Status of the iDREAM project

industrial Detector for REactor Antineutrino Monitoring

A. Chepurnov

SINP MSU, Moscow

On behalf of the team from SINP MSU, RNC Kurchatov Institute, INR RAS

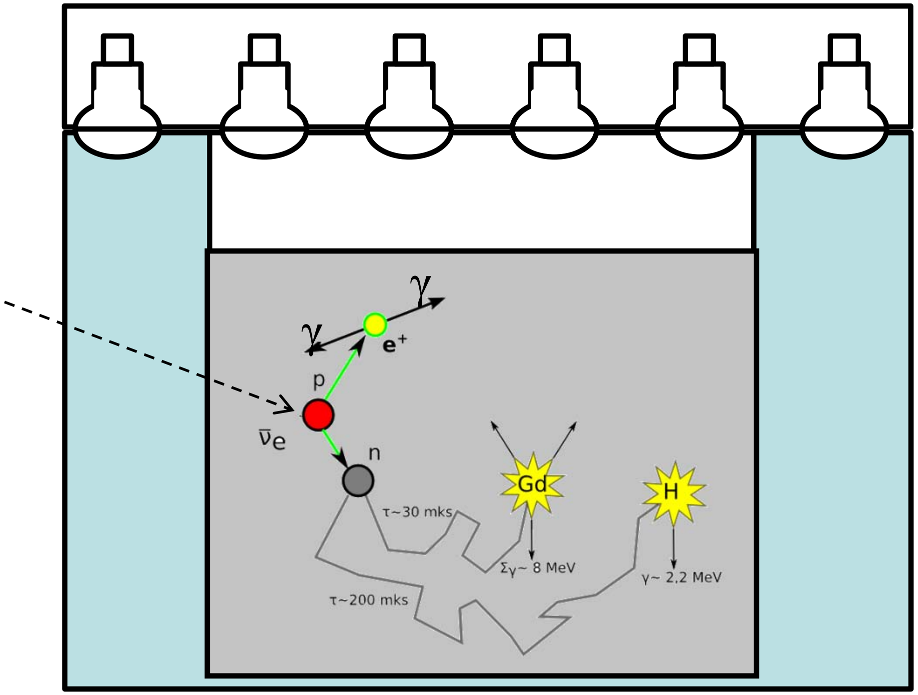
AAP-2014, December 15-16, 2014

Detector based on LS

Antineutrino is detected via IBD reaction by means of the delayed coincidences:

- The "positron" signal $T = E(\overline{\nu}_e) - 1.8 MeV (threshold) + m_e c^2$
- The "neutron" signal $n + H \,\&\, Gd \rightarrow \gamma ... (2.2 MeV (\sim 200 mks - 20\%) \,\&\, \sim 8 MeV (\sim 30 mks - 80\%)$

3 MW reactor (WWR-1000) emits ~ 6×10^{20} $\overline{\nu}$/s **σ ~ 10^{-43} sm^2 per fission**



¼ with energy > 1,8 MeV

Detectors advantages:
- background/signal ratio 1:10
- neutron detection efficiency 60%
- spectrometry capability
- pulse shaping discrimination
- on line operation

Detectors disadvantages is a leakage of gammas because of compact sizes:
- a decrease of efficiency
- an increase of uncertainty

1 m^3 of LS target -> 15-20 m from reactor core -> 2000-3000 events per day

The most deeply studied and developed detector for reactor neutrino monitoring

History of the Applied Antineutrino Physics in Russia

1974-1977

Studies of reactor antineutrino spectra (*Kurchatov Institute)* :
- calculations of the spectra, generated by ^{235}U and ^{239}Pu, ^{238}U and ^{241}Pu.
- measurements of the beta spectra for ^{235}U and ^{239}Pu.

It has been shown that the number of antineutrinos per fission from ^{239}Pu is less than the number from ^{235} - *U. A.Borovoi, Yu.Dobrunin, V.Kopeikin. Nucl. Phys. (Rus.), 1977, 25, 264*

1977

Ideas were proposed by L. Mikaelyan at the conference *"Neutrino-77":*
- The rate of antineutrino detection gives a mean for remote measurements of power production, due to direct dependence *N(anti-nu) ~ N(fissions),*
- The shape of the antineutrino spectrum can provide additional information concerning the isotopic composition of a reactor core

1978-1982

Several types of reactor antineutrino detectors have been developed (*Kurchatov Institute)* .

1983-1994

Feasibility study was done at Rovno NPS (USSR) and later at Bugey NPS (France) in collaboration between Kurchatov In. and IN2P3.

Start of the industrial phase

2003-2006

R&D of the industrial prototype of compact unattended LS detector to guaranty nonproliferation *(cooperation of Kurchatov Institute, Duhov FSUE VNIIA, Scobelcyn INP MSU*)

