Overview of screening facilities

Meeting on next generation ^{76}Ge experiment

IBZ, Munich, Germany

April 25th – 27th 2016

- Many thanks to:

Yuri Efremenko, Grzegorz Zuzel, Marcin Wójcik, Stefano Nisi, Maria Laura Di Vacri

for providing information

MJD screening and more

MJD Assay program

Yuri Efremenko

Dec 4th, 2014

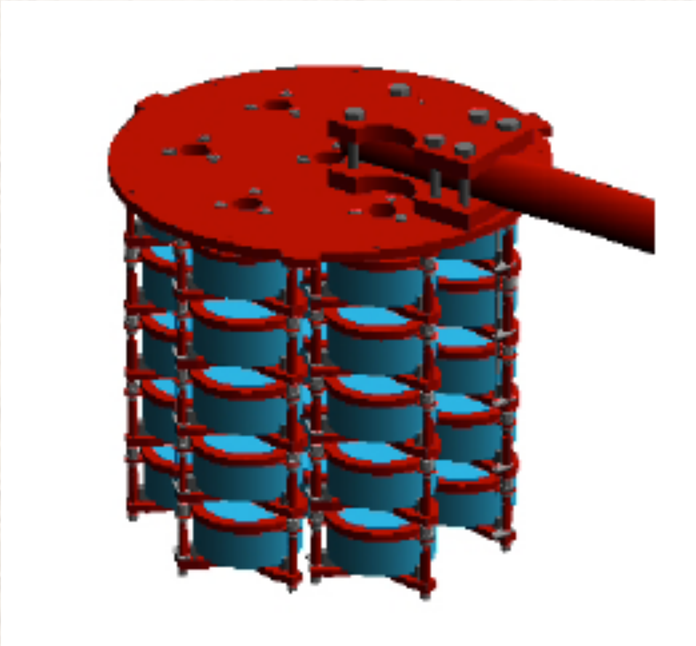
Majorana-GERDA meeting

Heidelberg, Germany

MJD low background philosophy

Ultra strong requirements for detectors (purity, performance)

Ultra strong requirement on radiopurity of copper

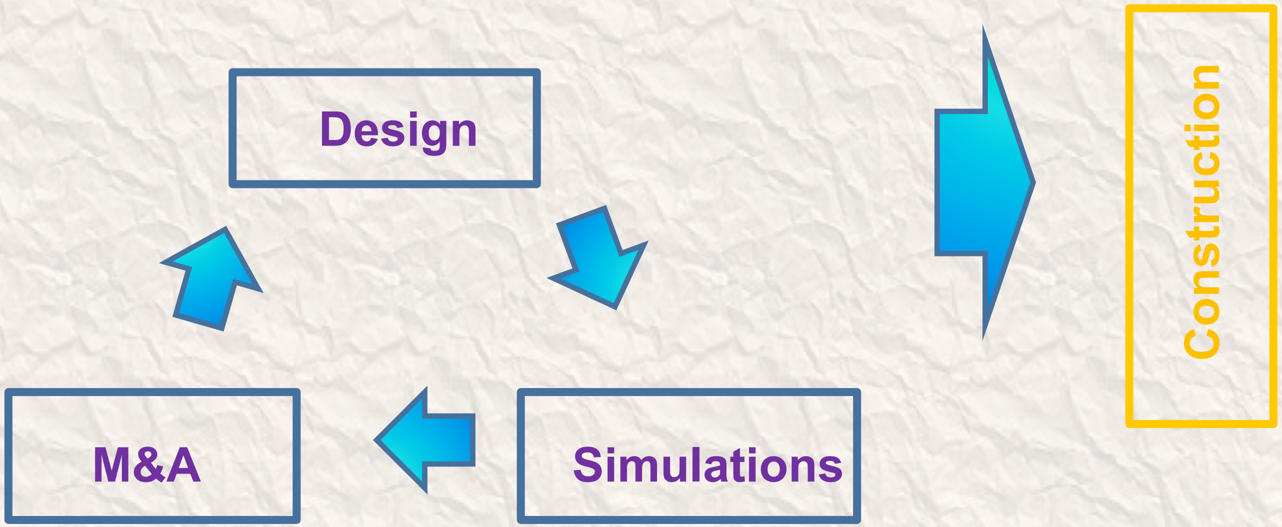


Strong requirements on radiopurity of all other components and strong efforts to minimize mass of all materials except copper

Minimize number of different materials

Methodical Approach

Selection of materials and assay significantly affect design



A few rounds of iterations were taken before we achieved final conclusions

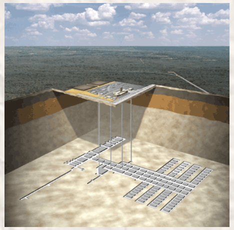
MJD Used Multiple Facilities & Methods

Gamma Counting

Sensitivity is ~ mBq/kg

Oroville (LBNL)
180 m.w.e.

