + PPO + bis-MSB;
- the buffer volume(0.4 m^3): only LAB.
Also it has additional systems: - liquids filling and nitrogen purging systems, slow control system, DAQ system, calibration system. Detector target is based on Gd-loaded liquid scintillator - linear alkylbenzene(LAB). Gd-isotope improves the efficiency of neutron detection, thanks to its large thermal neutron capture cross-section. Registration of a delayed signal on gadolinium is used to detect a neutrino event and suppress the background. The PMTs are Hamamatsu R5912. In total, 28 PMTs are installed as shown in this detector: 16 PMTs in the inner volume and 12 PMTs in the outer volume.

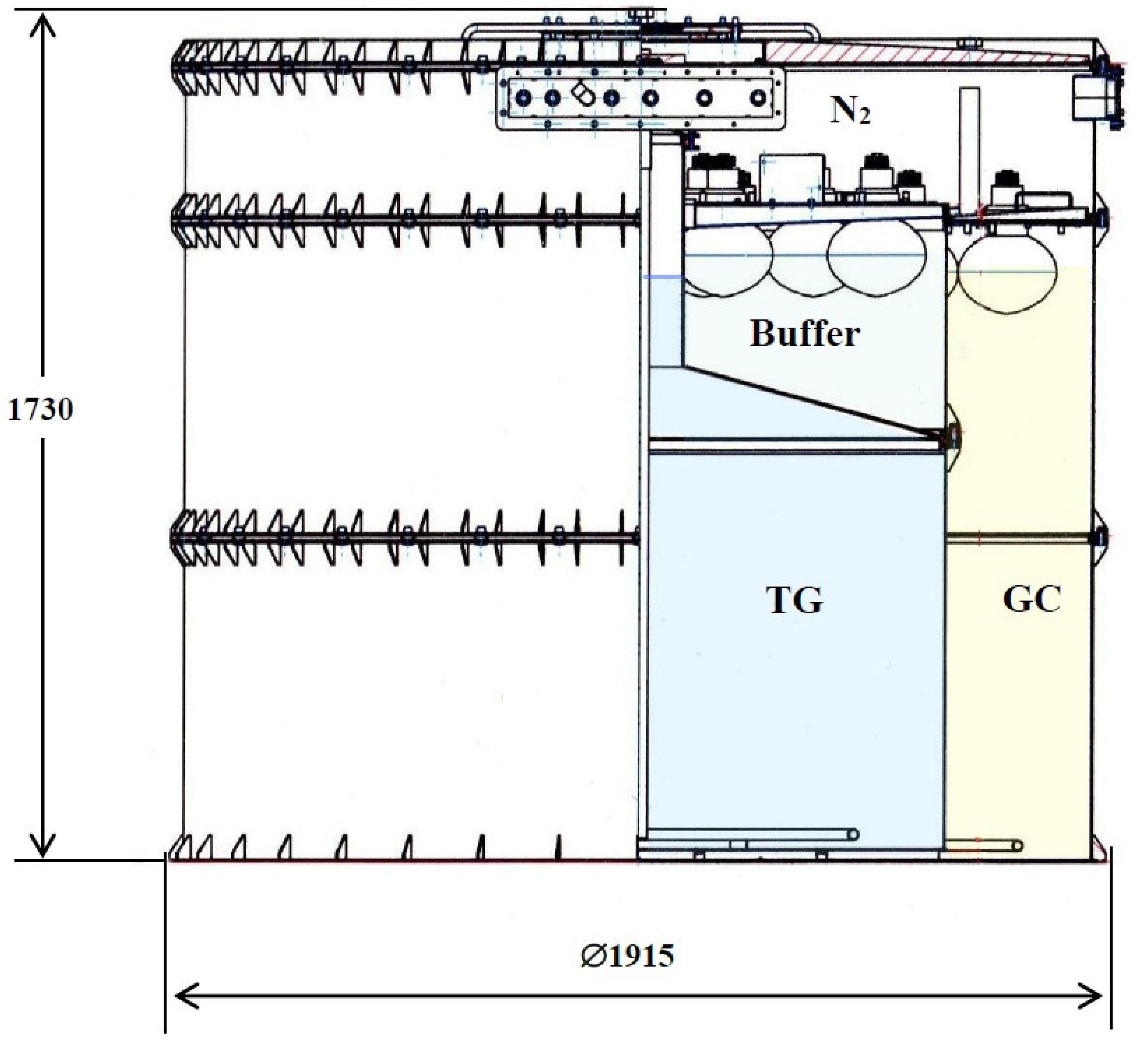

Figure 1. iDream design. Detector has 3 volumes – target, buffer, gamma-catcher.

