Yu.V. Grigoriev, D.V. Hliustin, O.N. Libanova

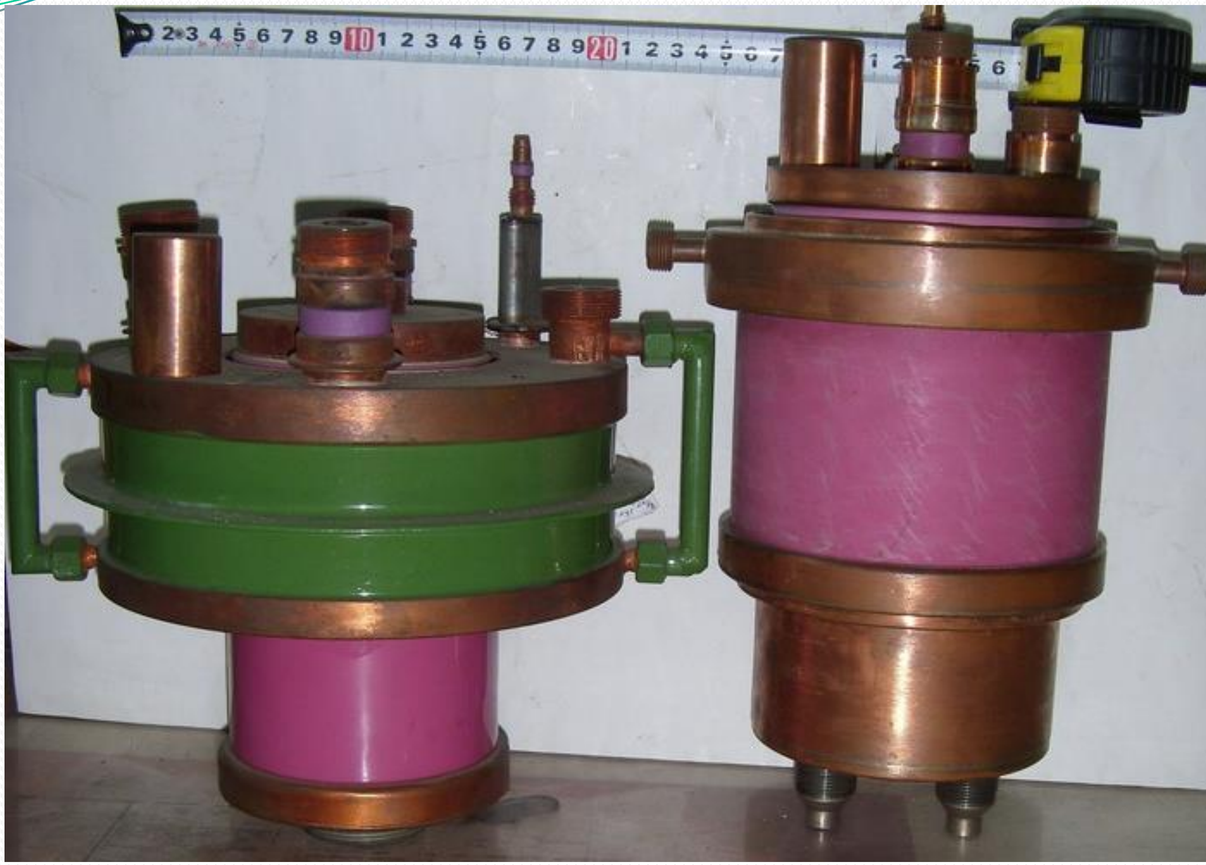
Measurements of transmittion and self-indication functions on samples of structural materials.

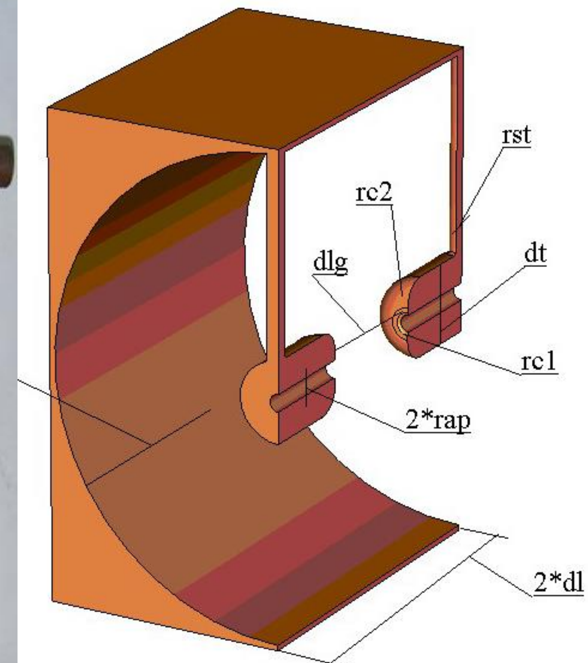
- Proton linac of Moscow Meson Factory.
  Injector 0-400 Kev, RFQ 400-750 kev,
  198.2 MHz Alvaretz 0.75-100 Mev,
  vaveguide 991 MHz accelerating structure 100 – 600 Mev.
  Pulsed power of single channel, both for 198.2 triode and for 991 MHz klystrone channel, was chosen 5 MW that is enough to accelerate pulsed current 100 mA. Mean project RF power of triode channel, garanted by producer, 500 kW for triode and 120 kW for klystrone channel.

- Project mean current and power are 0.5 mA (1 mA) and 300 kW (600 kW) for first (second) stage of launch. Rechargeable injection of H-minus into storage ring can provide on tungsten target 100 Hz of 2 Kilojoules 300 nanosecond pulses with mean beam power 200 kW.
  Project peak current, determined by space charge in storage ring, is 10 Amperes and provides peak power 6000 MW.

Gallery contains 33 channels of 991 MHz RF amplifiers, length is 360 meters.
Now achieved, experimentally proven proton energy is 502 Mev.
Significant part of time accelerator works for export metastable isotope production with energy 143 Mev, optimized for yield and purity of corresponding isotope.
During april 2016, accelerator was turned on with energy 209 Mev.

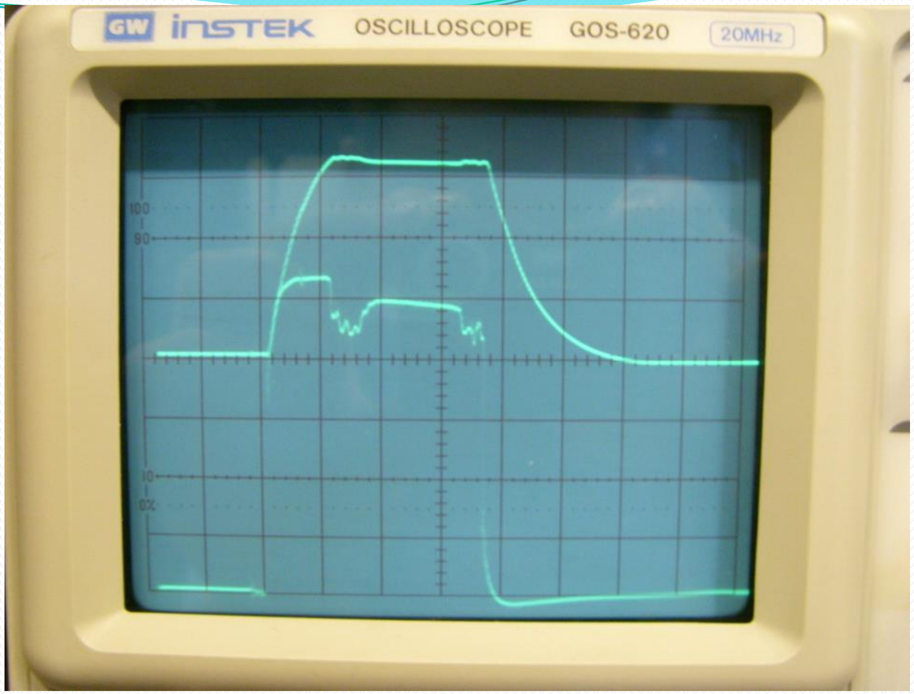
- At accelerating 991 MHz structure, those internal aperture is 40 mm, was achieved high quality of beam transporting and low levels of gamma-ray background activation.



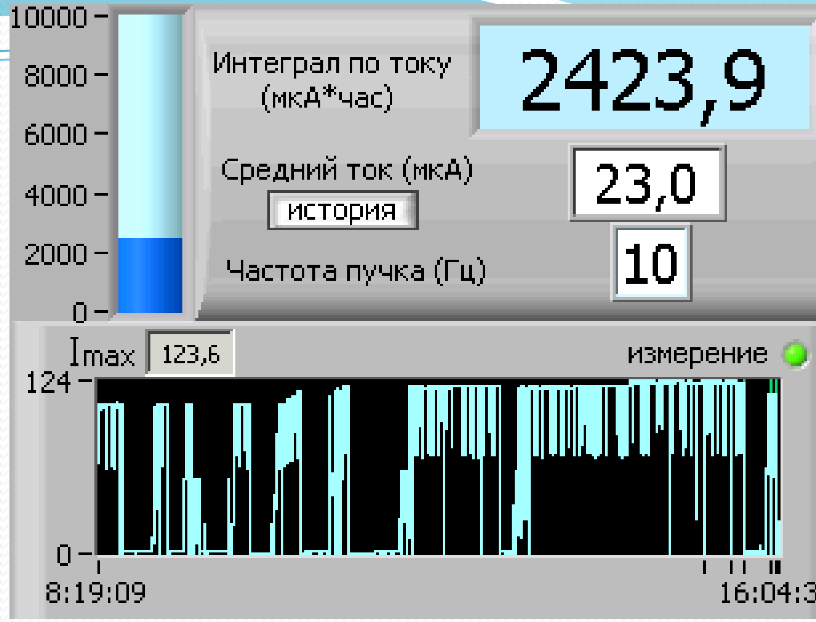


- Big work was done to remake preamplifier cascades:
  from using tetrodes GI-51A (left side) to use of triodes GI-57A (right side), which currently remain to be produced by industry.
  Pulsed power 300 kW at 198.2 MHz, efficiency 60%.

