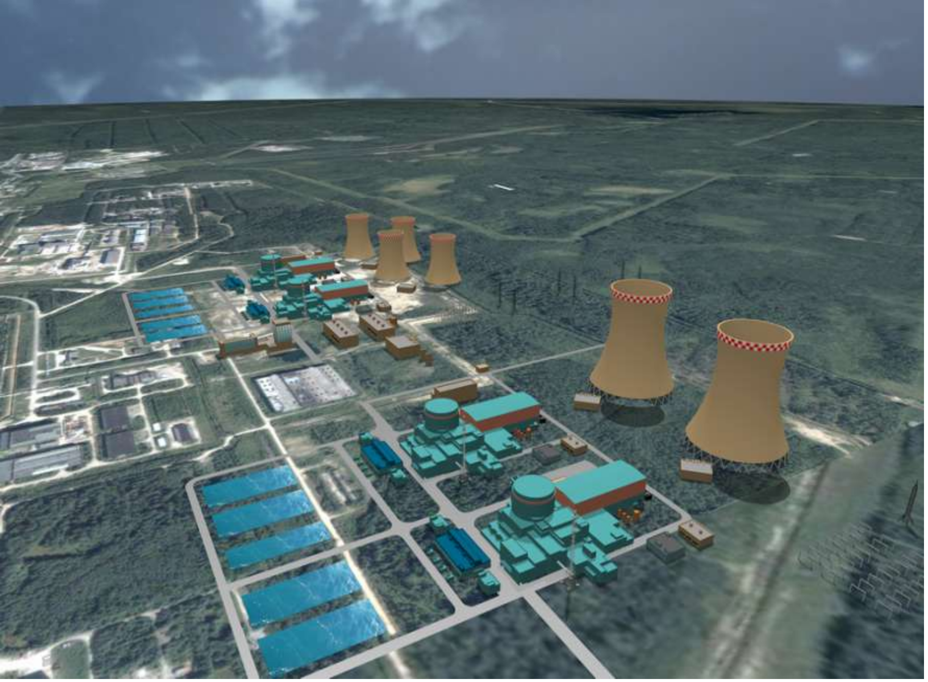


Antineutrino Detectors

(for BelNPP)

V. Gilewsky

on behalf of

Belarus Reactor AntiNeutrino Detector (BRAND)

(I.S. Satsounkevich, V.I.Kuvshinov, – JIPNR-Sosny NAS Belarus,

V. Dunin – JINR Dubna, M.Korjik, A.Lobko – INP BSU,

V.M. Redkov – Inst.of Physics, O.M. Boyarkin – Sakharov BSU)

Antineutrino detector – internal goals

- First international HEP project on our territory (not a part of other projects)
- We have some specific specialists
    - Theoretical schools
    - Electronics engineers
    - Detector designers
- Best place for education (students will work with real online data)
- On-line NPP monitoring (on the first NPP of new type)
- National project – in future

Goals of neutrino project – official

A. Additional (independent) NPP monitoring

- Search for neutrino flux variations [$N\nu$ (t)] and possible reasons of these changes
- Spectral measurements in real time [$N\nu(E\nu)$], (it is not only definition of real fuel composition - Pu-U – they are essential to define the time of reloading)
- We may organize the **reactor tomography** [we need 3 detectors or one movable - mobile]?

B. Place to educate nuclear physicist (students and…)

C. What kind of physics (ν-properties) can we study by neutrino detector? – i.e. pure scientific part

- Search for sterile neutrino
- New interactions ?

Detecting reaction – IBD (main) and (to check) some other reaction!

The most often ν detected in invers beta-decay(IBD):

$$\bar{\nu}_e + p \rightarrow e^+ + n \qquad \text{(threshold 1.8 MeV)}$$

neutrino interacts with (quasi) free protons from hydrogen-reach media (fiducial volume) = scintillator.

Photo-multipliers register an annihilation photon pair, and latter (10-100 μs) a signal of neutron capture (Gd-doped or ^{3}He)

– These two signals ensure good signal/noise ratio .

May be exists some more interesting reaction?

We have to measure two reaction simultaneously (SNO lessons)

Possible detecting reactions in SM

	σ_{tot} in 10^{-44} cm^2/fission	Reaction Threshold (MeV)
$\bar{\nu} + p \rightarrow n + e^+$	60	1.80
$\bar{\nu} + d \rightarrow n + n + e^+$ $\bar{\nu} + d \rightarrow n + p + \bar{\nu}$	1.2 1.9	4.0 2.3
$\bar{\nu} + e^- \rightarrow \bar{\nu} + e^-$	0.4 @ 1 MeV	~ 0.5 Signal/background ?
$\bar{\nu} + e^- \rightarrow \bar{u} + d$	40 @ 10 MeV	
	1.7 @ 1 MeV 168 @ 10 MeV	Low mass hadrons?

Reactor neutrino experiments

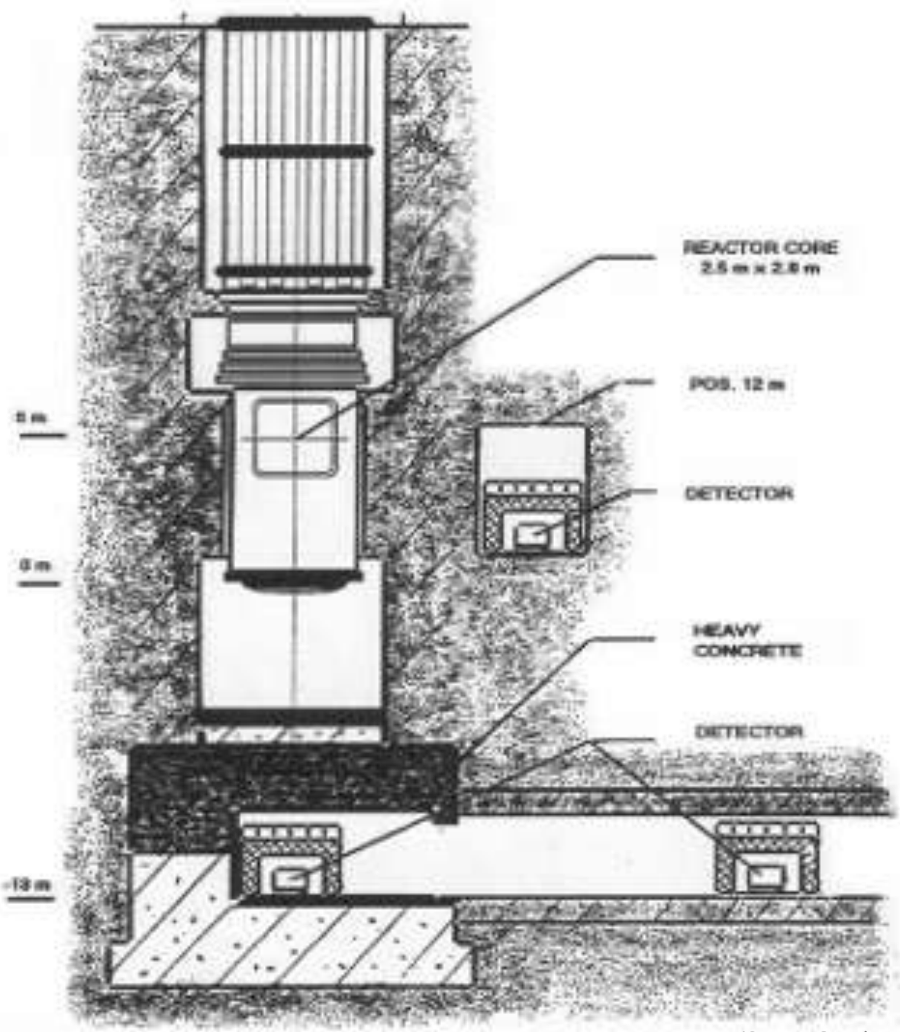
Reactor Large experiments(several Kt)

