Report on JINR activities and tasks accomplished in 2013 in Laboratoire Souterrain de Modane

Dubna, 2013

December 2013

Report on JINR activities and tasks accomplished in 2013 in frame of agreement about “Joint Underground Laboratory in Europe” (“LEA-JOULE”)

The JOULE agreement has been signed between JINR and LSM (represented by CNRS and CEA) on 24 October 2005. The agreement reflects long historical participation of JINR scientists at different research activities conducting at LSM. With regards of highly fruitful cooperation between JINR and LSM in time of 2005-2012 years thanks to the agreement, in November of 2012 it has been extended for 4 more years. Now together with LSM and JINR participants of the agreement are Russian Foundation for Basic Research and Czech Technical University in Prague.

LEA-JOULE activity in LSM is linked with all experiments conducted in it. In particular with:

SuperNEMO dedicated to further development of $0\nu2\beta$ decay search on an unprecedented level of sensitivity;

EDELWEISS dedicated to direct search for non-baryonic dark matter;

TGV dedicated to search for double beta decay processes ($\beta^+\beta^+$, β^+EC, EC/EC) of ^{106}Cd;

SHIN dedicated to search for the presence of super heavy elements in nature.

Also, in a frame of the LEA-JOULE program, JINR group continue study of background environment of LSM, in particular neutron flux measurements and measurements of radon activity with highly sensitive radon monitors developed and built by JINR. In 2010-2013 this program has been further extended with development of new radiochemical methods for detection of ultra low radioactivity of samples using in investigation of rare processes as well for development of methods of purification.

This document compiled on behalf of JINR LSM users by E. Yakushev [1]

[1] Contact information: yakushev@jinr.ru

Reports about particular activities of JINR group at LSM are given below.

EDELWEISS

E. Yakushev

The EDELWEISS program searches for evidence of direct WIMPs from Milky Way galaxy scattering of Ge nuclei within cryogenic Ge crystals. The EDELWEISS detectors are cryogenic (work temperature is about 20 mK) Ge bolometers with simultaneous measurement of phonon and ionization signals. The comparison of the two signals provides a highly efficient event-by-event discrimination between nuclear recoils (induced by WIMP and also by neutron scattering) and electrons. The experiment is located in the LSM laboratory to reject background caused by cosmic radiation. To go beyond the present EDELWEISS sensitivity and to be competitive with other experiments, a third phase (EDELWEISS-III) of the experiment is foreseen. The EDELWEISS-III project consists in an upgrade of both the current EDELWEISS setup and detectors. Thus, in 2013, the EDELWEISS collaboration main work's direction was testing and calibration of newly installed detectors with an active rejection of the surface background. New 800 g FID detectors with significantly increased fiducial volume were commissioned in a few months run for its applicability in EDELWEISS.

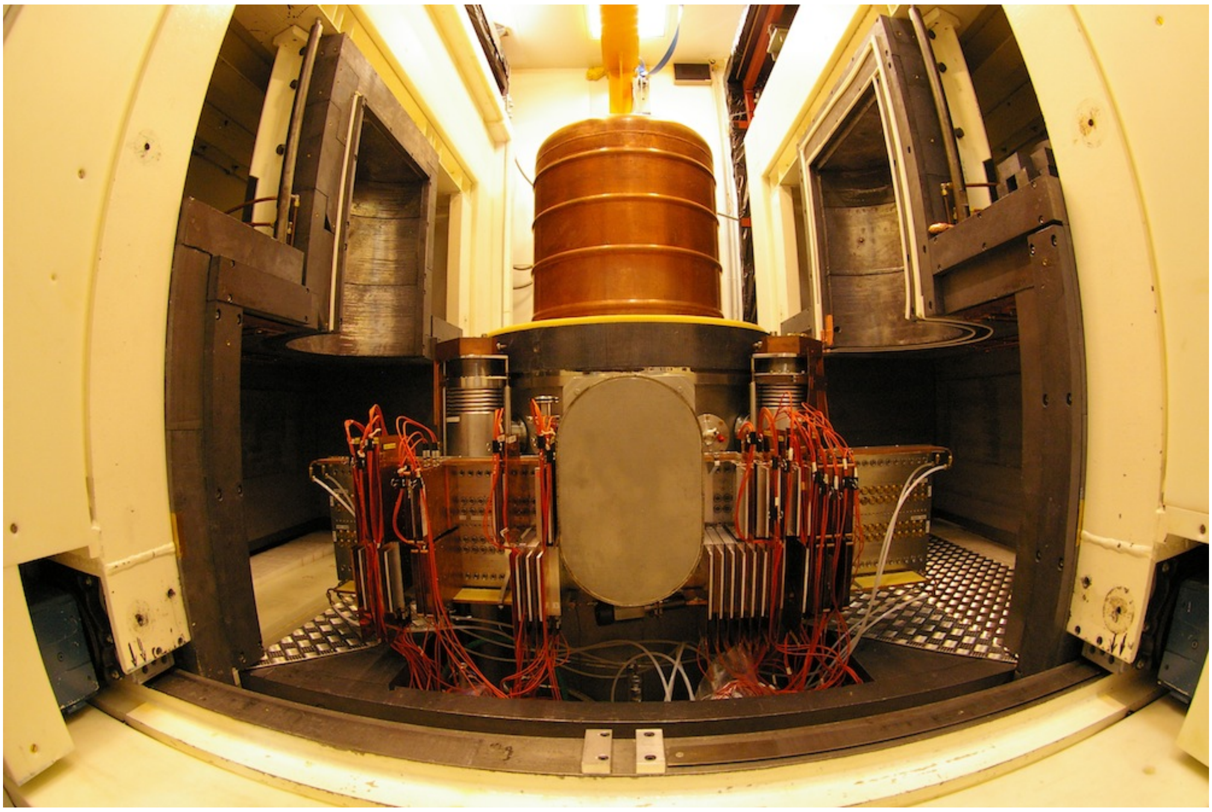


Fig. 1.1: *View of the assembled cryostat of the EDELWEISS (shield is open).*

The FID800 detector's technology developed in 2012-2013 (all surfaces covered by ring electrodes - fully interdigitized 800 grams detectors) shows at least an order improvement of surface background suppression (Fig 1.3). About 10 kg of new detectors were tested and intensively calibrated in 2013. Together with new detectors whole experimental setup has been updated in 2013, improvements were related to cryogenic system, shielding, new fast data acquisition.

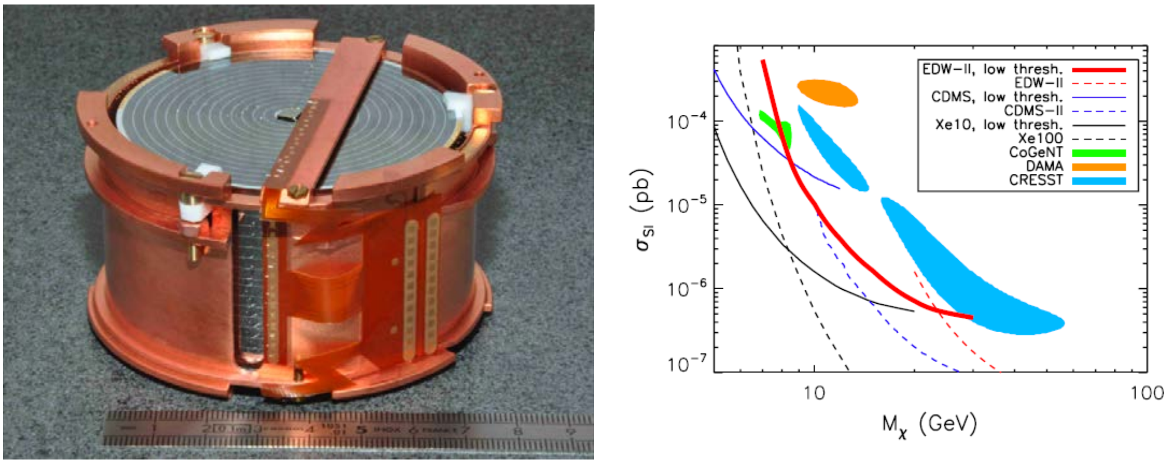


Fig. 1.2: *Left: FID800 detector. Right: 90% C.L. Poisson limit on σ_{SI} as a function of WIMP mass derived from the analysis of the four EDELWEISS bolometers (bold red line).*

During upgrading of the setup the collaboration continue to extract interesting physics results from already accumulated data. In 2013 we performed high sensitive search of axion's signal in our experimental data. The result is demonstrated on fig. 1.3.

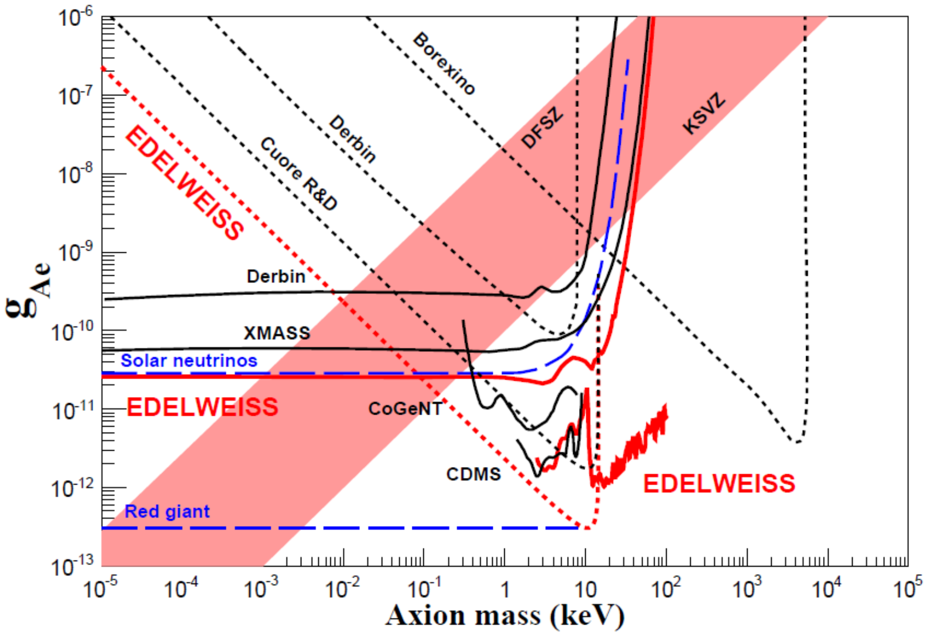


Fig. 1.3: *Summary of the constraints obtained by EDELWEISS on the g_{Ae} axion coupling as a function of m_A. The EDELWEISS limits are in red. See more details in* http://arxiv.org/pdf/1307.1488v1.pdf

Dubna team participates and makes commitment to follow parts of EDELWEISS project: 1) Assembly and commissioning; 2) Development procedures and methods for work in low radioactive conditions, such as certification of radioactive sources,using of radioactive materials on the site, procedures for clean room using, etc; 3) Data taking (include daily routine procedures, as well as regular and special calibration runs); 4) Low background study and development of methods of neutron and radon detection; 5) Development of new low threshold detectors; 6) Detector simulations and data analysis.

The EDELWEISS experiment required unprecedented level of background understanding. In the collaboration we target it study from both sides: experimental and modelling. In EDELWEISS the 2 important sources of background: neutrons and radon are under continuous control. Monitoring of neutron field at LSM is going on with 2 high sensitive low background neutron detection systems developed by JINR group. Continuous measurements of neutrons in LSM last from 2006. Now both fast and thermal neutron fluxes are under control. Mobility of the thermal neutron detector was allowed to conduct measurements at different places at LSM, and even inside of EDELWEISS's shields. Level of the detector's sensitivity on an order of 10^{-9} n/cm^{2}/sec was applied for direct test of efficiency of EDELWEISS shields to ambient neutron background. This measurement is extremely important from point of view WIMP background free experiment. Measurements at different locations at LSM further improving and make broaden our knowledge about neutron flux and it changes in the underground laboratory. In 2013 an important investigation has been done with neutron detector installed in a profound hole drilled in a LSM wall. The received result on neutron activity is important for future EURECA development in new LSM laboratory. Another dangerous source of background is radon. Radon is a noble gas which due to it mobility and radioactivity of its daughters is extremely dangerous for EDELWEISS experiment. With build by JINR group high sensitive radon detection system now the radon level at environment of the EDELWEISS' cryostat is under continuous control during WIMP data taking. In 2012 JINR group produced and installed at LSM new radon detector with sensitivity on a level 10 mBq/m^{3} for continuous control of air quality produced by the LSM anti-radon factory. From April 2013 the detector is continuously controls air on exit from the LSM anti-radon factory. Another activity of JINR group is neutron activation analysis of PE samples of PE used for construction of additional neutron shield. R&D for widening of the WIMP search for low energies (low WIMP mass region) has been targeted with built by JINR low threshold point contact HPGe detectors. In 2011-2013 a test of one such detector with weigh ~200 g has been started at LSM. Reasonably low threshold (700 eV) (limited by electronics) has been reached. In 2012 4 450 g point contact detectors were produced in Dubna with an aim to use it for low mass WIMP investigation. In 2013 these detectors were properly tested and implemented in a low background cryostat that going to be delivered to EDELWEISS experimental site at end of 2013 or beginning of 2014.

Main results received in our collaboration in 2013 have been published at:

E. Armengaud et al. (EDELWEISS collaboration), Axion searches with the EDELWEISS-II experiment, Journal of Cosmology and Astroparticle Physics 11(2013)067 1-23;

E. Armengaud et al. (EDELWEISS collaboration), Background studies for the EDELWEISS dark matter experiment, Astroparticle Physics 47 (2013) 1-9;

B. Schmidt et al. (EDELWEISS collaboration), Muon-induced background in the EDELWEISS dark matter search, Astroparticle Physics 44 (2013) 28-39.

In the frame of LEA-JOULE collaboration next personal been at LSM for EDELWEISS experiment needs:

E. Yakushev: from 29.03.2013 to 22.04.2013 and from 10.06.2013 to 28.06.2013, activity been shared with other projects (radon measurements, neutron measurements, low activity measurements, Ge detector works, low threshold detector, etc).

S. Rozov: from 21.03.2013 to 22.04.2013 and from 10.06.2013 to 28.06.2013, activity been shared with other projects (radon measurements, neutron measurements, low activity measurements, Ge detector works, low threshold detector, etc)

DEMONSTRATOR SuperNEMO

O. Kochetov

There are three very important open questions in neutrino physics that can best be addressed by next generation zero-neutrino double beta decay (0νββ) experiments. Are neutrinos Majorana particles that differ from antineutrinos only by helicity? What is their mass-scale? Is lepton number conservation violated? While searches for double beta decay have been carried out steadily throughout many decades, it is very interesting time to launch next generation experiments. Measurements of atmospheric, solar and reactor neutrino oscillation have revealed scenarios in which the effective Majorana mass of electron neutrino could be larger than 0.05 eV. Recent developments in plastic scintillators technology the search for 0νββ-decay of ^{82}Se or/and ^{150}Nd by means of a track – calorimetric method at this scale now feasible. For recent comprehensive experimental and theoretical reviews see.

NEMO-3 is a double beta decay experiment was spent in the Frejus Underground Laboratory in Modane, France. Its major goal is to look for neutrinoless double beta decay(0ν2β) of ^{100}Mo and ^{82}Se, as well as to measure precise two neutrino decay (2ν2β) of five other isotopes:^{116}Cd, ^{150}Nd, ^{96}Zr, ^{48}Ca and ^{130}Te, including decays to excited states, search for 0ν2β-decay with Majoron emission. NEMO-3 experiment has been stopped in January, 2011. The NEMO-3 has been taking data from February 14th 2003 up to January 11th 2011. Total time of data collection for ββ studies is 6.1 years, 1.15 x 10^9 events have been triggered in 6391 runs. No evidence for 0ν2β-signal was observed. At the moment there is a dismantling of a spectrometer data analysis is in progress. Preliminary results shows the overall success of the NEMO-3 project reached all its goals claimed in the initial proposal. Final NEMO-3 results will be published in Nucl. Phys. A, in 2014.

SuperNEMO Demonstrator Project continue. Dubna group produced plastic scintillator VETO and Calorimeter-blocks. With Czech Tech. University Dubna paid additionally 200.000 $ US for part of fabrication of plastic scintillators for SuperNEMO Demonstrator calorimeter. Active job for radioactive Se-82 cleaning in Dubna and LSM(France), calibration radioactive sources production continue. In autumn 2013 was started DEMONSTRATORs calorimeter production (CENBG, Bordeaux + JINR, Dubna). In autumn 2014 will start installation of DEMONSTRATOR spectrometer in LSM, France. Dubna group will active take part in all these processes.