External cascades of all 7 RF 198.2 MHz amplifiers are now equipped by triode GI-71A (right side), which provides 3 MW of pulsed RF power and 140 kW of mean RF power.
Also as GI-57A, triode GI-71A is currently produced by industry.
This lamp is now also used in modulators.
Thus, installation of 14 triodes GI-71A and 7 triodes GI-57A succesfully provides RF power for Alvarets.
Previous design required 7 GI-54A, 7 GMI-44A for modulators and 7 GI-51A, which are not produced by industry.



- Klystrons provide 991 MHz RF power for main part of linac:
  Pulsed RF power 5 MW, mean RF power 120 kW.
  For proton energy 600 Mev must be installed 33 klystrons and 28 of them turned on.
  At the right picture stabilized RF field signal (upper curve) achieved during acceleration of pulsed current 16 mA. Modulator current (low curve) expresses that available even some reserve in pulsed RF power.



- Turning of proton beam while accelerator is turned on.
  Frequency 50 Hz is turned on after all gistogram is near zero.

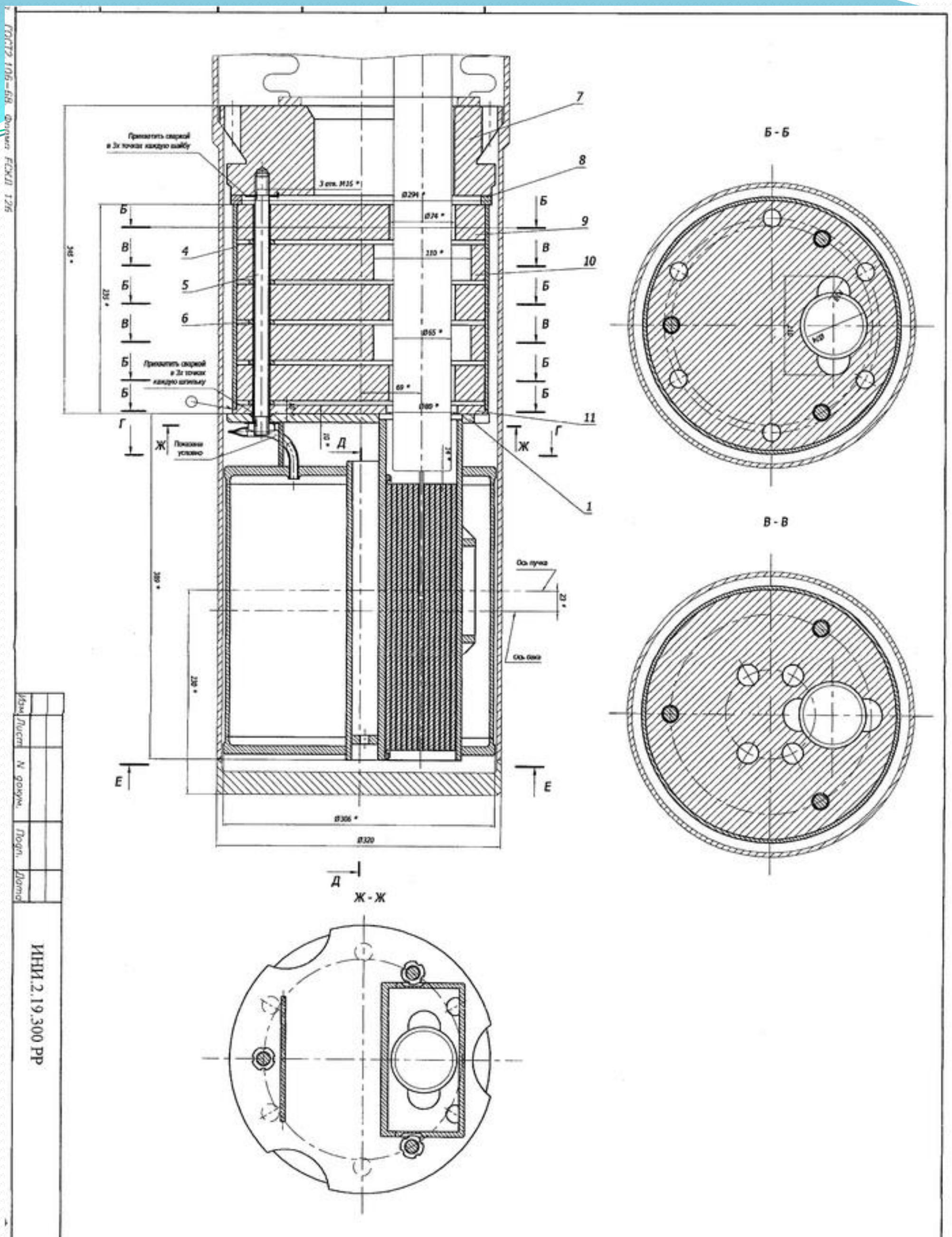
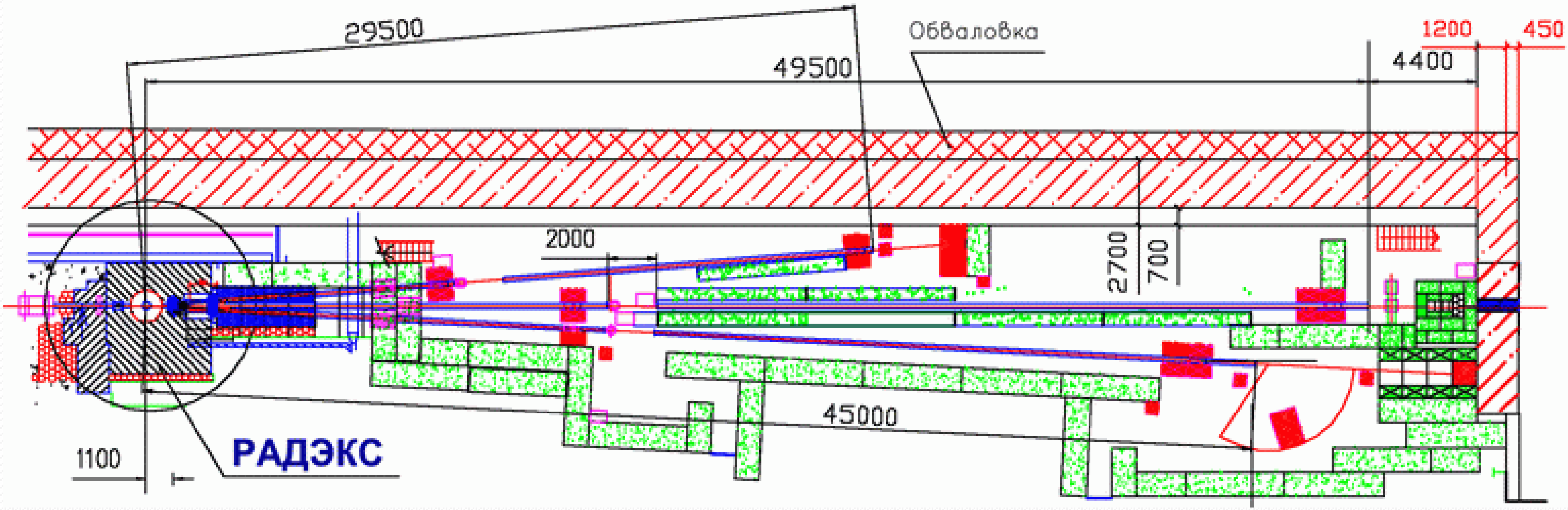