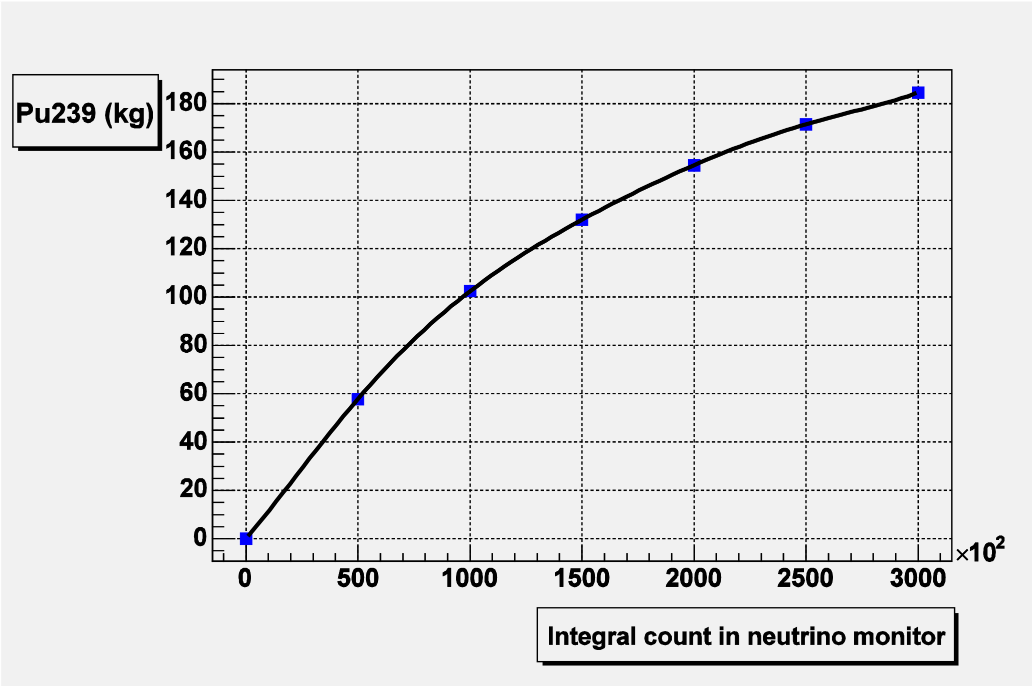
Pause

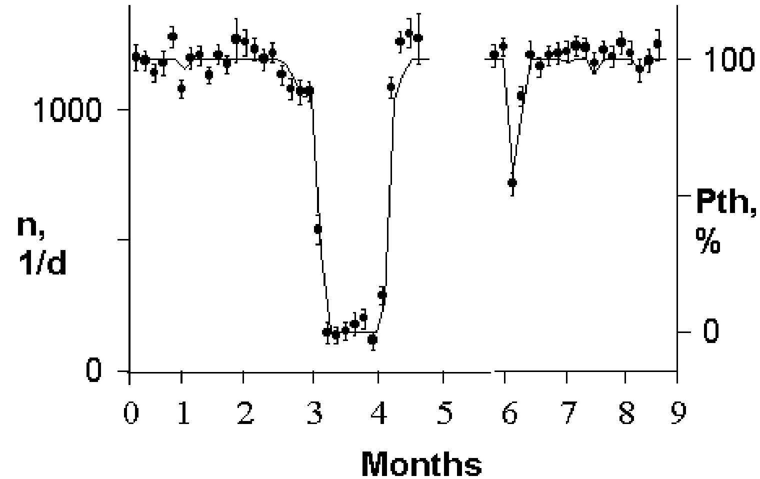
2012-now

Development of an industrial prototype of the liquid-scintillator detector for the neutrino monitoring of nuclear reactors *(cooperation of Scobelcyn INP MSU, Kurchatov Institute, Duhov FSUE VNIIA, INR*)

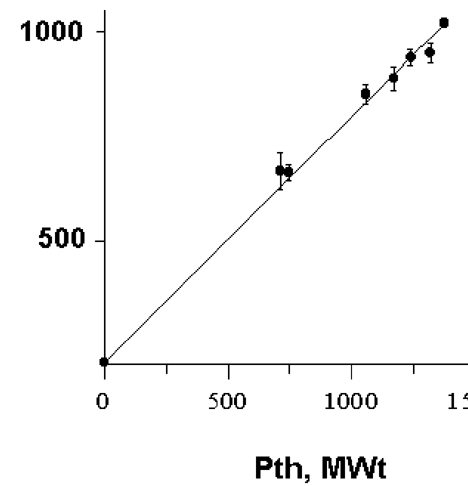
Parallel researches of reactor antineutrinos proceeded in USA, Germany and France

Detector RONS experimental data





Monitoring of energy release per day



The detector count as a function of power

R = 18 m Rate ~ 2 10^3 neutrino per day (1.4GW)
~100 b-g events per day

Data confirmed the following possibilities:
- to check a level of irradiation of fuel in the real time,
- to evaluate the plutonium content in the fuel,
- to detect a reactor shutting down, even for one day.

The main problem
– degradation of Gd-LS

Климов Ю.В., Копейкин В.И., Микаэлян Л.А., и др. Измерение спектра электронных антинейтрино ядерного реактора// Ядерная физика, 1990, Т.52, вып.6(12), с.1579-1584

iDREAM project
It is focused on the following issues:

- detailed mechanical design together with test and supplementary subsystems which **could be easily and serially produced. Each part should be moveable and fit the size of the standard doors**

-R&D of **Gd-doped LS** with Russian **LAB** as a solvent, which will be chemically stable and compatible with main construction materials - **stainless steel** and Ti

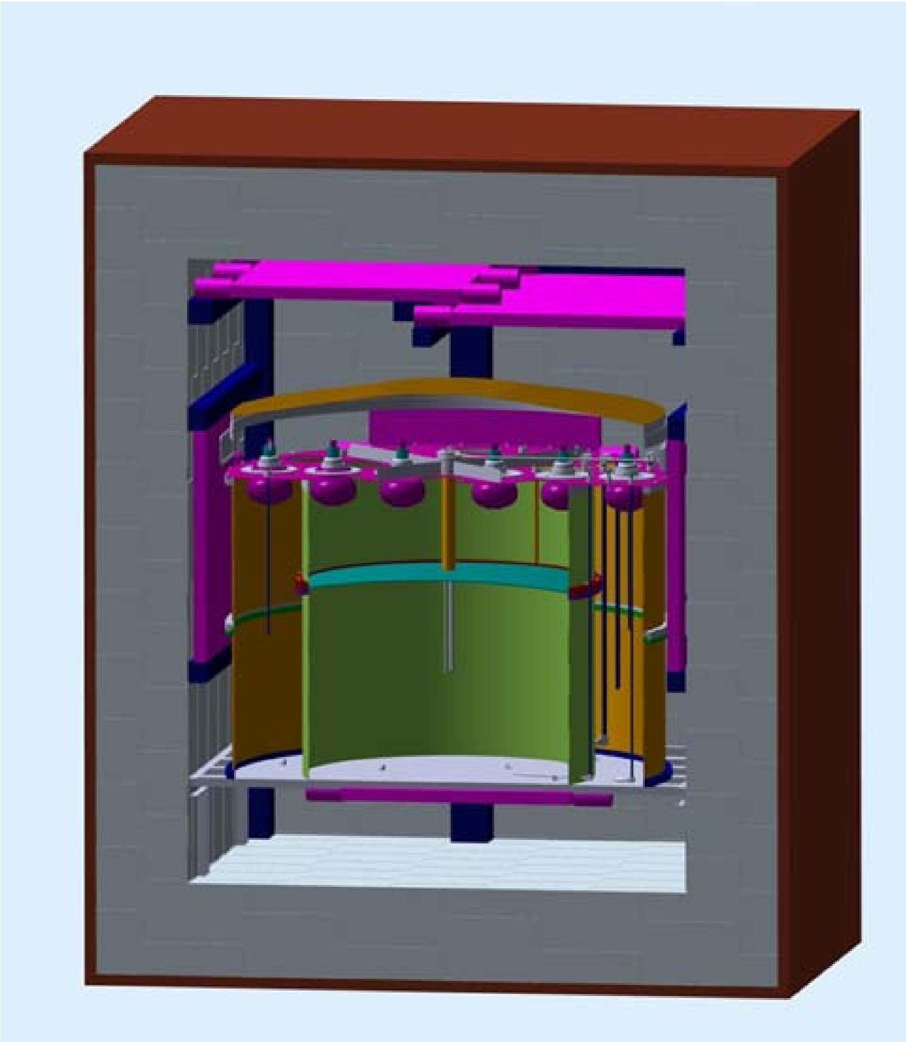
- "industrial" slow control, HV and DAQ which will **work remotely and unattended**