KURF (UNC)
1400 m.w.e.

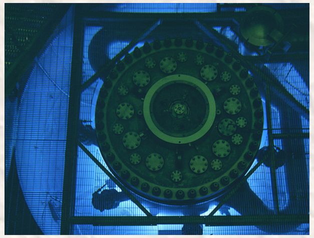


WIPP (LANL)
1600 m.w.e.

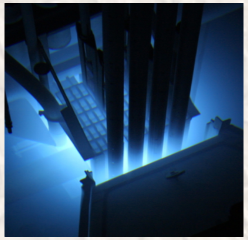
NAA

Sensitivity is ~ 0.1 µBq/kg
Low Z materials - plastics

MNRC (U.C. Davis) 2 MW
$1.5 \cdot 10^{13}$ n/cm^2 sec^{-1}



HFIR (ORNL) 85 MW
$4 \cdot 10^{14}$ n/cm^2 sec^{-1}



Pulstar (NCSU) 1 MW
$4\text{-}8 \cdot 10^{12}$ n/cm^2 sec^{-1}

ICP-MS and GD-MS

PNNL

ORNL

LBNL

Canadian Research Council

Sensitivity is ~0.1 µBq/kg

Background Summary Table

Material	Part of Demonstrator	Decay Chain	Achieved Assay	
			[μBq/kg]	[c/ROI/t/y]
EFCu	Inner Cu Shield, Cryostat, Coldplate, Thermal Shield, Detector Mounts	Th	0.06	0.15
		U	0.17	0.08
OFHC	Outer Copper Shield (O.Cut)	Th	1.1	0.26
		U	1.25	0.03
Pb	Lead Shield	Th	5	0.26
		U	36	0.07
PTFE	Detector Supports	Th	0.1 ± 0.01	0.01
		U	<5	<0.01
Vespel	Cold Plate Support	Th	<12	<0.01
		U	<1050	<0.4
Parylene	Cu coating, Cryostat seals	Th	2150	0.27
		U	3110	0.09
Silica / Au, Epoxy	Front-End Electronics	Th	6530	0.32
		U	10570	0.28
Cu Wire + PFA	Signal /HV Cable and Connectors	Th	2.2	0.01
		U	145	0.08
Stainless Steel	Service Body	Th	$(18 \pm 3) \times 10^3$	<0.04
		U	<5000	<0.03
Completely assembled connector	Connectors	Th	210	0.13
		U	335	0.06