Abbr. Name	Full name	Type	Induced reaction	Detector	Threshold energy	Location	Operation
KamLAND	Kamioka Liquid Scintillator Antineutrino Detector	ν_e	$\bar{\nu}_e + p \to e^+ + n$, $\bar{\nu}_e + e^- \to \sim\nu_e + e^-$	Water and Gd-doped LAB (LOS)	1.8 MeV	Kamioka, Japan	2002–
Daya Bay	Daya Bay Reactor Neutrino Experiment	ν_e	$\bar{\nu}_e + p \to e^+ + n$	Gd-doped LAB (LOS)	1.8 MeV	Daya Bay, China	2011–
Double Chooz	Double Chooz Reactor Neutrino Experiment	ν_e	$\bar{\nu}_e + p \to e^+ + n$	Gd-doped LAB (LOS)	1.8 MeV	DChooz, France	2011–
RENO	Reactor Experiment for Neutrino Oscillation	ν_e	$\bar{\nu}_e + p \to e^+ + n$	Gd-doped LAB (LOS)	1.8 MeV	South Korea	2011–

Small Reactor experiments (about 1 t)

	Name	W (MW), fuel	H (mwe)	L (m)	Type	Days On-Off	Coun t/day	signa l/bkg
1	Nucifer	70		7	Gd-LOS	145-106	280	0.25
2	NEOS	3000, LEU	~8	24	Gd-LOS	180-30	2000	2.3
3	STEREO	58, 235U	~15	10	Gd-LOS			
4	Neutrino-4	90	~10	6-11	Gd-LOS			
5	iDREAM	3000, LEU			Gd-LOS			
6	DANSS	3000, LEU	~50	11	Gd+plastic		5000	
7	Vidarr	1600		60	Gd+plastic	210-5	0.2	UK-Lv
8	mTimeCub	20		5	B-PS			
9	NuLAT	20, 235U		4.7	6Li-plastic			
10	PROSPECT	85, 235U		~7-12	6Li-plastic	PSD-liquid		
11	SOLiD	72, 235U	~10	5.7	6LiZnS-plastic	5 cm cubes		
12	CHANDLER	72, 235U	~10	5.4	6LiZnS-plastic	6 cm cubes		

One of the first m^3 neutrino detector (RONS) worked 25 years ago at Rovno NPP - RONS (1986-1990)



Liquid scintillator (~1 m^3)
in special laboratory

Near detector – 25 m Lawrence Livermore National Lab at SanOnofre

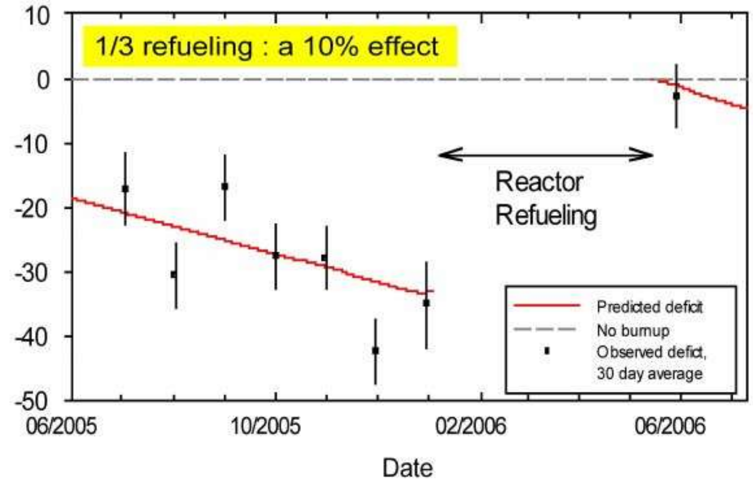
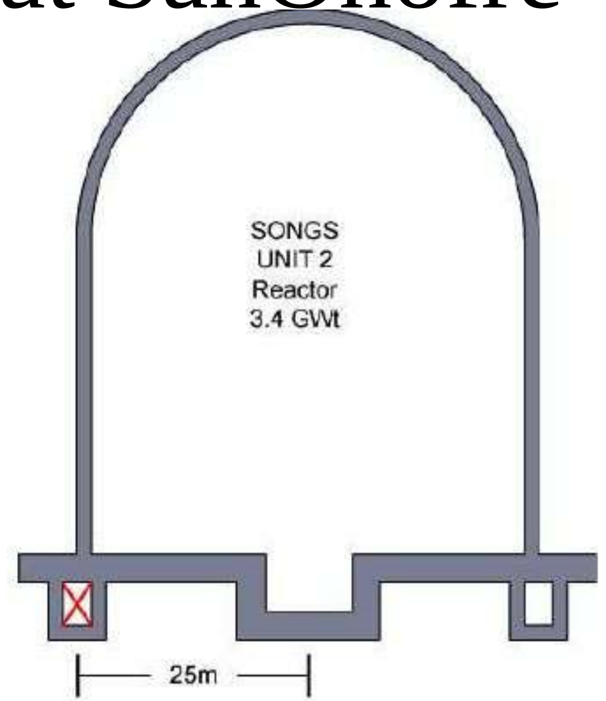


Figure 2. The impact of the refueling is clearly seen on the antineutrino record



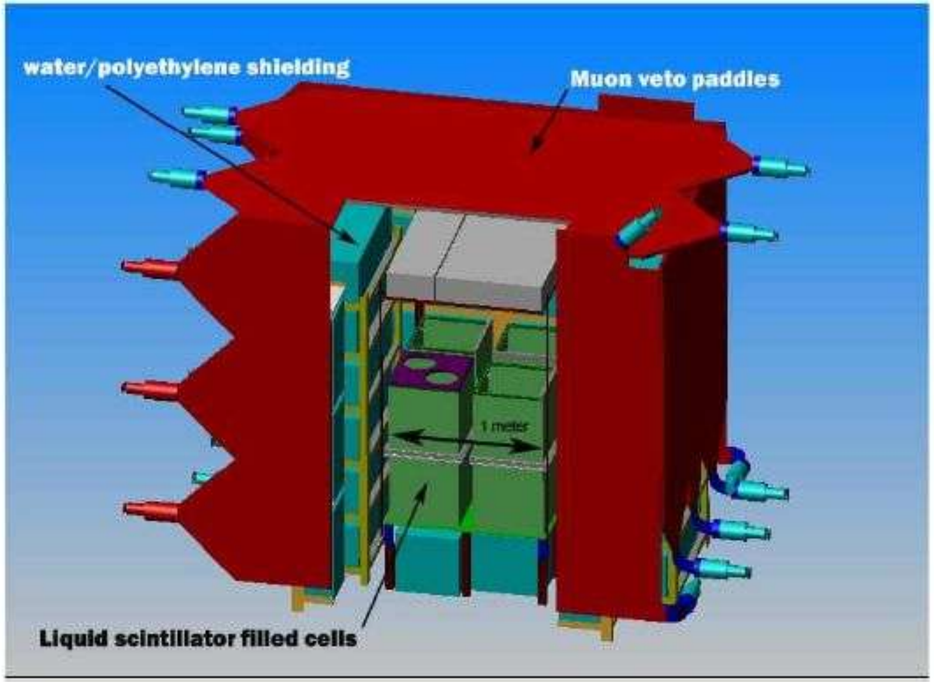


Figure 1. The SONGS detector (right) located in the tendon gallery (left)

France project NUCIFER – compact detector for IAEA (3m x 3m x2.5 m)

- Cylinder from stainless steel: height=1.7 m, diameter=1.2 м, filled with 0.85 m^3 scintillator (Gd-enriched).
- 16 PMT from top thought 25 cm acryl window (calibrated by laser LED signal)

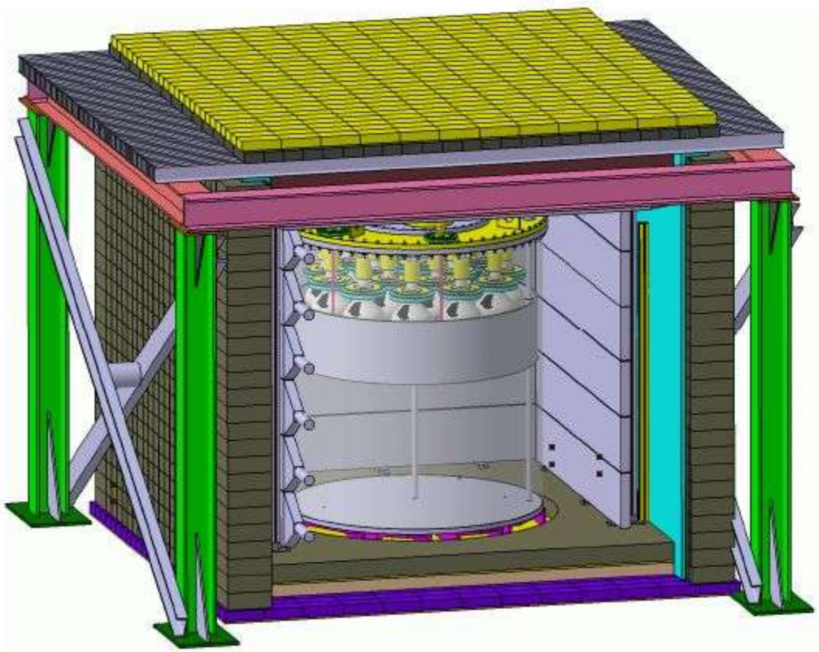


Figure 1. The Nucifer detector.