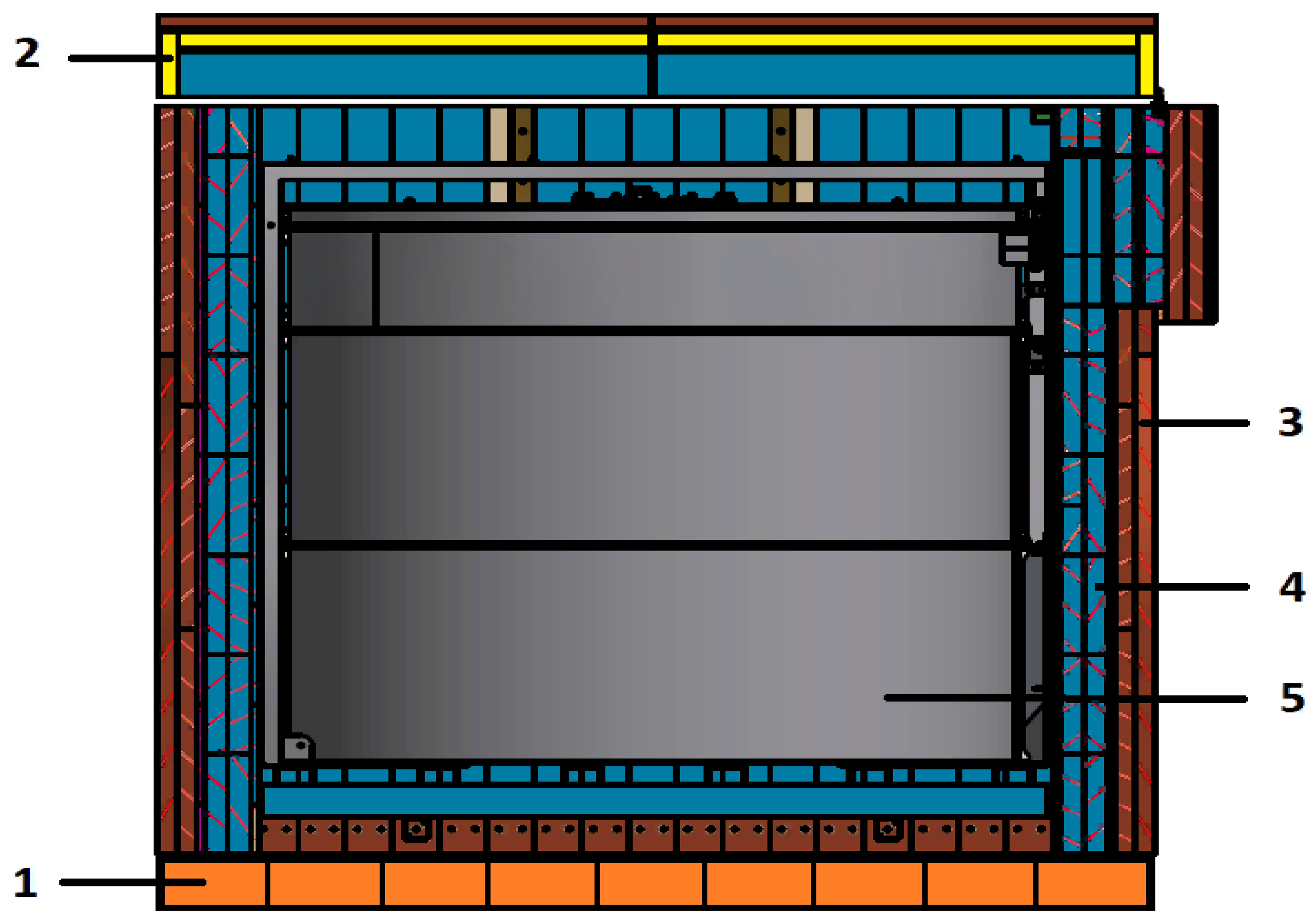

Figure 2. Detector shielding:1(orange)–cast iron,2(yellow)–lead, 3(brown)–pure polyethylene,4(blue)–borated polyethylene,5–detector.

iDREAM detector has muon veto and passive shielding. Active shielding consists of 2 scintillation plates made of organic plastic on the basis of polymethylmethacrylate with dimensions 1900x1200x33 mm and each of them has 6 PMT-85 (three on each side) and located on top of the detector. The passive shielding consists of:
- sidewall shield of the detector from left to right: 2 layers of "NEUTRONSTOP" C-type bricks, each 80 mm thick and two layers of pure polyethylene plates, each 50 mm thick, are installed;
- 2 shielding plates on top of the detector: lead (50 mm) + pure polyethylene (40 mm) + borated polyethylene (160 mm);
- cast-iron platform under the detector: cast-iron layer (140 mm) + pure polyethylene (80 mm) + borated polyethylene (100 mm).