$\Sigma < 2.7$ c/ROI/T

User Facility	Detector Name	Detector Category	Sensitivity
Berkeley Low Background Facility	Merlin	HPGe	Passive Counting: U series 0.5 ppb, 6 mBq/kg; Th series 2.0 ppb, 8 mBq/kg; K 1.0 ppm, 30 mBq/kg Neutron Activation Analysis also available for U,Th, K; or others.
Berkeley Low Background Facility	MAEVE	HPGe	Passive Counting: U series 50 ppt, 0.6 mBq/kg; Th series 200 ppt, 0.8 mBq/kg; K 100 ppb, 3 mBq/kg Samples are typically pre-screened at a surface BLBF detector prior to this detector.
Boulby Underground Laboratory	Lunehead	HPGe	Approximately 50 ppt (0.6 mBq/kg) for U238 decay series; 200 ppt (0.8 mBq/kg) for Th232 decay series; K 100 ppb (3 mBq/kg), assuming typical sample mass O(kg).
Boulby Underground Laboratory	Chaloner	HPGe	Approximately 50 ppt (0.6 mBq/kg) for U238 decay series; 200 ppt (0.8 mBq/kg) for Th232 decay series; K 100 ppb (3 mBq/kg), assuming typical sample mass O(kg).
Boulby Underground Laboratory	Lumpsey	HPGe	Approximately 100 ppt (1.2 mBq/kg) for U238 decay series; 200 ppt (0.8 mBq/kg) for Th232 decay series; K 100 ppb (3 mBq/kg)
Boulby Underground Laboratory	Wilton	HPGe	Pre-screen detector: U series 0.5 ppb, Th series 2.0 ppb
SNOLAB Low Background Counter Center	PGT HPGE Detector	HPGe	Typical sensitivities for standard size samples are: 238U at 0.15 mBq/kg; 232Th at 0.13 mBq/kg; 40K at 1.70 mBq/kg; 60Co at 0.06 mBq/kg; and 137Cs at 0.17 mB/kg.
SNOLAB Low Background Counter Center	Canberra Well Detector	HPGe	Typical sensitivities for standard size samples are: 238U at 0.05 mBq/kg; 232Th at 0.4 mBq/kg; 228Ac at 0.2 mBq/kg; 235U at 0.02 mBq/kg; and 210Pb at 0.15 mB/kg.
Sanford Underground Research Facility - CUBED LBC	Roadrunner	HPGe	0.7 mBq/kg for U/Th
Soudan Underground Laboratory	Gopher	HPGe	<~ 1 mBq/kg
SDSM&T Particle Astrophysics Research Center	Alpha Duo	alpha/beta counters	~0.15 alphas/day/cm^2 (surface)
Southern Methodist University	Peruna	alpha/beta counters	0.001 alphas/cm^2/hr (surface)
Pacific Northwest National Laboratory	ICPMS	mass spectrometry	< 1 microBq/kg forTh/U for surface or bulk
UCL HEP	ICPMS	mass spectrometry	U/Th to ppt levels
SDSM&T Particle Astrophysics Research Center	Radon Emanation System	radon emanation / atom trap analysis	~100 uBq/m^2 (expected) (surface)