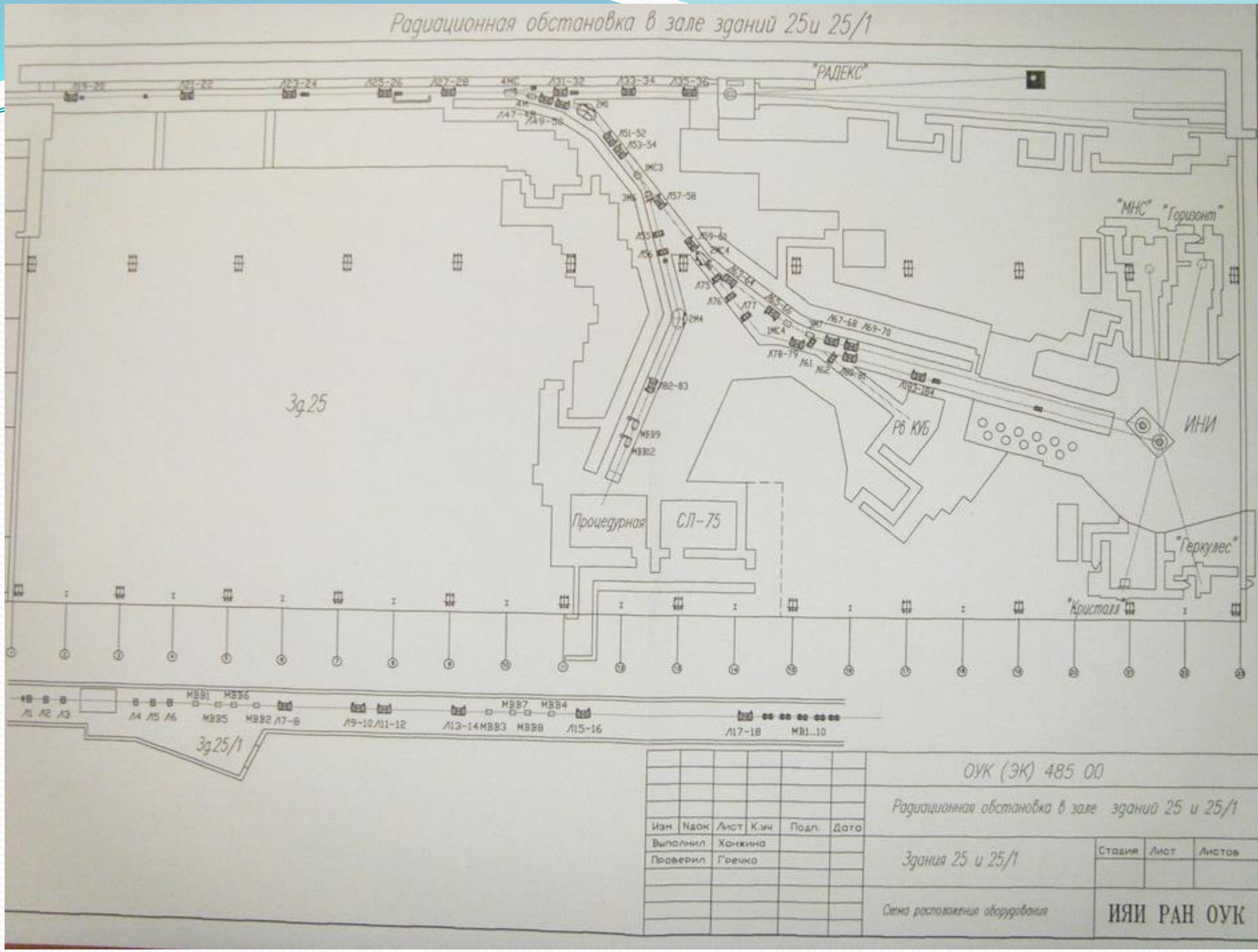
Рисунок 1 - Кассета в сборе

- Proton beam target of installation RADEX uses tungsten water cooled plates and water moderator, which is forming spectrum with cascade, spallation, resonance and thermal neutrons.
  Vertical channel is used both for irradiation of samples and for control of target temperature.



- TOF spectrometer RADEX has 4 evacuated neutron guides (3 horizontal and 1 vertical), two of them are currently 50 meters flight path. At frequency 50 Hz it corresponds to recycle neutrons energy 0.032 eV, so spectrums can be taken without cadmium filters.
  Measurements were held at the right 50 meter neutron guide.

- External view of RADEX facility.
  Concrete walls shielding provide ability to enter the experimental hall without switch off proton beam of the accelerator. So each experimental group can work independently during simultaneous measurements at few experimental installations.

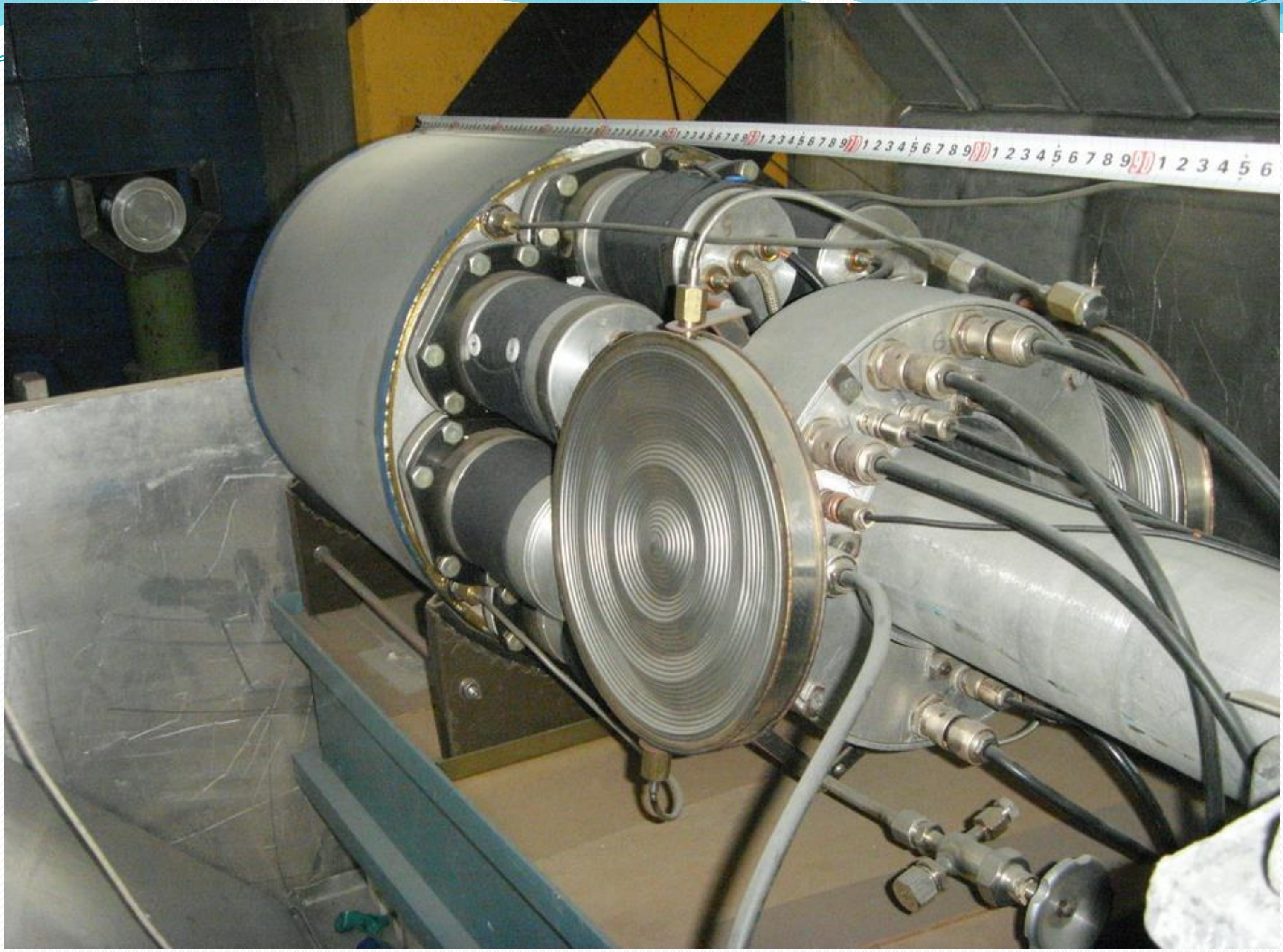


- During year 2015 beam transport equipment of the 25th experimental hall was significantly upgraded, high stability of beam achieved at all 4 installations, among them:
  * pulsed source of fast and resonance meutrons RADEX
- * pulsed source of thermal and cold neutrons IN-06
  * spectrometer by slowing neutrons in lead, 100 tonn lead cube SVZ-100
  * medicine facility

- Installation REPS is situated at the 50 meter flight base of RADEX. Aperture of the neutron guide is 200 mm.
REPS is designed for measurements of self-indication gamma ray spectra using multiplicity coincidences method. Its electronic equipment includes opportunity to change upper and lower thresholds of registered signals for turning of measurement of different samples.
Co-60 and Cs-137 standard gamma sources are used for calibration before measurements.

- For providing better gamma-ray background conditions, during year 2015 the 40-sm thickness lead wall around neutron guides was made at 12 meter flight path of RADEX.