- development of **application scenarios as monitoring instrument together with safe data transfer channels**

- demonstration experiment on NPP

The final goal is to develop and test the industrial detector ready to be produced serially and be the option of NPP safety systems in the interests of the IAEA

iDREAM composition



Detector itself

Detector body

PMT with DAQ and trigger

Slow control with HV PS

Muon active veto (PMT, DAQ)

Embedded self-calibration tools

Passive shielding

Fire-fighting equipment

Supplementary tools

Assembling/disassembling tools

LS refilling

N_2 source

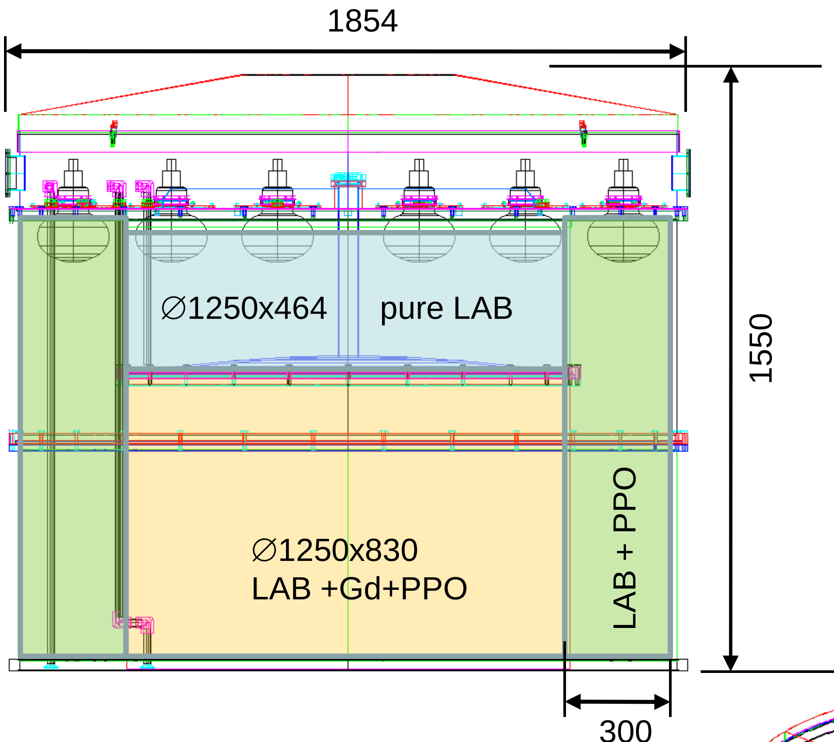
Calibration tools

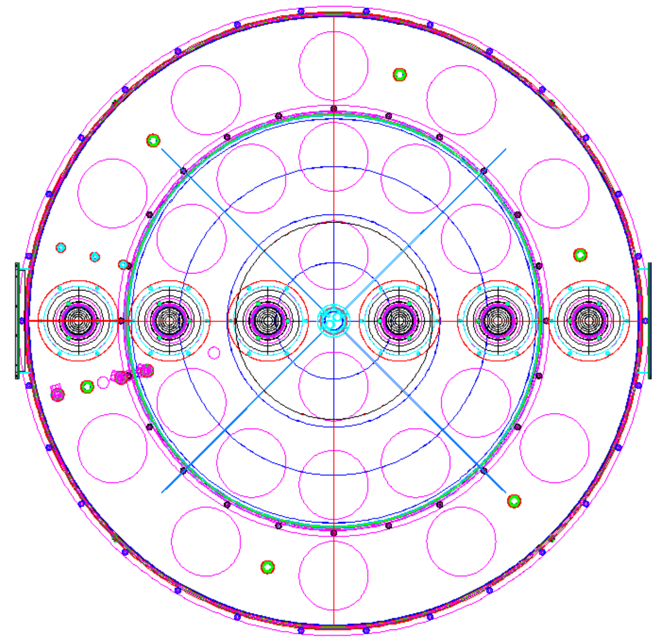
Liquid Scintillator

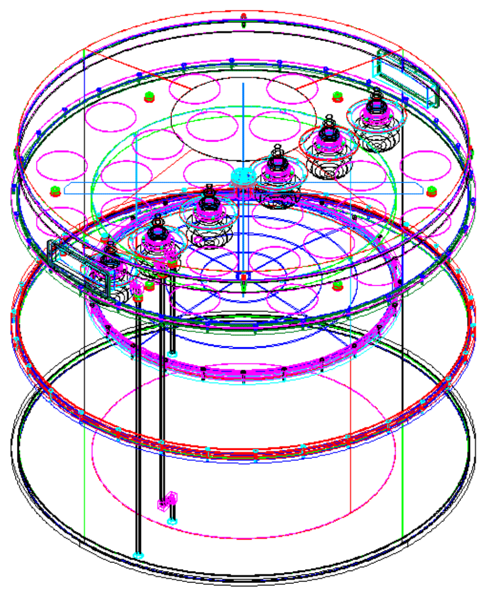
Liquid Scintillator mass production

Liquid Scintillator long-term tests

Mechanical construction







The internal Gd dopped target
∅ -1250x830 mm
PMT Gamma shield & Light diffuser
∅ -1250x464 mm
Leaked Gamma catcher - 300 x1300 mm

The external tank ∅ - 1854 mm

Acrylic Membrane 6 mm

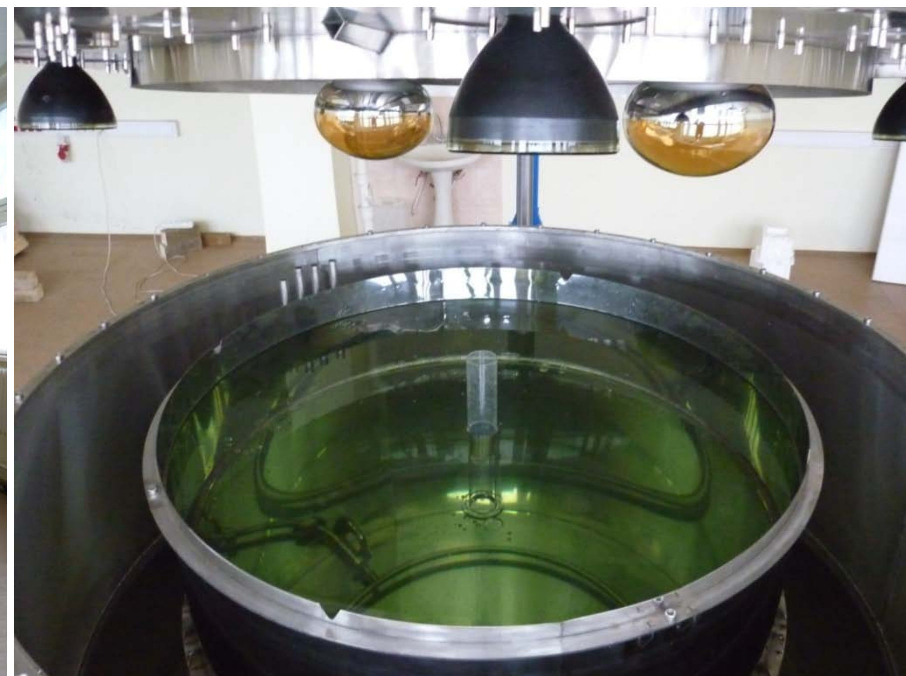
White polyester reflecting film

600 kg of 2 mm
AISI 321 (08X18H10T)