A new low-background spectrometer based on a HPGe-detector with a sensitive volume of 600 cm^3 is developed to investigate radio purity of construction materials for SuperNEMO DEMONSTRATOR, rare nuclear processes such as resonance neutrinoless electron capture and two-neutrino and neutrinoless double beta decay to excited states of daughter nuclei. The spectrometer is installed at the Modane underground laboratory (LSM, France) and the spectrometer sensitivity is determined for measuring sources of double beta decay (NEMO-3).

The results obtained have been presented at NEMO-3/SuperNEMO collaboration meetings in Prague and Bratislava, MEDEX’2013, TAUP2013, Mariond’2013, RPSCINT2013, EPS HEP 2013, Pontecorvo100 Symposium (Pisa, September 18-20, 2013),INFO13 workshop in Santa Fe, Blois 2013, 2013 Villa Olmo conference, MANNP 2013, LRT 201, CAP-S2013, INFO13 Workshop.

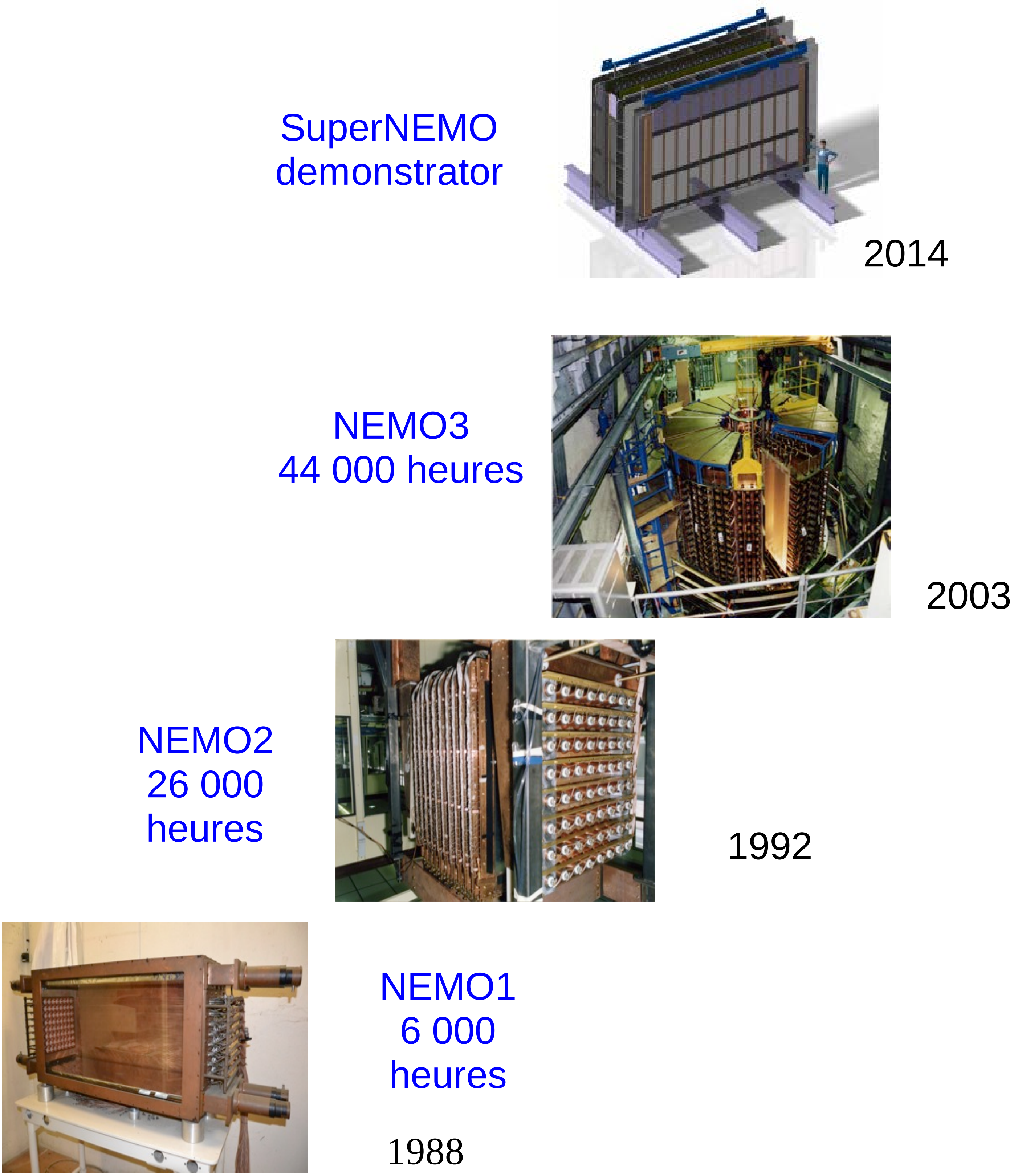


Fig. 2.1: *NEMO-experiments in Laboratoire Souterrain de Modane*

The scientific program for the future 12 months and the estimated duration.

The analysis of the NEMO-3 data and preparation of publications will be continued and finished during 2014. The Dubna group will take essential part in these activities. Software development and data processing also require presence of members of Dubna group in LSM (Modane), LAL (Orsay), LPC(CAEN) and CENBG(Bordeaux). Several software, calorimeter meetings and NEMO-collaboration meetings (France and Dubna) in one year are required for coordination of the data analysis.

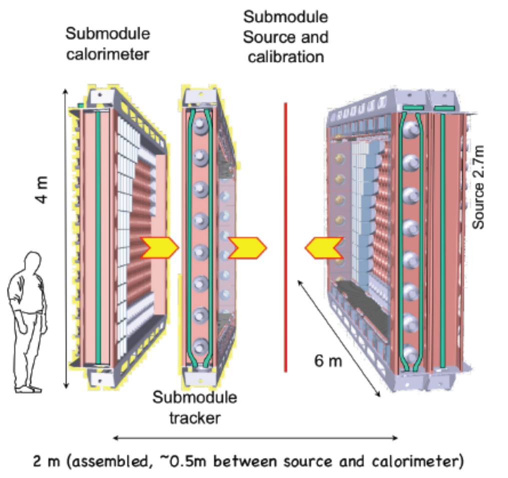
The NEMO collaboration in association with new UK, USA, Russian, Japanese and Spanish groups (the SuperNEMO **collaboration**) is studying the feasibility of extrapolation of the NEMO-3 technique to the next generation double beta decay the SuperNEMO detector capable to fit 100-150 kg of enriched ββ isotopes (^{82}Se or ^{150}Nd are the best current candidates) and to reach sensitivity to ββ0ν-decay mode at level of $T_{1/2} \sim 10^{26}$ years. It corresponds to ~ 50 meV level of the effective neutrino Majorana mass. R&D program is carrying out intensively in order to deliver the TDR of the SuperNEMO detector. JINR group is contributing essentially in the R&D of the SuperNEMO calorimeter specializing on: i) "VETO" detectors based on plastic scintillators; ii) long-term low background calibration and monitoring techniques based of alpha sources; iii) software development and simulations of the SuperNEMO detector. Efficient fulfilment of the SuperNEMO R&D program and construction of the DEMONSTRATOR (the first module) of the SuperNEMO detector requires intensive contacts between Russian and French physicists in the frame of current agreement and their joint work in France.

In 2014 we will perform further development and production of organic scintillators for the SuperNEMO demonstrator detector. Also we will continue our long-term tests of calibration and monitoring techniques based on alpha-sources. These measurements are in progress since March 2009 taking place in Dubna and in LSM simultaneously. Other plans are further methodical tests of PMTs stability, response uniformity, and aging of plastic scintillator blocks. Calorimeter R&D will be continued as well as development of absolute and daily calibration survey with radioactive sources, LED and laser light.

Creation of the first module (the Demonstrator) of the SuperNEMO detector has been started in autumn of 2014. It consist of: i) source foils, 6.3 kg of ^{82}Se (40mg/cm^2, 12 m^2); ii) tracking chamber with 2100 drift cells; iii) calorimeter with 600 PS blocks equipped with 5" and 8'' PMTs. The Demonstrator is aimed to: i) confirm R&D results on large scale mass production; ii) prove that backgrounds measured satisfy the levels required; iii) perform a competitive physics measurement. It is expected that the Demonstrator will reach sensitivity $T_{1/2} \sim 6.5 \times 10^{24}$ yr (90% CL) by 2015, which is equivalent to 3×10^{25}yr for ^{76}Ge or ~ 4 expected "golden 0ν2β events" if 0ν2β-observation claimed by H.V. Klapdor-Kleingrothaus et al., is true.

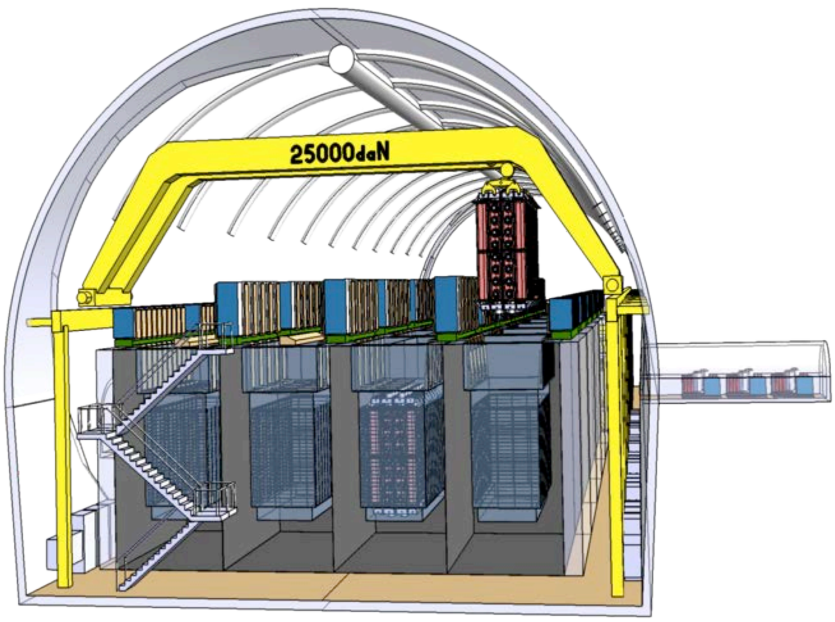
Enriched ^{82}Se will be measured in the Demonstrator. The Russian and French radio chemists are doing joint work on chemical purification of ^{82}Se in JINR, Dubna and in LSM,Modane. R&D on ^{150}Nd enrichment by hot centrifugation are charring out together with experts from Krasnoyarsk and St-Petersbourg. Efficient coordination of enrichment and purification R&Ds is impossible without close contacts between specialists from both countries.

DEMONSTRATOR



- ❑ **DEMONSTRATOR** construction will started in the LSM in autumn 2014
- ❑ Installation and commissioning @ Modane Underground Laboratory
- ❑ Data taking in 2014 - 2015
- ❑ No background expected for 7 kg of ^{82}Se and 2 years of data
- ❑ Sensitivity after 2 years : $T_{1/2} > 6.6\ 10^{24}$ y and $<m_n> < 0.2$ -0.4 eV

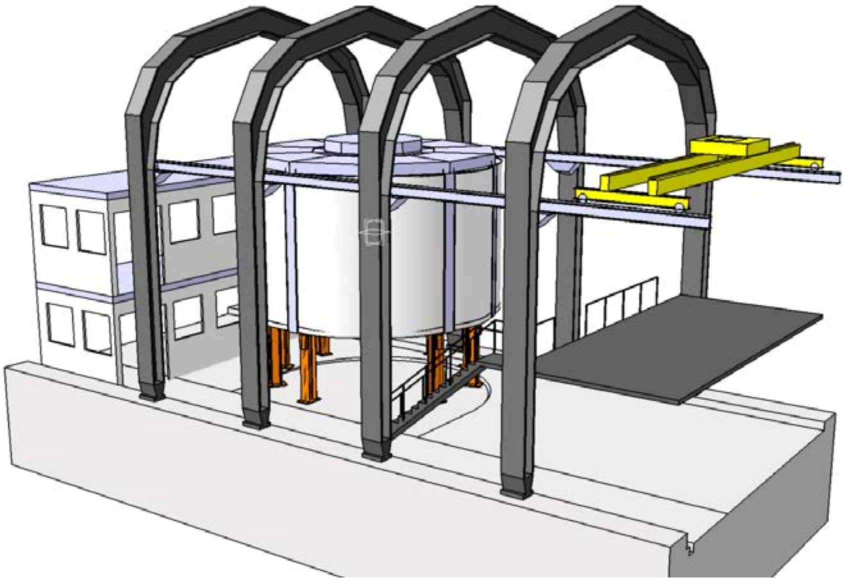
SuperNEMO in extantion laboratory



Extention laboratory

- ✓ 5 times the present LSM
- ✓ Digging in 2014 -2015
- ✓ In Operation 201

NEMO-3 integration into the LSM



DEMONSTRATOR – integration in LSM

The SuperNEMOdemonstartor will be installed @ LSM, after NEMO-3 removal. The final SuperNEMO detector should be installed in the LSM extension

In the frame of JOULE collaboration next personal was at LSM for SuperNEMO experiments needs:

O. Kochetov from 18.04.2013 to 16.05.2013, from 5.08.2013 to 28.08.2013 and from 27.11.2013 to 28.12.2013.

SHIN experiment (Search for Super-Heavy elements In Nature)

E. Sokol

Proceeding from the analysis of experimental data on the synthesis of super-heavy nuclides and structural calculations of nuclear masses, performed within modern theoretical models, the search for long-lived isotopes of super-heavy elements (SHE) in nature is reconsidered.

The SHIN experiment is aimed at searching for EkaOs (Z=108 element) in an Osmium sample by measuring its spontaneous fission (or/and that of its descendants) by the detection of the multiple neutron emission following the SF. A neutron multi-detector developed at FLNR-JINR is now in operation in the (LSM), Modane Underground Laboratory (60 detectors (^{3}He filled) in a polyethylene moderator). The sample to be measured is placed in the central cavity.

Fig. 3.1: *Upper view of SHIN setup.*

In the SHIN experiment measurements with the 550g of Os were carried out during 2008- 2009. The new set of the Os sample measurements have been performed in 2012-2013 to improve statistical accuracy of the experiment. These measurements confirmed the previously detected effect.

We have carried out measurements with Os sample during 13000 hours totally. Following numbers of events with multiplicity 3 and above were detected: **n6=1, n5=2 n4=1 n3=11 → (0.83±0.21) event/month** (where ni –number of events with i detected neutrons). The concentration of Z=108 in the Os sample no more than ~ 10^{-14} g/g (for half-life $T_{1/2}$~10^9 y) has been obtained from counting rate of events with neutron multiplicities ≥3.

We have carried out background measurements during 7700 hours totally: n4=1, n3=2 → (0.28±0.14) event/month. It is very difficult to control all sources of background at the counting rate equal to several events of multiple neutrons emission per year. That is why only the limit of possible concentration of element Z=108 in the sample of osmium has been received. With an assumption that the total counting rate was originated from spontaneous fission one gram of osmium contains up to $3*10^8$ atoms of element 108 that is enough for identification of this element by high-sensitivity methods of mass spectroscopy (*).