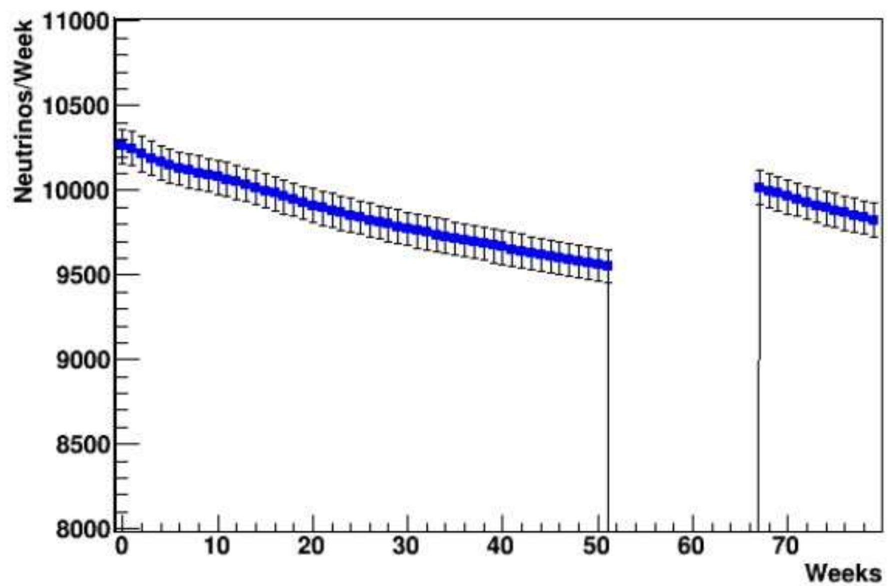


Figure 2. Weekly neutrino rate detected during one cycle by Nucifer installed 25 m away from a 2.9 GWth PWR.

SNIF
(Secrete Neutrino Interaction Finder)

- Detector in large tanker. Moved in desired (suspicious) regions.
- Target –
- 10^{34} protons

(~100 K tones water or

scintillator)

- $100 M

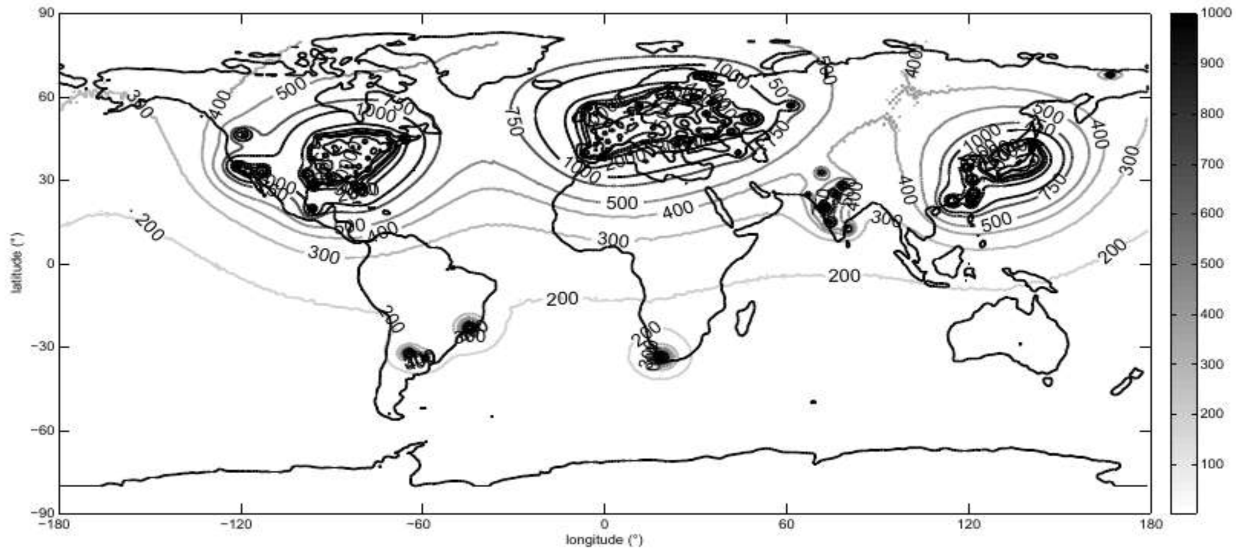


FIG. 2. Maps illustrating the number of neutrino events that would be detected in a 10^{34} free protons detector ($E_{\rm vis} > 2.6$ MeV, 4,000 m operating depth) after half a year of data taking. 201 nuclear power stations have been included, accounting for a 78% global load factor on averaged. This map includes all non-neutrino backgrounds which are negligible at this depth in the northern hemisphere (see Section VI).

Typical reactor building
with **WWER-1000**

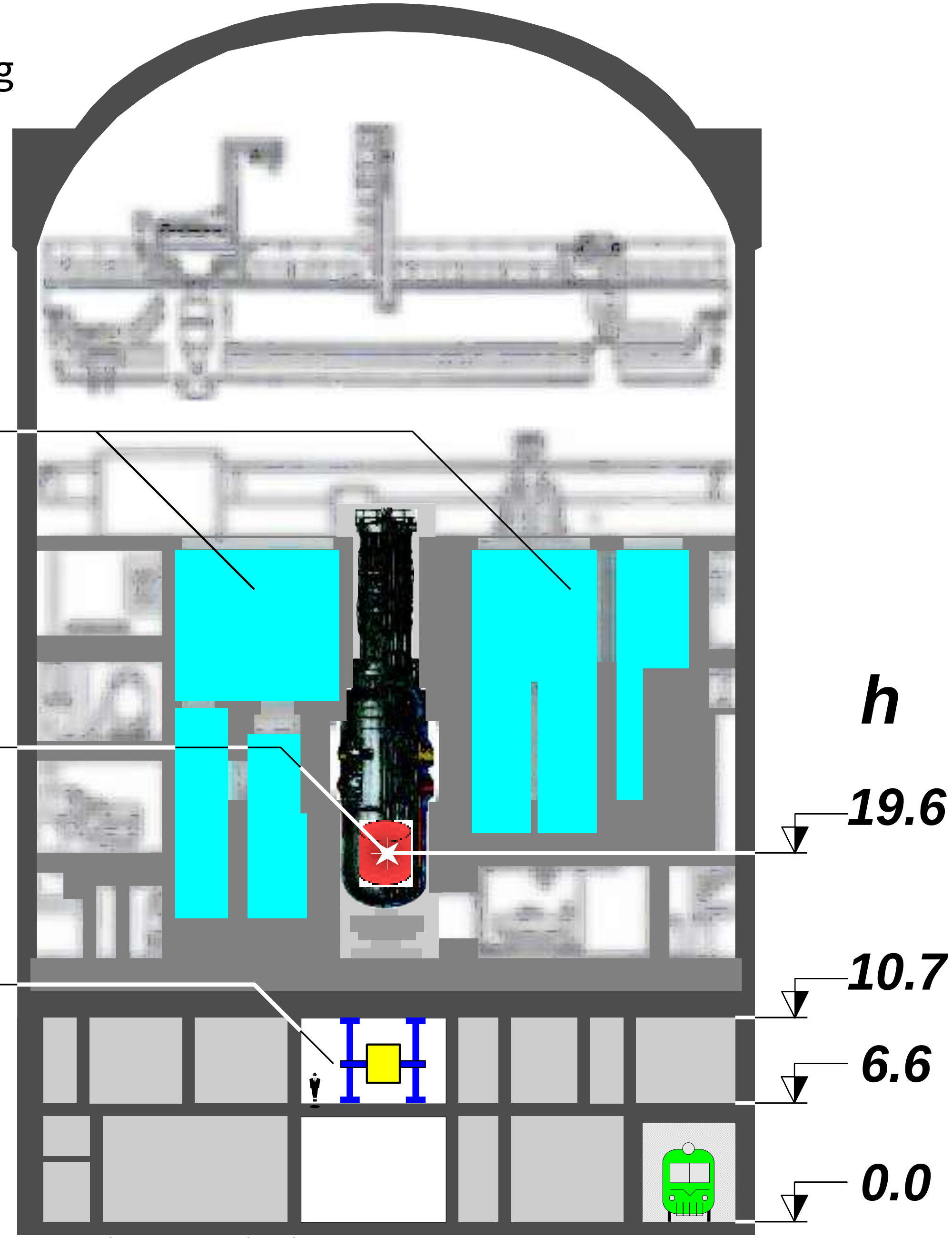
Reservoirs with
technological liquids
(cooling pond,
boric acid, etc.)

