Cooperation of Czech Republic and Laboratoire Soutterain de Modane (LSM, France)

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A) Basic description of LSM

B) Information about cooperating institutions of CR

C) Fundamental experiments:

(1) TGV and SPT experiment – measurement of 2νEC/EC decay of ^{106}Cd

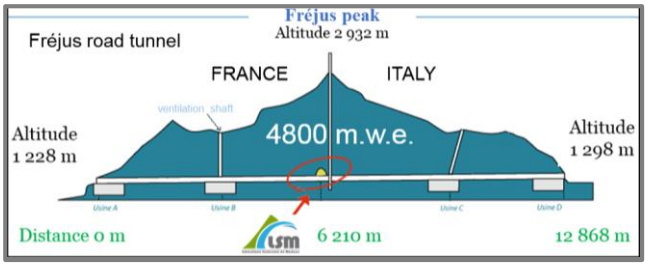
(2) NEMO 3 experiment results – measurement of 0ν and 2νββ decay of several isotopes

(3) SuperNEMO – R&D, measurement of 0νββ decay of ^{82}Se

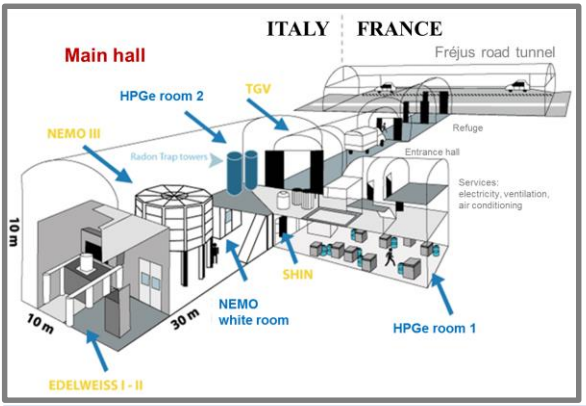
(4) OBELIX detector – detection of excited states of ββ decay

D) Applied research: cooperation with industrial partners from CR (e.g. ATEKO, NUVIA)

Laboratoire Souterrain de Modane (http://www-lsm.in2p3.fr/)



- Road tunnel Fréjus (France – Italy border)
- Depth of ~ 4800 m.w.e. (muon suppression factor ~ 10^6)
- Muon flux: 4×10^{-5} $\mu.m^{-2}.s^{-1}$
- Neutron flux: 4×10^{-2} $n.m^{-2}.s^{-1}$(fast);1.6×10^{-2} $n.m^{-2}.s^{-1}$ (thermal)
- Radon: 15 $Bq.m^{-3}$



Research areas:

- Neutrino physics: SuperNEMO, TGV
- Search of dark matter: Edelweiss, SEDINE, MIMAC
- Nuclear physics: TGV/SPT, SHIN, Obelix, BiPo
- Environmental sciences (oceanography, effects of human activity on the environment ….), biology, nano-electronics

Operators: CNRS/IN2P3 and Grenoble-Alpes University (headed by Arnaud Lucotte)

Users: 200 researchers from 40 laboratories (France, Russia, Czech Republic, UK, Germany, USA, Slovakia, Japan, Ukraine, Greece)

Agreement of International Associated Laboratory JOULE: LSM, JINR Dubna, CTU in Prague and Comenius University (Bratislava).

Outreach: 3 500 visitors per year in our outreach space for general public

Cooperation of Czech side:

- Czech Technical University in Prague; National Radiation Protection Institute; Faculty of Mathematics and Physics, Charles University; Nuclear Physics Institute of the CAS (in total 45 scientists, engineers and students - 7 PhD. students)
- cooperation on construction and operation of experimental and infrastructural facilities
- home infrastructure, R&D of detector technologies (e.g. 2 patents for scintillating detectors, testing of the clean room with radon free atmosphere in NRPI)
- for detailed information see: lsm.utef.cvut.cz

(1) Underground laboratory LSM – included into Roadmap of Czech RIs

Period: 2016-2022
Hosting institution: IEAP CTU in Prague
Participating institution: National Radiation Protection Institute
Purpose: service to other users of LSM (open access)