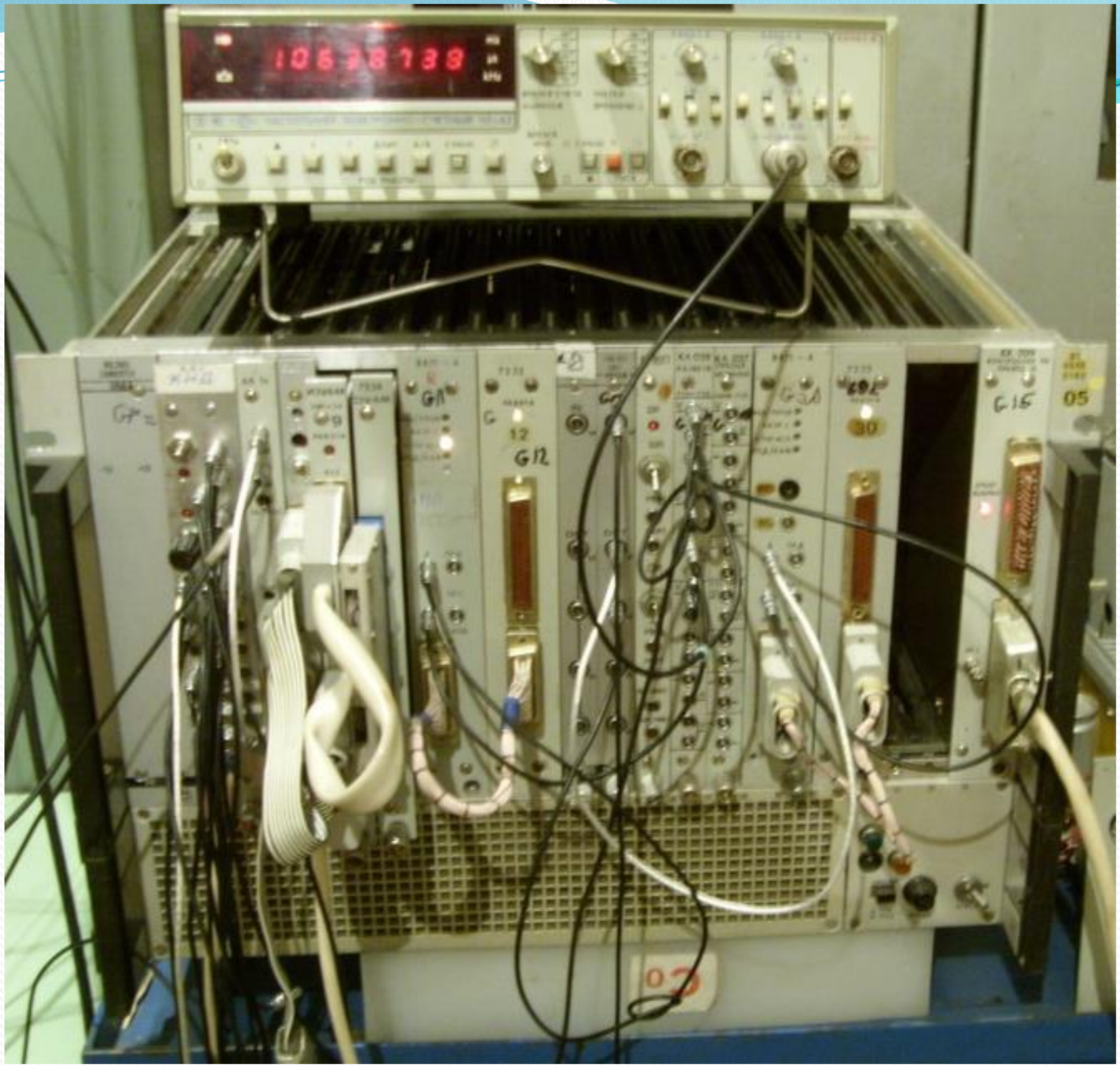
- Gamma rays were detected using a 8-sectional liquid scintillator consisting of 86% tholuol ($C_6H_5CH_3$) and trimethylborate ($B(OCH_3)_3$) by volume, where boron was enriched to 94% in B_{10} to capture the scattered neutrons. The liquid scintillator is contained in 40-liter cylindrical tank with 10 cm perforation in center. The total gamma detection efficiency amounts to about 30%.



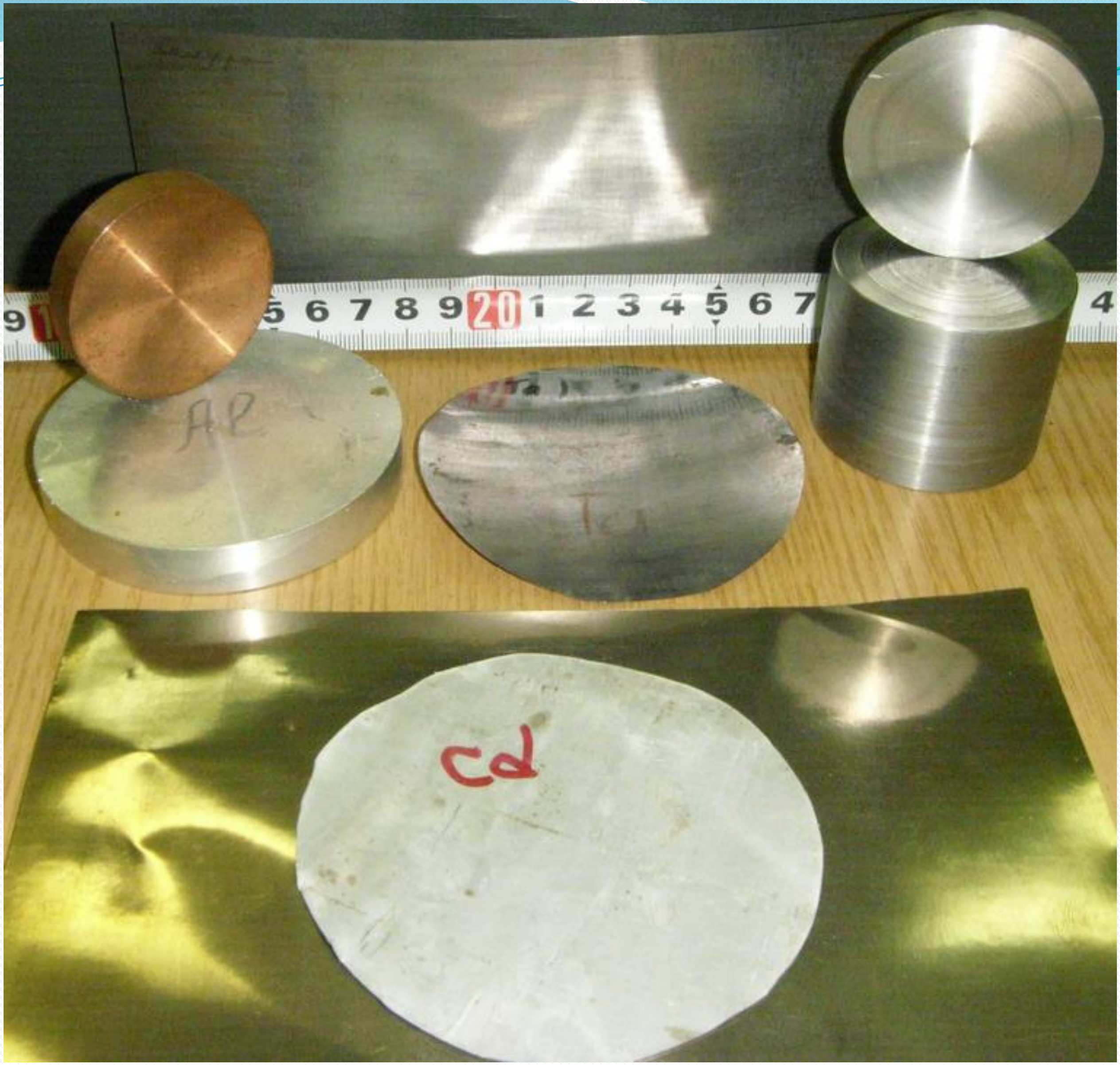
- Gamma-detector with 8 FEU-110s is installed after the evacuated neutron guide, samples are installed inside the detector. Helium-3 monitor is installed before beam trap, MnO2 filter was installed between gamma detector and neutron source.

- Photomultipliers FEU-110 are used in 8-sectional liguid gamma-detector.

- High efficiency helium-3 counter was used as proton beam intensity monitor.