GerDA screening and more

Radon emanation and large surface area assay

G. Zuzel, M. Wójcik

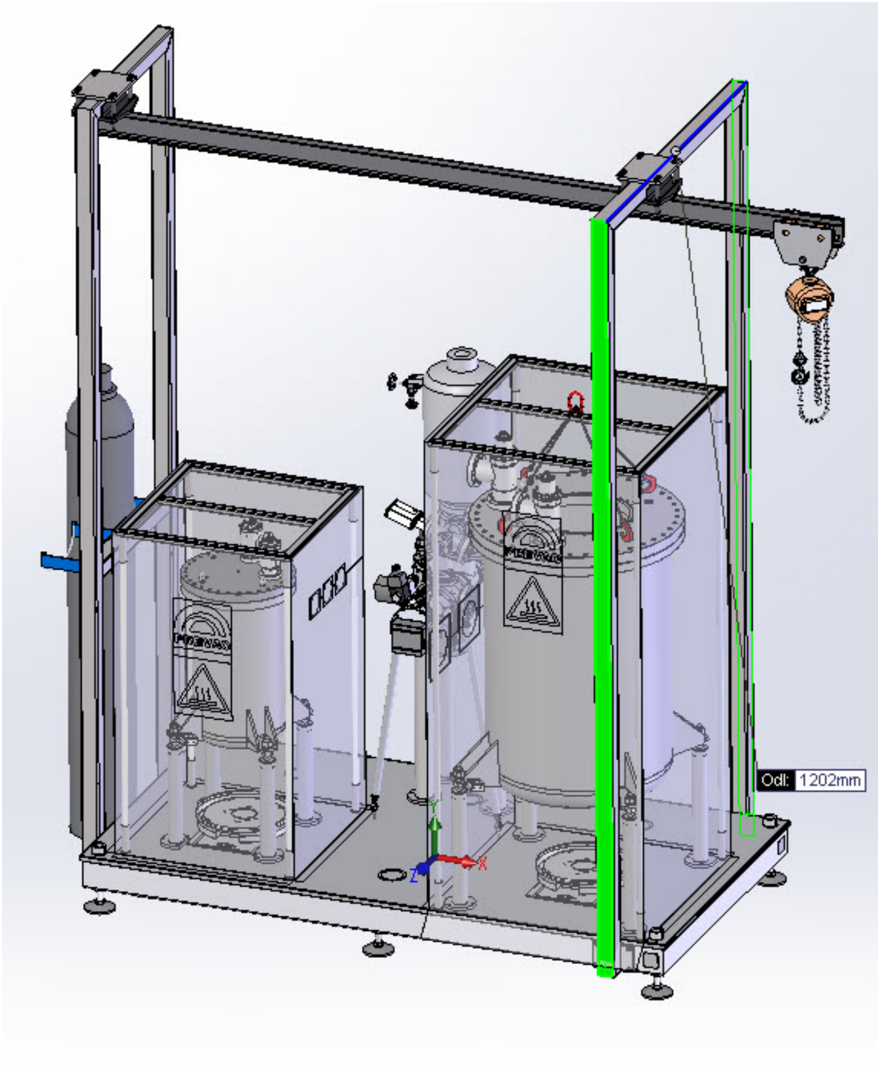
Portable cryogenic Rn detector

- Cryogenic adsorption of Rn with subsequent counting of the alpha decays of Rn and the daughters
- Simultaneous and real-time detection of emanated ^{220}Rn and ^{222}Rn (under vacuum)
- **Emanation tests of small samples**
- **Attachable to vacuum vessels for direct emanation measurements**
- Volume of ~2 L

- Detection efficiency : 25 %
- Resolution (5.5 MeV) : ~40 keV

- **Background (^{222}Rn) : ~0.8 cpd**
- **Detection limit : ~20 μBq (10 ^{222}Rn atoms)**

System of emanation chambers



- Three UHV chambers, fully electro-polished and metal-sealed, 12 L, 50 L and 250 L, available
- Chambers coupled to the cryogenic Rn detector
- Integrated automatic pumping system
- Integrated automatic heating system (emanation tests up to 150 ^{o}C possible)
- Simultaneous real-time detection of emanated ^{220}Rn and ^{222}Rn

System of emanation chambers

Blanks

Detector / Vessel	Volume [L]	Blank values in saturation [mBq]	
		^{222}Rn	^{220}Rn
Rn detector	~2	~0.02	~0.02
Small chamber	12	0.18	0.19
Middle chamber	50	0.17	0.85
Big chamber	250	0.36	1.2

VERY PRELIMINARY
Still Counting

Large surface area screening

- XIA Ultra-low alpha spectrometer
- Ar used as a counting gas
- Sample size: 43x43 cm, 1-3 mm thick
- Background rate: ~25 cpd (~140 $\alpha/d/m^2$)
- Used mainly to study surface α-activities (Teflon/Cu/SS/Ti) and various cleaning methods (etching, electro-polishing)

Large surface area screening

Large surface area screening

- The spectrometer may also be used to study bulk $^{210}Po/^{210}Pb$
- Alphas coming from a sub-surface layer have reduced energy contributing to the measured spectrum from the detector threshold up to 5.3 MeV
- Estimated sensitivities at the level of ~50 mBq/kg

Chemical method for $^{210}Pb/^{210}Po$ determination

- Dissolving a small sample (up to ~20 g) in acid
- Adding ^{209}Po as a tracer
- Deposition of $^{210}Po/^{209}Po$ on an Ag disc
- Counting with a low-background alpha spectrometer
- Determination of ^{210}Pb requires secular equilibrium („old” samples)
- Sensitivity of the method for metals: ~1 mBq/kg

Studies of Rn emanation at low temperatures

Cryogenic Rn detector

Cryostat for cooling the Rn sources (may be filled with liquid kept at certain temperature by a cryo-cooler)

Metallic surface source of ^{220}Rn / ^{222}Rn installed in vacuum, and thermally coupled to the cryostat