(2) Operational program MEYS – Science, Research, Education: support of our research connected with RI LSM-CZ

Period: 2017-2019 (with the possibility to continue up to 2022, new call in May 2019)
Hosting institution: IEAP CTU in Prague
Participating institution: National Radiation Protection Institute
Research: theory of ββ decay and DM; experiments of ββ decay (SuperNEMO, TGV, OBELIX, R&D of CZT detectors, zero dose in radiobiology)

List of activities of Czech team in LSM:

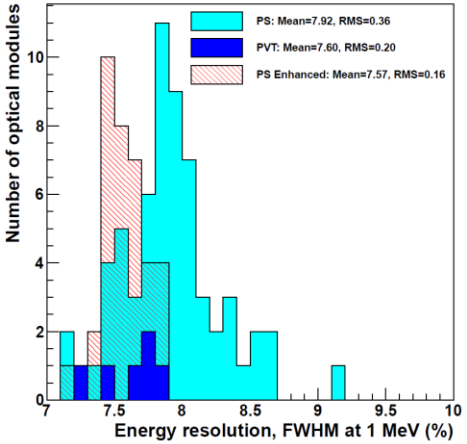
1) *Cooperation with NEMO 3/SuperNEMO:* calorimeter (improvement of scintillating detectors, tests of calibration sources, shielding, common PhD thesis – CENBG,CTU,CU), radon programme, theory (nuclear matrix elements), supporting frame, data analysis of ^{100}Mo and ^{150}Nd

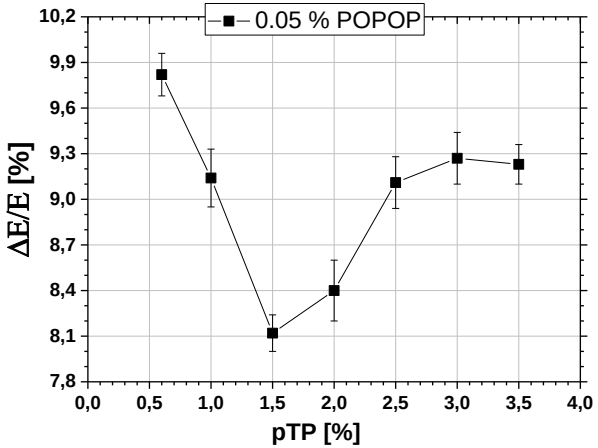
2) *Experiment TGV and SPT* (EC/EC decay of ^{106}Cd) : cooperation with JINR, half-life of 2νββ decay of ^{48}Ca (2 results in the world), highest limit for 2νEC/EC decay of ^{106}Cd

3) *HPGe spectroscopy*: OBELIX (600 cm^3, IEAP CTU-JINR-LSM, $T_{1/2}$ of 2νββ decay of ^{100}Mo on excited state – only 6 results), IDEFIX (IEAP-CU-JINR-LSM), 2 HPGe detectors from NRPI

4) *LSM infrastructure:* clean room for biological research (ISO 5, radon free environment, 110 kEURO); antiradon facility (providing air with Rn activity < 10 mBq/m^3, success story transfer of R&D into production, ATEKO company produced similar facilities - 70 mil. CZK)

5) *Automatic system for HPGe detectors* (sample charger): produced by NUVIA





Experiment NEMO-3 (2003-2011)

(France, UK, Czech Republic, Russia, Spain, USA, Japan, Ukraine, Finland, Slovakia)

Source: 10 kg of ββ isotopes, cylindrical, S = 20 m^2, 60 mg/cm^2

Tracking detector: drift wire chamber operating in Geiger mode (6180 cells)

Calorimeter: 1940 plastic scintillators coupled to low radioactivity PMTs

Magnetic field: 25 Gauss

Gamma shield: Pure Iron (18 cm)

Neutron shield: borated water (~30 cm) + Wood (Top/Bottom/Gaps between water tanks)

