Status of Experiments on the Neutrino Magnetic Moment Measurement

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Science motivation of the searching for μ_ν

- *minimally-extended Standard Model:*

$$\mu_\nu \sim 10^{-19}\, \mu_B \times (m_\nu / 1eV)$$

($\mu_B = e \cdot h / 2m_e$ *Bohr magneton*)

- *number of extensions beyond the MSM independently of neutrino mass:*

$$\mu_\nu \sim 10^{-10} - 10^{-12}\, \mu_B$$

- *limits for the NMM from astrophysics*

$$\mu_\nu \leq (0.4 - 0.05) \times 10^{-10}\, \mu_B$$

(model dependent !!!)

- *it is necessary to make laboratory μ_ν measurements sensitive enough to reach ~ $10^{-11}\, \mu_B$ region and test hypotheses beyond the MSM .*

Experimental measurements μ_ν

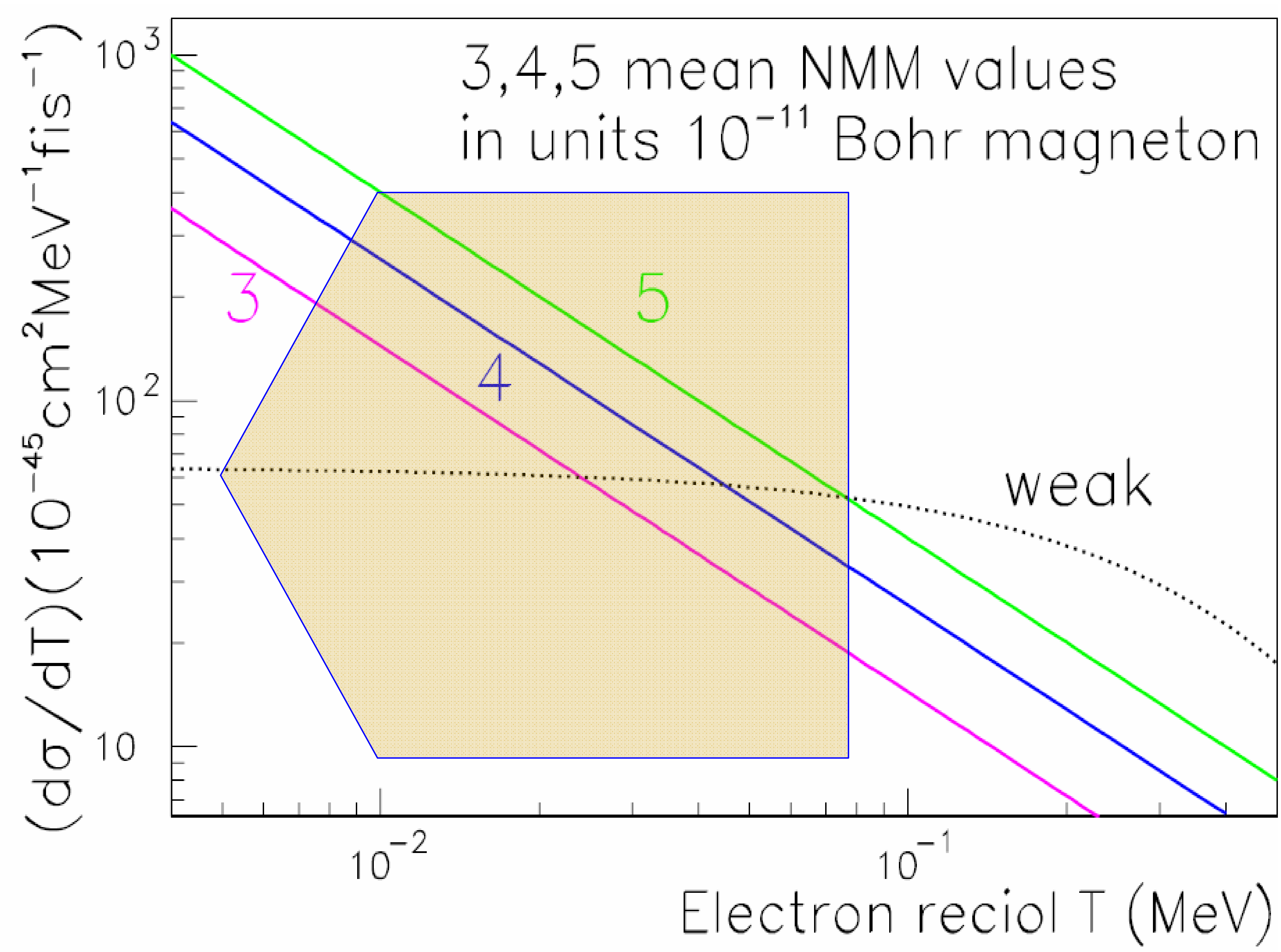
- *The effects of the NMM can be searched for in the recoil electron spectrum from ν - e scattering.*

- ***For a non-zero NMM the differential over the kinetic energy T of the recoil electron cross section $d\sigma/dT$ is given by***

$$(d\sigma/dT)_{weak} + (d\sigma/dT)_{EL}$$

- ***At small recoil energy in $d\sigma/dT$ the weak part practically constant, while the EL one grows as 1/T towards low energies.***