Core:
h =3.50   ∅ = 3.12

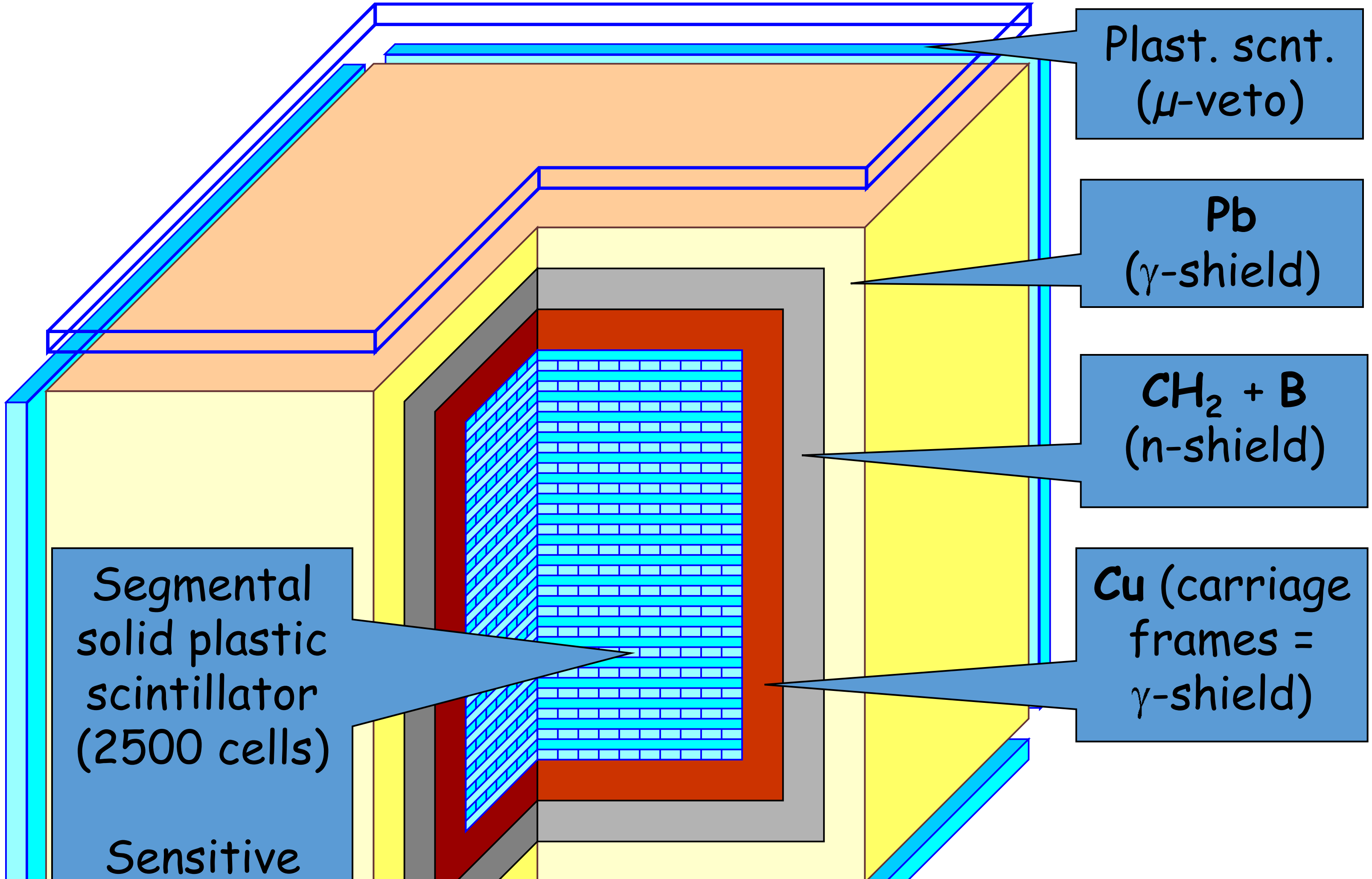
DANSS on a movable
platform with a lifting gear.

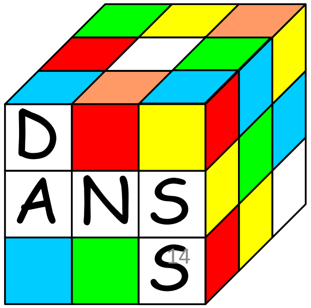
ν flux ≈ 5 × 10¹³ ν / cm² / s

Overburden ≈ 50 m w. e.



Forbidden to use dangerous materials (LS) nearby the reactor


Plast. scnt. (μ-veto)
Pb (γ-shield)
CH2 + B (n-shield)
Cu (carriage frames = γ-shield)
Segmental solid plastic scintillator (2500 cells)
Sensitive volume=1 m³

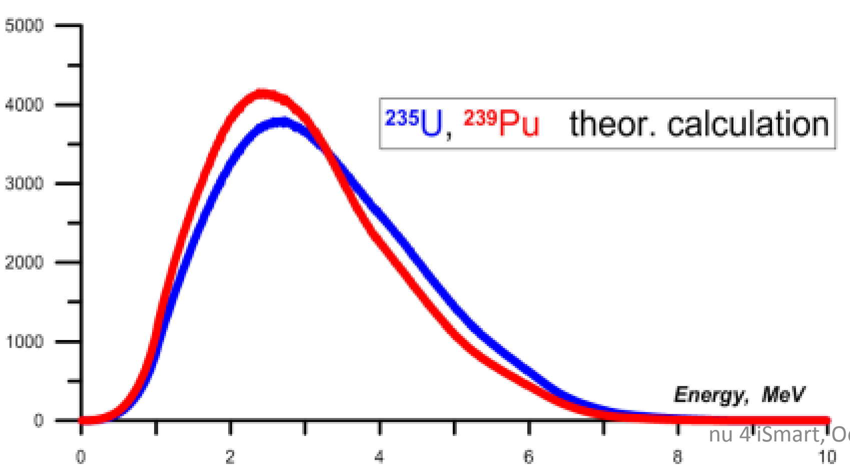

DANSS

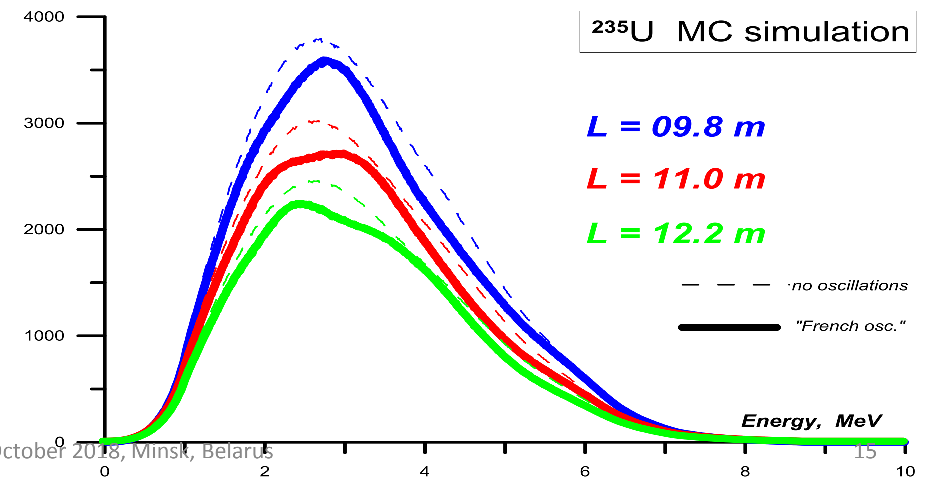
Expected parameters:

- Sensitive volume : 1 m^3 =100×100×100 cm
- Scintillator: Polystyrene based (~7.7 $\%_{wt}$ of H)
- Structure: (25 X + 25 Y) intercrossing modules =2500 strips

  1 module 20×20×100 cm = 50 parallel strips
- Mass with (CHB+Cu+Pb)-shield: 16-18 tonnes
- Site: reactor unit#4 of Kalinin NPP (standard industrial WWER-1000,

  Ø3.12 x h3.50 m, 3000 MW_{th})
- Reactor–Detector distance : **9.8–12.2 m** *(variable on-line)*
- Count rate: (**10 000 IBD** + **50 BG**) /day @11 m
- Energy resolution @ Eν =4 MeV: 25% (FWHM)





iDream

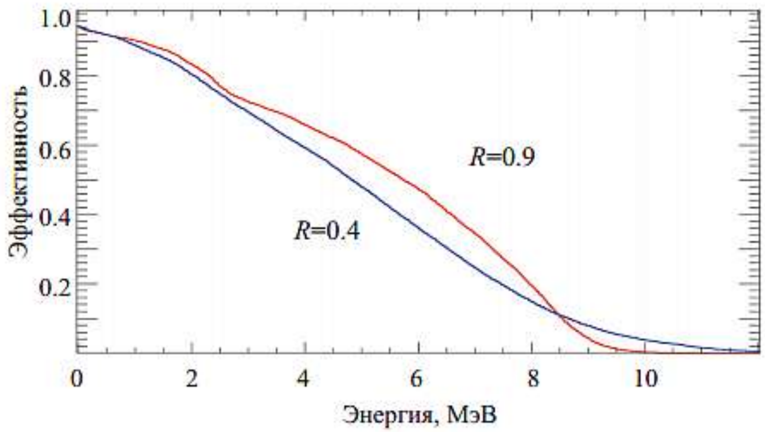


Рис. 4. Зависимость эффективности регистрации детектором как целым нейтронов реакции обратного бета-распада в потоке реакторных антинейтрино

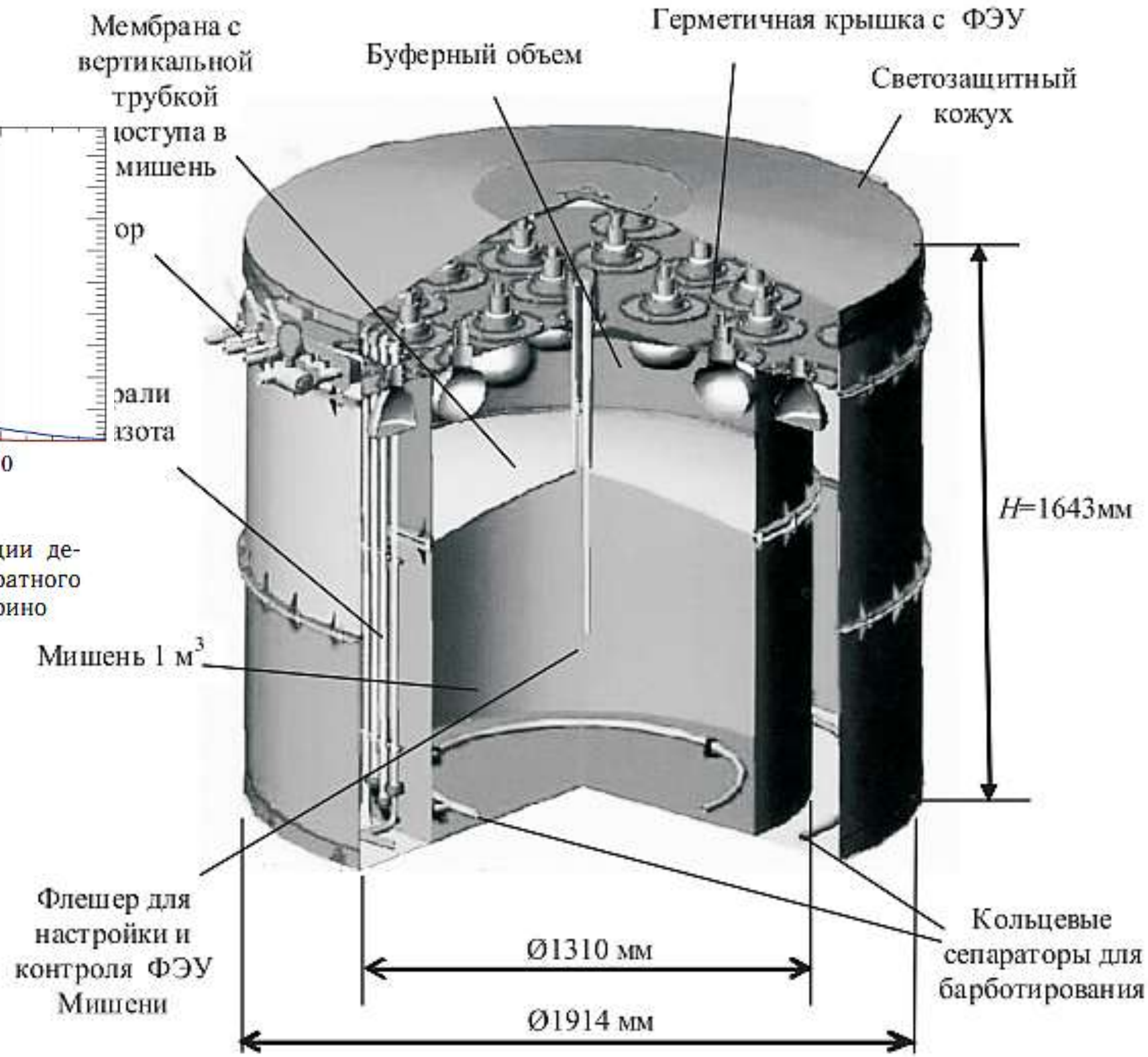
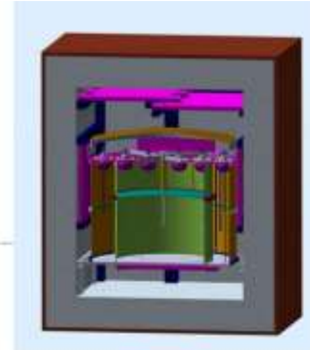