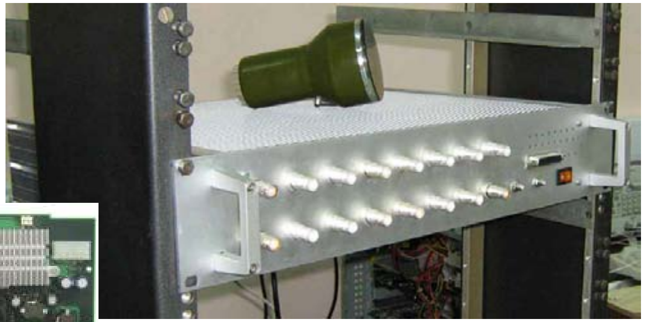
	Sample 1	Sample 2
	ppb /mBq/kg	ppb/mBq/kg
Th	2.2 / 9	8.4 / 34
U	<0.01 / 0.1	2.6 / 32

20% accuracy of ICP-MS



iDREAM electronics

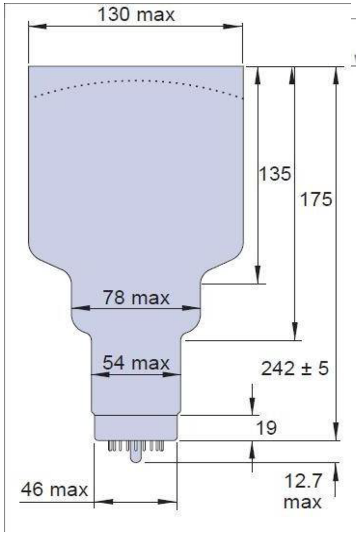


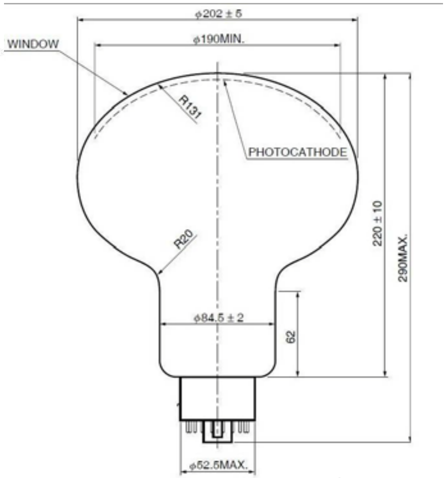
Front-end
Custom-designed 19” fast adder-discriminator with embedded HV decouplers, counters with CANopen interface

DAQ   1Gs/s flash ADC   PCI

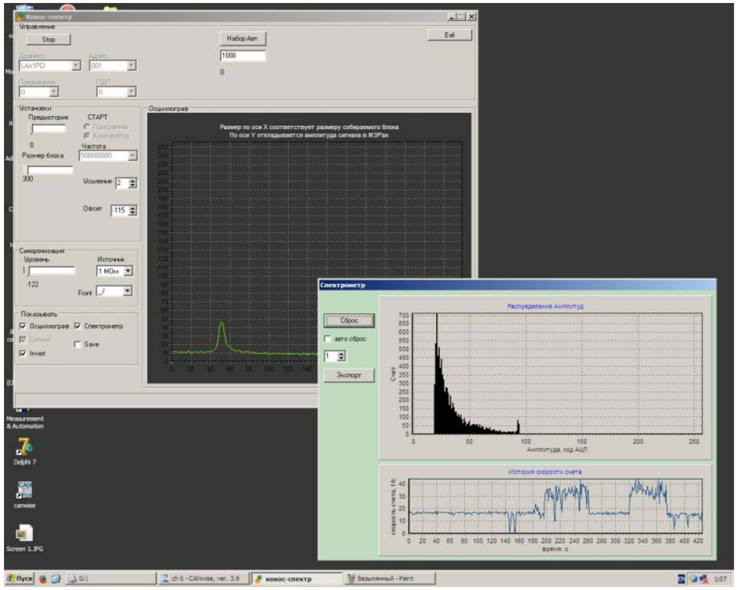
Slow control
 distributed real time industrial fieldbus CANopen with industrial I/O modules