- ***As a neutrino source in the experiments it's used solar neutrino and reactor antineutrino. In future it's planes to use artificial neutrino sources.***



3,4,5 mean NMM values
in units 10^-11 Bohr magneton
3
4
5
weak
10^3
10^2
10
10^-2
10^-1
(dσ/dT)(10^-45 cm^2 MeV^-1 fis^-1)
Electron reciol T (MeV)

Reactor as a source of antineutrino

The average figures for LWR:

Fuel composition → $^{235}U : 58$, $^{239}Pu : 30$, $^{238}U : 7$, $^{241}Pu : 5\%$

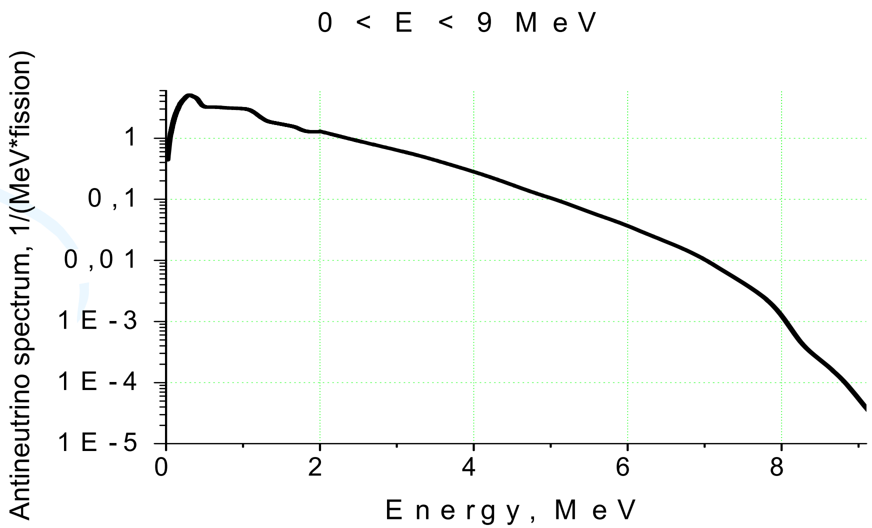
Average energy per fission E_f = 205.3 Mev.

Number of the fiss. / sec $N_f = W/E_f = 9.14\times10^{19}$ f/s

n_ν per fiss. = 7.2 → 6.0 (fiss. fragments) ⊕ 1.2 (^{238}U n,γ $^{239}U \rightarrow {}^{239}Np \rightarrow {}^{239}Pu$)

$$F_\nu = n_\nu W/E = 6.4\times10^{20}\ \nu/3GWth/sec$$

At R = 15 m $\quad f_\nu \approx 2\times10^{13}\ \nu/cm^2\cdot sec$



The history of the reactor experiments

1976 – Savanna River. The first observation of ν - e scattering.
F. Reines et al. [P.R.L.37,315(1976)].
~ 16 kg plastic scintillator, ν flux of $2.2\times10^{13}\ \nu / cm^2 / s$

1989 - A revised analysis by P. Vogel and J. Engel [P.R.,D39,3378(1989)] gave
$\mu_\nu \leq (2 - 4) \times 10^{-10}\ \mu_B$

1992 – Krasnoyarsk. G.S. Vidykin et al. [Pis'ma v ZhETPH, 55,206(1992)]
~ 100 kg liquid scintillator C_6F_6, 254 days "on"/78 days "off "
$\mu_\nu \leq 2.4 \times 10^{-10}\ \mu_B$ (90% CL)

1993 – Rovno. A.V. Derbin, L.A. Popeko et al. [JETP Letters, 57,768(1993)]
75 kg silicon multi – detector, 600 Si(Li) cells,
ν-flux of ~ $2\times10^{13}\ \nu / cm^2 / s$, 30 days "on"/17 days "off "
$\mu_\nu \leq 1.9 \times 10^{-10}\ \mu_B$ (95% CL)