Conclusions

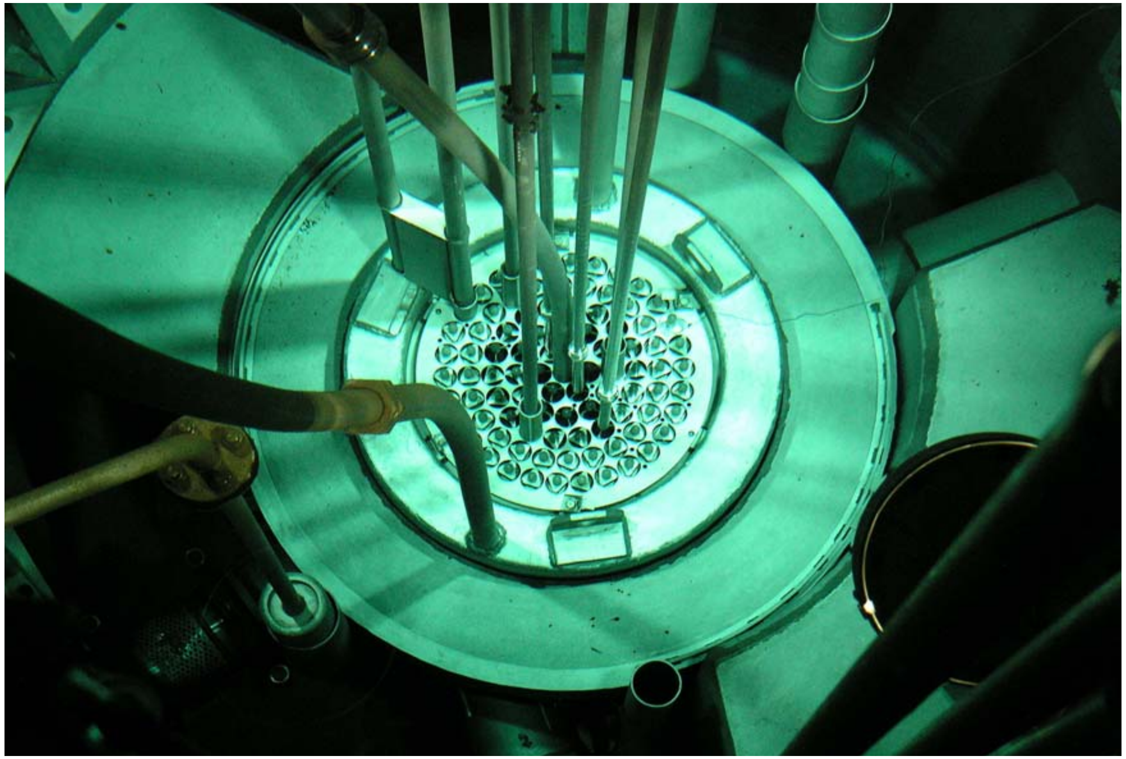
- A new Rn assay system for emanation tests has been developed
- High counting sensitivities (down to single atoms) achieved
- Vacuum vessels or large samples (up to 250 L volume) may be screened
- Unique possibility to investigate ^{220}Rn emanation
- Emanation system still under extensive tests, improvements for ^{220}Rn expected
- Studies of low-temperature Rn emanation recently started
- Another Rn detector with a 50 L chamber under construction
- Large surface area spectrometer available for surface and bulk ^{210}Po studies
- Tests of various samples (Cu/SS/Ti/Teflon) and cleaning methods ongoing

NAA @ LENA (Pavia, Italy)

TRIGA Mark II reactor

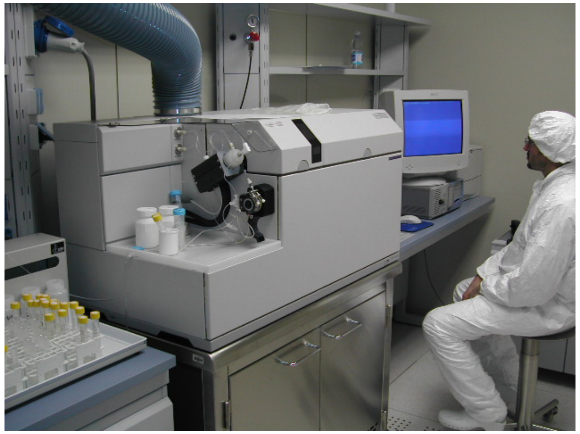
Nominal power in stationary mode: 250 kW

Maximum neutron flux: 2×10^{13} n cm^{-2} s^{-1} ➔ (1 -10) µBq/kg

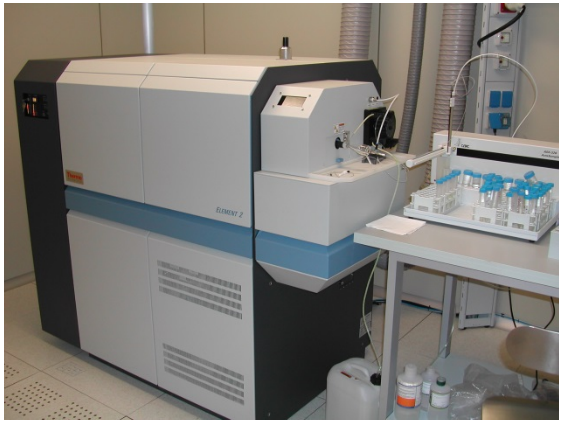


Mass spectrometry @ LNGS

ICP MS



Agilent 7500a quadrupole mass analyzer



Thermo Element2 double focusing high resolution mass analyzer equipped with ESI APEX-Q desolvator