(*) - *Ch. Briançon, M.Chelnokov, S.Dmitriev, A.Kuznetsov, Yu.Oganessian, E.Sokol, Search of eka-osmium in Nature, submitted to Mendeleev Communications, 2013*

TGV

N. Rukhadze

The goal of the experiment TGV is to search for two-neutrino double beta decay processes ($\beta^+\beta^+$, β^+EC, EC/EC) of ^{106}Cd using a low-background and high efficiency spectrometer TGV-2 (Telescope Germanium Vertical) (Fig. 4.1). The detector part of the TGV-2 is composed of 32 HPGe planar type detectors with the sensitive volume of 2040 mm^2 x 6 mm each (about 3 kg of Ge) (Fig.4.1). The total sensitive volume of detectors is as large as 400 cm^3. The detectors are mounted one over another together with double beta emitters in a common cryostat. Double beta emitters are 16 foils of ^{106}Cd with a thickness of 50 -70 μm and a diameter of 52 mm inserted between the entrance windows of neighboring detectors. The coincidences between two characteristic KX-rays of palladium detected in neighboring detectors are analyzing to search for two-neutrino EC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd. Several experimental runs were performed using the TGV-2 spectrometer with samples of enriched ^{106}Cd and natural Cd (to specify the TGV-2 background in a low energy region). In the last run performed with ~13.6 g of ^{106}Cd (enrichment 75%) the best experimental limits on two-neutrino EC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd were obtained - $T_{1/2}$ >4.2 x 10^{20}y (90% CL),. Investigations of others branches of ^{106}Cd decay - 2νEC/EC decay to the 2^+,512 keV and 0^+_1,1134 keV excited states of ^{106}Pd, $0\nu\beta^+$EC, $0\nu\beta^+\beta^+$, $0\nu\beta^+$EC and $2\nu\beta^+\beta^+$ decays to the ground and excited states of ^{106}Pd were based on the analysis of KX-γ and γ–γ coincidences. New limits on EC/EC decay of ^{106}Cd to the 512 keV and 1134 keV excited states of ^{106}Pd, and $0\nu\beta^+\beta^+$, $0\nu\beta^+$EC, $2\nu\beta^+\beta^+$, $2\nu\beta^+$EC decays of ^{106}Cd to the ground and excited states of ^{106}Pd were improved in the present investigations. However, the analysis of KX-KX coincidences in this investigation showed a small increase in the number of measured events in the region of ~21 keV, which might be the 2νEC/EC decay of ^{106}Cd. But the statistics was not enough to make any significant claim about the presence of the process searched. A new investigation of EC/EC decay of ^{106}Cd was needed to be performed with TGV-2 spectrometer and a higher mass of enriched ^{106}Cd. For this purpose a new portion of enriched ^{106}Cd with a mass of ~25.6 g and enrichment of ~99.57% was bought by JINR in 2013. 16 foils with a diameter of 52 mm and a total mass of ~23.2 g were produced from this material and installed into TGV-2 cryostat in November – December 2013 (Fig.4.2). The new search for double beta decay was started in December 2013.

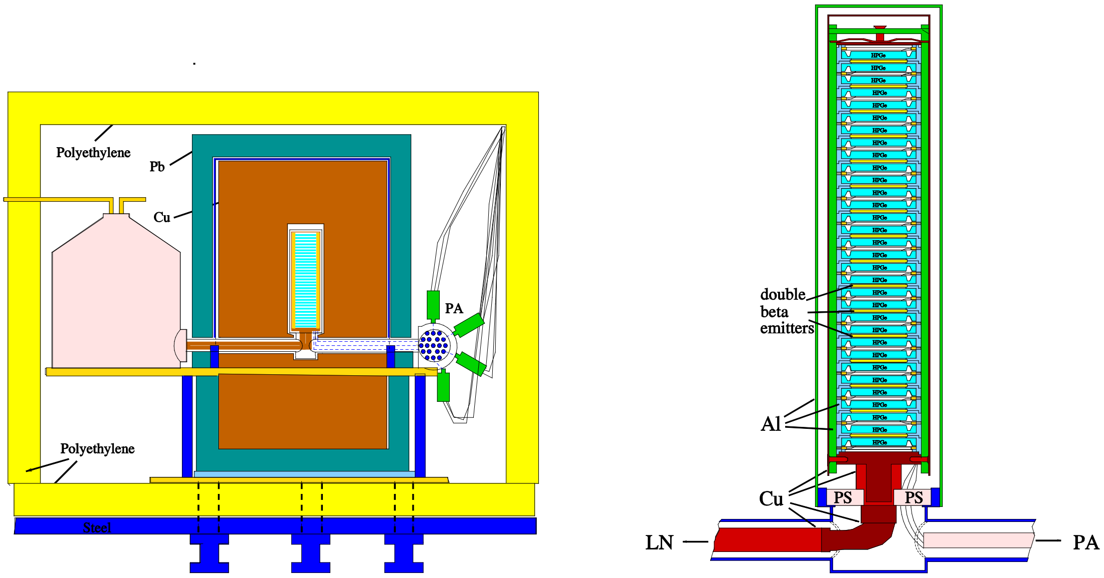


Fig. 4.1: *Low background spectrometer TGV-2 (left part) and detector part with double beta emitters (right part).*

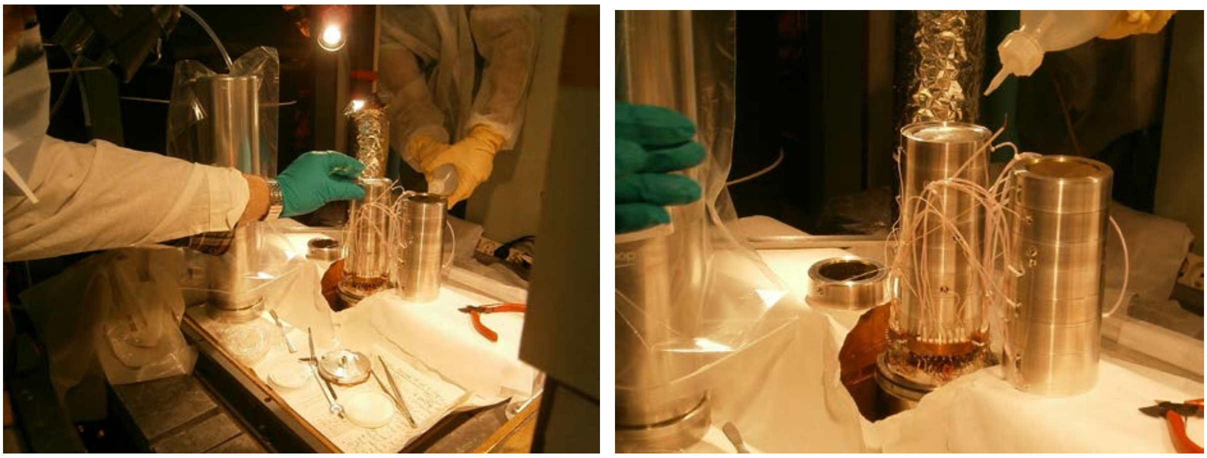


Fig. 4.2: *Disassembling of the TGV-2 detector system and installation of investigated samples.*

<u>Participants of TGV project from JINR:</u> V.Brudanin, V.Egorov, N.Rukhadze, V.Timkin, A.Klimenko, S.Rozov, A.Salamatin, Yu.Shitov, E.Yakushev

<u>Some recent publications</u>:

- N.I.Rukhadze et al., “Experiment TGV-2. Search for double beta decay of ^{106}Cd” *Journal of Physics: Conference Series 375, 2012, 042020.*
- N.I.Rukhadze et al., “Experiment TGV-2 - search for double beta decay of ^{106}Cd” *Nuclear Physics B (Proc. Suppl) 229-232, 2012, 478.*

Other activities and smaller experiments

Obelix project

N. Rukhadze

At the end of 2010 a new low background detector "Obelix" with a sensitive volume of 600 cm^3 was bought by JINR (Dubna) and IEAP (Prague) and mounted at LSM (Fig.5.1). The main goals of the detector "Obelix" are investigations of rare nuclear processes accompanied by emission of γ–quanta, such as 0νEC/EC resonant decay of ^{106}Cd, two-neutrino double beta decay to the excited states of daughter nuclei (^{100}Mo, ^{150}Nd), measurements of radioactive contaminations of various samples for NEMO-3, SuperNEMO, TGV, Edelweiss and Eureca experiments. In 2013 detector Obelix was used mainly for measurements of materials for SuperNEMO project. Several measurements were performed to obtain the detector efficiency for "standard" geometries. For this puspose special low-active volume samples with known mass and activity were produced in small plastic boxes (Fig.5.2), a Marinelli beaker (Fig.5.3) and a bobbin (Fig.5.4). Using pointed radioactive sources (^{152}Eu, ^{133}Ba), measured in different geometries and volume samples prepared on the base of La_2O_3, the efficiency curves for some standard geometries were obtained (Fig.5.5). The experimental efficiency is in a good agreement with the calculated efficiency obtained with the Monte Carlo simulations with GEANT 4 and GEANT 3. Fig.5.6. shows the experimental and calculated efficiency curves for the measurement with Obelix detector the bobbin with the metallic foil of 97.5% enriched ^{100}Mo with a mass of 2588 g (NEMO-3 source). On the base of this measurement and our calculations the half-life for the two-neutrino double beta decay of ^{100}Mo to the excited 0^+_1 state in ^{100}Ru was obtained to be $T_{1/2} = [7.5 \pm 0.6(stat) \pm 0.6(syst)] \times 10^{20}$ yr. For other (0ν + 2ν) transitions to the 2^+_1, 2^+_2 , 0^+_2 , 2^+_3 and 0^+_3 levels in ^{100}Ru, limits are obtained at the level of $(0.25 - 1.1) \cdot 10^{22}$ yr.

Fig. 5.1: *Low background detector "Obelix" (left part) and inner part of a passive shielding (right part).*

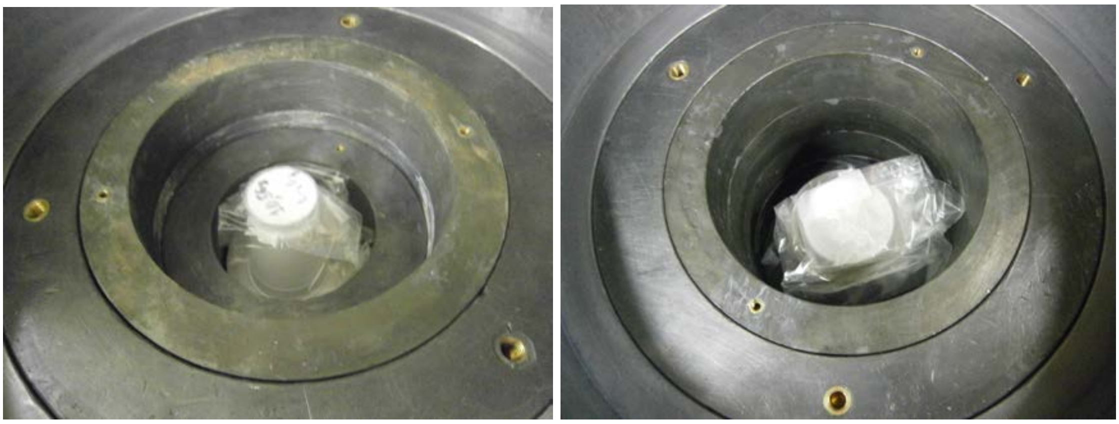


Fig. 5.2: *Measurements of a small plastic box with powder of La_2O_3 (left part) and a plastic box with a mix prepared on the base of La_2O_3 (right part).*

Fig. 5.3. *A low-active sample on the base of La_2O_3 in a big Marinelli beaker (left part) and using the sample for the efficiency calibration of the detector (right part).*

Fig. 5.4. *A low-active sample on the base of La_2O_3 in a bobbin (left part) and using the sample for the efficiency calibration of the detector (right part).*

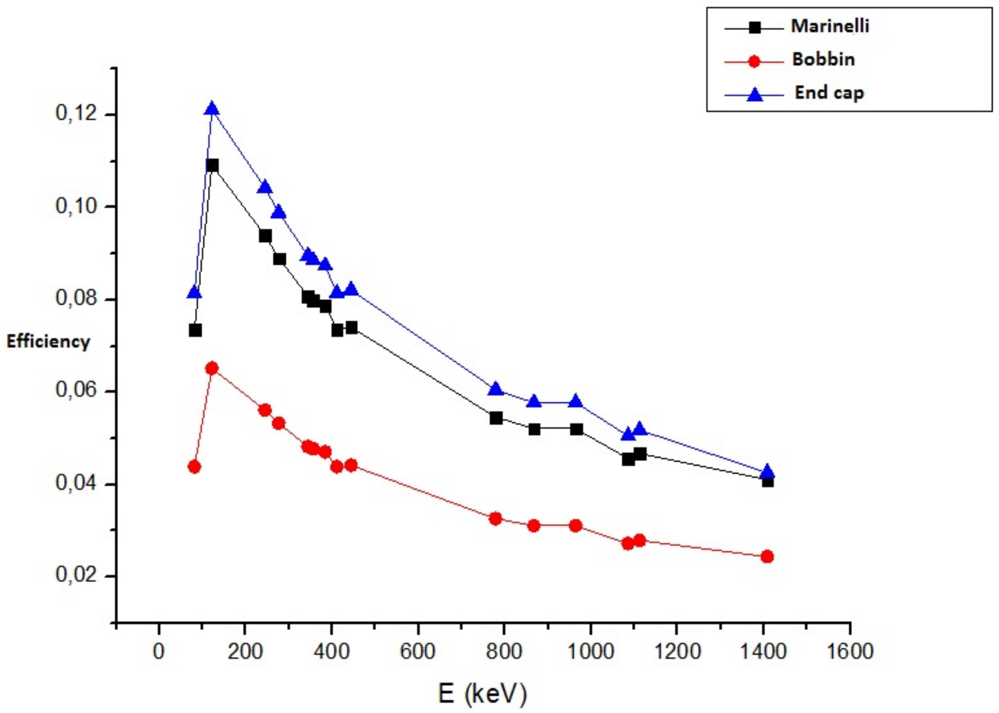


Fig.5.5. *Efficiency curves for some "standard" geometries.*

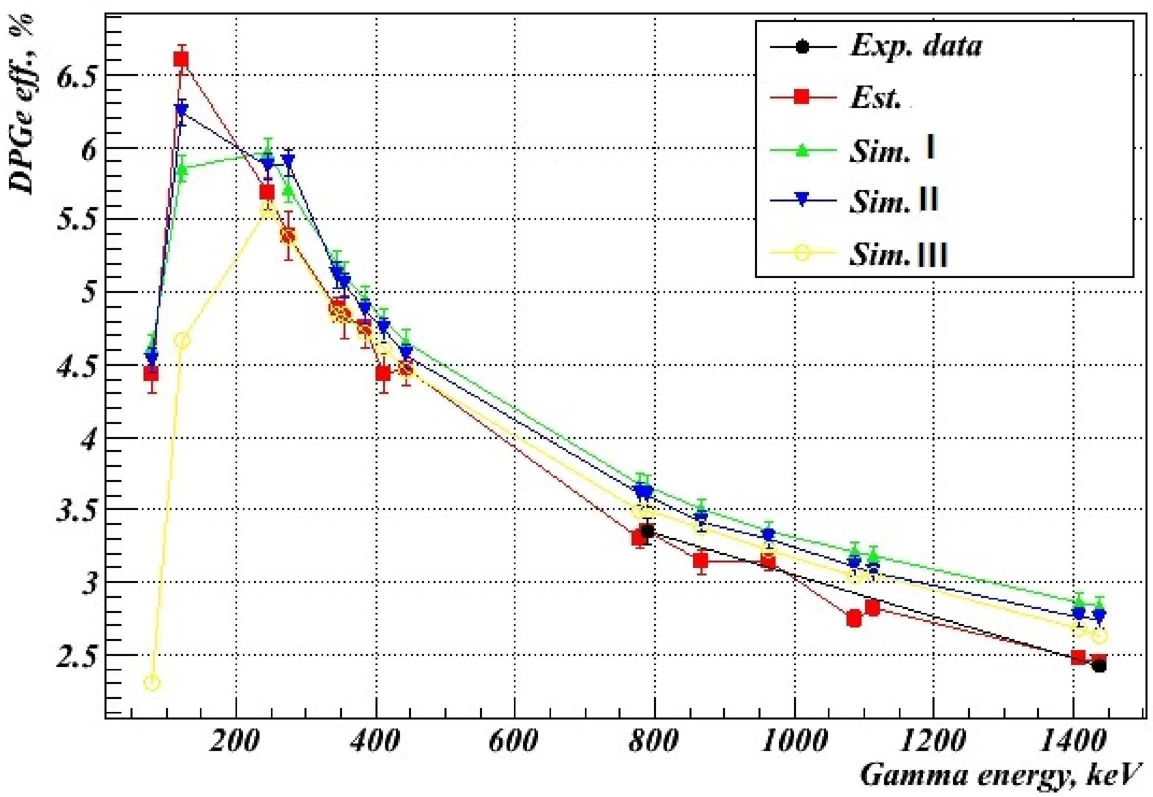


Fig.5.6. *Efficiency curves of the HPGe spectrometer for measurement of Marinelli bobbin with metallic foil of ^{100}Mo (experiment and MC simulations).*

Some publications at 2013:

- N.I.Rukhadze et al., "A Highly Efficient HPGE Gamma_Ray Spectrometer for Investigating ββ Decay to Excited States" *Bulletin of the Russian Academy of Sciences. Physics, 2013, Vol. 77, No. 4, pp. 379–382.*
- N.I.Rukhadze et al., "New detectors in investigation of 2β decay" Proceedings of the 4-th International Conference Current Problems in Nuclear Physics and Atomic Energy (NPAE-Kyiv2012), Kyiv 2013, p.408-411.
- R.Arnold et al., "Investigation of double beta decay of 100Mo to excited states of ^{100}Ru", submitted in Nuclear Physics A.