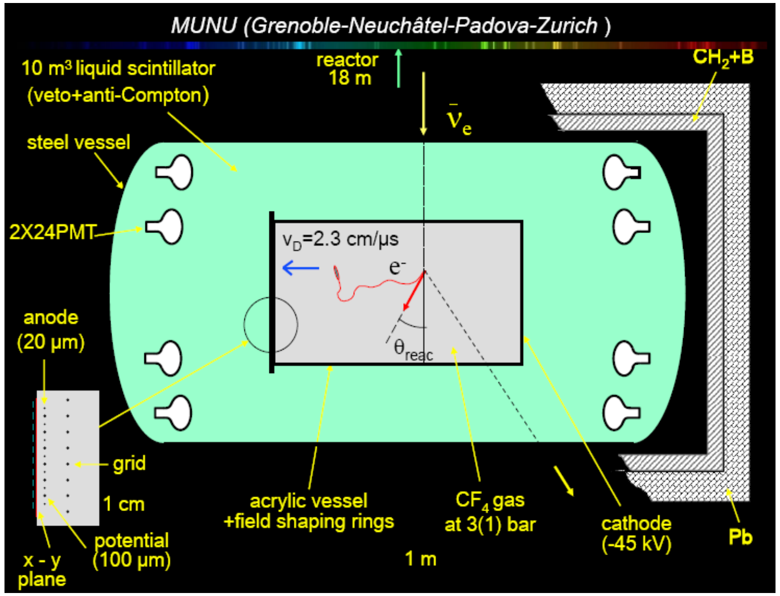
MUNU experiment

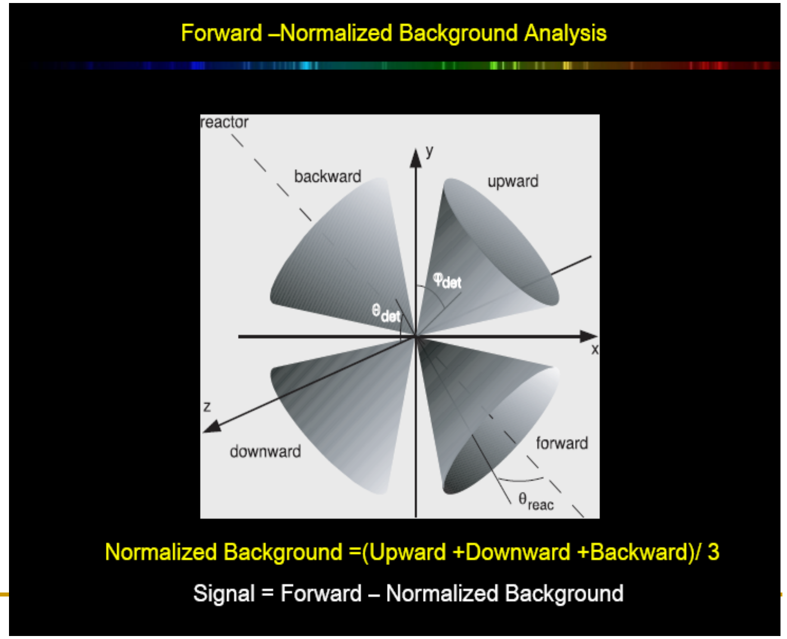
- France, Switzerland, Italy
- NPP (2800MWth) Bugey, France
- CF4 TPC total mass 11.4 kg
- Measurements e - scattering angle with respect to R core direction
- MUNU data (66.6 d ON/16.7 d OFF) [PLB 564, 2003; hep-ex/0502037]
- Limits depends on energy range taken :
  - T > 900 keV [PLB 564, 2003]

$\mu_\nu < 1.0 \times 10^{-10}\ \mu_B$ (90% CL)

  - T > 700 keV [hep-ex/0502037]

$\mu_\nu < 9.0 \times 10^{-11}\ \mu_B$ (90% CL)





TEXONO experiment

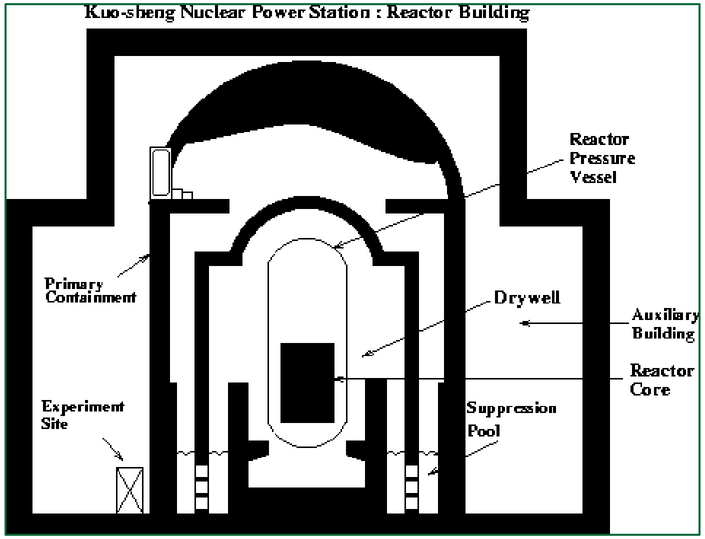
- **Collaboration: Taiwan, China, Turkey**

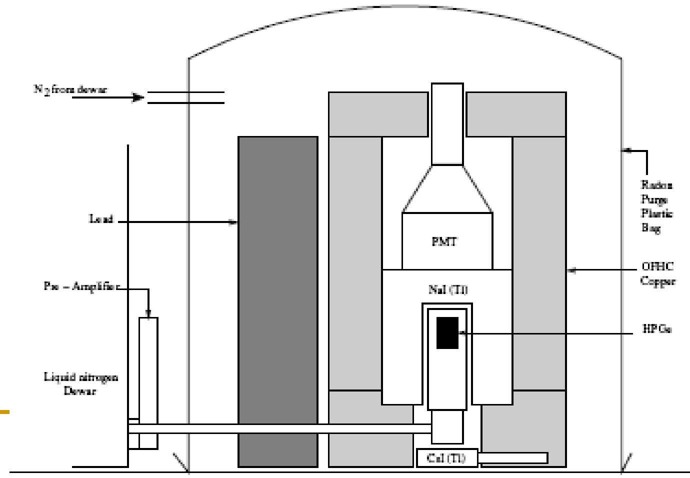
- **Kuo-Sheng PP in Taiwan. Reactor thermal power - 3 GW.**