Able to identify e^-, e^+, γ and α–delayed

700 000 2νββ events ^{100}Mo, Signal/Backgr. ratio: 80

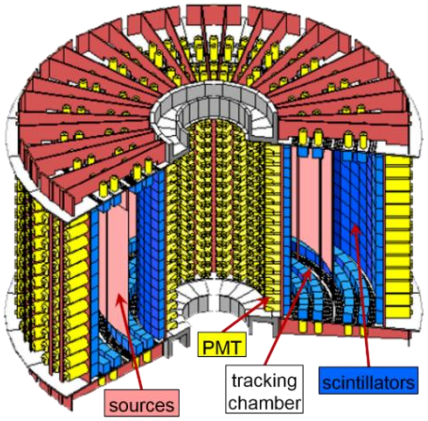
^{100}Mo $T_{1/2}$ (ββ0ν) > 1.0 10^{24} y, $\langle m_\nu \rangle$ < 0.3 – 0.9 eV
[Phys. Rev. D. 89.111101 (2014)]

Isotope	Half-life (10^{19} years)	S/B	Comment	Reference
^{82}Se	9.6 ± 1.0	4	World's best	Phys.Rev.Lett. 95, 483
^{116}Cd	2.74 ± 0.18	10	World's best	Phys. Rev. D 95, 012007
^{150}Nd	0.93 ± 0.06	2.7	World's best	Phys. Rev. D 94, 072003
^{96}Zr	2.35 ± 0.21	1	World's best	Nucl.Phys.A 847(2010) 168
^{48}Ca	6.4 ± 1.2	6.8	World's best	Phys. Rev. D 93, 112008
^{100}Mo	0.71 ± 0.05	80	World's best	Phys.Rev.Lett. 95, 483
^{130}Te	70 ± 14	0.5	First direct detection	Phys. Rev. Lett. 107, 062504

NEMO3		SuperNEMO
^{100}Mo		^{82}Se (^{150}Nd or ^{48}Ca)
7 kg	isotope mass	100 - 200 kg
18 %	signal efficiency	> 30 %
^{208}Tl ~ 20 µBq/kg ^{214}Bi < 300 µBq/kg Rn ~ 5 mBq/kg	contaminations in the source foil Rn in the tracker	^{208}Tl ~ 2 µBq/kg ^{214}Bi < 10 µBq/kg Rn ≤ 0.2 mBq/kg
~ 15 % @ 1 MeV	Calorimeter FWHM	~ 8 % @ 1 MeV
$T_{1/2}(0\nu\beta\beta) > 2 \times 10^{24}$ y $\langle m_\nu \rangle < (0.3 - 0.9)$ eV	half-life sensitivity effective neutrino mass	$T_{1/2}(0\nu\beta\beta) > 1 \times 10^{26}$ y $\langle m_\nu \rangle < (0.04 - 0.11)$ eV

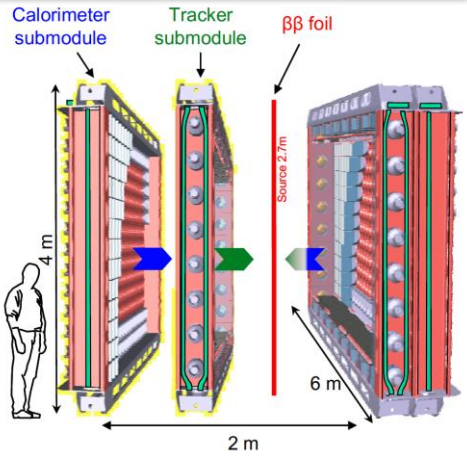
Since 2006

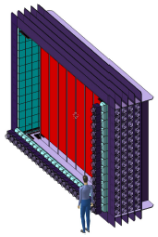
R&D



Inauguration Day:
9.11.2017 at LSM
SN demonstrator (6,2 kg of ^{82}Se)