Participants of Obelix from JINR: V.Brudanin, N.Rukhadze, S.Rozov, E.Yakushev

In the frame of JOULE collaboration next personal was at LSM at Obelix experiment needs:

N. Rukhadze: from May 10 to June 01, and from August 19 to September 01, 2013 for Obelix works connected to producing of low-active samples for efficiency calibration, cleaning of passive shielding, calibration and background measurements.

ZZ-top project

E. Yakushev

In 2013 we continue works with repaired and commissioned for use in 2010 HPGe detector EURISYS MESURES EGSP 2500-R.

Next works were performed in 2013:

1) We changed previously installed into the cryostat point contact HPGe detector on the original EURISYS MESURES EGSP 2500-R HPGe crystal;
2) Test of applicability of archeological lead instead of indium for electrical and heat contact in the detector holder;
3) Replacement of first cascade of the detector;
4) Measurement natural radioactivity γ-spectra in several places in LSM;
5) Development of method of direct definition of fiducial volume of Ge detectors with cosmogenic neutrons.

In 2012 we performed first attempt to run point contact detector with archeological lead instead of indium for electrical and heat contact in the detector holder. The ZZ-top cryostat has been used for the test. Due to problems with first cascade this test was not finished. In 2013 we 1) start to use original ZZ-top HPGe crystal; 2) replaced first cascade of the detector on new one produced at JINR; 3) after tests with indium, the original ZZ-top HPGe crystal was wrapped in archeological lead.

Result of the test is: the detector works with archeological lead from June 2013 up to now. The indium peaks previously clearly seen in the data completely disappeared (compare fig. 6.4 with indium and fig. 6.5 without indium)

Fig. 6.1: *View of the ZZ-top detector wrapped in archeological lead (inside of it holder). Work performed by E. Yakushev and S. Rozov in June 2013.*

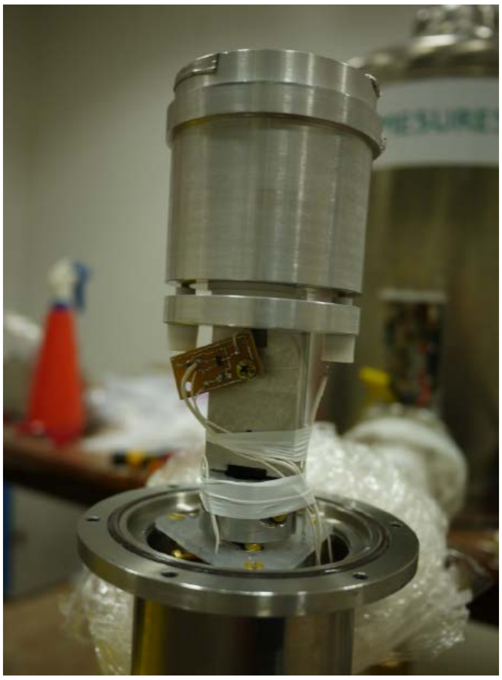


Fig. 6.2: *New first cascade of ZZ-top detector installed in March 2013.*

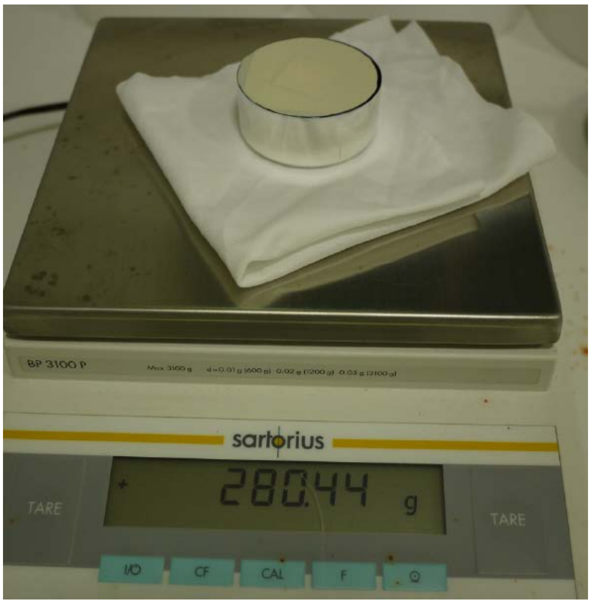


Fig. 6.3: *Weight measurement of ZZ-top HPGe crystal. The weight of Ge is 279.54 g.*

In December of 2012 we used ZZ-top project for development of a simple method of determination of working volume of Ge detectors. The idea behind of the method is quite simple: the natural Ge has 21.23% of Ge-70. This isotope has a cross section for activation by thermal neutrons at 3.43(17) barn. Result of activation is radioactive Ge-71 with $T_{1/2}$ 11.43 days. It decays (100%) by EC on the ground state of Ga-71. In Ge detectors it reveals as lines corresponding to capture on K and L shells. Intensity of decay and thus intensities of these lines can be carefully calculated if neutron flux and time length of activation is known. Comparison of this with experimental intensities (after correction on live time of Ge-71) gives direct information about detector efficiency at low energy region (from 1 to 11 keV). The procedure tested in frame of ZZ-top project is:

1) The Ge crystal of a detector (HPGe crystal of ZZ-top detector in our case) must be hold underground (neutron less environment) for a long time thus activity of Ge-71 become negligible, activity of Ge-68 and Zn-65 must be measured.
2) Detector of thermal neutrons with well known sensitivity must be set at a surface laboratory, the place where germanium will be activated (LSM Modane building in our case).
3) Ge crystal must be taken out of the cryostat, packed with a minimal amount of materials, delivered to the above place and set at proximity to the neutron detector, still on a such a distance that influence of neutron detector on neutron flux at Ge crystal can be neglected.
4) Keep the crystal activated for a reasonable amount of time (several days) but not too long, thus influence of fast neutrons and other cosmogenic activations are still minimal.
5) Bring the crystal back underground and start measurements immediately after cooling down.
6) Based on information from neutron detector activity of Ge-71 peaks can be estimated, thus efficiency of the detector can be determined.

To test the method, first we used semi-planar HPGe detector of ZZ-top project. The reason for this is that it working volume is expected to be about 100%. First test was performed in December 2012 with 70h14’ of activation under average neutron flux 2.665×10^{-3} $n/cm^2/sec$. Due to a technical reasons with FET measurements with activated detector were not possible.

In March 2013 we repeated the test with the detector exposed to cosmogenic neutrons from 11h35 25.03.2013 to 16h08 1.04.2013. Calculated activity of Ge-71 on 16h08 1.04.2013 was expected to be 1645.3 μBq. Underground measurements with the detector started on April 9. The 10.4 keV peak was clearly seen in the experimental spectrum. It activity changed by exponential low with expected decay time for Ge-71.

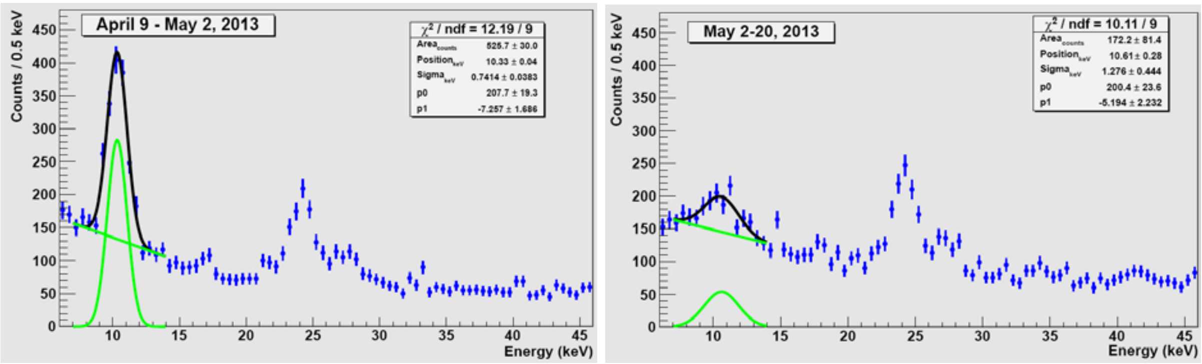


Fig. 6.4: *Left: spectrum received from April 9 to May 2, 2013, with accumulated live time ~18 days (about 5 days lost); Right: spectrum received from May 2 to May 20, 2013, with accumulated live time ~18 days (total background slightly increased because no radon-free air was available).*

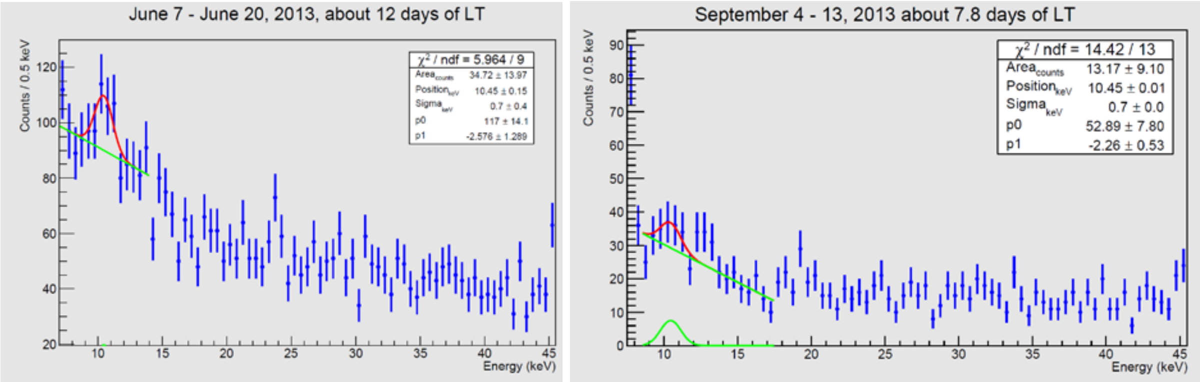


Fig. 6.5: *Spectra received in June and September with ZZ-top detector inside of EDELWEISS-I shield. In beginning of June 2013 detector wrapping been changed from indium to archelogical lead.*

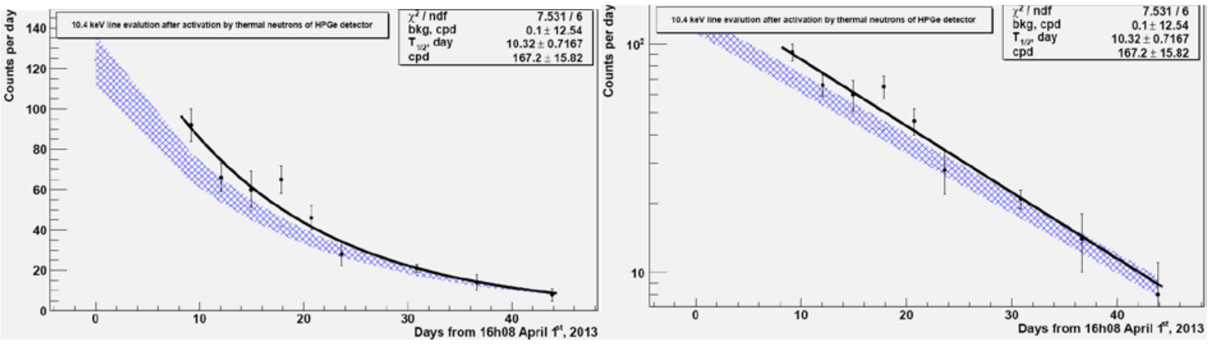


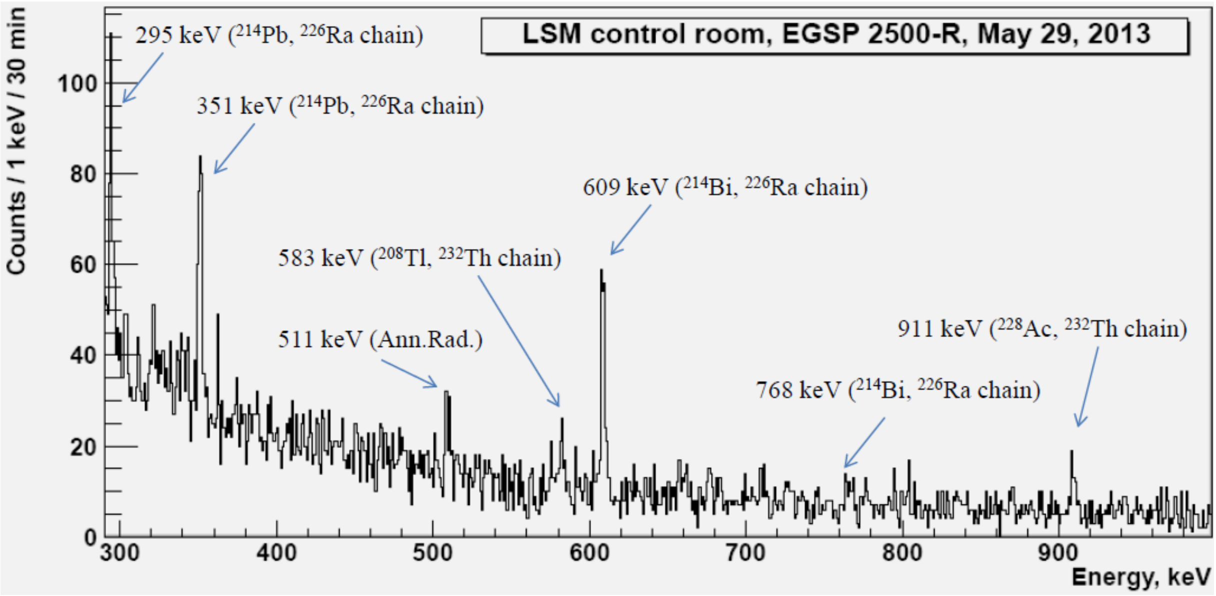
Fig. 6.6: *Changes of intensity of 10.4 keV line with time. Filled region – expected signal. Dots with error bars – experimental data. Solid line – result of fit of experimental points by exponential.*

After comparison of measured and calculated activity (weight of the crystal was measured) we received $\mathbf{I_{exp}/I_{calc} = 1.20 \pm 0.15}$. The main uncertainty arises due to the uncertainties of sensitivity of the He-3 thermal neutron detector (7.7%), neutron capture cross section (5%) and accumulated statistics (with background). At this moment we have no exact estimation of influence of epithermal neutrons on the above result. By an approximate estimation this can yield about 10% increase of calculated flux and thus shift the received ratio more close to 1. The main conclusion from the performed investigation is: the received result clearly demonstrated applicability of the method for determination of working fiducial volume of germanium crystal.

The ZZ-top detector in 2013 been used for measurements of γ-spectra of natural radioactivity in different places in LSM. The starting motivation for these measurements was in determination of influence of LSM anti-radon factory on total radioactive background of the laboratory. The influence was expected due to accumulation of radon daughters inside of anti-radon factory towers. We started measurements in end of May 2013 in time when anti-radon factory been stopped for more than 40 days (more than 10 periods of decay of Rn-222). We continue in September 2013 when anti-radon factory been continuously working for more than 40 days. For comparison of spectra measured in proximity to the factory we performed reference measurement in LSM control room.