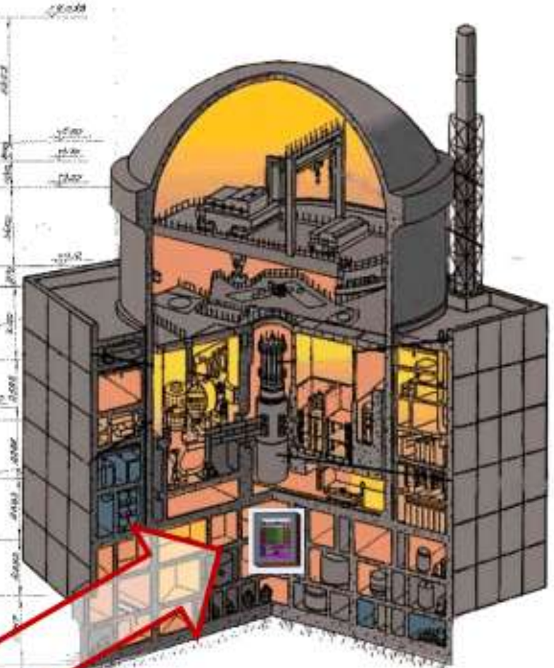
Рис. 1. Конструкция детектора iDREAM

iDREAM roadmap

~ 0 m Kurchatov Institute
Test Laboratory
Physical startup
2014



~ -30 m SINP MSU
Underground Lab
Background tests
2015

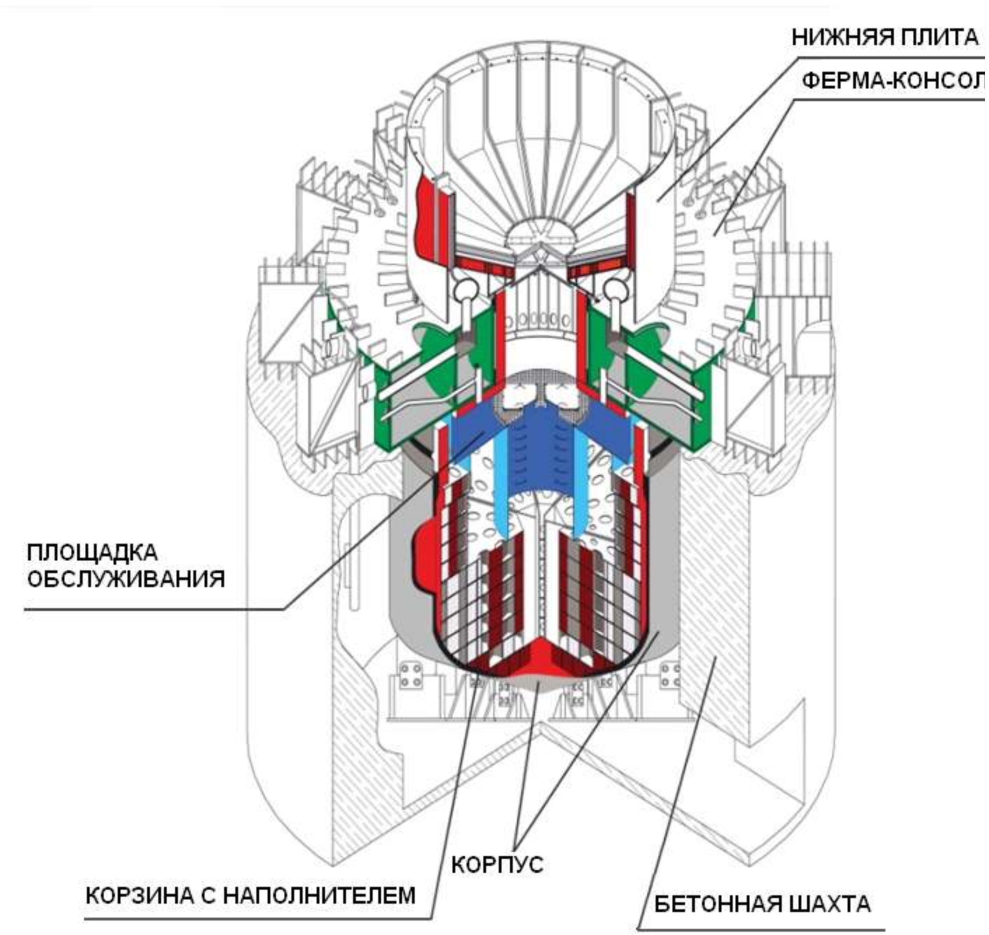


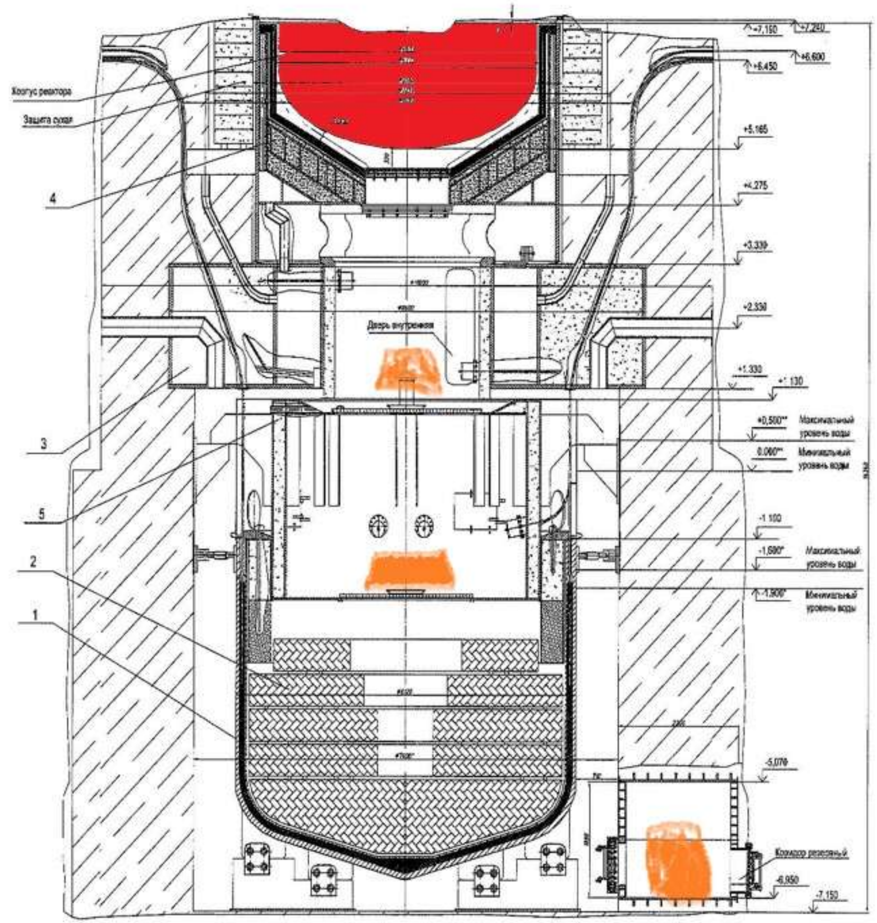
WWR-1000 NPP

Demonstration
experiment
(2015-2016)

WHERE ??

BelNPP core catcher construction





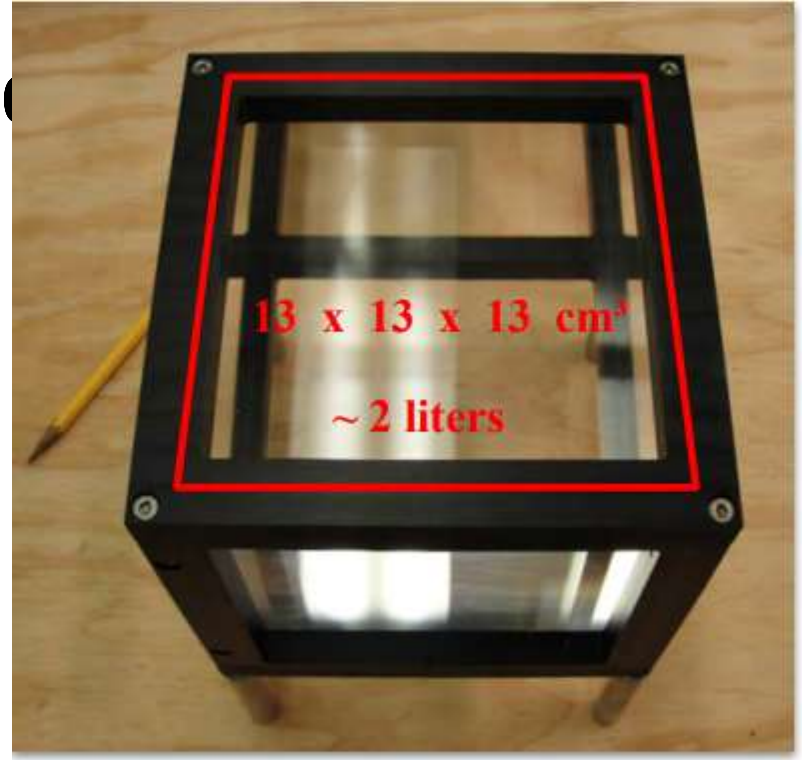
Demands to detector

- Constructed from independent blocks (not monolithic – portable)
- Easy serviceable (by blocks replacement on the go)
- Fast mountable (during the NPP work)
- Extended on demand ($1m^3$-$5m^3$)
- Remotely controlled over net
- Detecting IBD and at least one other reaction (to check – SNO lessons)