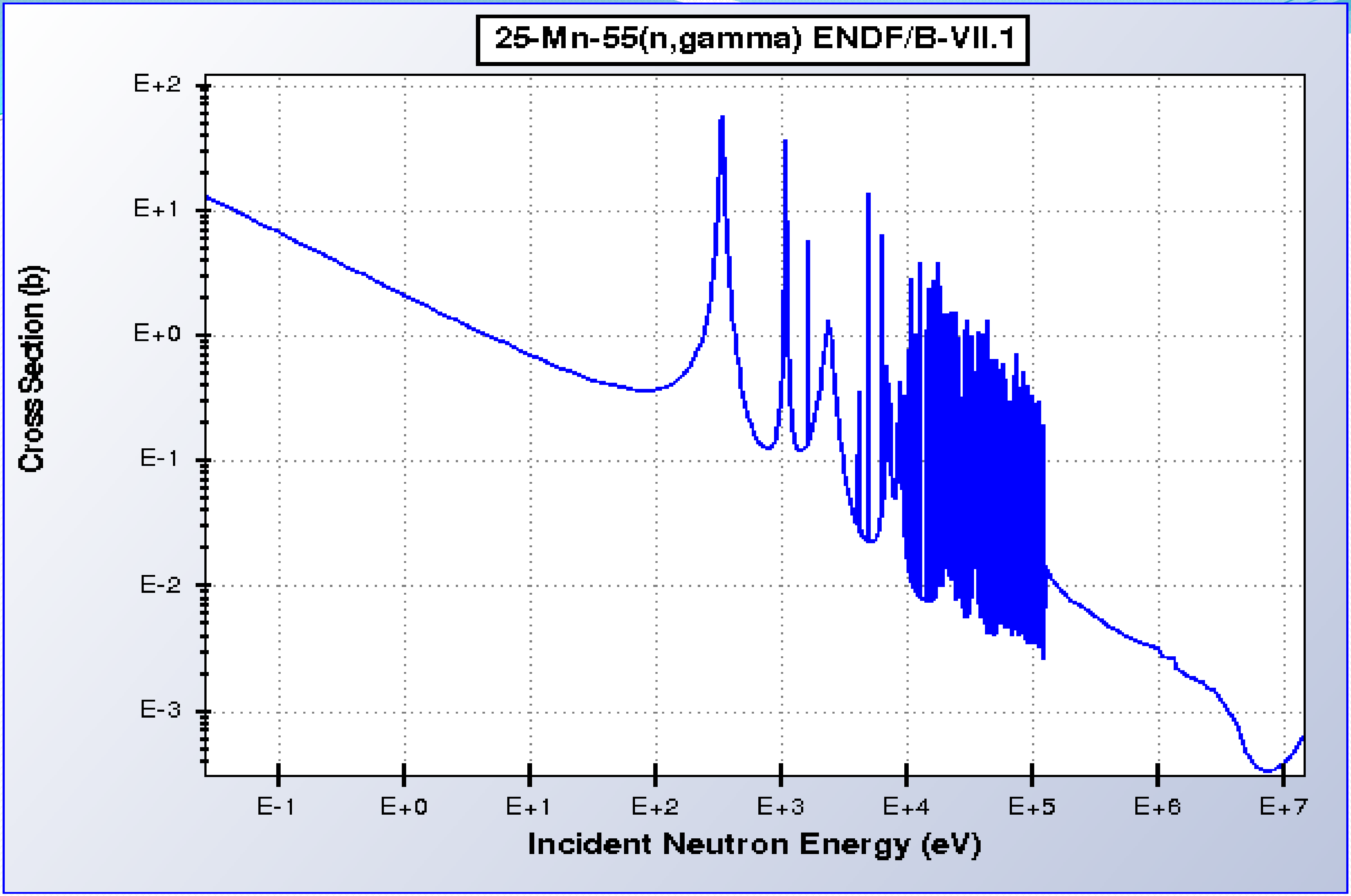


- Old measurement system made in CAMAC standard is used to control correctness of new fast system's work. Minimum time width is 1 microsecond, maximum data receiving frequency 80 kHz.
New measurement system at crystal frequency 60 MHz provides time channel 121 nanosecond and data collecting frequency 2 MHz.

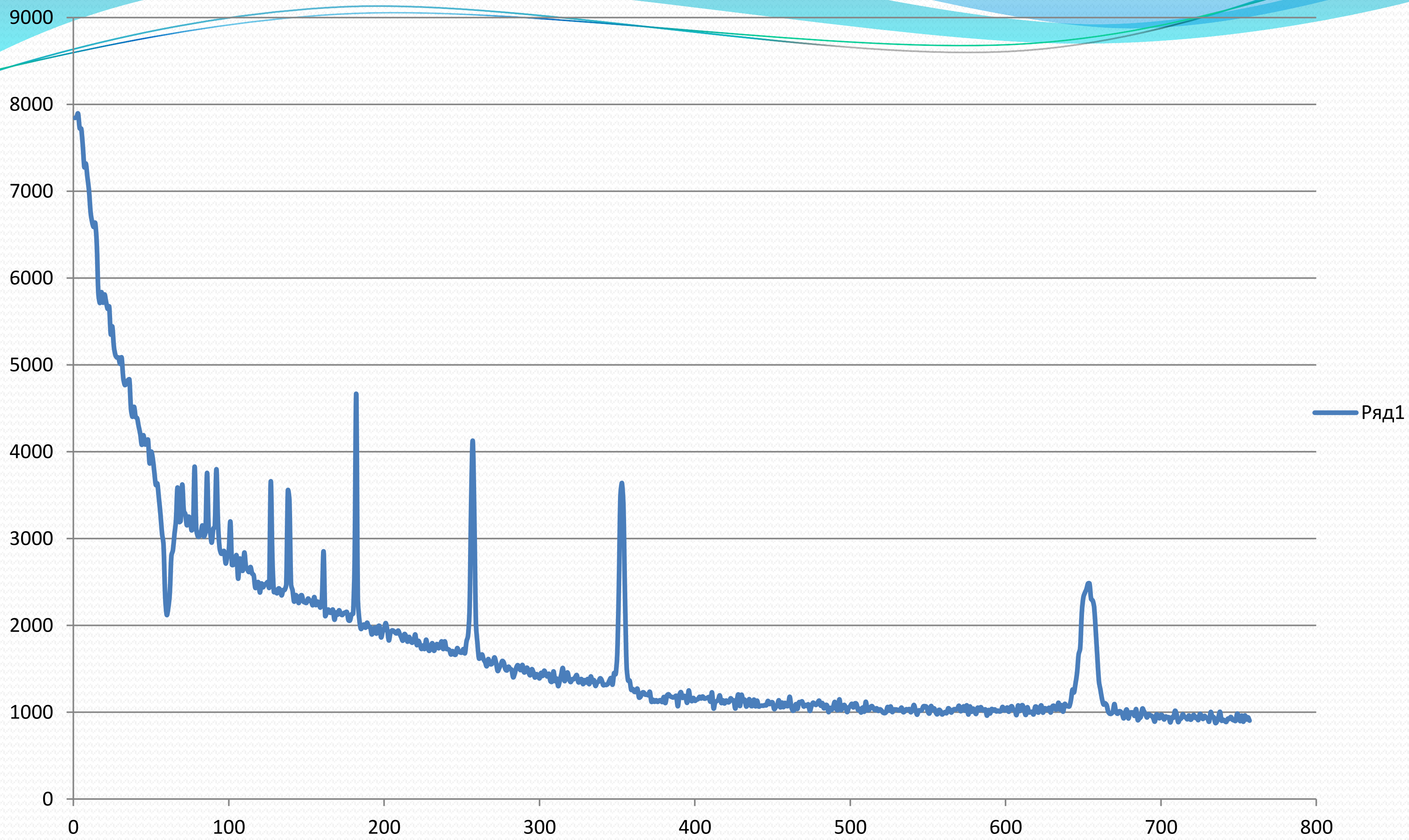


- Some of radiator samples (Ta, Fe, etc) which were used during measurements. Cadmium was used as a filter to determine thermal neutron spectrum component.

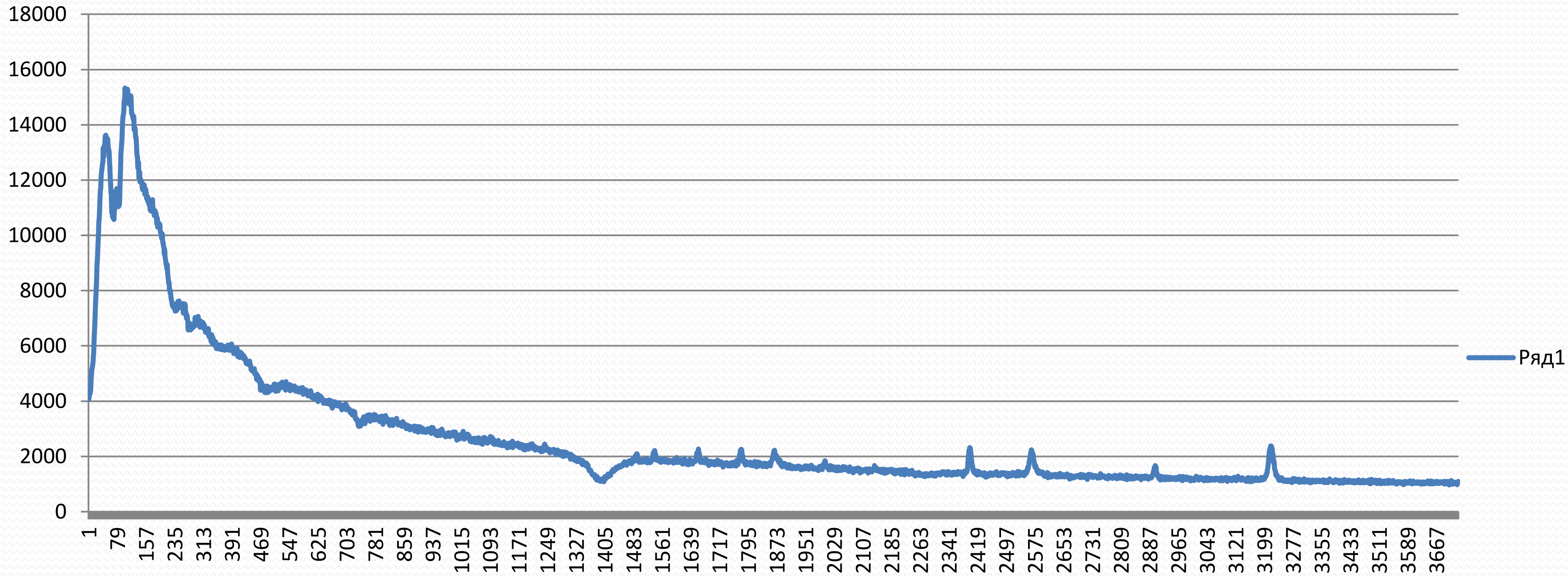
- Natural uranium U3O8, mass 100 g. Right dosimeter indicates gamma background due to decay of U238 and its products. Left dosimeter shows spontaneous neutrons fission background.