PMTs : HAMAMATSU R5912 & ETE 9823

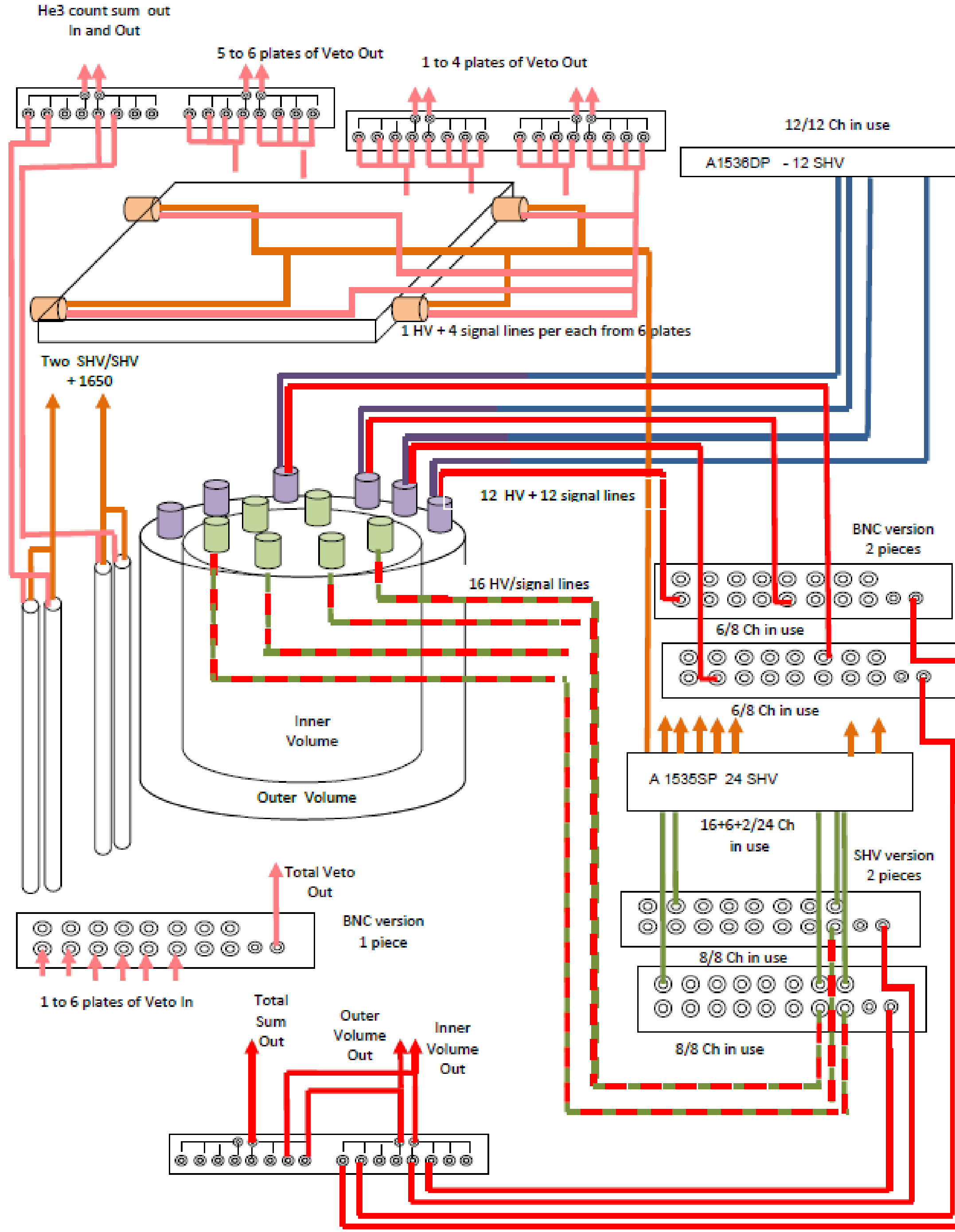




PMT HV: HV Multichannel Power Supply System



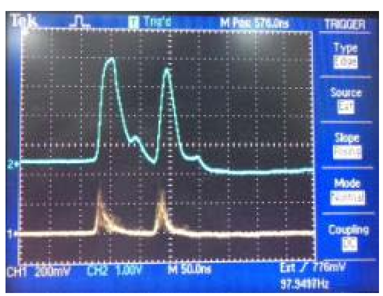
FlashADC screen



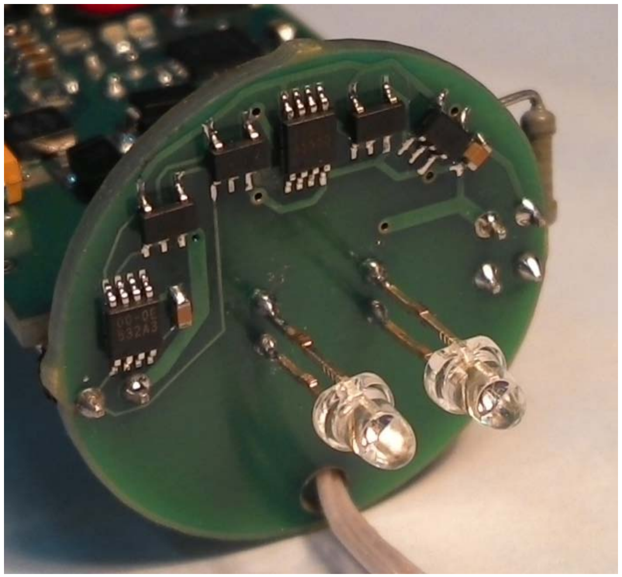
Double-flasher calibration

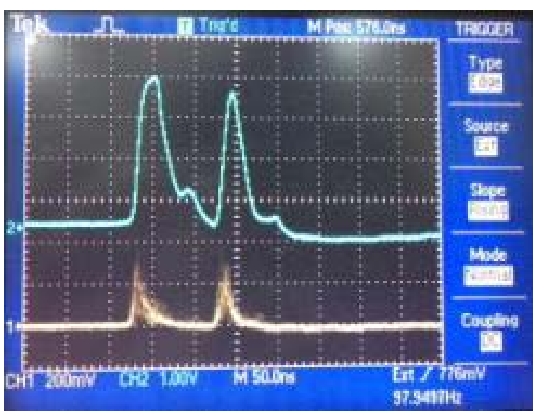
SUM of 4 ext PMTs

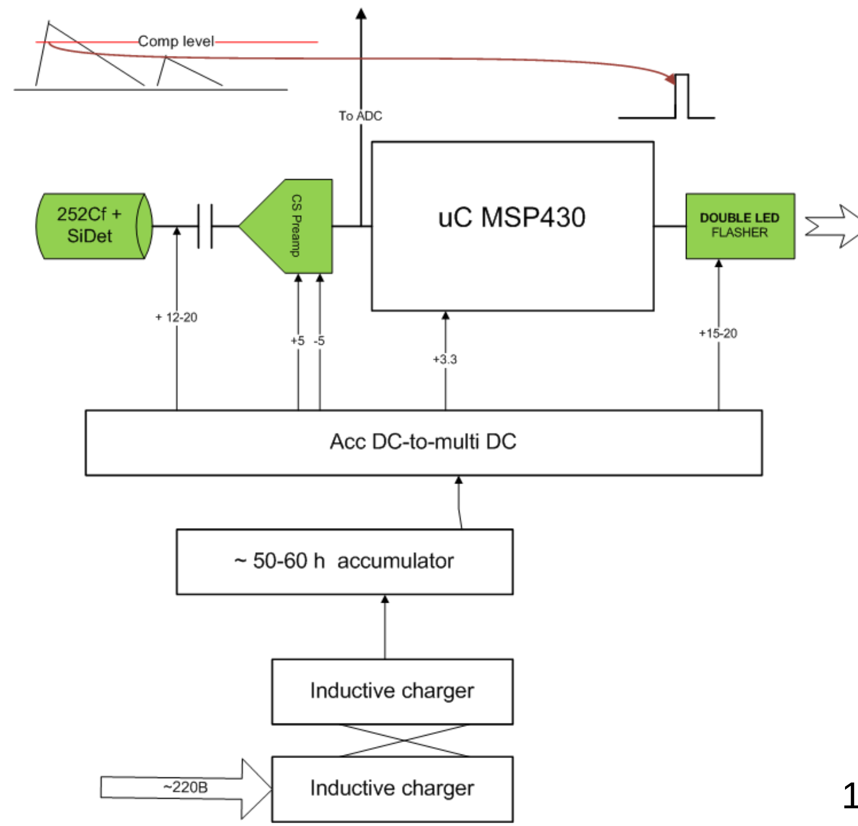
SUM of 4 int PMTs



“Bobber” LED (self) Calibration tool



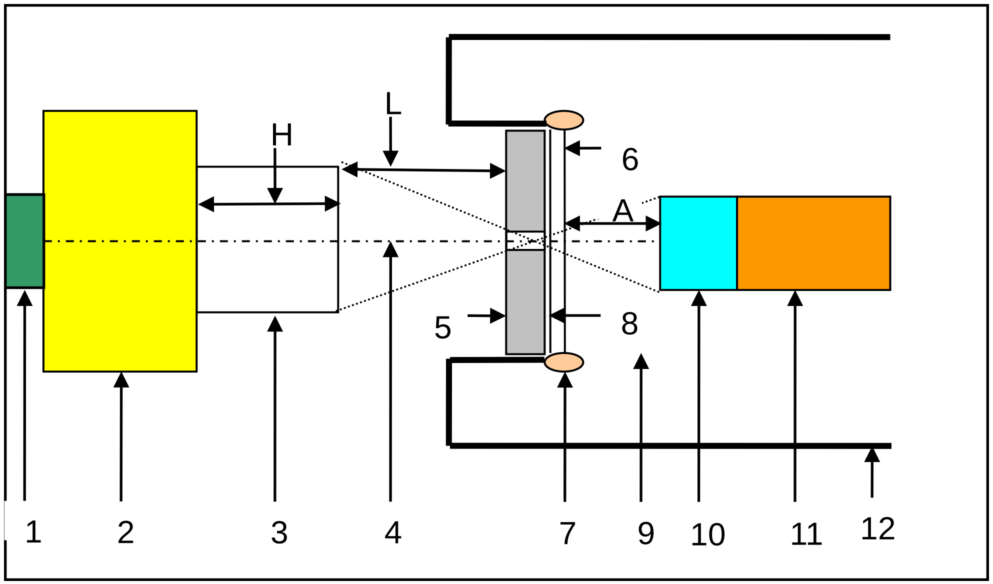