20×





Background reduction and **rejection**

SuperNEMO Demonstrator Module
35 tons

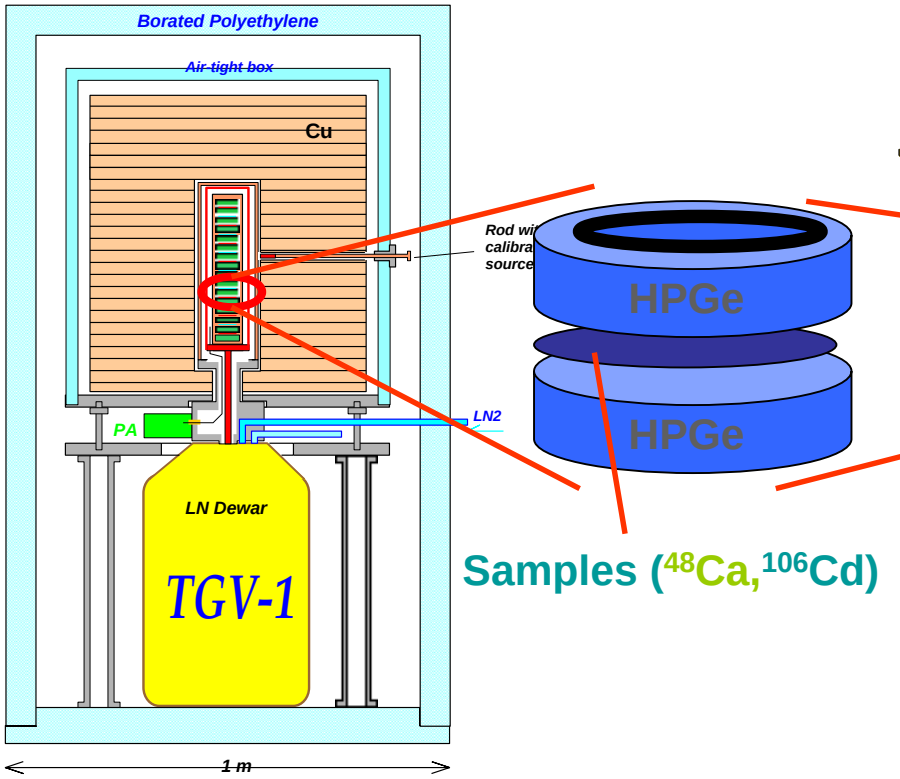
=

1kg of bananas

= 100 Bq (decays/sec)

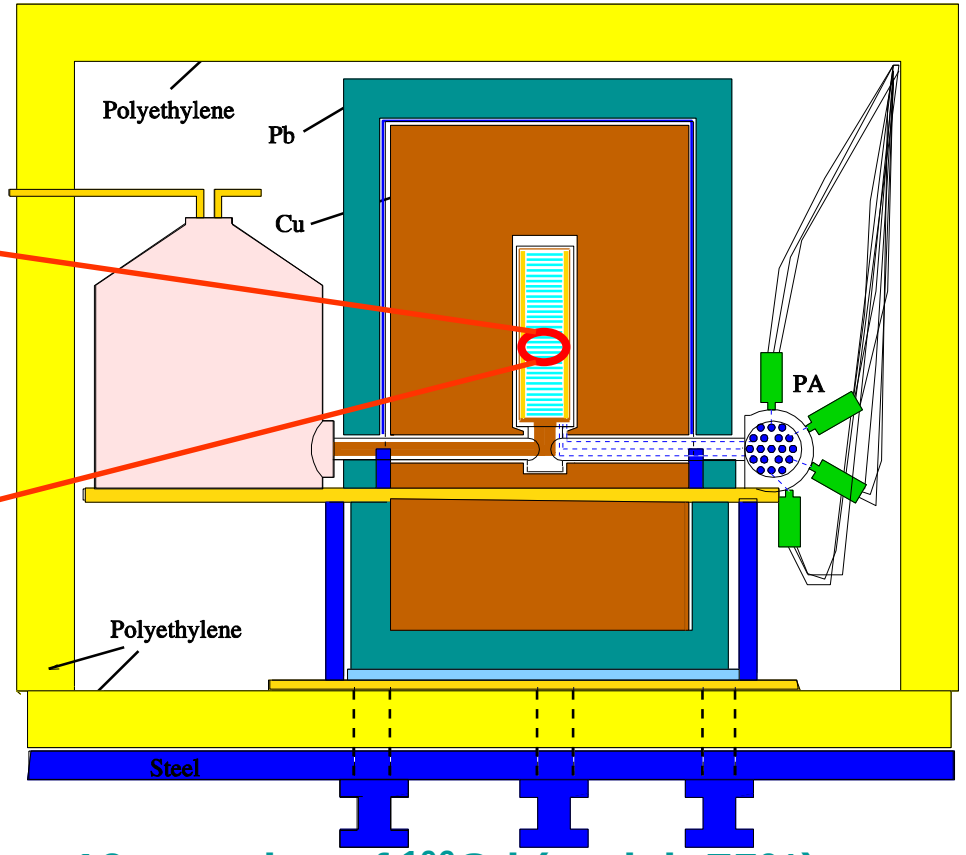
EXPERIMENT TGV (IEAP CTU, JINR, CSNSM, CU, RRC)