Fig. 6.7: *Some places of measurements with ZZ-top detector in proximity to the anti-radon factory.*

\



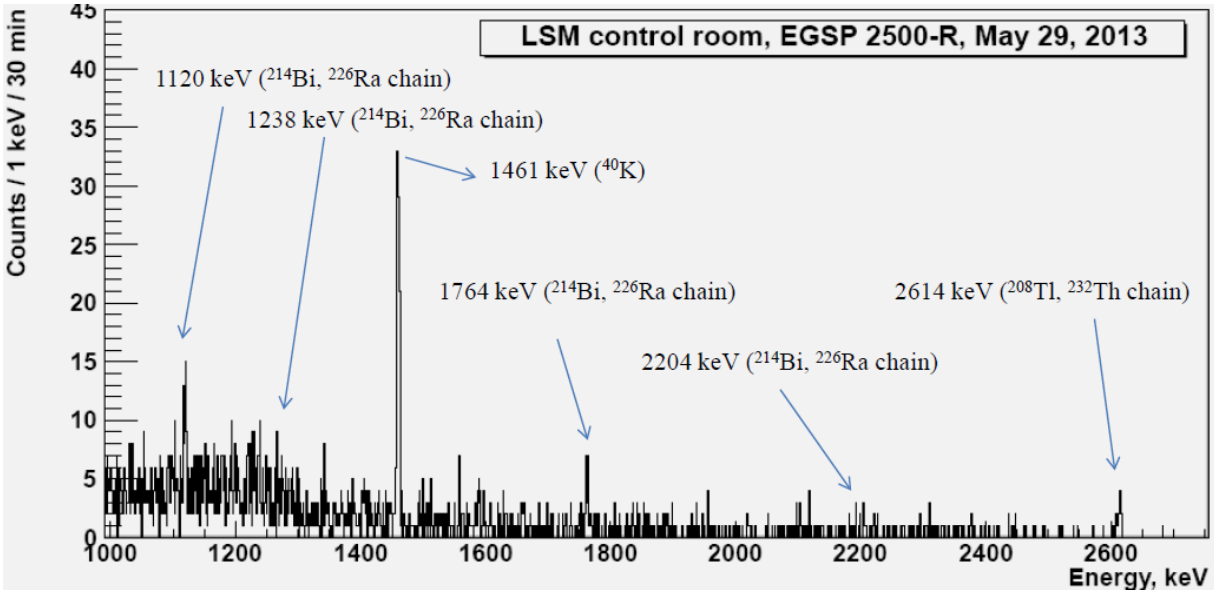


Fig. 6.8: *Measured with ZZ-top γ-spectra in the LSM control room (May 2013).*

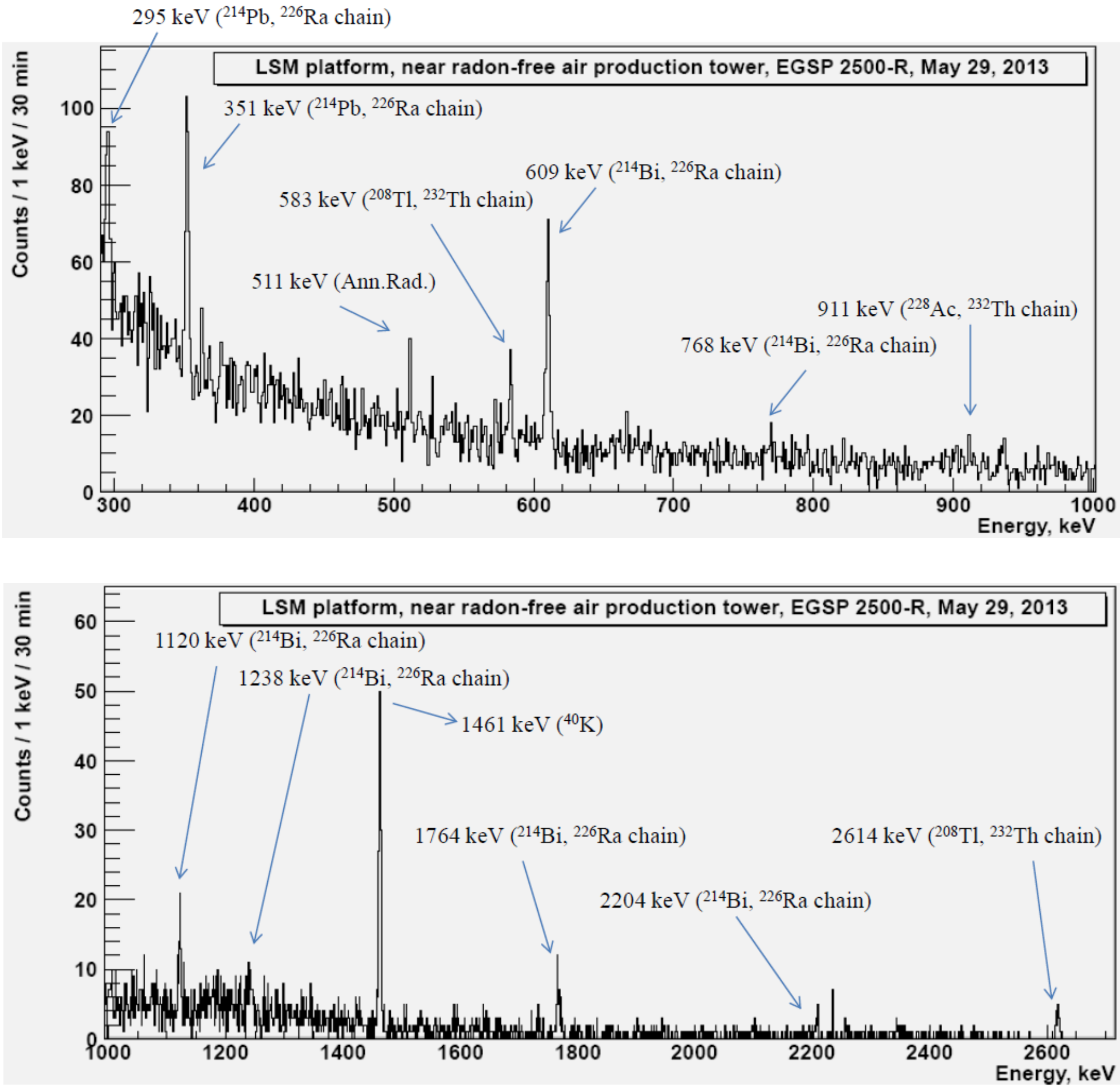


Fig. 6.9: *Measured with ZZ-top γ-spectra in the proximity to the anti-radon factory. Place of the measurement: between two towers, about 1.5 m from the ground (fig 6.7 top, left). Measurements performed in end of May 2013, when anti-radon factory been stopped for more than 40 days.*

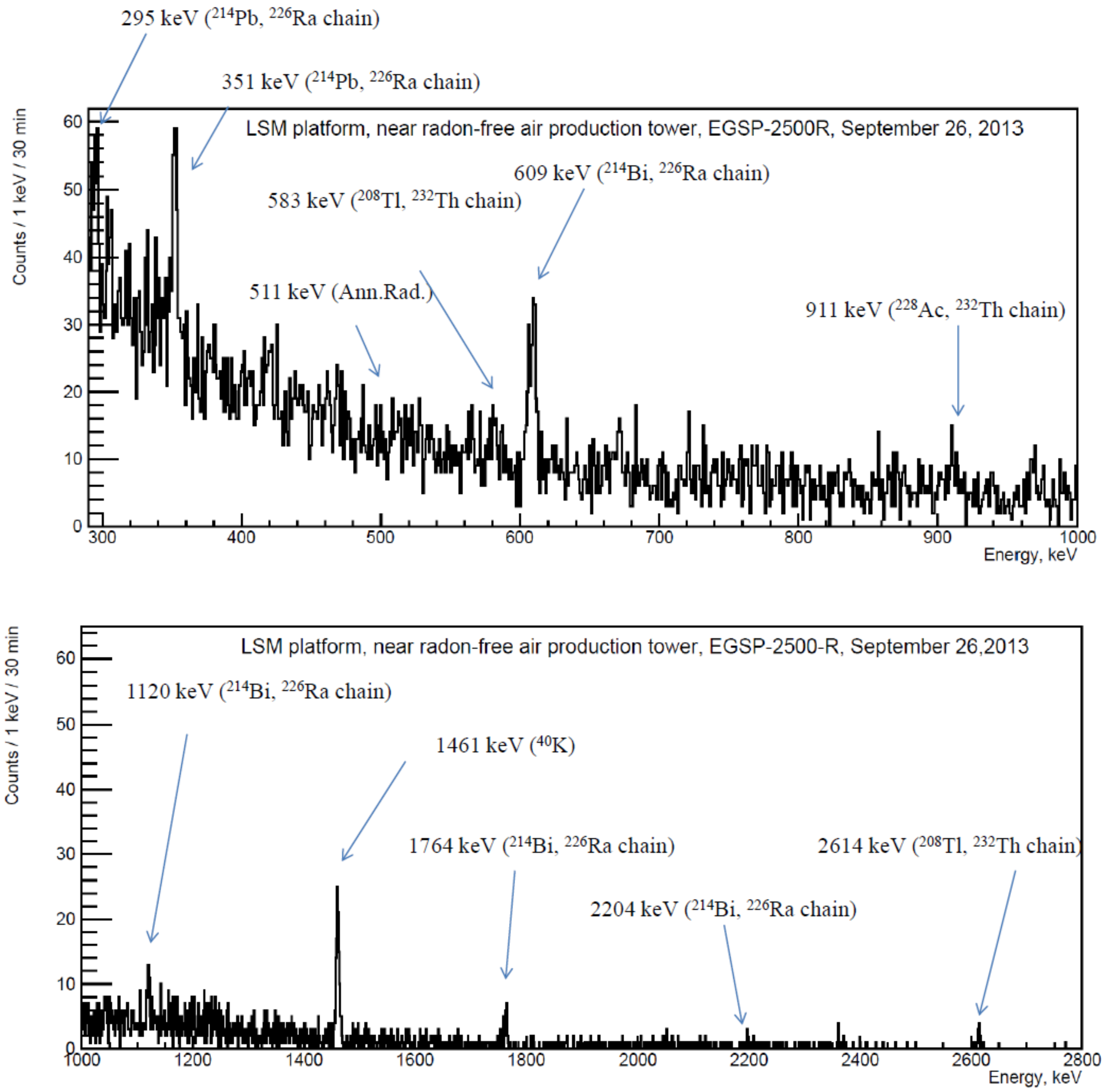


Fig. 6.10: *Measured with ZZ-top γ-spectra in the proximity to the anti-radon factory. The same place of measurement as for fig. 6.9, but the anti-radon factory is working more than 40 days.*

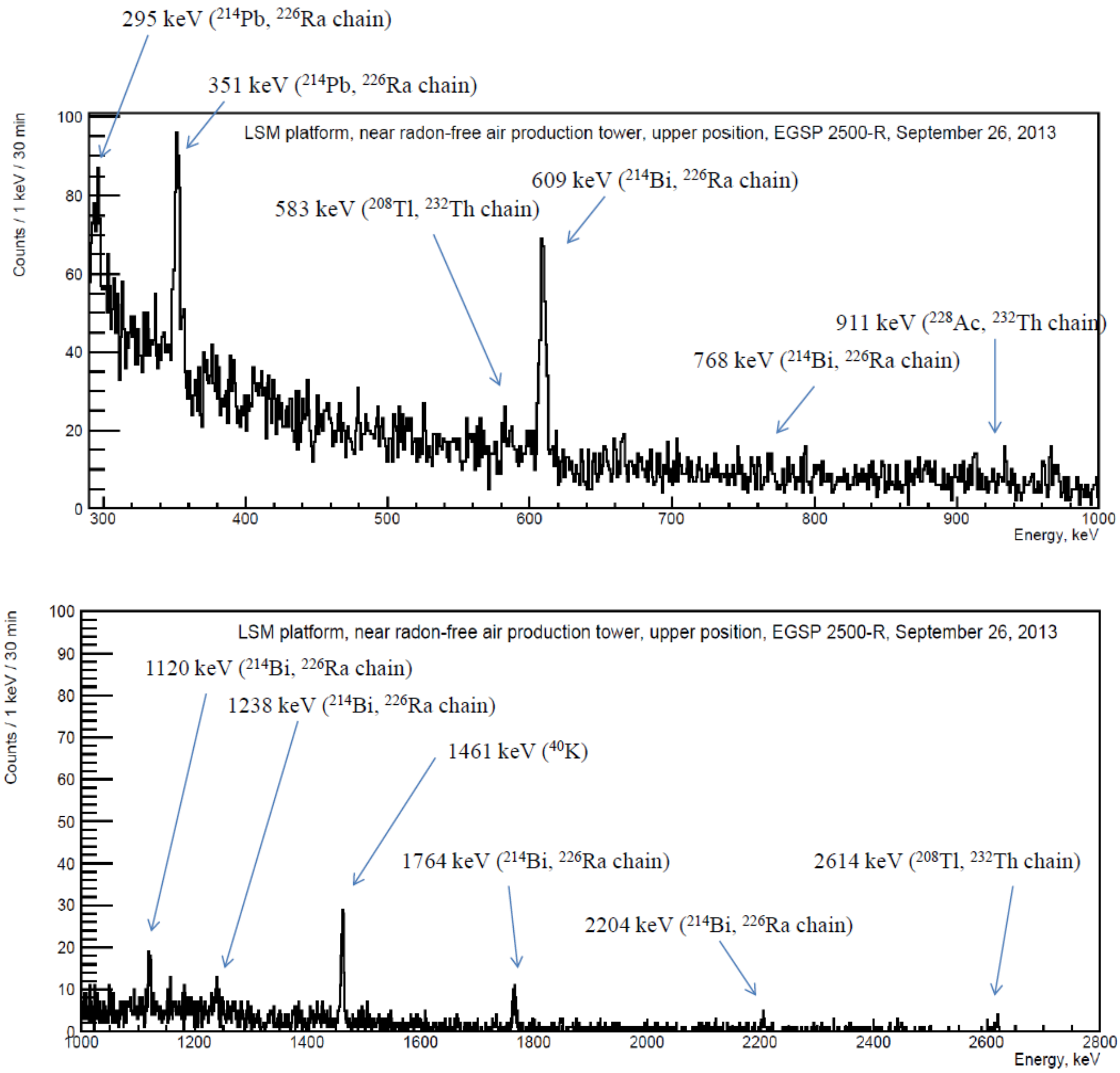


Fig. 6.11: *Measured with ZZ-top γ-spectra in the proximity to the anti-radon factory. Place of the measurement: between two towers, on the top(fig 6.7 top, right). Measurements performed when the anti-radon factory is working more than 40 days.*

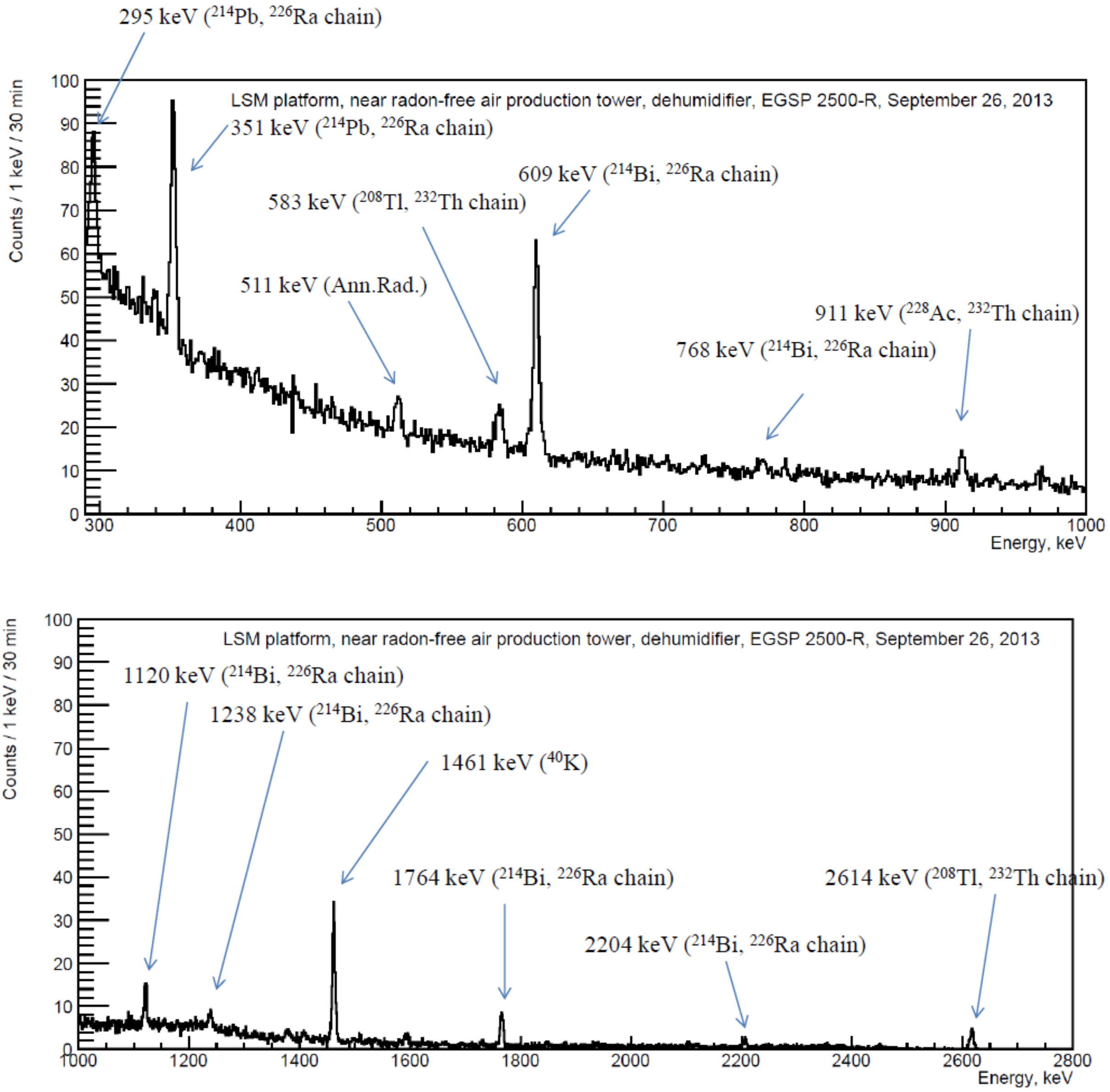


Fig. 6.12: *Measured with ZZ-top γ-spectra in the proximity to the anti-radon factory. Place of the measurement: near air dehumidifier on the platform (fig 6.7 bottom). Measurements performed when the anti-radon factory is working more than 40 days.*

The result of all above study is that anti-radon factory does NOT produce any significant γ-background on a distance from 1 m from it surface.