n (self)Calibration with compact pyroelectric neutron source

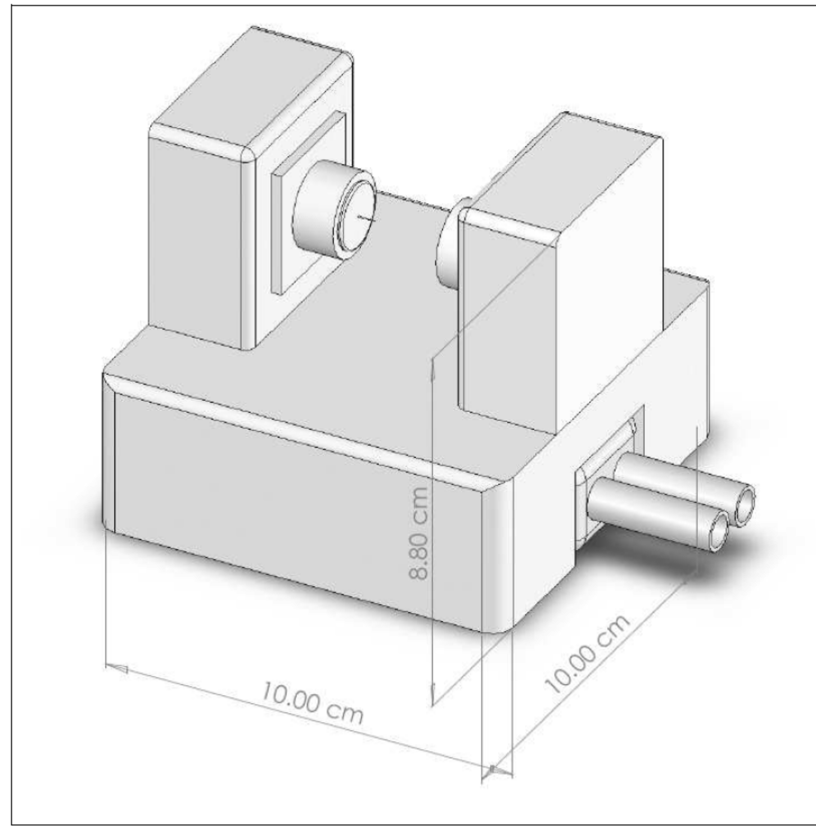
(in cooperation with Belgorod National Research University, Laboratory of Radiation Physics)

From pyroelectric X-Ray *to pyroelectric Neutron source*



Scheme of the experimental setup with pyroelectric crystal LiNbO3 (3), Si(Li) X-ray detector (10), 1.0 mm lead collimator (5), 20 mkm Cu foil (8), 20 mkm Be foil (6). L=8mm.