TIMS

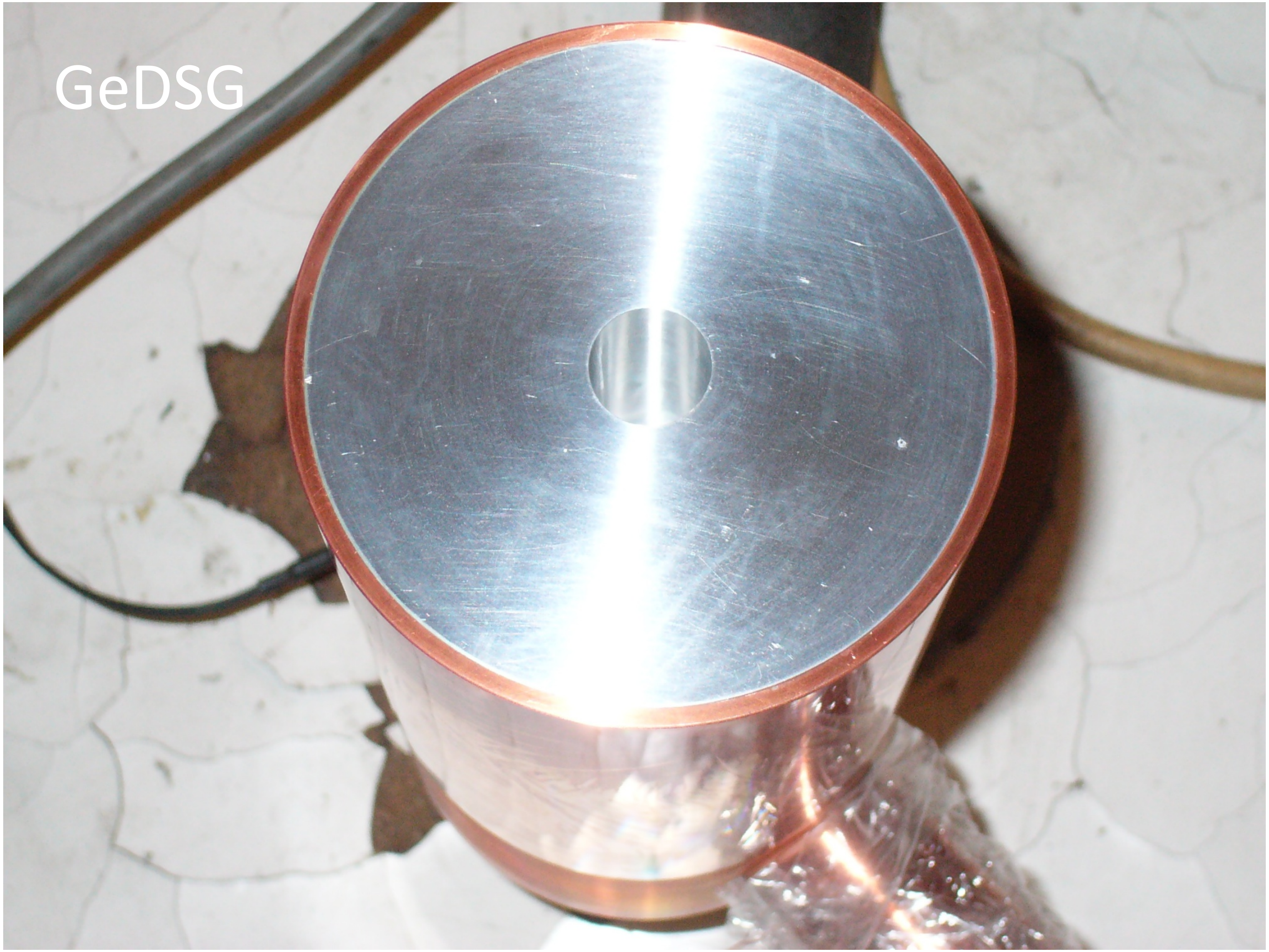
Finnigan MAT 261/262 Thermal Ionization MS Multicollector detector (precise Isotope analysis)

ICP-QMS sensitivity depending on matrix type

	Liquid Solution	Solid Metallic Samples		Solid Plastic Samples
		Dissolution	Separation and pre-concentration of analytes	
Sample amount	**0.5-5 mL**	**0.05-0.5 g**	**1-5 g**	**0.5-5g**
Element	**ppt**	**ppt**	**ppt**	**ppt**
K	**500**	**50000**	**-**	**50000**
Pb	**1**	**500**	**-**	**100**
Th	**0.01**	**100**	**0.5**	**10**
U	**0.01**	**100**	**0.5**	**10**

For now no validated separation procedures are available for K and Pb.