- **Distance from center of reactor core 28**

  ν-flux equal ~ 7×10^{12} ν / cm ^{2} / s

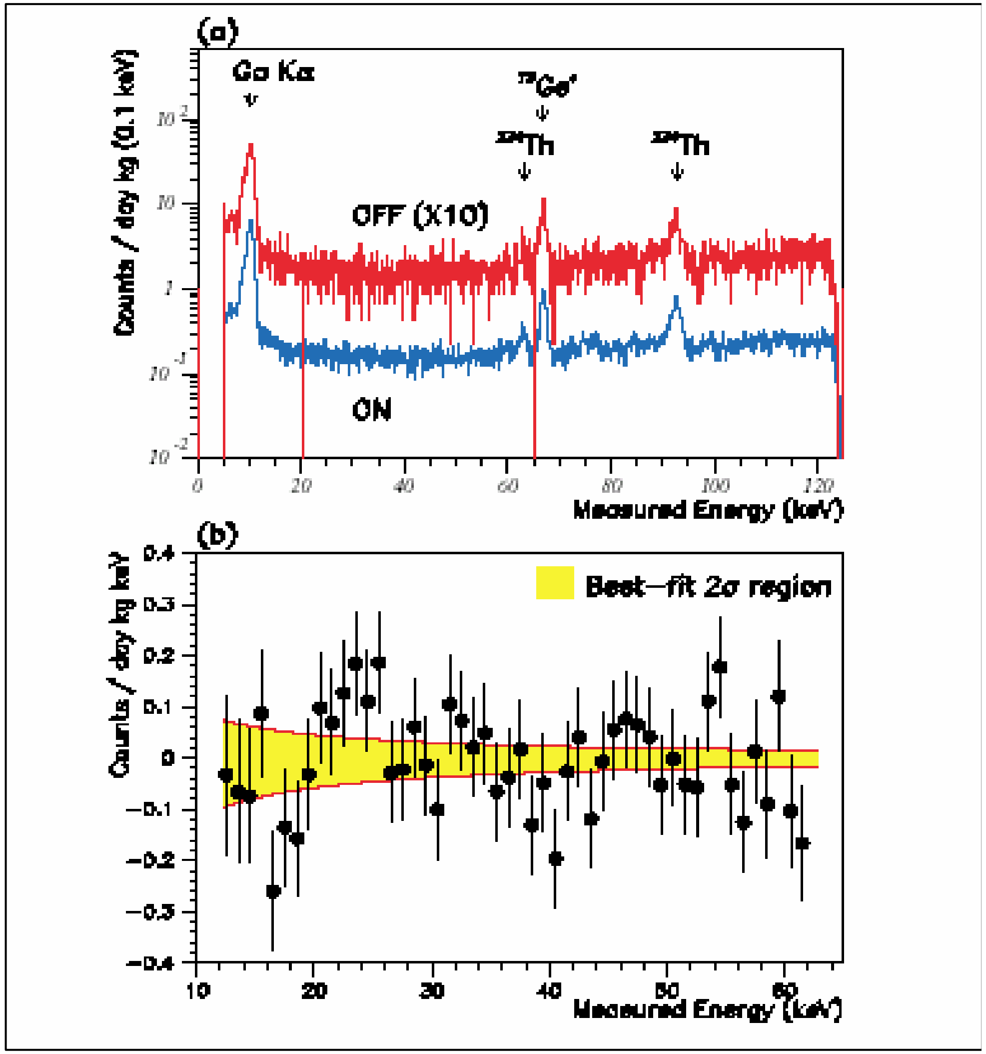
- **HPGe mass 1 kg enclosed by active NaI/CsI anti-Compton, further by passive shielding & cosmic veto**





TEXONO result

- **TEXONO data**
- **(197/52 days ON/OFF - 2003)**
  [PRL 90, 2003]
  (571/128 days ON/OFF - 2006)
  [hep-ex, 0605006]
- **BG level at 10-20 keV :**
  ~ 1 day^{-1} keV^{-1}kg^{-1} (cpd)
- **analysis threshold 12 keV**
- ***No excess* of counts ON/OFF comparison**
- **Limit:**
  $\mu_\nu < 7.2 \times 10^{-11}\ \mu_B$ (90% CL)