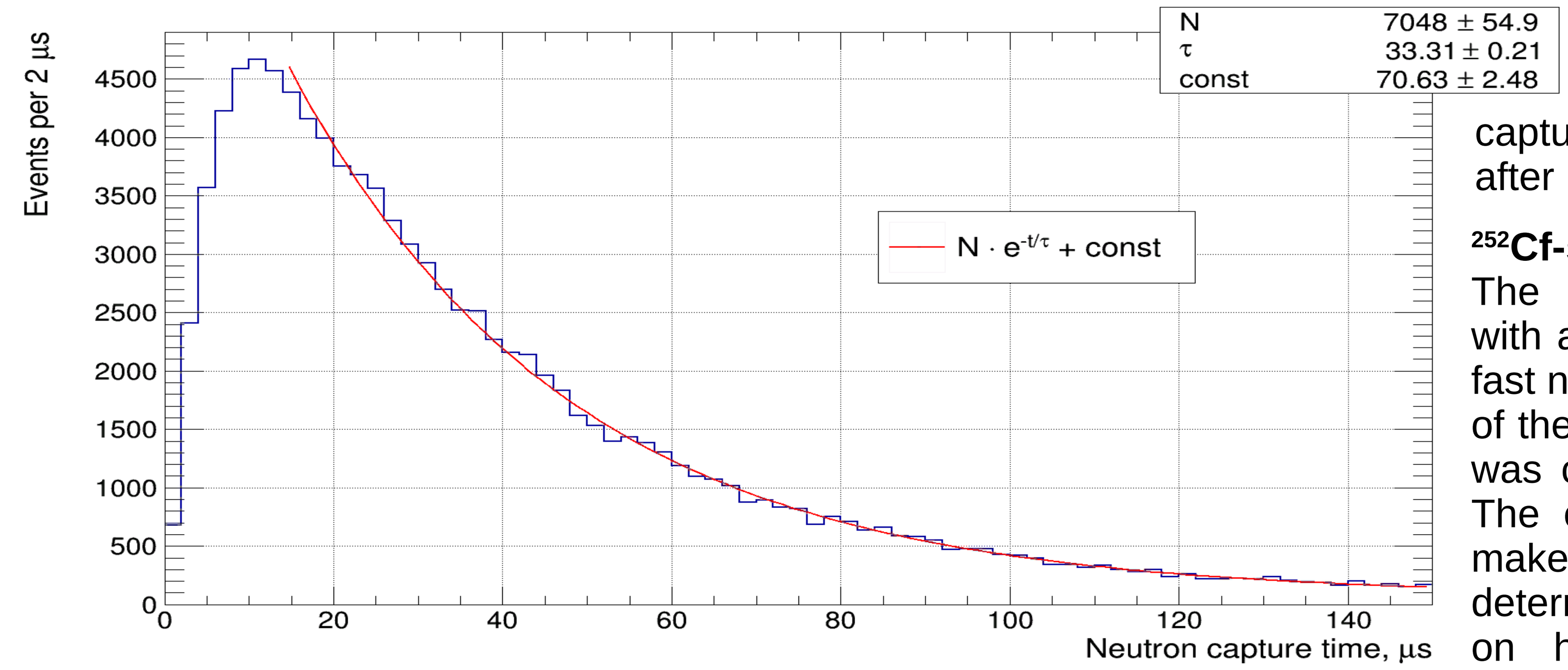

Figure 3. Distribution of neutron capture times in a window of 150 μs after registration of prompt γ-quants.

^{252}Cf-source callibration.
The detector is regularly calibrated with a ^{60}Co gamma source and a ^{252}Cf fast neutron source. The measurement of the neutron lifetime (τ) in the Gd-LS was carried out using a ^{252}Cf source. The calibration by a neutron source makes possible to additionally determine the ratio of neutron captures on hydrogen and gadolinium, the energy spectrum of absorbed neutrons, and the efficiency of the detector to neutrons. Figure 3 shows the distribution of the neutron capture times (source deployed in the detector center). The plot was fitted by $N \cdot \exp(-\tau/t)$ + const, and the τ is (33.3±0.2)μs, in concordance with the Gd concentration of 1 g/l. Figure 4 shows the charge spectrum of the neutron captures in Gd-LS.