Another action performed with the ZZ-top detector is it cleaning. Due to multiply opening of the ZZ-top cryostat and holding of the germanium crystal for long time under atmosphere pressure, the detector working characteristics were deteriorated with time. For example, it maximal working voltage bias decreased from 2500V to 1500V. In order to improve the detector we cleaned it out in a warm methanol bath as shown on the fig. 6.14. As result, the detector now holds up to 2000V for long continuous measurements and up to 2500V for short measurements. Further longer cleaning is planned for 2014.

Fig. 6.14: *Cleaning of ZZ-top crystal by methanol.*

<u>Participants of ZZ-top project from JINR:</u> V. Brudanin, S.Rozov, E.Yakushev

Neutron background study in LSM

E. Yakushev

An unbiased interpretation of results of experiments conducting at LSM requires a detailed understanding of all background sources. In the near future, it is planned to enlarge LSM to host the next generation of experiments searching for Dark Matter and $0\nu\beta\beta$. These will require further background reductions and a precise knowledge of the remainder. As part of the program of precise neutron background's study at LSM JINR group in frame of the LEA-JOULE agreement operates 2 sensitive detectors of thermal and fast neutrons (Fig. 7.1). Both detectors installed in LSM were continuously used for monitoring of day by day stability of the neutron flux.

Fig. 7.1: *Detector of fast neutrons (left) and thermal neutrons (right).*

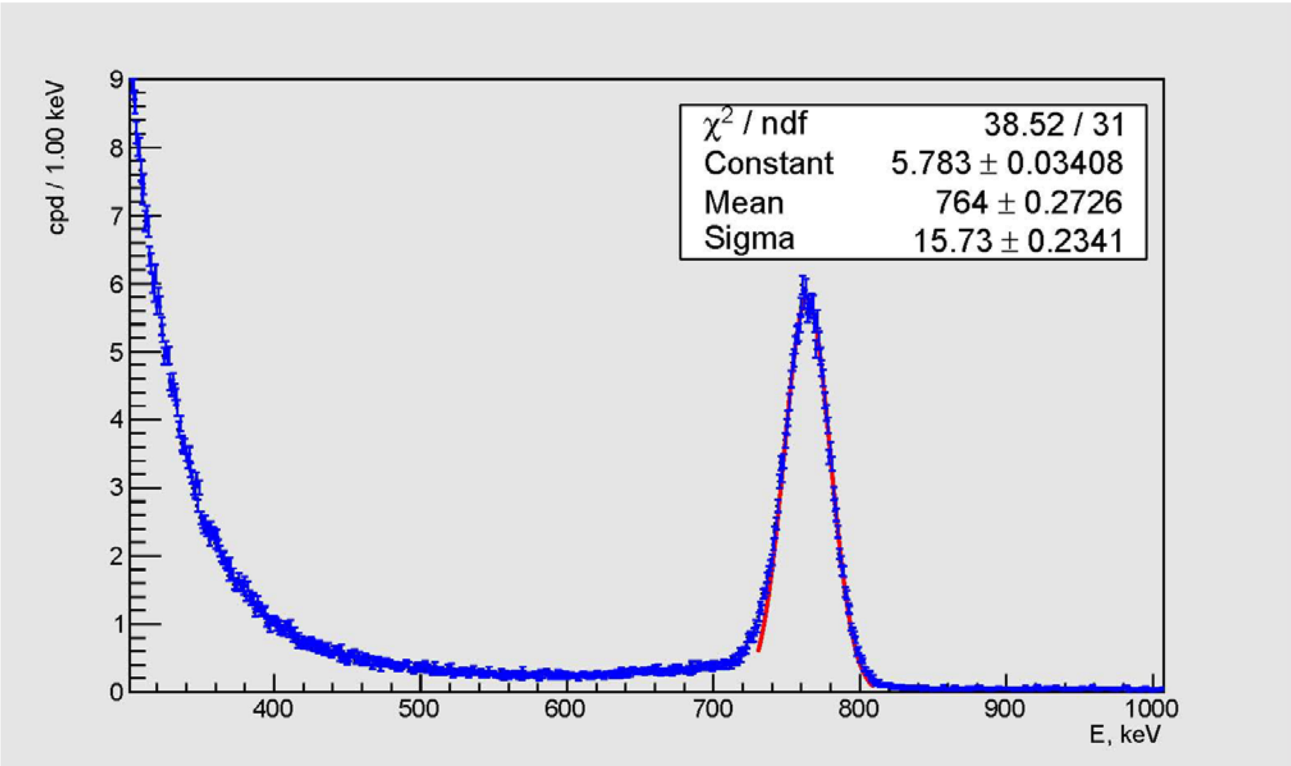


Fig. 7.2: *Experimental spectrum accumulated with 4 He-3 filled proportional counters in a polyethylene moderator (the detector of fast neutrons). The spectrum accumulated from September 2012 until August 2013.*

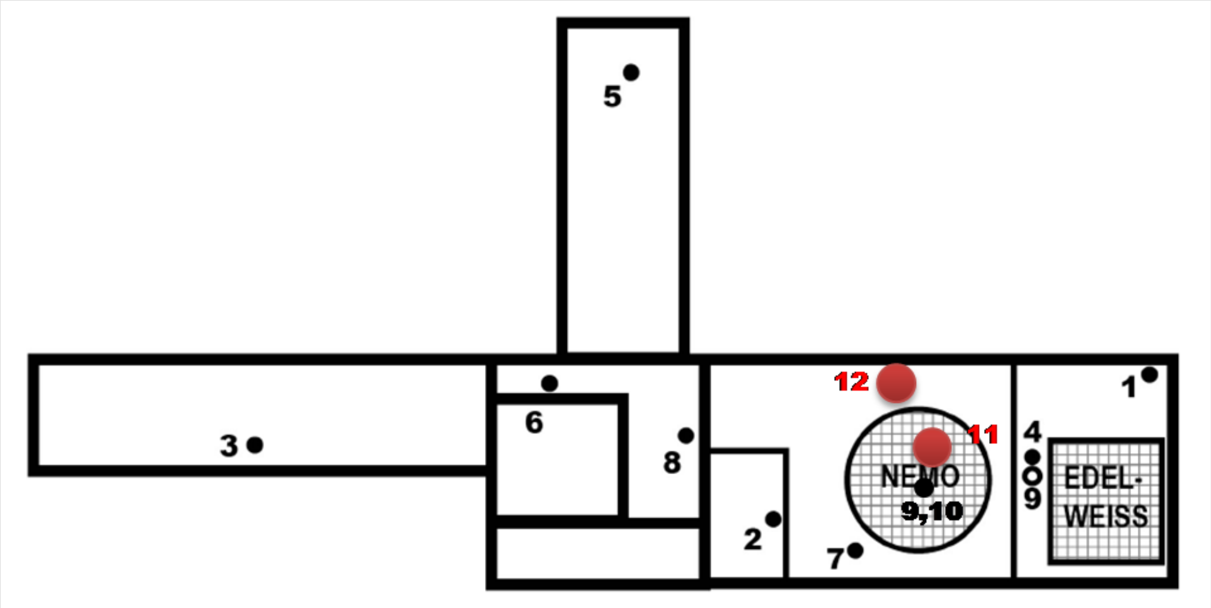


Fig. 7.3: *Points at LSM were neutron flux has been measured. Points 11 and 12 - new places of measurements in 2013.*

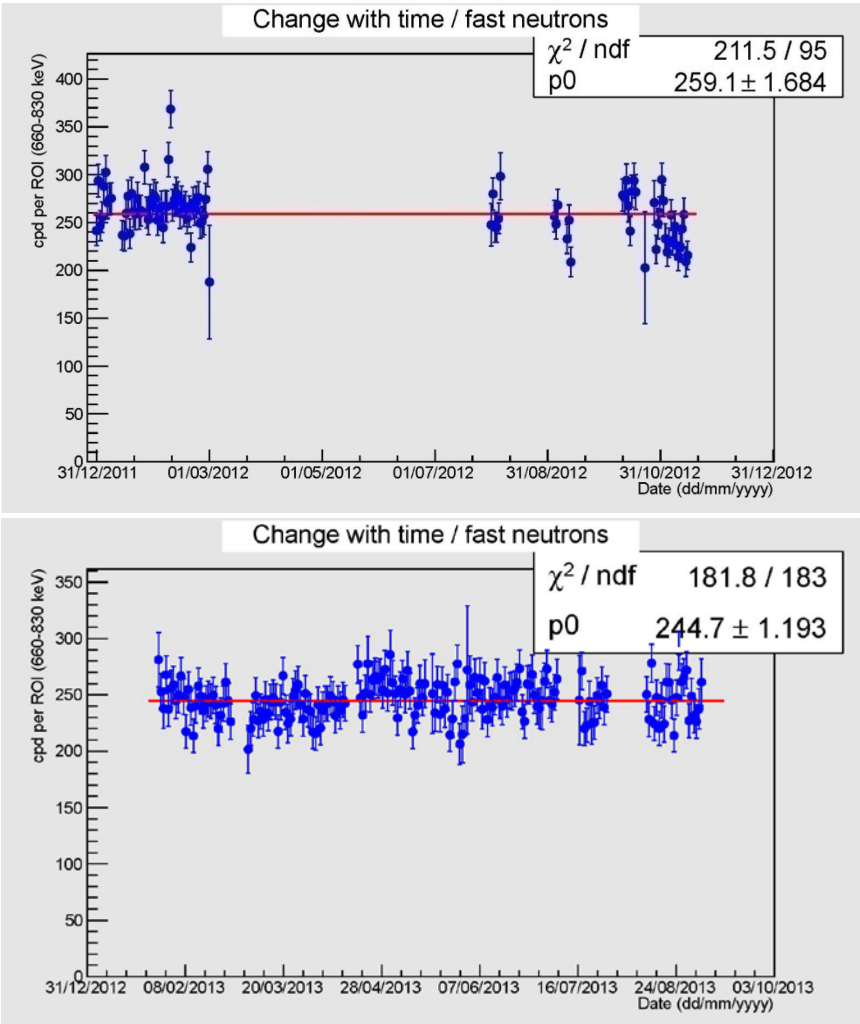


Fig. 7.4: *Day by day data registered by detector of fast neutrons in LSM in 2012 and 2013.*

The above data corresponds to average neutron fluxes (all spectrum) shown in the table 7.1.

Table. 7.1: *Year by year full neutron fluxes in one place of measurement at LSM (point 1, (fig. 7.3)).*

Year	*Full neutron flux, 10^{-6} n/cm^2/sec*
2010-2011	*9.57 ± 0.04*
2012	*9.73 ± 0.07*
2013	*9.14 ± 0.05*
Average	*9.54 ± 0.03*

The registered flux slightly increased in 2012. This correlated with time when NEMO3 detector been dismounted. In 2013 we observed small (but significant) decreasing of the flux. By our investigation this is connected with storage in a near proximity to the detector some parts of polyethylene shield of EDELWEISS-3 setup, as shown on fig. 7.5.

Fig. 7.5: *Part of EDELWEISS-3 shield that due to it proximity to the point 1 (fig. 7.3) influenced during year 2013 on the neutron flux at that place.*

A similar but less pronounced effect has been observed for thermal neutron measurements at point 1 (fig. 7.3), with naked He-3 filled proportional counter (thermal neutron detector).

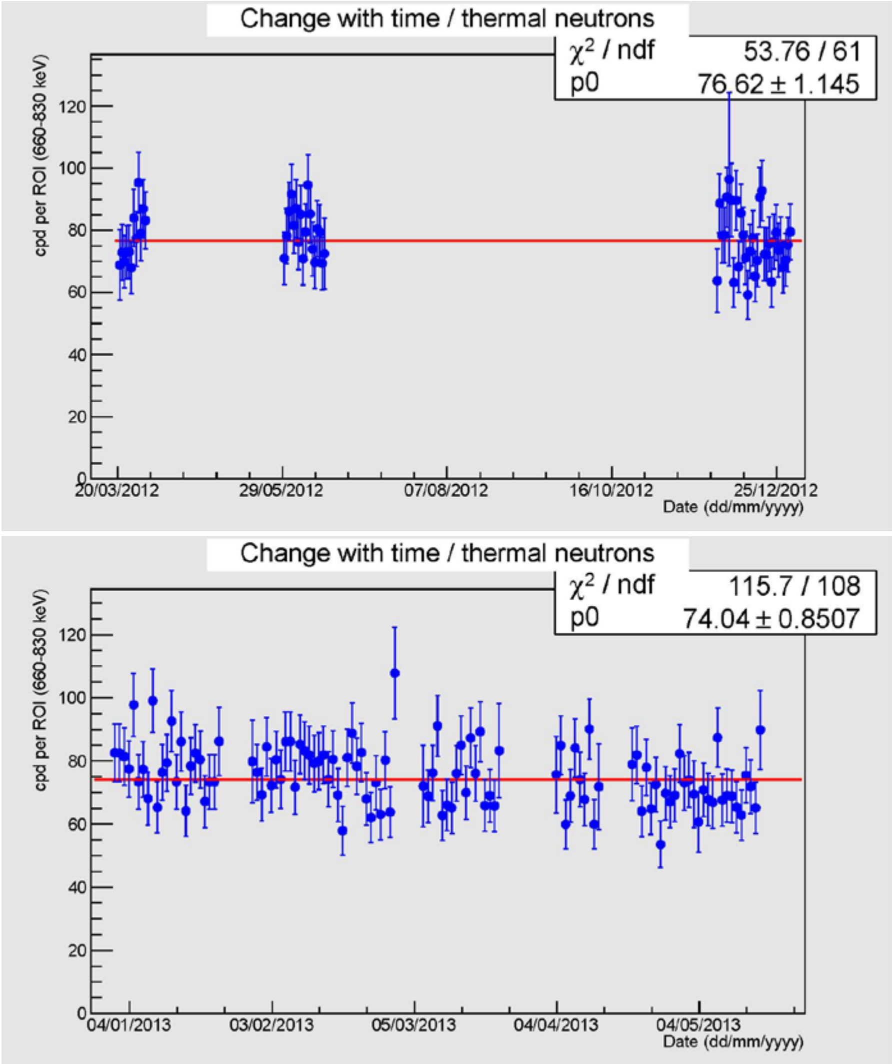


Fig. 7.6: *Day by day data registered by detector of thermal neutrons in LSM in 2012 and 2013.*

Table. 7.2: *Year by year thermal neutron fluxes in one place of measurement at LSM (point 1, (fig. 7.3)).*

Point	*Year*	*Counting rate at ROI, cpd*	*Thermal neutron flux,* 10^{-6} *n/cm*^{2}*/sec*
1	*2008*	*76.8 ± 1.5*	*3.64 ± 0.07*
	2012	*77.53 ± 1.15*	*3.69 ± 0.06*
	2013	*75.17 ± 0.9*	*3.58 ± 0.05*

One of the main investigations of neutron flux at LSM in 2013 has been performed with detector of thermal neutrons placed several meters inside of rocks, as shown on fig. 7.7.