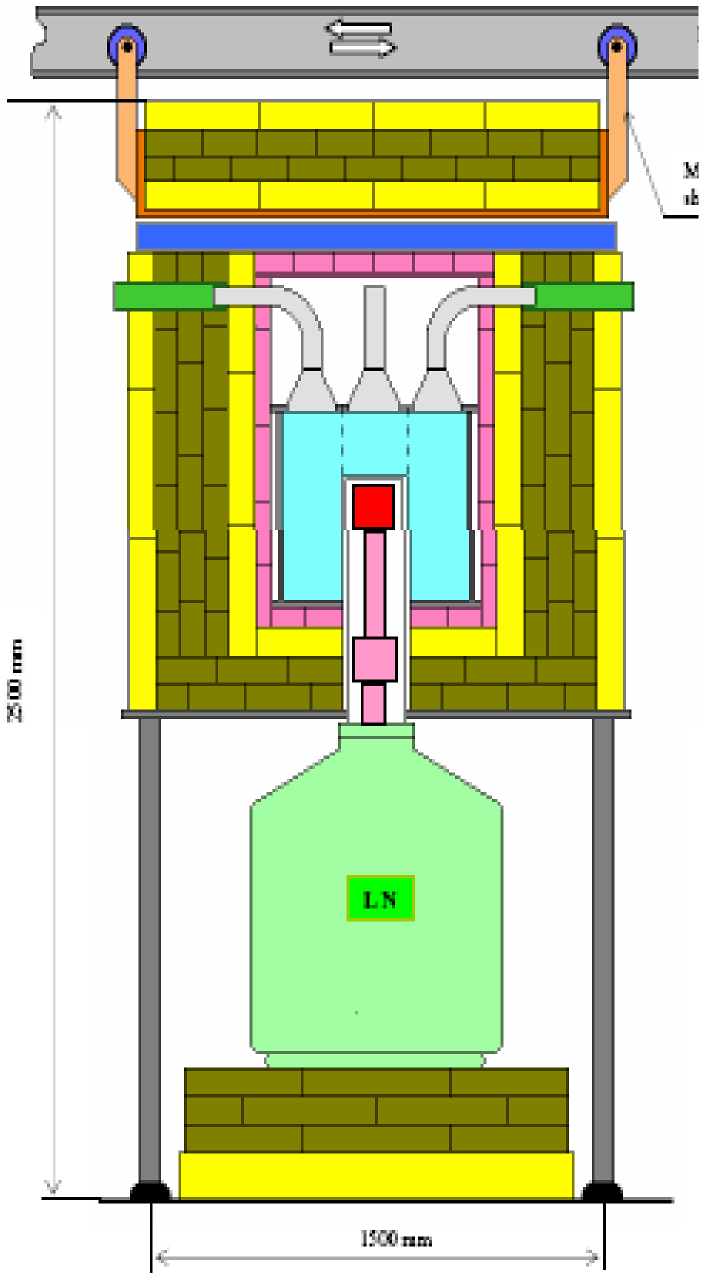
Experiment GEMMA

(**G**ermanium **E**xperiment for measurement of **M**agnetic **M**oment of **A**ntineutrino)

ITEP – LNP JINR Dubna

[Phys. of At.Nucl.,67,№11(2004)1948]

- Spectrometer includes a HPGe detector of 1.5 kg installed within NaI active shielding.
- HPGe + NaI are surrounded with multi-layer passive shielding – electrolytic copper, borated polyethylene and lead.
- Circuit noises were discriminated by means method of frequency analysis of signals.