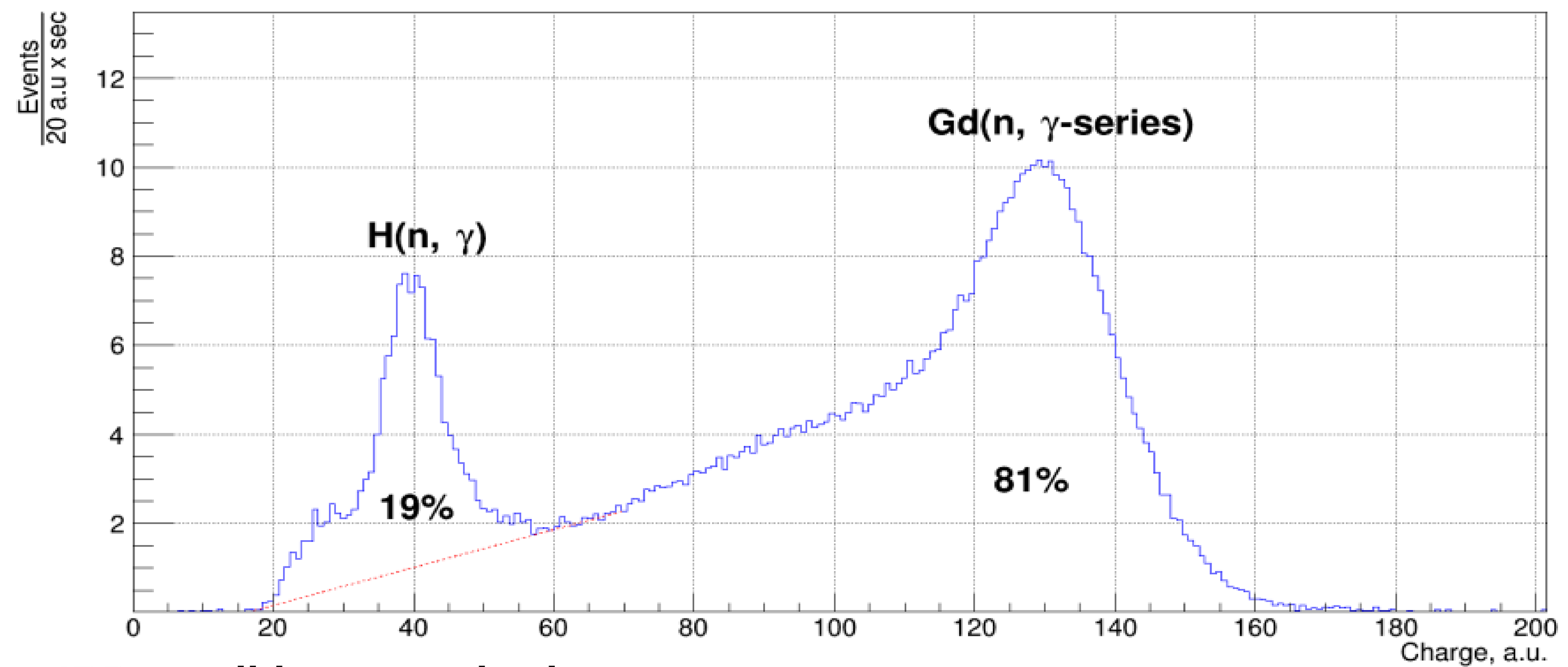

Figure 4. Charge spectrum of the neutron captures.

IBD candidates monitoring.
The data analysis is reduced to finding pairs of triggers correlated in time, corresponding to the detection of signals from a positron and a neutron, generated during the interaction of reactor antineutrinos with target protons. Such a pair of triggers will only be a candidate for the antineutrino interaction. It can also be due to a random superposition of background signals in the detector, as well as fast neutrons, stopped muons decay, etc. Such processes imitate the interaction of reactor antineutrinos and determine the background of the detector, which can be measured when the reactor is turned off. We provide the preliminary results of the antineutrino data taken during the R-ON period. So far we do not have statistically significant measurements with the reactor turned off. Figure 5 shows the iDREAM IBD count rate per day, for a chosen period of DAQ. Accidental coincidences subtracted. Candidate events selection was made using the following cuts:
- the energy of the prompt event (positron candidate) is within (3÷8) MeV;
- the energy of the delayed event (neutron candidate) is within (5÷10) MeV;
- the time between the prompt and the delayed events is within (2÷100) μs;
- there are not trigger event before the prompt signal during 100 μs and after delay signal also during 100 μs.