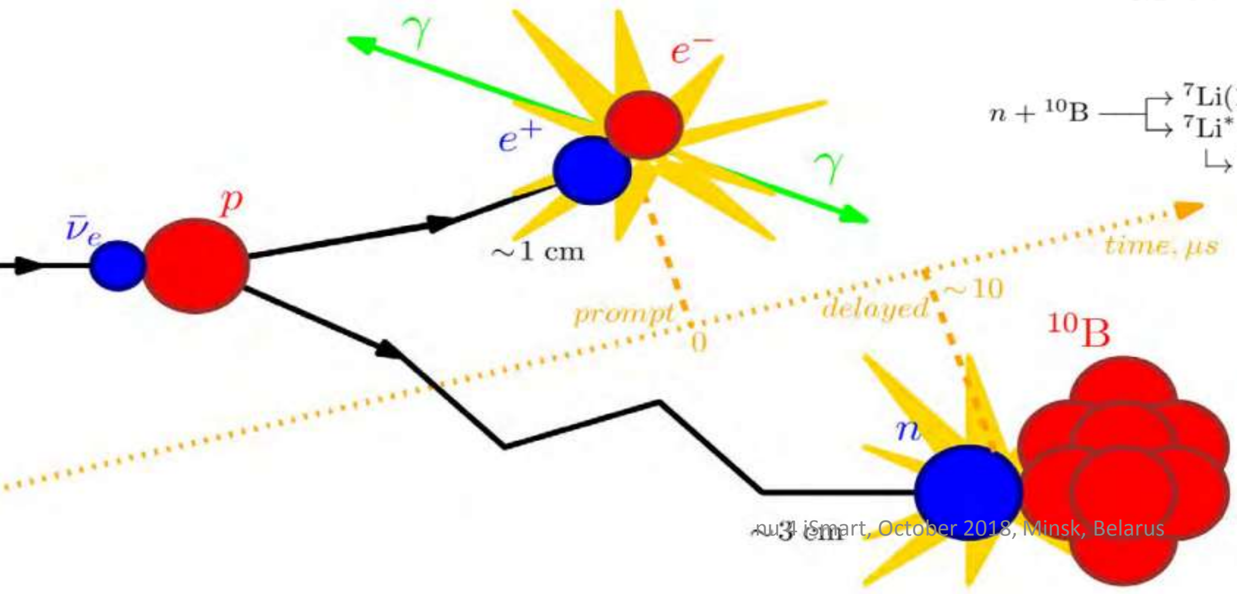
miniTimeCube as example

MCP-PMT

24 in total = 4 PMTs x 6 mTC faces



mTC scintillator cube inside Delrin frame

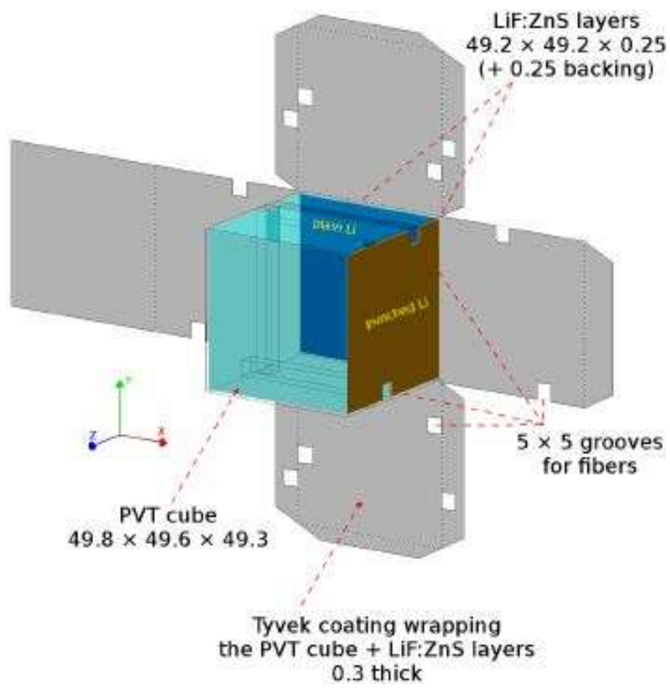


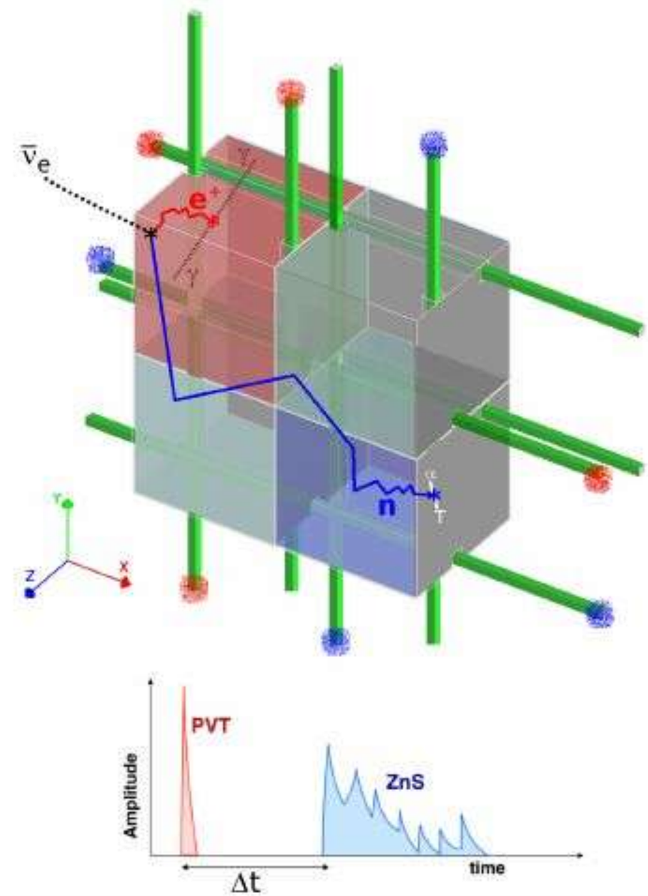
$n + {}^{10}\mathrm{B} \rightarrow {}^{7}\mathrm{Li}(1015\ \mathrm{keV}) + {}^{4}\mathrm{He}(1775\ \mathrm{keV}) \quad \sim 6\%$

$\rightarrow {}^{7}\mathrm{Li}^{*} + {}^{4}\mathrm{He}(1471\ \mathrm{keV}) \quad \sim 94\%$

$\hookrightarrow {}^{7}\mathrm{Li}(839\ \mathrm{keV}) + \gamma(478\ \mathrm{keV})$