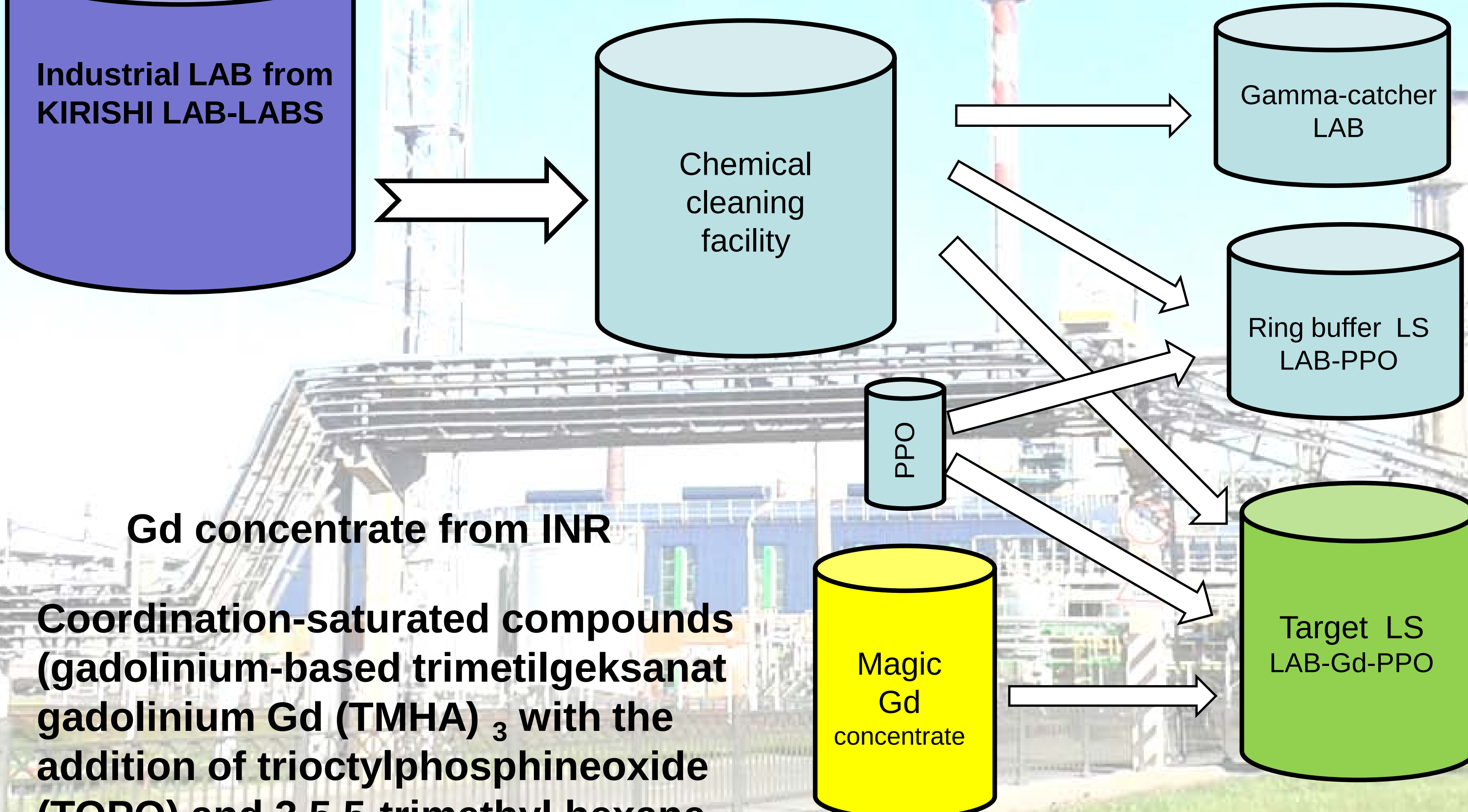
V.I. Nagaychenko, V.V. Sotnikov, B.I. Ivanov, A.M. Yegorov, A.V. Shchagin. The influence of size and surface condition of lithium niobate crystal on the energy and intensity of X-ray radiation of the pyroelectric generator. Surface. V. 3, 2007, p. 89-94.



Y. Danon A Novel Compact Pyroelectric X-Ray and Neutron Source DOE NEER Grant DE-FG07-04ID14596

Liquid Scintillator production approach

To clean or not ??
(still under investigation)



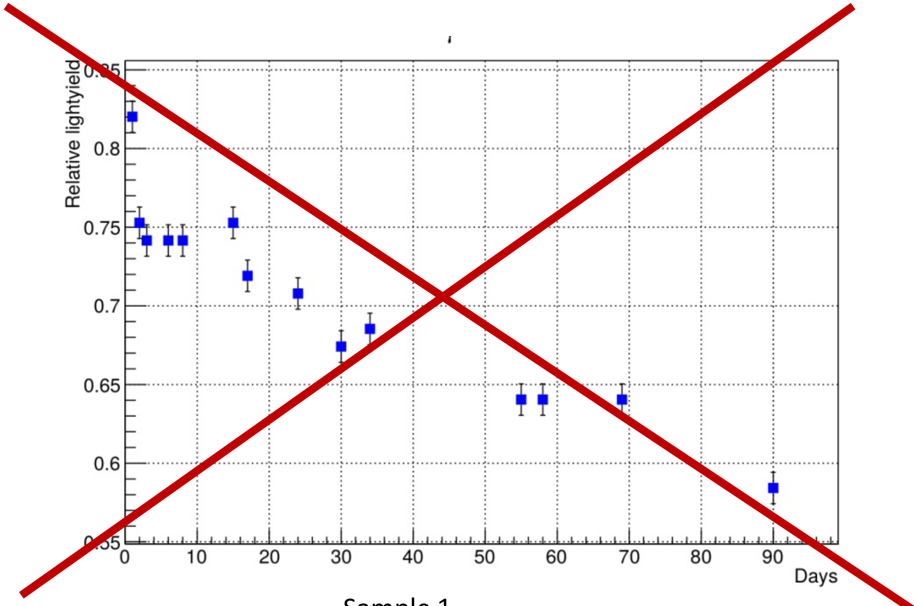
Gd concentrate from INR

Coordination-saturated compounds (gadolinium-based trimetilgeksanat gadolinium Gd (TMHA) $_3$ with the addition of trioctylphosphineoxide (TOPO) and 3,5,5-trimethyl hexane acid) synthesized and investigated.

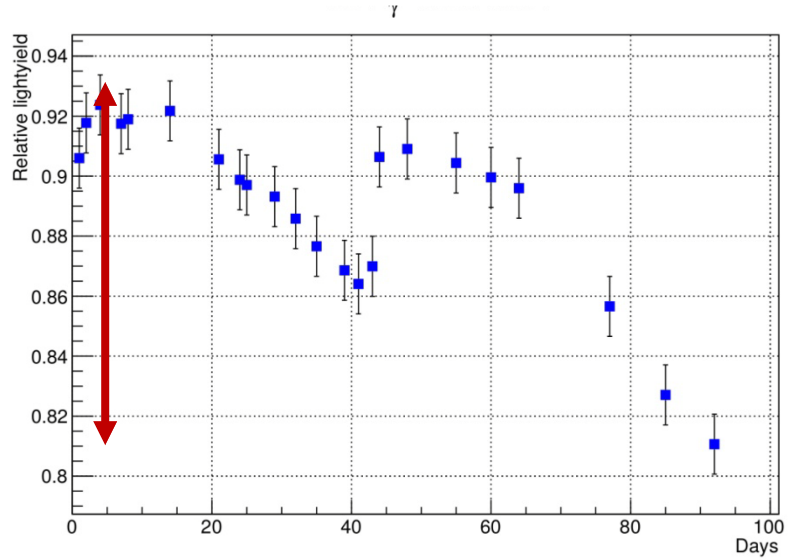
30 l prototype for LS long-time tests

Checking the compatibility of detector materials with the scintillator
Checking structural elements
Testing the electronic channel and PMTs
Checking the characteristics of the scintillator and PMTs