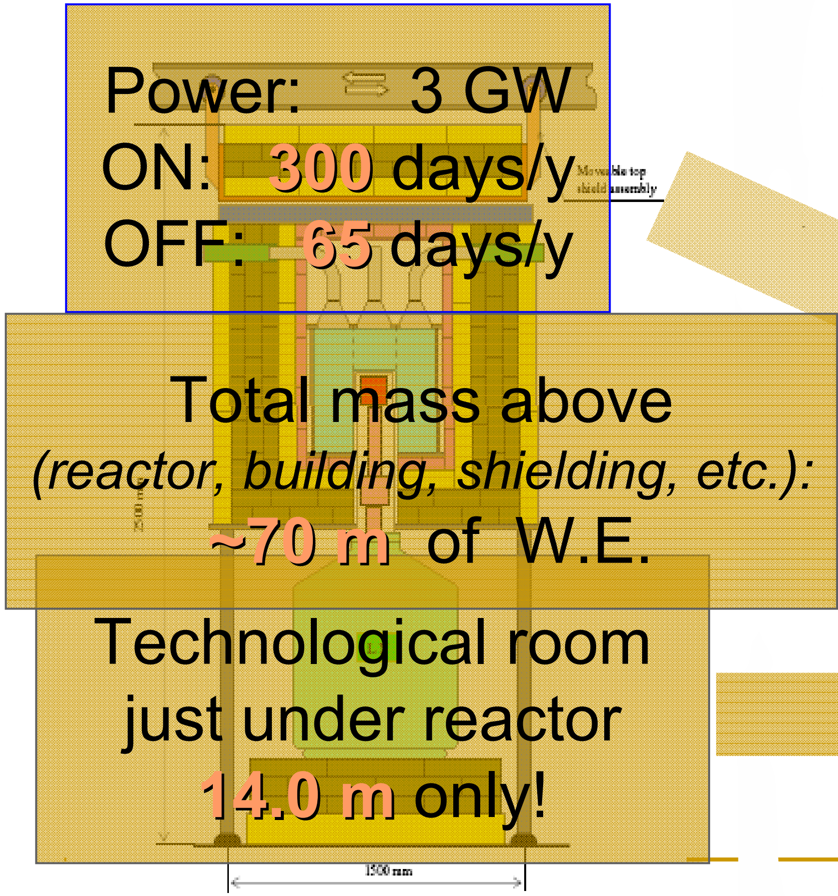


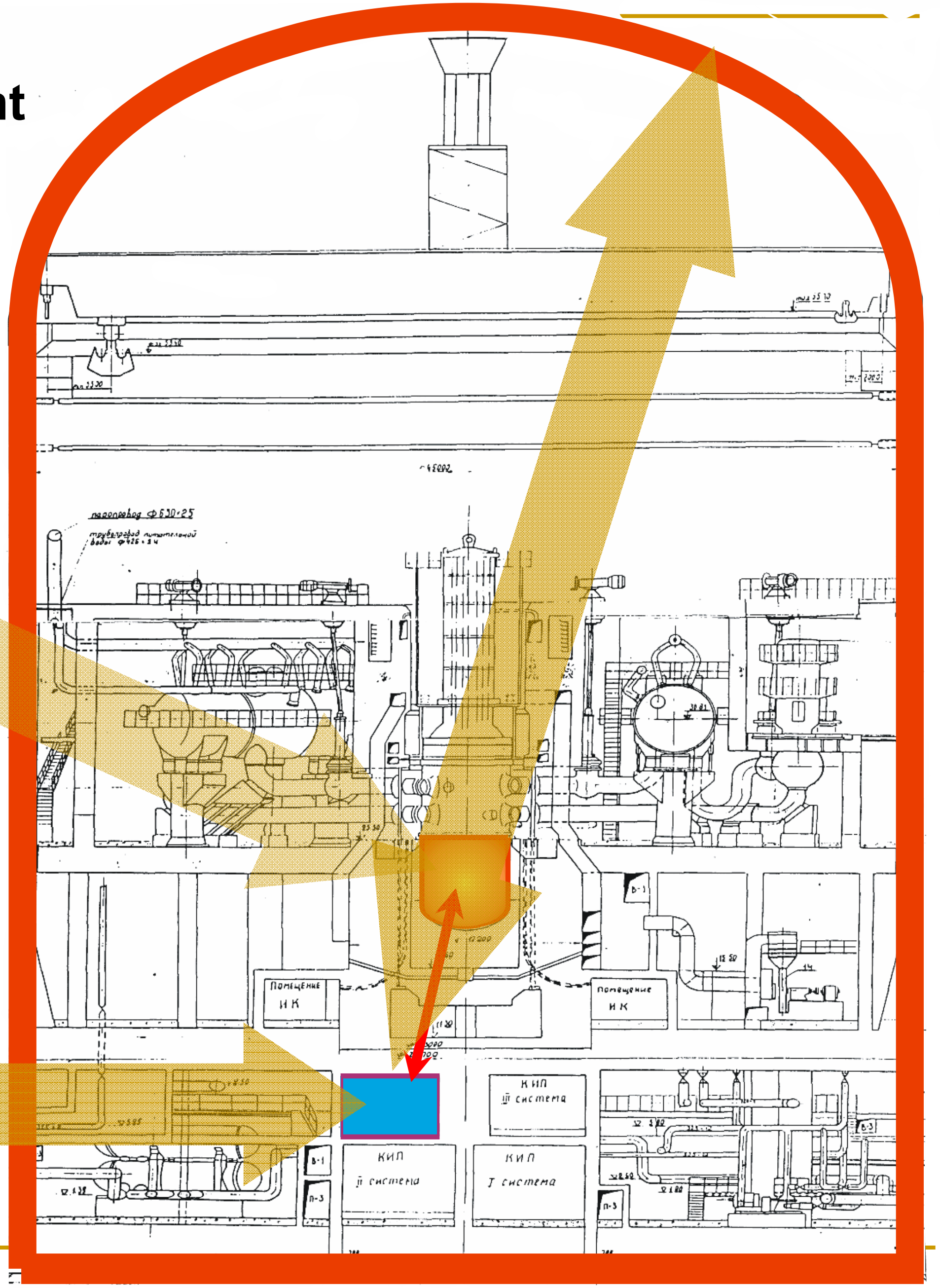
Reactor #2 of the "Kalininskaya" Nuclear Power Plant (400 km North from Moscow)