Detector cube as crystal spaghetti in plastic

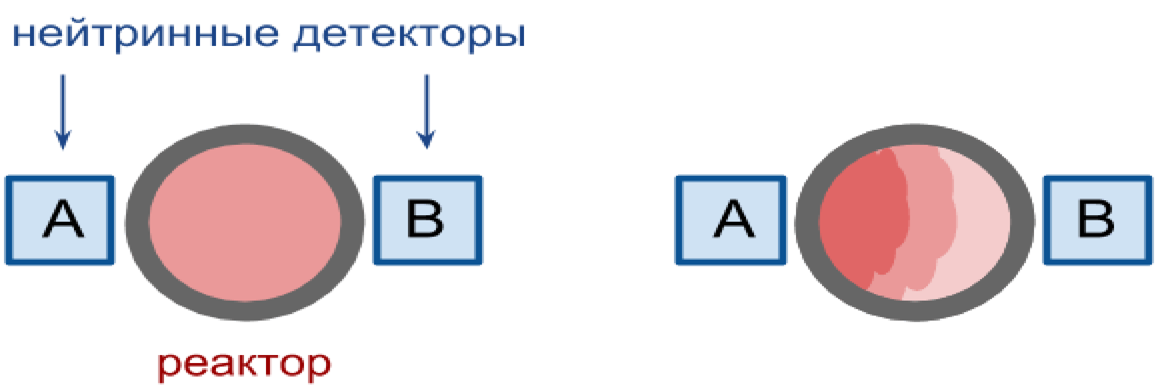




Several prototype designs

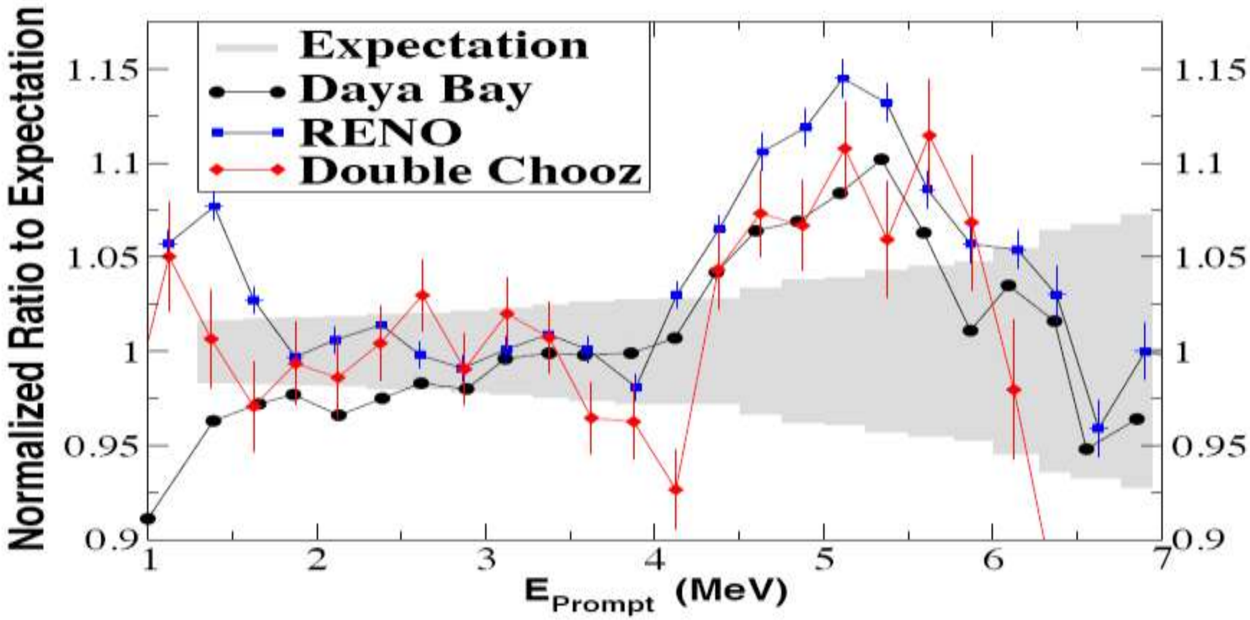
1. Plastic box (e.g. 25*25*25 cm) Gd-coated with SiPM
2. Scintillating box surrounded by ZnS (Li) films as light collectors. (e.g. 20*200 mm)
3. Box of GaGd crystals in “spaghetti” 20x20x100 mm in H-reach media.

4. Muon veto organized as 2 plates – upper and bottom.



Discrepancies of experimental data and theoretical predictions

All three recent reactor neutrino experiments observed a shoulder at 4-6 MeV, relative to expectations –the 'Bump'

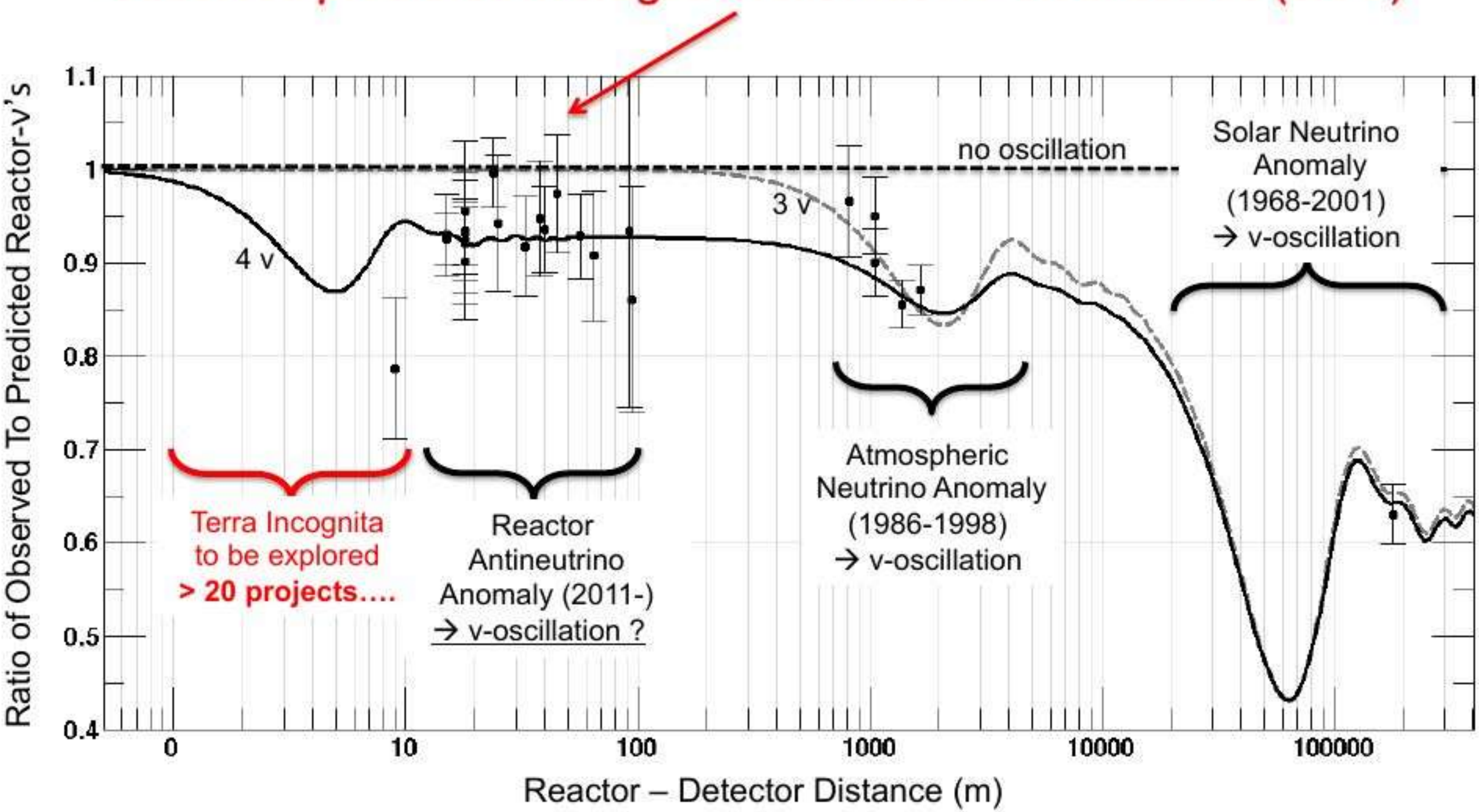


- **The current expectations are Huber (^{235}U,$^{239,241}Pu$) and Mueller (^{238}U)**
- **RENO observed the largest bump**
- **Double-Chooz used Huber and Haag (^{238}U) for expected flux**

P. Huber, Phys. Rev. C 84, 024617 (2011); Th. A. Mueller et al., Phys. Rev. C 83, 054615 (2011); N. Haag, Phys. Rev. Lett. 112, 122501 (2014).

Reactor antineutrino anomaly

- **Observed/predicted averaged event ratio: R=0.927±0.023 (3.0 σ)**



Thank for Your attention