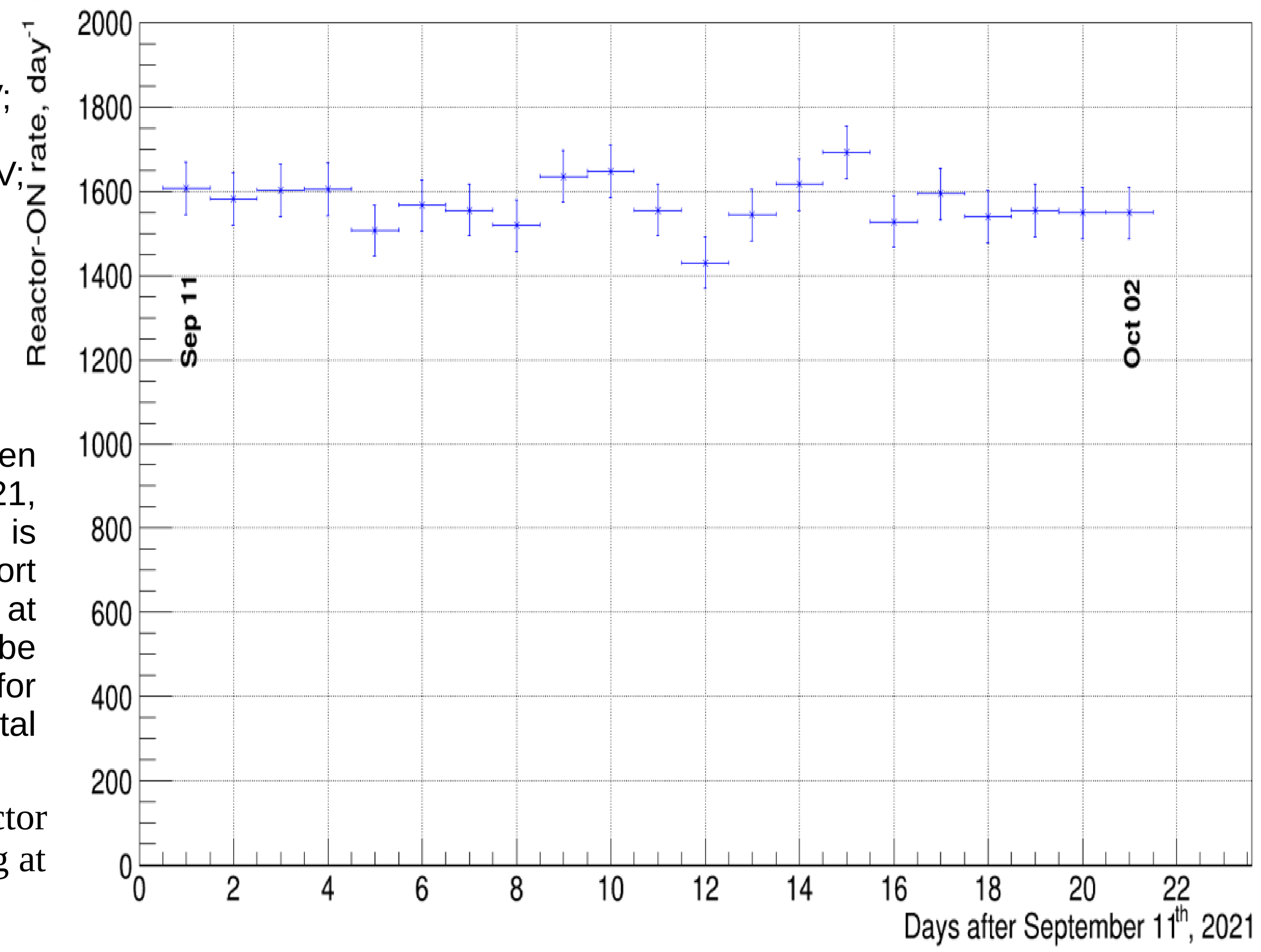

Figure 5. Rate of R-ON IBD candidates (accidental coincidences subtracted).

iDREAM status and prospects.
iDREAM detector has been commissioned at Kalinin NPP in 2021, antineutrino data taking is ongoing. It is currently the one of the few very short baseline neutrino experiments ongoing at a power plant. The detector should be able to provide useful data not only for applied studies, but also for fundamental physics.

Reference. iDREAM: Industrial Detector of REactor Antineutrinos for Monitoring at Kalinin nuclear power plant, https://arxiv.org/abs/2112.09372 (2021)

E-mail: konstantinov_av@nrcki.ru