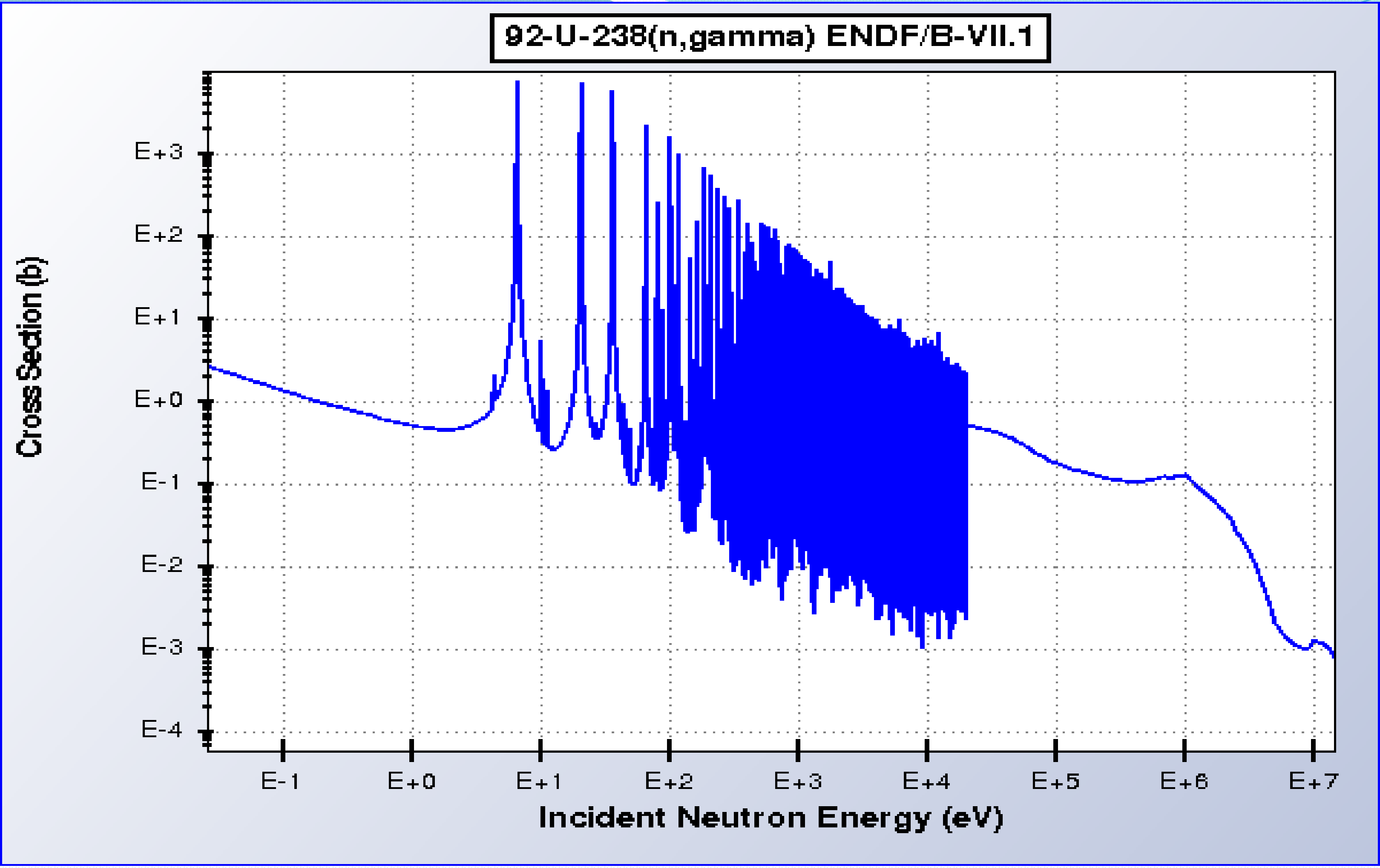
- Cross capture of Mn55, which was used as a filter. Energy of first resonance is 337 ev, 4^{th} resonance is at neutron energy 2327 ev.



- U238 measured by ROM system (part of spectrum).
  Beam pulse length is 1 mksec, channel width 1 mksec, L=50 meters, spectrometer resolution 28 ns/meter.



- U238 with Mn55 filter measured by new fast data accumulation system.
  Beam pulse width is 1 mksek, channel width was chosen 121 nanosecond, energy resolution of spectrometer is 20 nanosecond/meter.
  Mn55 resonances are observed at 337 ev, 2327 ev and higher.



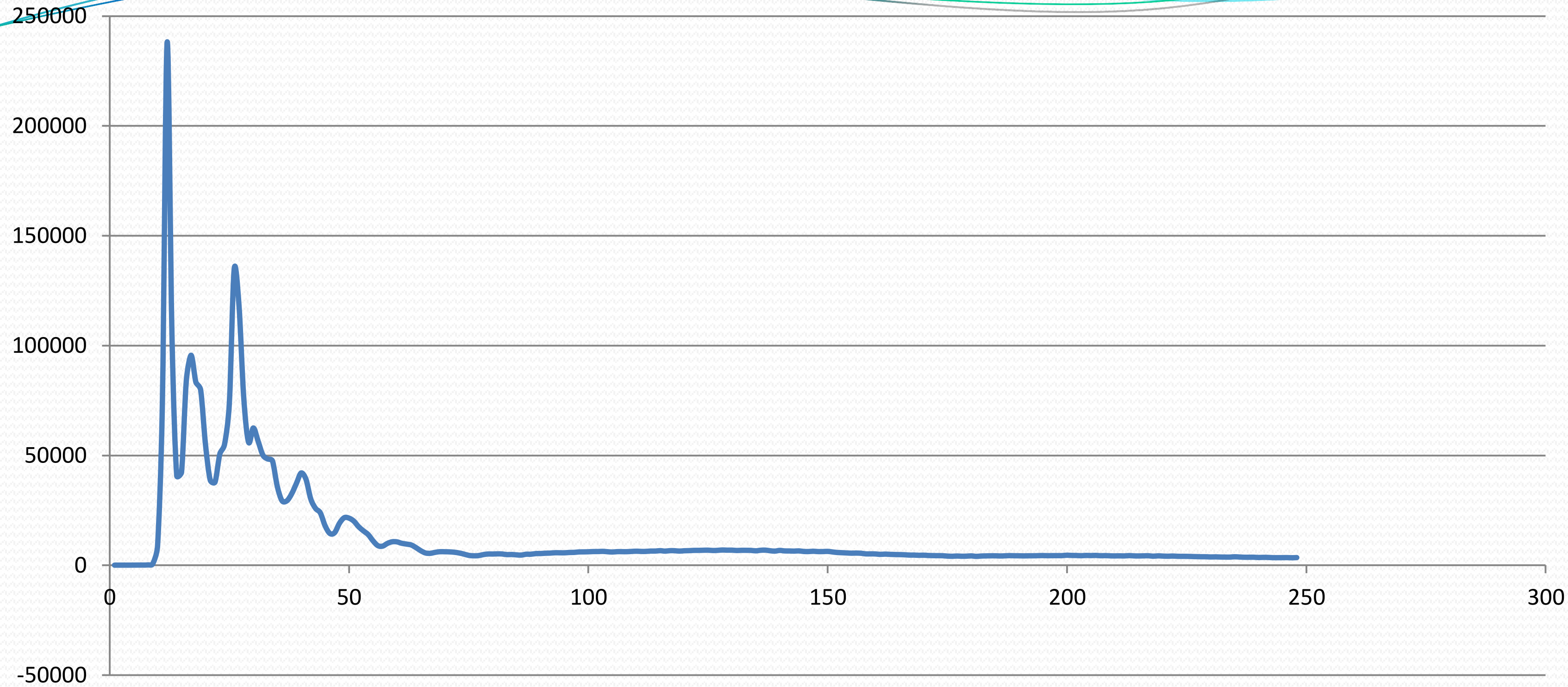
- U238 capture cross section (BNL). First resonance is at 6.7 ev.

Calculated energy resolution of TOF spectrometer at flight path 50 meters during beam length 1 microsecond. Energy borders from constant system BNAB-78