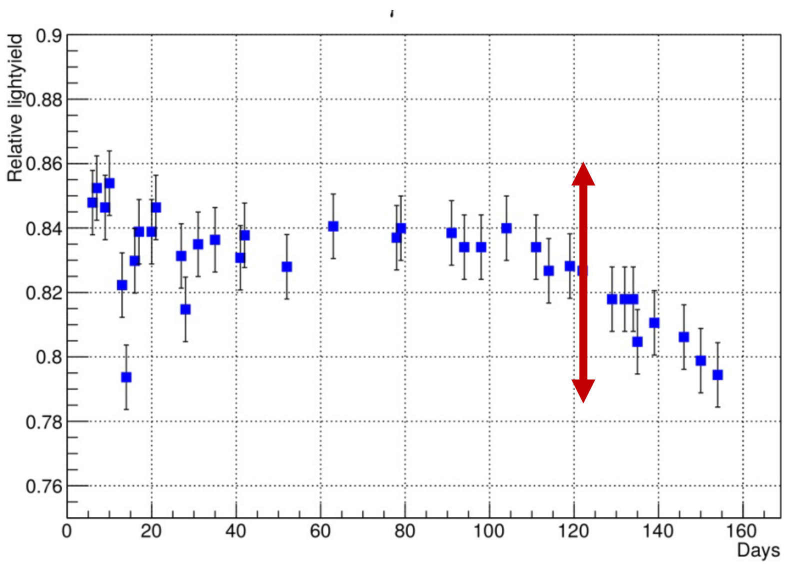
Stability of ^{137}Cs peak position for different Gd concentrates



Sample 1



Sample 3



Sample 2

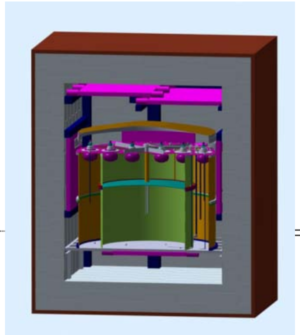
~ 10% drop down in 100 (160) days

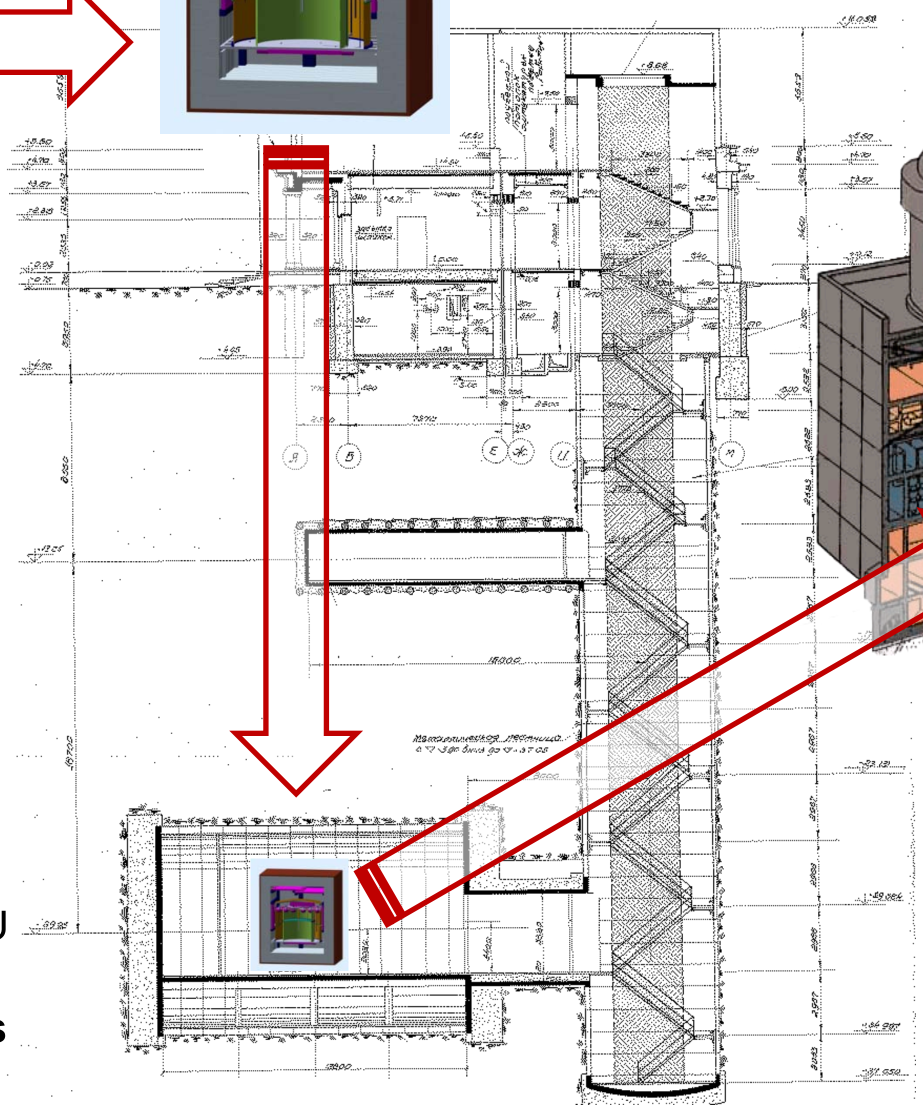
(acceptable)

…. to be continued before selection of the mixture for "industrial" production

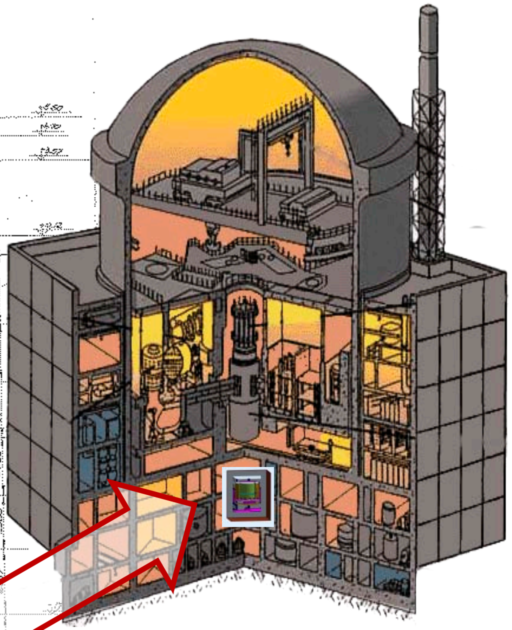
iDREAM roadmap

~ 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 ??

Possible places for future demonstration experiment on Russian NPR with iDREAM outside Russia

Conclusion

Feasibility of a remote reactor control and monitoring by means of neutrino method was shown in the several measurements at nuclear power plants.

The total knowledge in the field of reactor antineutrinos, new stable scintillators and high-performance electronics have made it possible to create a compact low-cost industrial detector based on liquid organic scintillator for applied application and scientific research.

We are looking for the nuclear power plant for demo experiment

Thank you for your attention !

This work is Supported by RFBR (grant 12-02-12129, 14-22-03013).