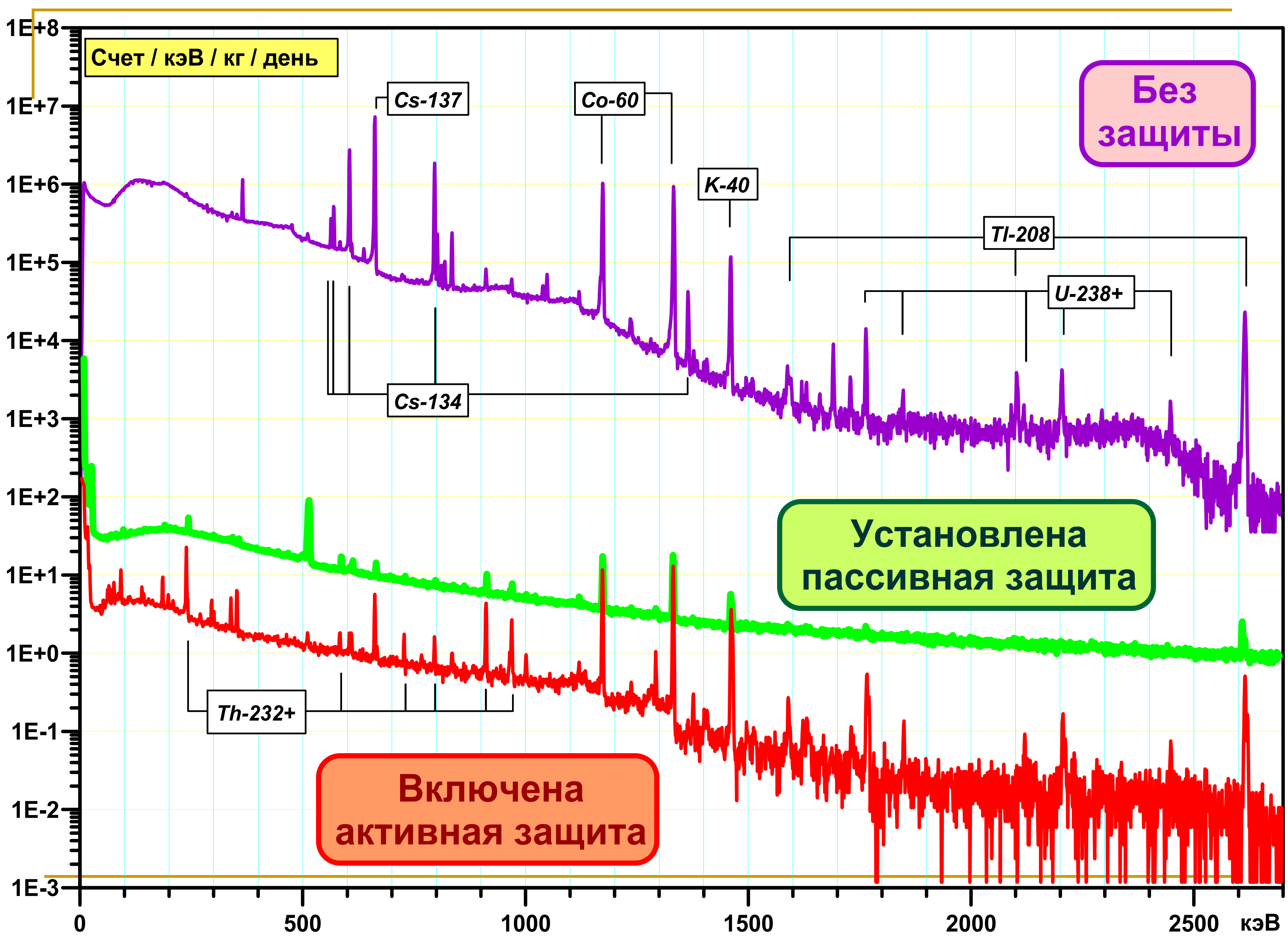
Power: 3 GW
ON: 300 days/y
OFF: 65 days/y