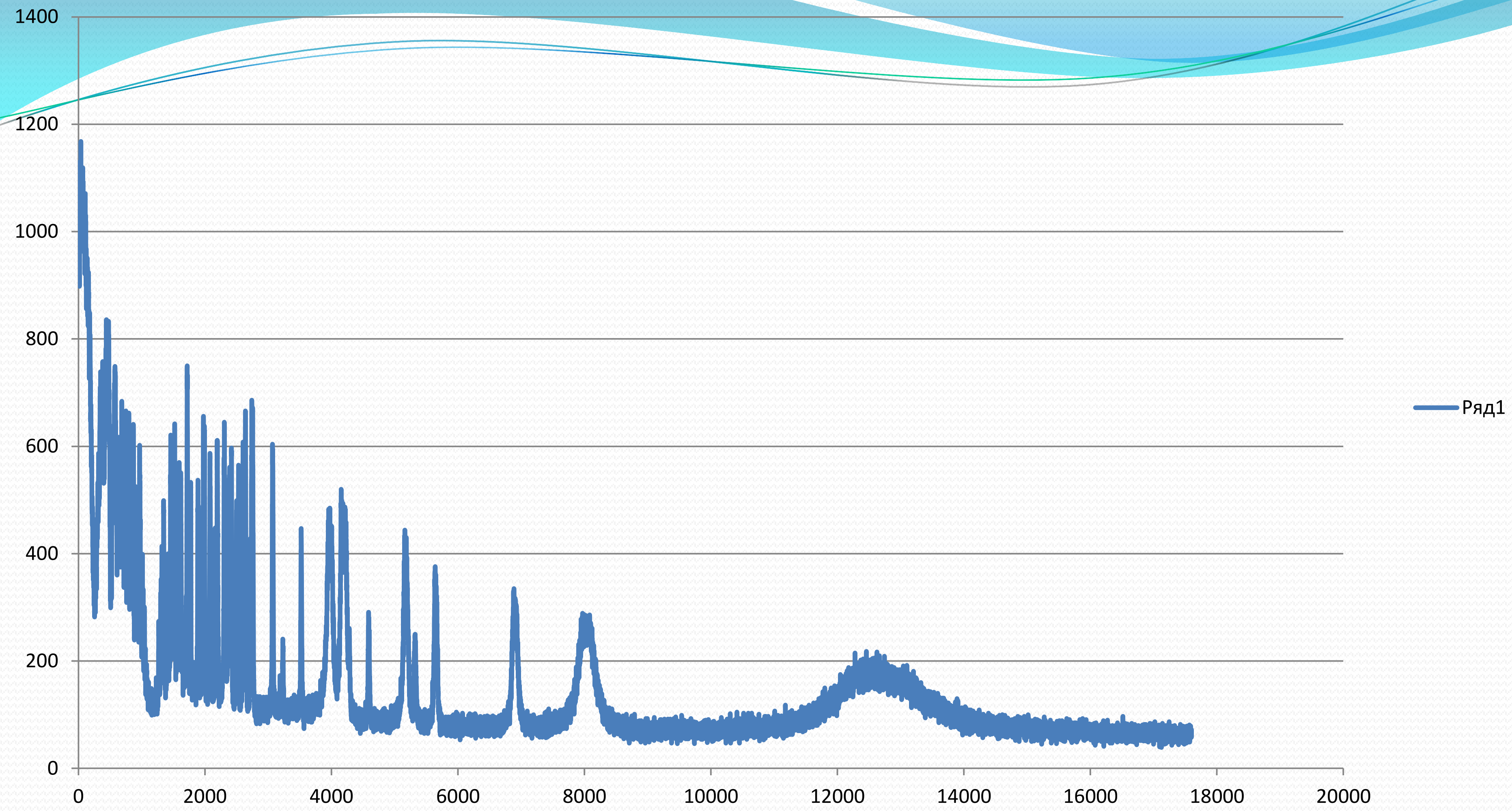
Group number	Upper border	Lower border	ΔE, ev	ΔE/E	Time from synchro-pulse, μs	Channel number at width 121 ns
-1	14.5 Mev	14.0 Mev	29E6	2.07	0.95	8
0	14.0 Mev	10.5 Mev	19E6	1.80	1.103	9
1	10.5 Mev	6.5 Mev	9.28E6	1.42	1.402	12
2	6.5 Mev	4.0 Mev	4.48E6	1.12	1.787	15
3	4.0 Mev	2.5 Mev	2213594	0.885	2.261	19
4	2.5 Mev	1.4 Mev	927641	0.662	3.021	25
5	1.4 Mev	0.8 Mev	400703	0.500	3.997	33
6	0.8 Mev	0.4 Mev	141670	0.354	5.652	47
7	0.4 Mev	0.2 Mev	50087	0.250	7.994	65
8	0.2 Mev	0.1 Mev	17708	0.177	11.30	93
9	0.1 Mev	46.5 Kev	5615	0.12	16.58	137
10	46.5 Kev	21.5 Kev	1765	0.082	24.38	201
11	21.5 Kev	10.0 Kev	560	0.056	35.75	295
12	10.0 Kev	4.65 Kev	177	0.038	52.42	433

Calculated energy resolution of TOF spectrometer at flight path 50 meters during beam length 1 microsecond. Energy borders from constant system BNAB-78

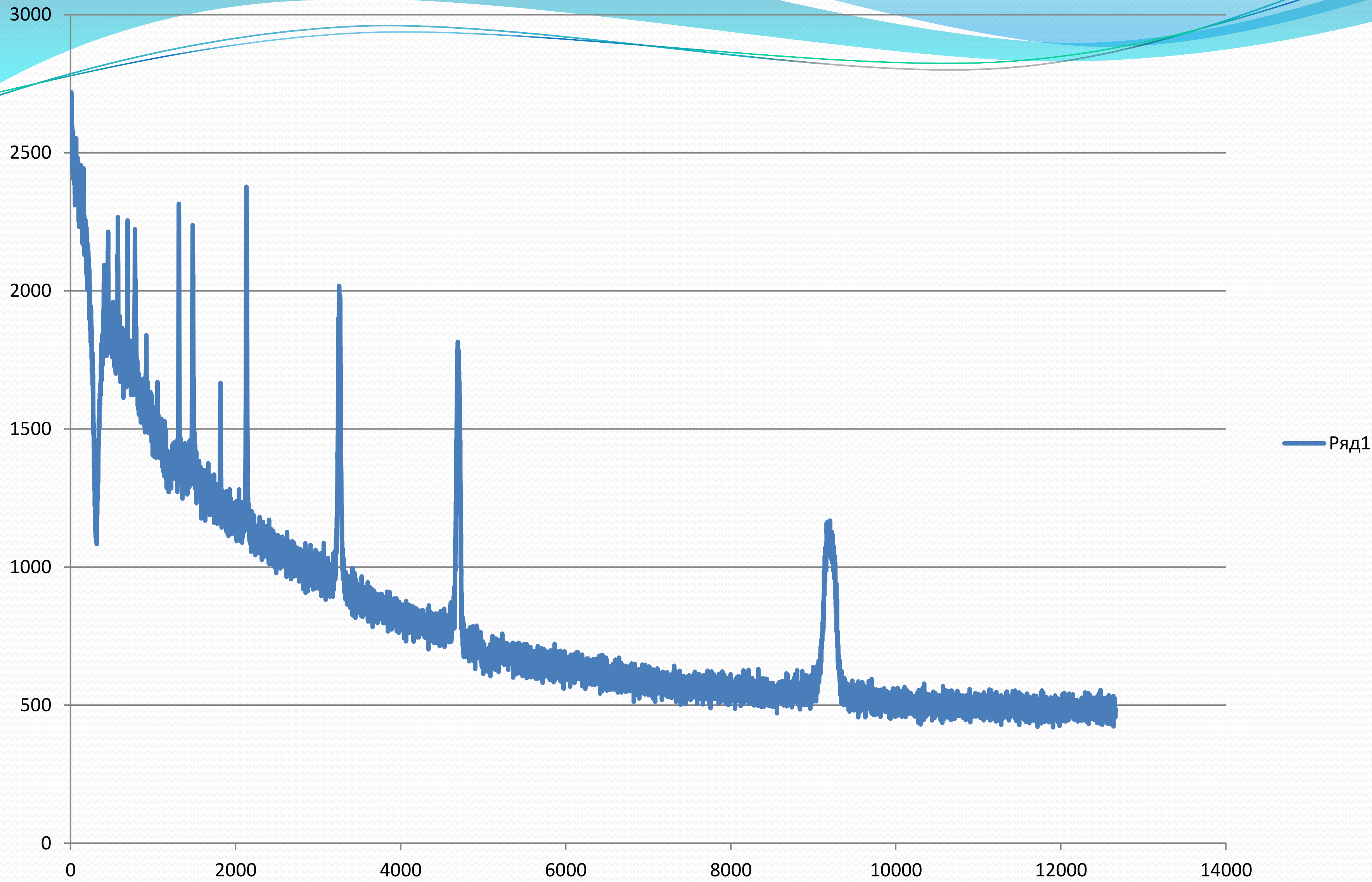
Group number	Upper border	Lower border	ΔE, ev	ΔE/E	Time from synchro-pulse, μs	Channel number at width 121 ns
13	4.65 Kev	2.15 Kev	55.8	0.026	77.10	637
14	2.15 Kev	1.00 Kev	17.7	0.0177	113.0	933
15	1.00 kev	465 ev	5.56	0.0119	165.7	1369
16	465 ev	215 ev	1.77	0.0082	243.8	2014
17	215 ev	100 ev	0.556	0.00558	357.5	2954
18	100 ev	46.5 ev	0.177	0.0038	524.2	4332
19	46.5 ev	21.5 ev	0.056	0.0026	771.0	6372
20	21.5 ev	10.0 ev	0.0177	0.00177	1130	9339
21	10.0 ev	4.65 ev	0.0056	0.0012	1657	13694
22	4.65 ev	2.15 ev	0.00177	0.00082	2438	20148
23	2.15 ev	1.0 ev	0.00056	0.00056	3575	29545
24	1.0 ev	0.465 ev	0.000177	0.00038	5242	43322
25	0.465 ev	0.215 ev	0.000056	0.00026	7710	63719
Thermal	0.0253 ev	-------------		----------	22475	185743