TGV I (1996-2000) *NIM A372 (1996) 222*



Samples (^{48}Ca, ^{106}Cd)

TGV II (2004-2010) *NIM A569 (2006) 737*



8 samples of enriched ^{48}Ca:
1.08 g ≈ 1.35•10^{22} atoms
16 HPGe detectors 1200 mm^2 x 6 mm

16 samples of ^{106}Cd (enrich.75%)
13.6 g ~ 5.79 x 10^{22} atoms of ^{106}Cd
32 HPGe detectors 2040 mm^2 x 6 mm

$$T_{1/2}^{2\nu\beta\beta}(48Ca) = (4.2\,^{+3.3}_{-1.3}) \times 10^{19}\ yr$$

$$T_{1/2}^{2\nu ECEC}(106Cd) > 4.2 \times 10^{20}\ yr\,(90\%CL)$$

Phys. Lett. B495 (2000) 63

Nucl. Phys. A 852 (2011) 187-206

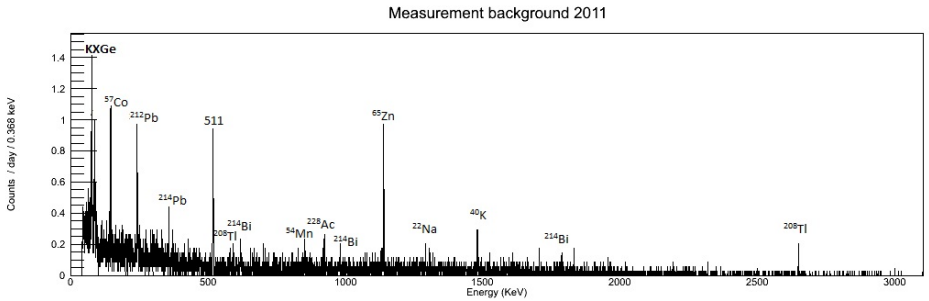
Detector “Obelix” (JINR/IEAP CTU/LSM)

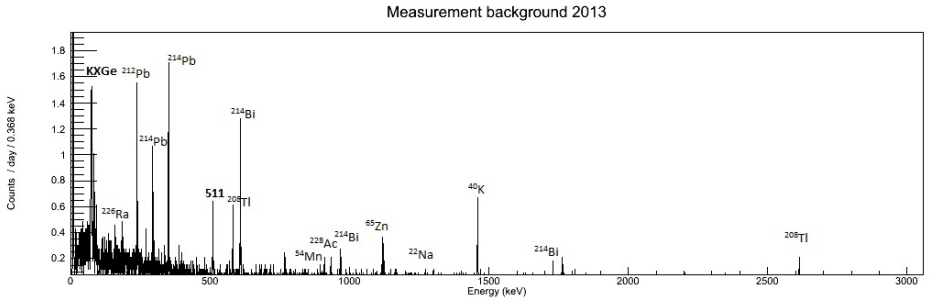
P type coaxial HPGe detector (U-type ultra low background cryostat located at LSM (4800 m w.e.)