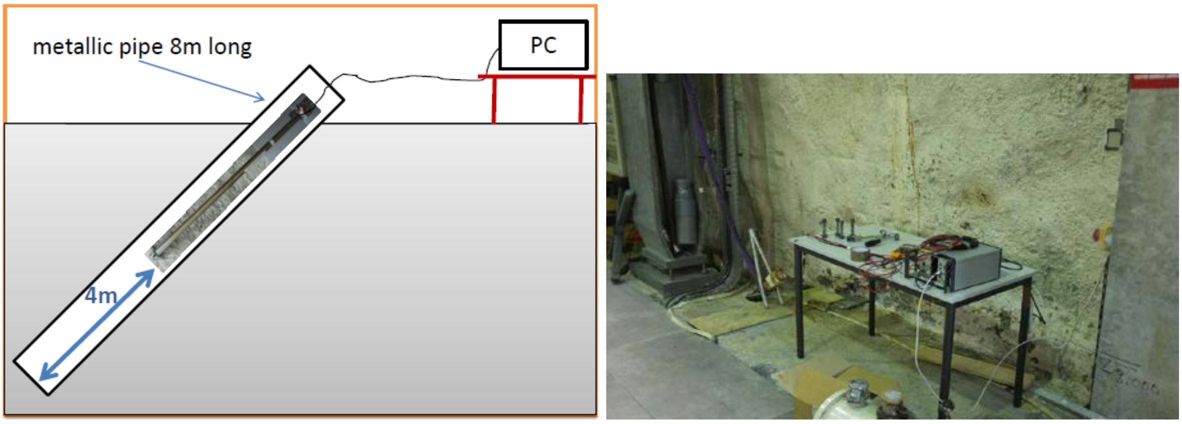


Fig. 7.7: *Scheme (left) of the measurement of thermal neutrons deeply inside rocks and photo of the setup (right).*

In order to perform these measurements the preamplifier part of the thermal neutron detector has been significantly modified. The main new requirement was to decrease size of the preamplifier and HV filter housing in a way that it can go inside of tube with diameter at 9 cm.

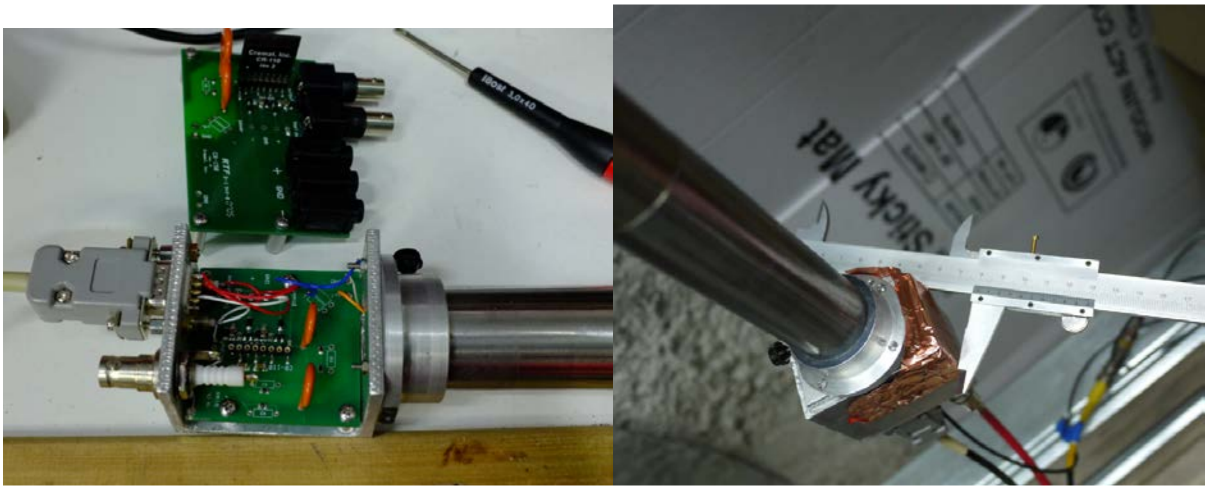


Fig. 7.8: *Left: Old and new preamplifier part of thermal neutron detector. Right: the new preamplifier in it housing.*

Table. 7.3: *Results of thermal neutron measurements in the point 12 (deep inside rocks). 2013+PE corresponds to the measurements performed with the polyethylene neutron stopper set in the hole entrance.*

Point	Year	Counting rate at ROI, cpd	Thermal neutron flux, 10^{-6} n/cm^2/sec
12	2013	207.09± 7.1	9.86 ± 0.34
	2013+PE	200.81± 1.6	9.56 ± 0.08

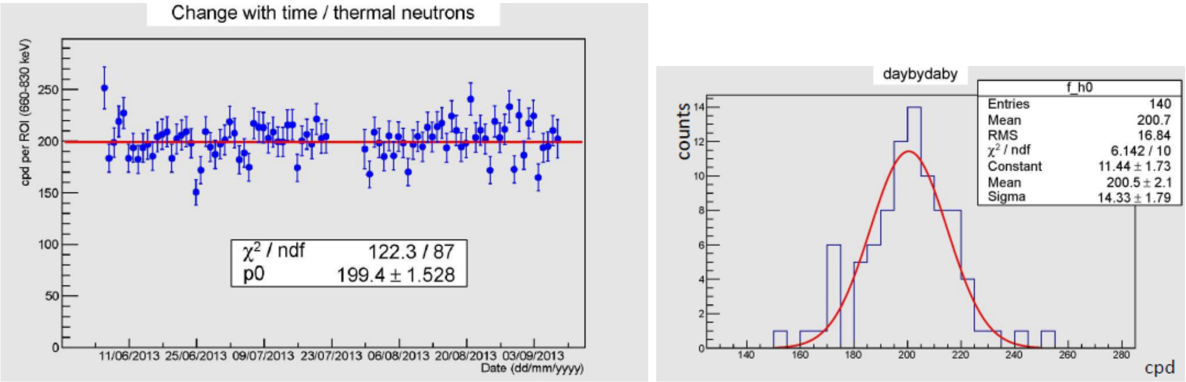


Fig. 7.9: *Left: day by day data registered by detector of thermal neutrons in point 12. Right: day by day statistical distribution of registered neutrons, clearly shows absence of any additional systematical deviations in the neutron flux.*

Table. 7.4: *Neutron fluxes in all studied places at LSM. New places studied at 2013 shown in red.*

Thermal neutron flux, 10^{-6} n/cm^2/sec			
Point	Year	Counting rate at ROI, cpd	Thermal neutron flux, 10^{-6} n/cm^2/sec
1	2008	76.8 ± 1.5	3.64 ± 0.07
	2012	78.2 ± 2.3	3.72 ± 0.11
	2011	74.35 ± 0.6	3.54 ± 0.03
2	2008	97.7 ± 9.3	4.7 ± 0.5
	2012	106.1 ± 7.3	5.1 ± 0.4
3	2008	130.7 ± 12.2	6.3 ± 0.6
	2012	148.2 ± 12.3	7.1 ± 0.6
4	2008	43.3 ± 4.0	2.1 ± 0.2
	2012	59.7 ± 4.5	2.9 ± 0.2
5	2008	94.7± 9.7	4.5 ± 0.5
	2012	112.1 ± 7.5	5.3 ± 0.4
6	2008	43.3 ± 4.0	2.1 ± 0.2
	2012	59.7 ± 4.5	2.9 ± 0.2
7	2008	43.3 ± 4.0	2.1 ± 0.2
	2012	59.7 ± 4.5	2.9 ± 0.2
8	2008	43.3 ± 4.0	2.1 ± 0.2
	2012	59.7 ± 4.5	2.9 ± 0.2
9	2012	93.3 ± 5.1	4.4 ± 0.3
10	2012	86.1 ± 5.4	4.1 ± 0.3
11	2013	76.13 ± 5.0	3.63 ± 0.24
12	2013	207.09± 7.1	9.86 ± 0.34
	2013+PE	200.81± 1.6	9.56 ± 0.08

The new results received in measurements performed deep inside of rocks together with previous results in points 3 (LSM tambour region) clearly show that using of low radio-activity concrete (main LSM hall) reduces neutron flux by factor 2 and more (with respect to rocks, or not as good or thick concrete at the SAS). This conclusion is extremely important for construction of LSM extension and should be taken into consideration.

Participants in neutron study at LSM project from JINR: V. Brudanin, S.Rozov, and E.Yakushev

Radiochemical project for LSM

D. Filosofov

The collaboration of radiochemical group DzLNP JINR and LSM in 2013 has been mainly devoted to development of effective methods of separation of uranium, thorium, protactinium, actinium, radium and potassium from the target element ("low-background samples" for physical measurements, construction materials, natural samples, reagents) including their ultra small concentrations. With this aim following investigations were carried out:

- For efficient purification of selenium distribution coefficients of ^{234}Th, ^{230}U, ^{223}Ra, ^{225}Ac, ^{60}Co, ^{88}Y, ^{137}Cs,^{139}Ce, ^{143}Pm, ^{167}Tm, ^{169}Yb and ^{173}Lu on the cation-exchange resin DOWEX 50W-X8 were determined at various concentrations of selenium and nitric acid and ethanol in solutions;
- For several metals, those are interesting for double beta decay search experiments (Nd, Ca, …), a special studies devoted to investigation of sorption of alkaline-earth and rare-earth elements on Sr-resin in solutions of mineral acids have been performed. Distribution coefficients for these elements were experimentally determined.
- Chromatographic separations of Sr, Ra, Ba were performed. Separately such chromatographic separations were done for lanthanides and Ac in systems «Sr – resin» - solutions $HClO_4$.
- Some studies were devoted to investigations of reduction of selenium with SO_2 from a solution medias such as water, ethanol, glue adds-on to solutions (polyoxyethylene glycol, etc). Promising results at the reduction of selenium with SO_2 using glue adds-on to solution have been obtained.

Main results received in our collaboration in 2013 have been published at:

1. A.V. Rakhimov., G. Warot.,D.V. Karaivanov., O.I. Kochetov., N.A. Lebedev., N.M. Mukhamedshina., I.I. Sadikov., D.V. Filosofov. Purification of selenium from thorium, uranium, radium, actinium and potassium impurities for the low background measurements. Radiochimica acta, 2013, Vol. 101, issue 10, pp. 653-659.

2. D. V. Filosofov, A. V. Rakhimov, G. A. Bozhikov, D. V. Karaivanov, N. A. Lebedev,Yu. V. Norseev, and I. I. Sadikov. Isolation of Radionuclides from Thorium Targets Irradiated with 300-MeV Protons. Radiochemistry. 2013, V. 55.Issue 4. pp. 410-417.

Personal involved in this activity from JINR side: D. Filosofov, A. Rakhimov

Radon measurements at LSM

E. Yakushev

In 2007 JINR developed, build and delivered to LSM high sensitive radon detector. In 2008-2013 this detector was mainly used for continuous control air environment at upper part of the EDELWEISS cryostat. This is one of the key information need for interpretation of EDELWEISS data. The general scheme of anti-radon protection of EDELWEISS experiment is shown on the Fig. 9.1.

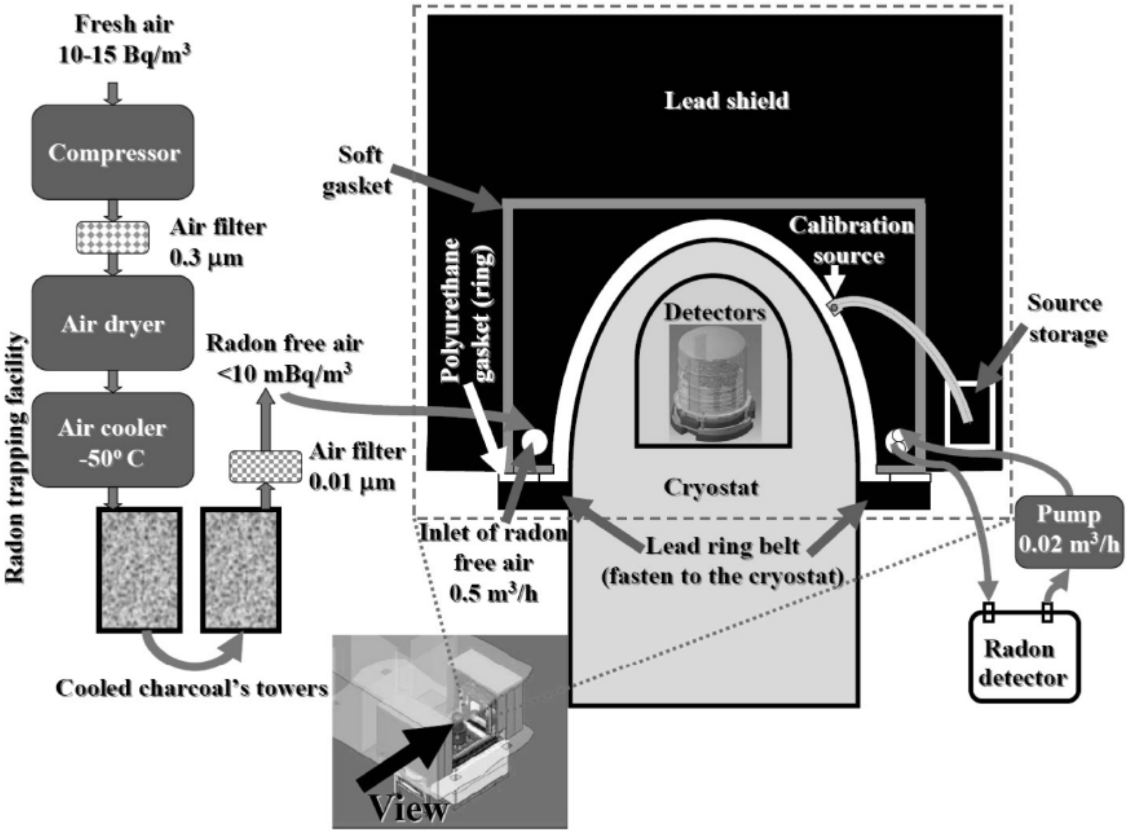


Fig. 9.1: *Scheme of radon environment of EDELWEISS cryostat. Only upper part of the shield is shown.*

After update of the cryogenic system of EDELWEISS, the 2 parts of it shield when closed have an increased gap. To fix this problem, in 2012 we measured the gap between 2 parts of EDELWEISS shield (see previous year report) and found a special low radioactive tube (radioactivity has been measured with low background HPGe detector at LSM). The tube in 2013 was attached in form of arc to one of the part of the shield. By this simple solution we were able to return the radon activity in air inside of closed shields to a level below 50 mBq/m^3.

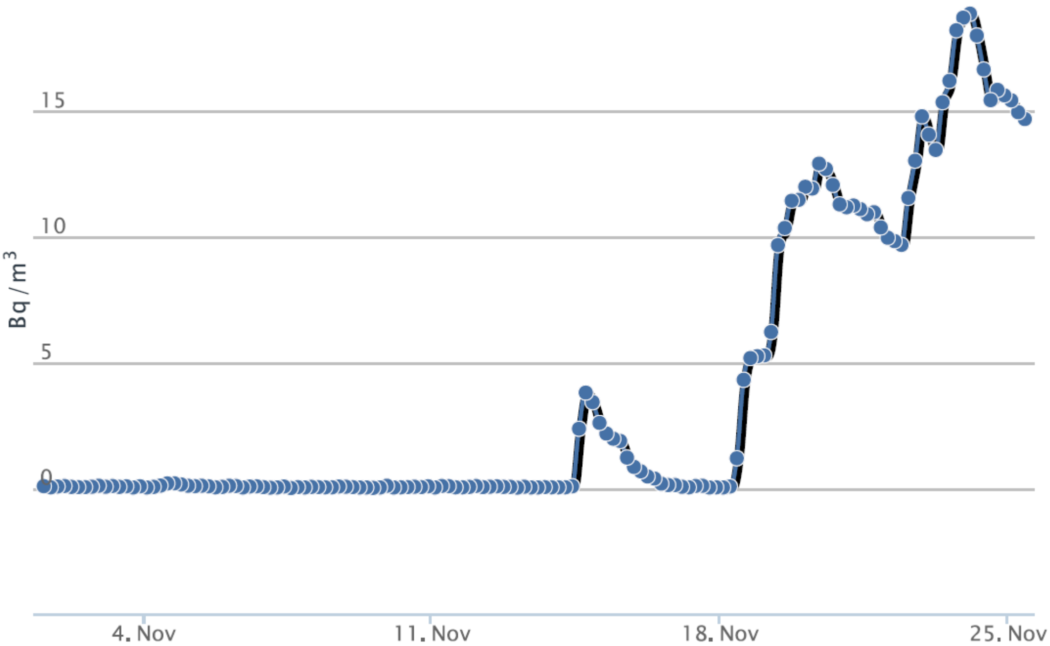


Fig. 9.2: *Changes of radon level with time at proximity to the EDELWEISS cryostat during November 2013. High radon level corresponds to stop of the anti-radon factory.*

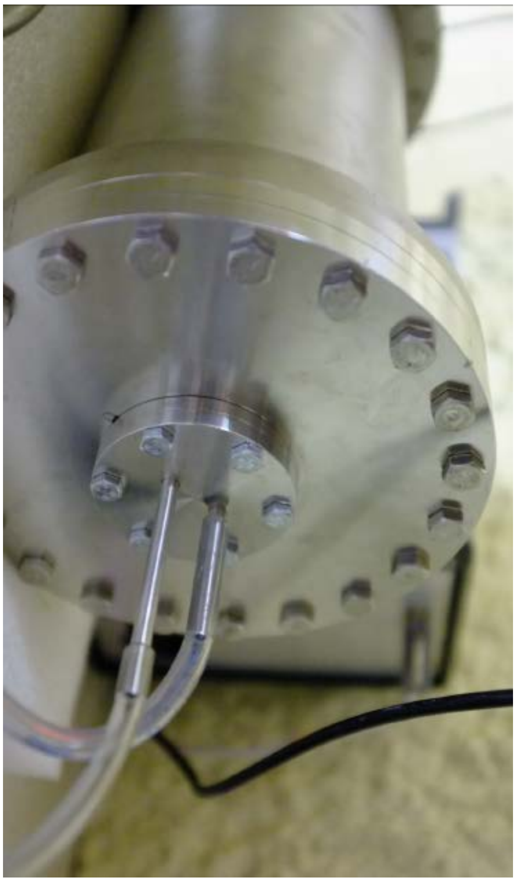


Fig. 9.3: *Mobile high sensitive radon detection system.*

In 2013 we completed development of small radon detector (fig. 9.3) with 6l chamber delivered to LSM in 2012. A software for automatic analysis of accumulated by the detector data has been created. The software performs regular checks of accumulated data, extracts noise, automatically makes report files and sends warning messages by e-mail in case of increasing of radon level above of a set limit. It also sends a warning message in case of any problems with data taking. The software as well provides a possibility to check intensities of chosen region of interest in accumulated data, thus to check intensities of Po-218 and other alpha peaks in the data. The user interface of the software shown on the fig. 9.4.