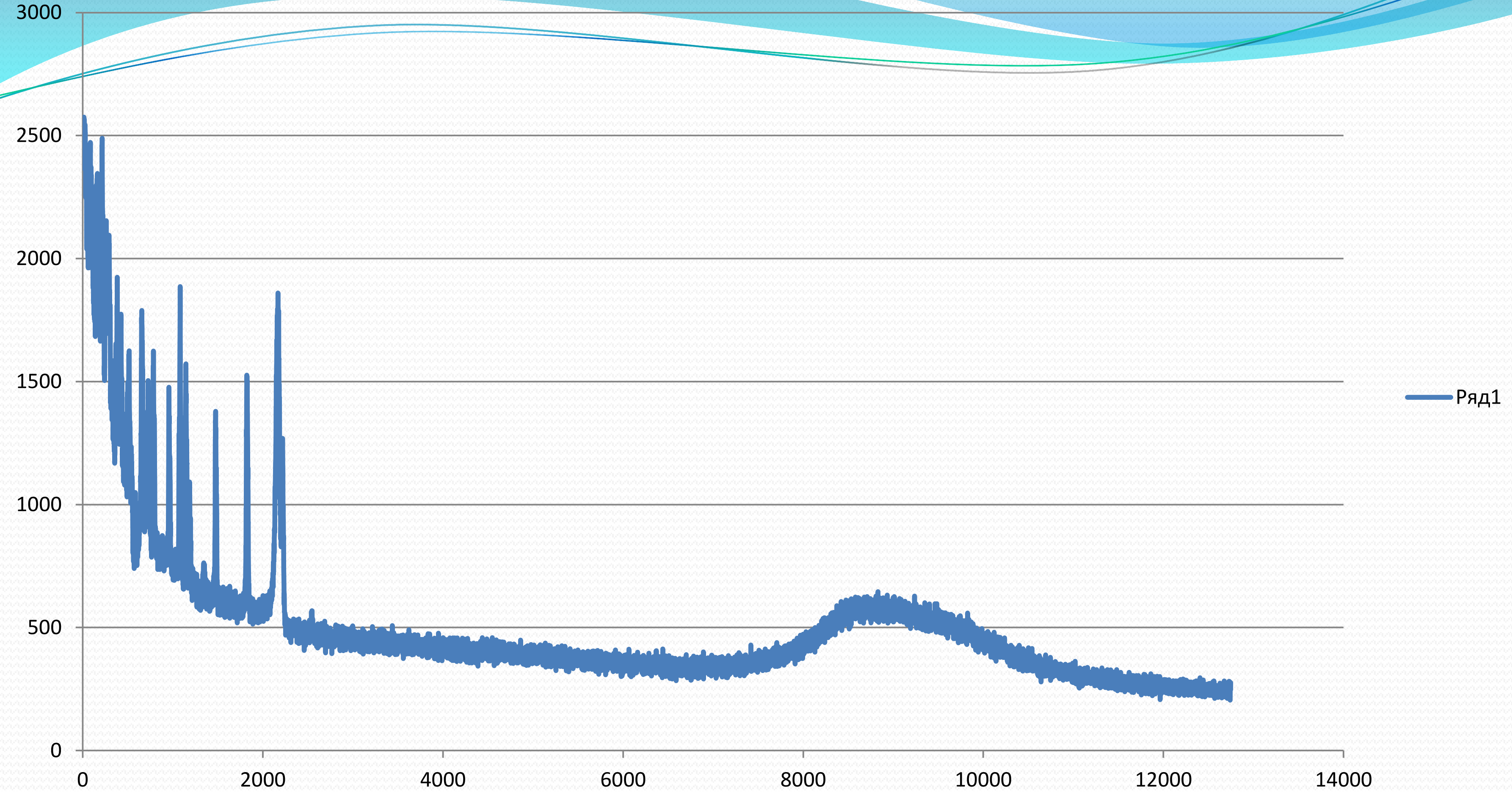
- 'Beam' structure:
  first pulse can be caused by target gamma rays,
  second by cascade neutrons,
  third - spallation spectra modified by tungsten alloy resonances.
  Channel width 121 nanoseconds.



- Tantalum-181 measured at 50 meters.
  Beam 1 mksec, channel 121 nanoseconds.



- Natural uranium at 50 meters, beam 1 mksek, channel 121 nanosecond. At 337 ev is observed resonanse of Mn55 used on neutron guide as filter



Sample of Au197 measured at 50 meter TOF spectrometer base of pusled source RADEX during April 2016. Proton beam 1 mksek, channel width 121 nanoseconds.

Results:

* Energy resolution allows to observe separate resonances on nucleus with high level density, like Uranium-235, to energy 200 ev.

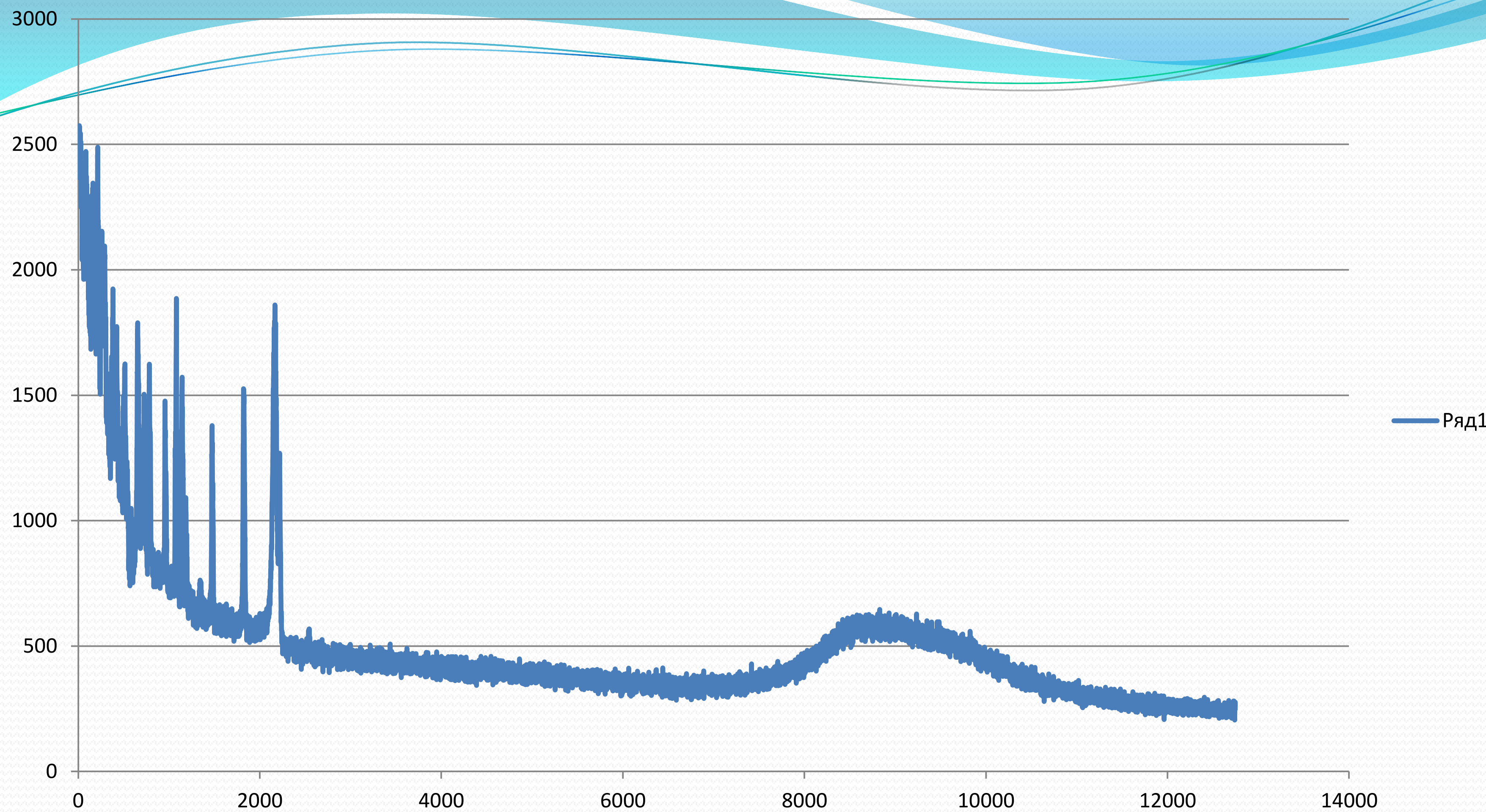
* Existing neutron source intensity and territory of INR allows to increase TOF base from 50 meters inside experimental building to 200 or even 500 meters and increase spectrometer energy resolution.

* All spectrum of fast sodium reactors, 14 Mev>En>50 Kev, is contained in the first 130 channels of data collection system at time channel width 121 nanoseconds. Energy resolution even in current state of spectrometer is enough for measurements of subcritical assembly's neutron spectrum, usual for fast neutron reactors BN-600 and BN-800.

* For measurements of pure fissile material spectrums, with average energy about 2 Mev, it is necessary to increase length of spectrometer neutron guides.

* Spallation neutron source, compared to subcritical reactor and some other types of sources, has excellent background conditions.

* Spectrometer energy resolution is enough to measure capture cross sections of construction materials in BNAB-78 energy borders. When alloy contains separated isotopes of Cr, Ni, Ti, W, rare earth elements, it is possible to check separation quality by direct measurement of alloy group capture cross sections on TOF spectrometer, even in the energy range upper then resolved resonances.



Acknowledgments

- The authors devote this work to memory of professor Yu.V.Grigoriev and would like to express their sincere thanks to the staff of the INR Accelerator Department for high stability of beam and to professor Yu.V.Ryabov who gave thick plate of Au-197 for measurements.