Sensitive volume **600 cm^3** ***Efficiency*** **162%** ***Peak / Compton*** **83**

Energy resolution **~1.2 keV at 122 keV (^{57}Co), ~2 keV at 1332 keV (^{60}Co)**

12 cm of arch. Pb, 20 cm of low active Pb, Radon free air



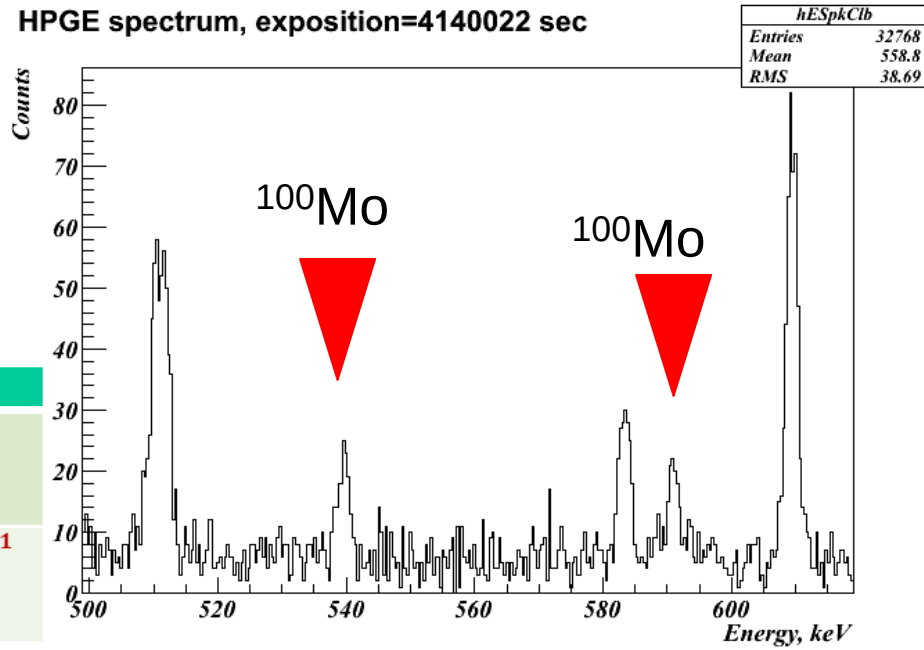


	Total [40-3000 keV]	time of meas.
	cts/min	
September 2011	0.24 +/- 0,002	40 days
June 2013	0,16 +/- 0,003	35 days

- **Mass of ^{100}Mo – 2517,15 g**
- **Total measurement time – 2288 h**

Published at:
Nuclear Physics A, Vol. 925, pp. 25-36 (2014)

Process	$T_{1/2}$ [years]
2v2β$^-$ decay to 0^+_1 [1130 keV]	7.5×10^{20}
2v2β$^-$ decay to 2^+_1 [540 keV]	$> 2.5 \times 10^{21}$