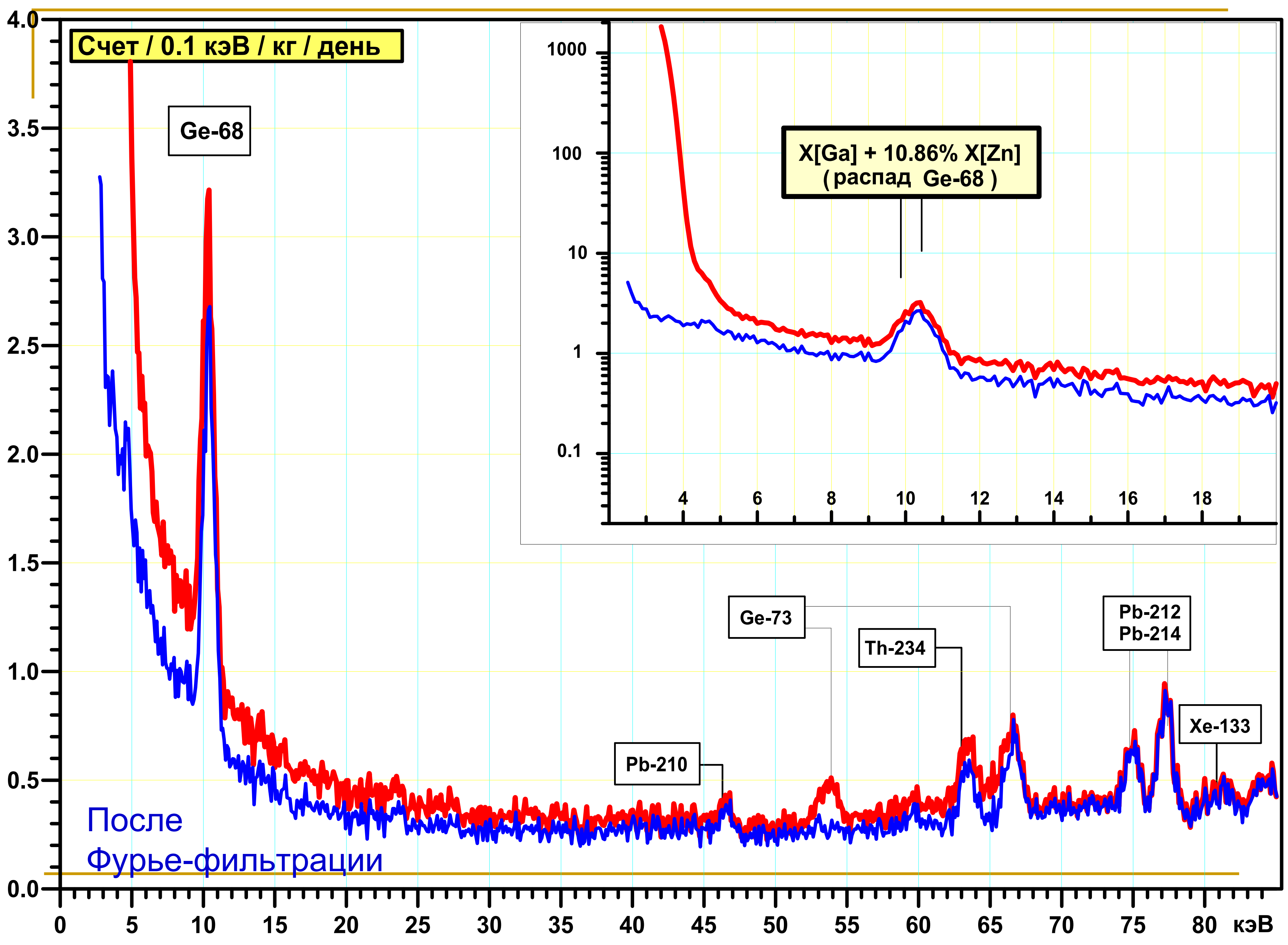
Total mass above
(reactor, building, shielding, etc.):
~70 m of W.E.

Technological room
just under reactor
14.0 m only!






Счет / кэВ / кг / день
Cs-137
Co-60
K-40
Tl-208
U-238+
Cs-134
Th-232+
Без защиты
Установлена пассивная защита
Включена активная защита
1E+8
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-3
0
500
1000
1500
2000
2500
кэВ



Счет / 0.1 кэВ / кг / день
Ge-68
X[Ga] + 10.86% X[Zn]
(распад Ge-68)
Ge-73
Th-234
Pb-212
Pb-214
Xe-133
Pb-210
После
Фурье-фильтрации
кэВ

Status : "on" 416.9 d / "off" 120.2 d – collected
"on" 216 d / "off" 77.2 d - processed

$$\mu_\nu \propto \frac{1}{\sqrt{N_\nu}}\left(\frac{B}{mt}\right)^{\frac{1}{4}}$$

- ***Nν*** : **number of signal events expected**
- ***B*** : **background level in the ROI**
- ***m*** : **target (=detector) mass**
- ***t*** : **measurement time**

$N\nu \sim \varphi_\nu \,(\sim Power / r^2)$

$\sim \log(Tmax \,/\, Tmin)$

GEMMA I 2005 – 2008

- φ_ν ~ **2.7 ×10^{13} ν / cm^2 / s**
- **t** ~ **3 years**
- **B** ~ **2.5 keV^{-1} kg^{-1} day^{-1}**
- **m** ~ **1.5 kg**
- **T**-th ~ **3.0 keV**

$$\mu_\nu \leq 4.2 \times 10^{-11}\,\mu_B$$

Preliminary result of the 1st year

- (anti)neutrino magnetic moment:

$$\boldsymbol{\mu}_{\nu} \leq 5.8 \cdot 10^{-11}\ \mu_B \ \ \textit{(90\% CL)}$$

\- *Available as hep-ex/0705.4576*

- Compared with the TEXONO experiment

$$\boldsymbol{\mu}_{\nu} \leq 7.2 \cdot 10^{-11}\ \mu_B \ \ \textit{(90\% CL)}$$

expected sensitivity in future experiments

GEMMA II 2009 - 2010

- **Distance: 14m → 10m**
- φ_ν ~ **5.4×10^13 ν / cm^2 / s**
- **t ~ 2 years**
- **B ~ 0.2 keV $^{-1}$ kg $^{-1}$ day^{-1}**
- **m ~ 6.5 kg (two detectors)**
- **T_{-th} ~1.5 keV**

$\mu_\nu \leq \mathbf{1.5 \times 10^{-11}}\, \mu_B$

BOREXINO claim (2010)

$\mu_\nu \leq \mathbf{3.0 \times 10^{-11}}\, \mu_B$

Summary

- For last years general results were obtained in reactor experiments

- Now best limit on NMM $\mu_\nu \leq 5.8 \cdot 10^{-11}\ \mu_B$ *(90% CL)*

- For three years the GEMMA II planes to reach sensitivity

  $$\mu_\nu \sim 1.5 \cdot 10^{-11}\ \mu_B$$