STELLA
EG&G ORTEC


GeDSG

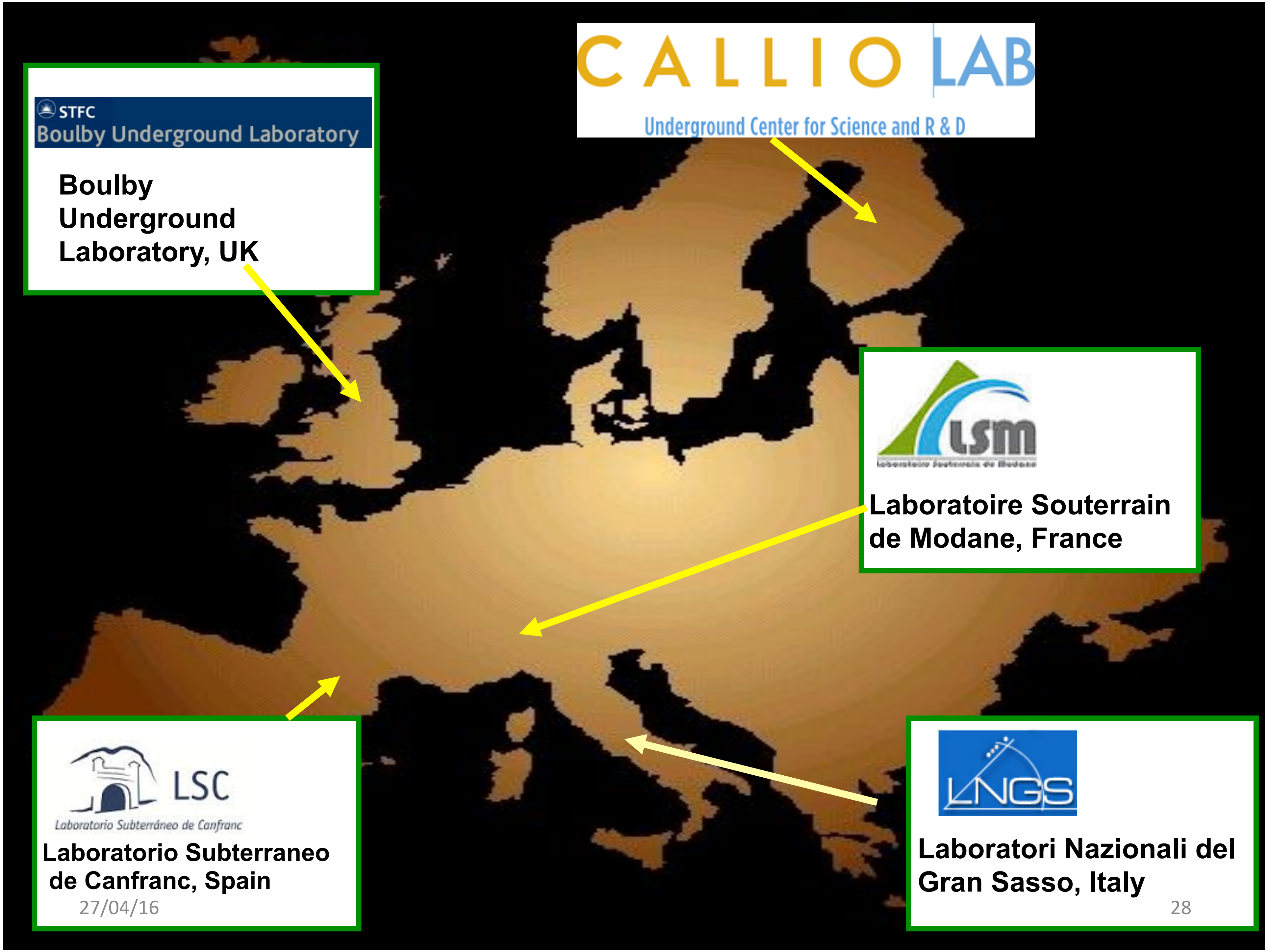
LNGS HPGe detectors

10 detectors installed, 8 p-type coaxial detectors, all LB or ULB configuration, one ULB well-type detector, one BEGe ULB detector

Sensitivity (U/Th):