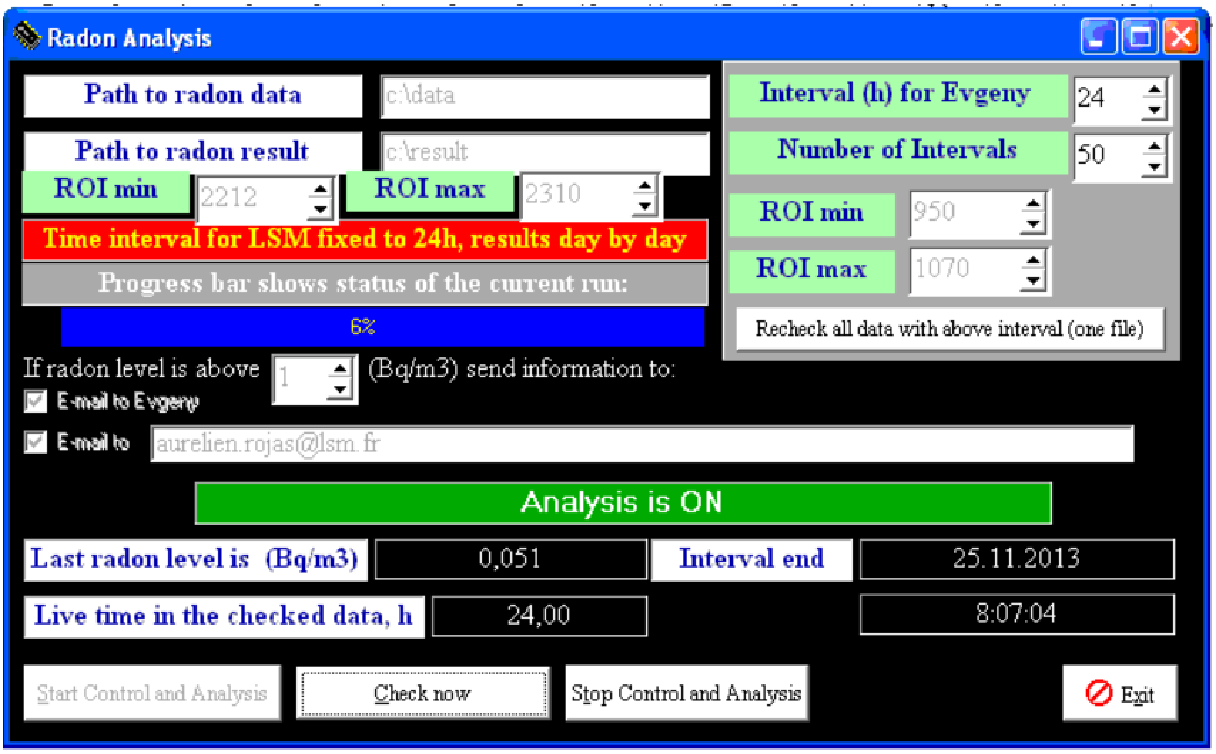


Fig. 9.4: *View of the user interface of the radon monitoring software.*

The detector itself has been significantly improved in 2013 with specially selected in Dubna alpha detector. We tested about 10 detectors on their resolution, own background, noise level, etc. In August 2013 we changed ordinary detector installed in the radon detector on the best one delivered from Dubna. We also significantly changed preamplifier and HV parts of the detector in order to improve its performance for work in very noisy environment (germanium detector hall of LSM).

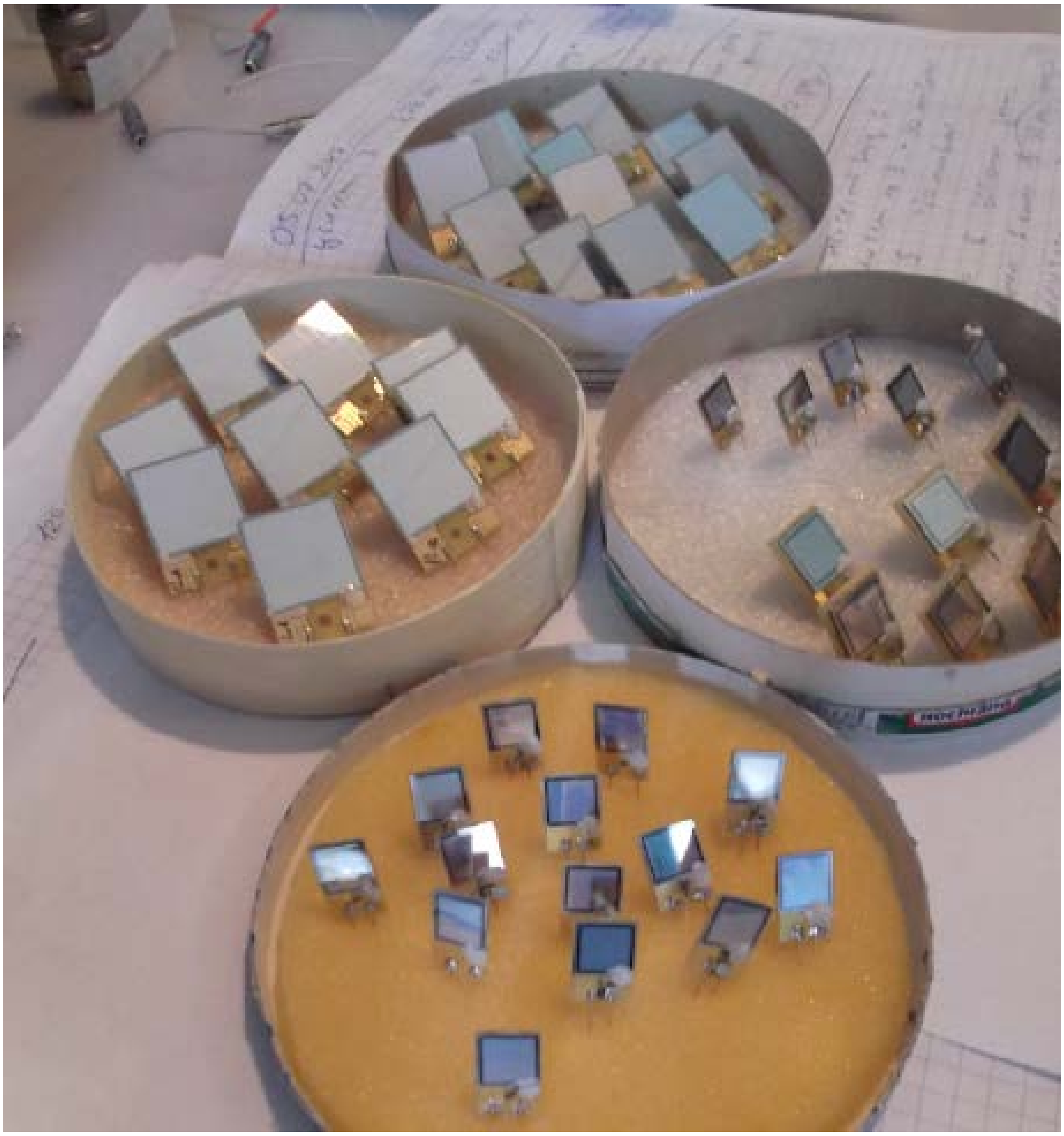


Fig. 9.5*: Set of alpha detectors tested at Dubna.*

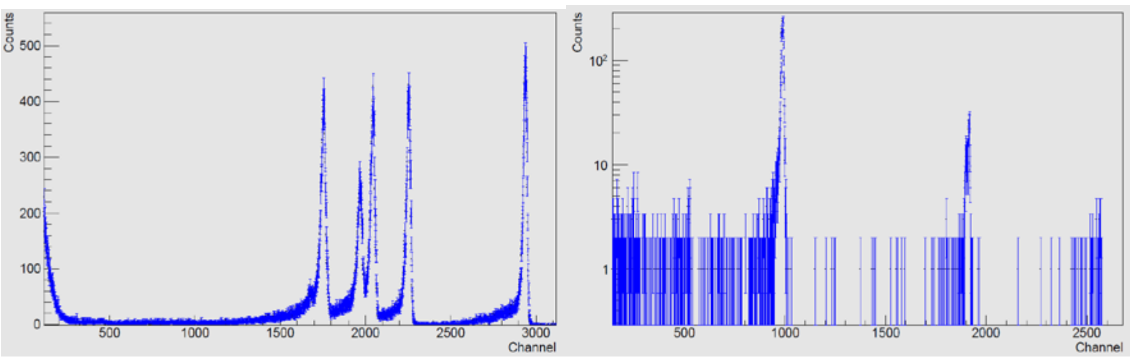
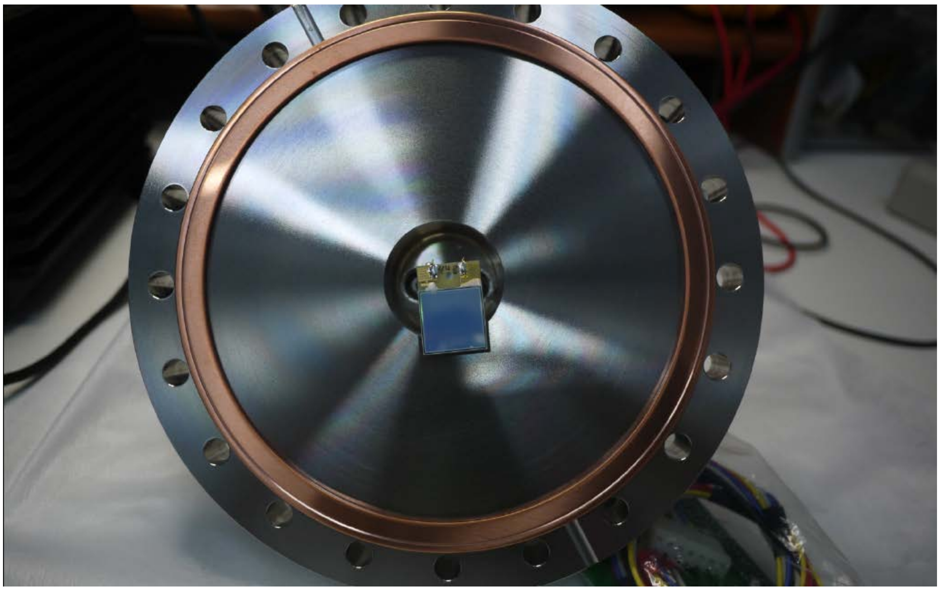


Fig. 9.6*: Example of calibration spectra for tested alpha detectors. Left: spectrum of Ra-226 alpha source; right: spectrum of Gd-Cm alpha source.*



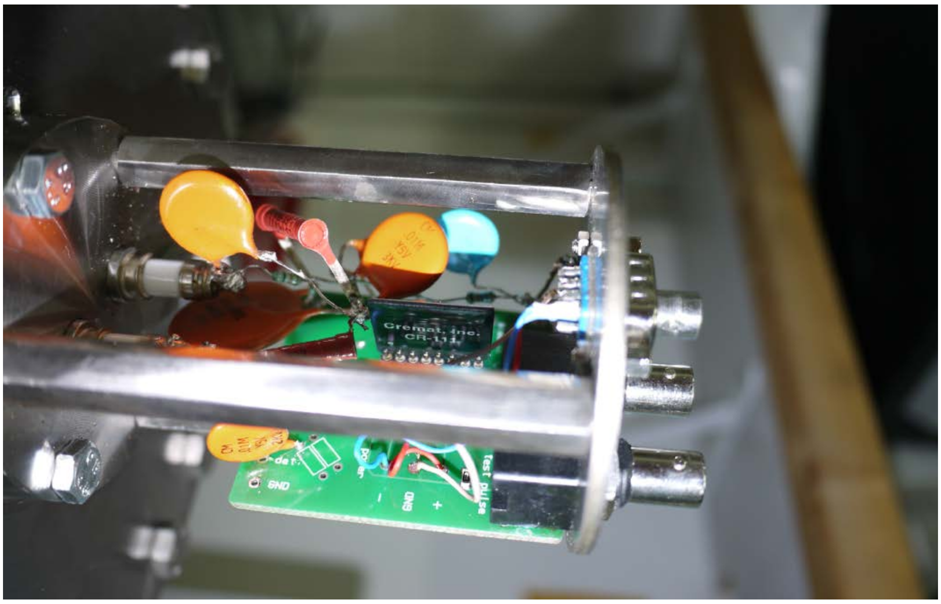


Fig. 9.7: *Top: new alpha detector installed into detector. Bottom: improved electronic part of the detector.*

<u>Participants in LSM radon study project from JINR:</u> V. Brudanin, S.Rozov and E.Yakushev

<u>SUMMARY OF JINR SPENDING AT FRAME OF LEA-JOULE FOR 2013</u>

Direct contribution to LSM:	**18000 euro**
Improved alpha detector for radon detector, new electronics for radon detector:	**1000 euro**
Cost of two UPS systems for ZZ-top and neutron detectors and its delivery on the site:	**500 euro**
New preamplifier part and it housing for He-3 detector of thermal neutrons (for measurements inside of the deep hole):	**700 euro**
Spending on radiochemical project at JINR (preparing purification column for LSM):	**3000 euro**
Archeological lead for ZZ-top detector, it purification and shaping at JINR:	**800 euro**
New first cascade for ZZ-top detector:	**500 euro**
Travel expenses for 10 visits to LSM of Russian scientists at frame of LEA-JOULE (flight tickets, train tickets, medical insurances, visas, etc):	**8000 euro**
<u>Total</u>:	**32500 euro**

SUMMARY OF JINR VISITOR DAYS AT LSM

Name	Activities involved	Dates of LSM visits	Number of days in LSM
O. Kochetov	SuperNENO	18.04.13-16.05.13 05.08.13-28.08.13 27.11.13-28.12.13	28 23 31
S. Rozov	EDELWEISS-III, LSM radon measurements, LSM neutron measurements, Ge zz-top, low threshold detectors	21.03.13-22.04.13 18.05.13-15.06.13	32 28
N. Rukhadze	new Ge, TGV	10.05.13-01.06.13 19.08.13-01.09.13	22 13
D. Filosofov	Radiochemistry project	05.12.13-15.12.13	10
E. Yakushev	EDELWEISS-III, LSM radon measurements, LSM neutron measurements, Ge zz-top, low threshold detectors	29.03.13-22.04.13 10.06.11-28.06.11	24 28
Total		**Visits 10**	**239**