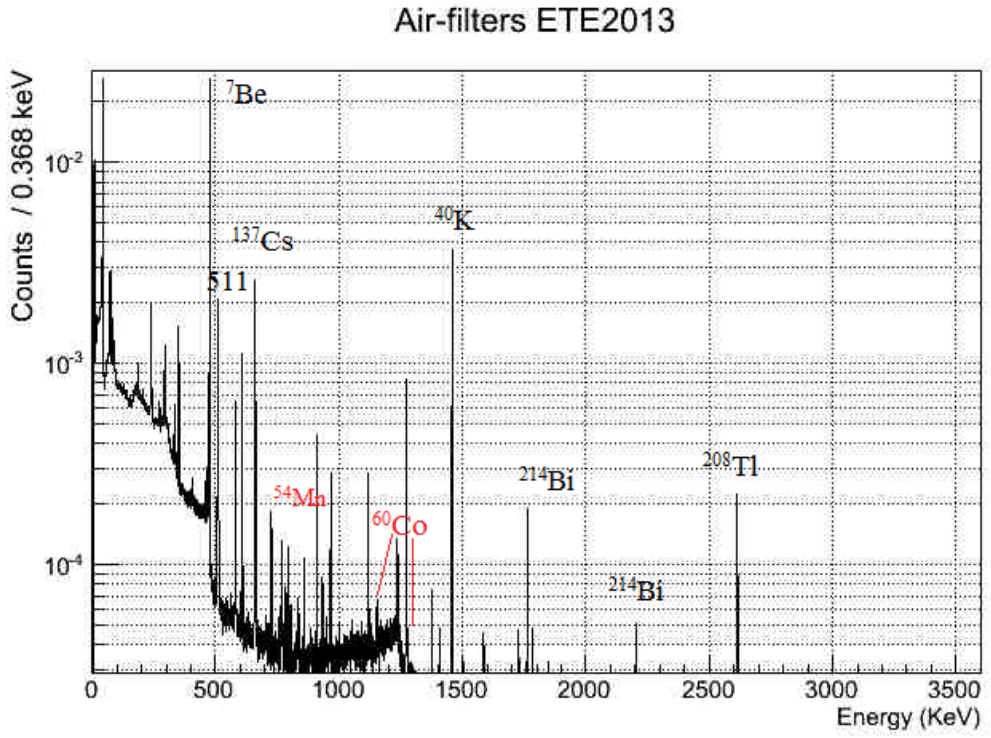


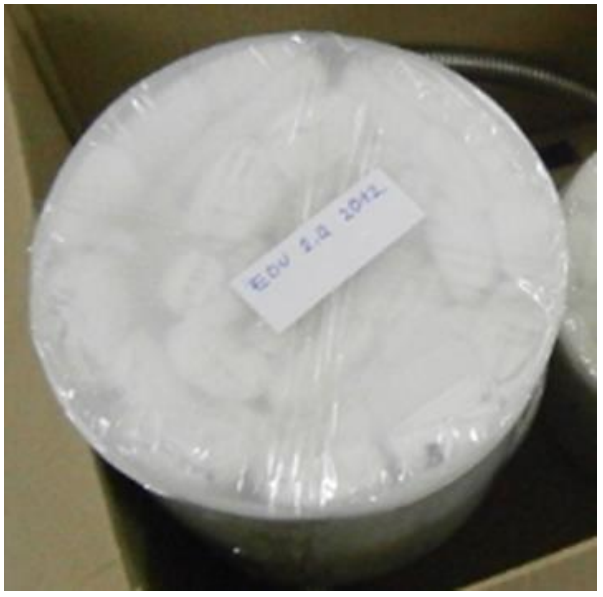
Air-filters close to nuclear power station

-Samples from NPP:
-Total measurement time - 56 days

^{54}Mn and ^{60}Co were first time seen in the spectrum

Sample	(II measurement)	(I measurement)
Time of measurement	33,3 days	22.3 days
Nuclide (Kev)	**MDA (Bq/m3)**	**MDA (Bq/m3)**
Mn-54 (834)	3.39E-09	8.79E-09
Co-60 (1173)	3.85E-09	1.5E-08
Co-60 (1332)	2.94E-09	9.9E-09
Ag-110M (884)	7.61E-09	2.01E-08





Most important future plans (CR and LSM):

a) *Infrastructure:*

- extension of clean room ("ZERO DOSE" radiation condition, class 5): for biologists, DAMIC experiment
- installation of automatic system for charging of samples for HPGe detectors
- R&D of cleaning system for gas purification in tracking detector of SuperNEMO
- installation of new 2 ultra-low background HPGe detectors (IDEFIX - 600 cm^3, efficiency 162%; second one financed and run by NRPI)
- active participation in the LSM extension – future project on EU level !!!

b) *Scientific:*

- finishing and running of SuperNEMO demonstrator ($0\nu\beta\beta$), cooperation on construction of other modules of SuperNEMO, data processing, strong group of theoreticians in IEAP (further development of the theory of double beta decay)
- use of pixel detectors in double beta decay
- increase of our participation in new collaborations, LEGEND (^{76}Ge), PICO (DM)
- biological research

c) *Educational:*

- summer schools (Pontecorvo Neutrino school, Romania 2019…)
- international conference MEDEX (Nuclear matrix elements, Prague 2019, 2021…)
- organization of collaboration meetings (SuperNEMO, COBRA…)

Benefits for Czech side:

- Participation in attractive research programme, progressive technologies (transfer to industry)
- Education of students and early carrier researchers
- Improvement of home infrastructure (attracts researchers from abroad to CR)
- Organization of international conference (see medex19.utef.cvut.cz)
- Pan-European cooperation, synergy and effective use of budget

Thank you very much for your attention