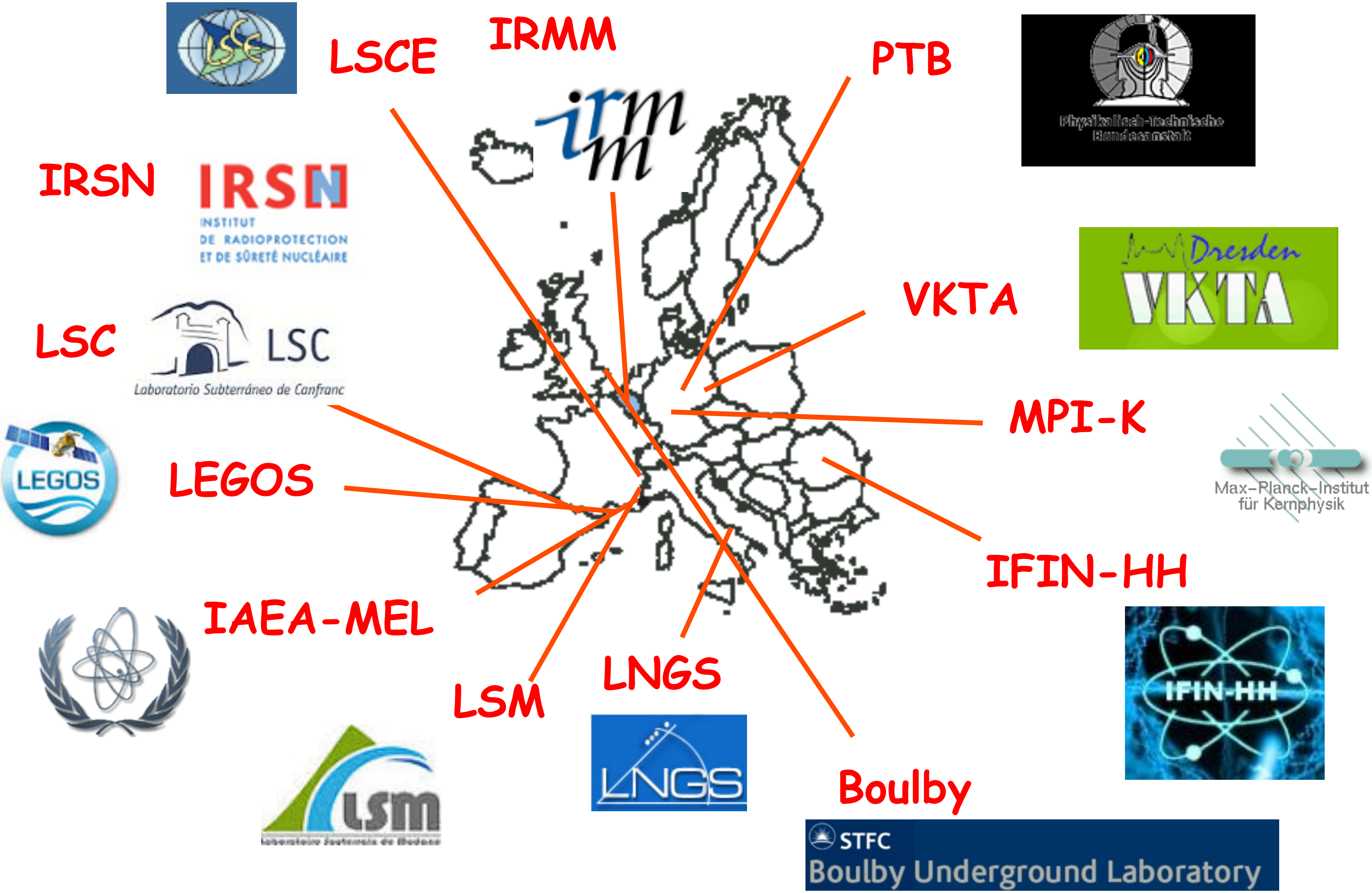
commercial LB detectors O(mBq/kg)
commercial ULB detector O(0.5 mBq/kg)
custom ULB detector O(50 **μ**Bq/kg)

MPI-K GeMPI detectors located at LNGS -> see slides presented later by Bernhard Schwingenheuer for MPIK.


STFC
Boulby Underground Laboratory
Boulby Underground Laboratory, UK
CALLIO LAB
Underground Center for Science and R & D
LSM
Laboratoire Souterrain de Modane, France
LSC
Laboratorio Subterráneo de Canfranc
Laboratorio Subterraneo de Canfranc, Spain
LNGS
Laboratori Nazionali del Gran Sasso, Italy

CELLAR

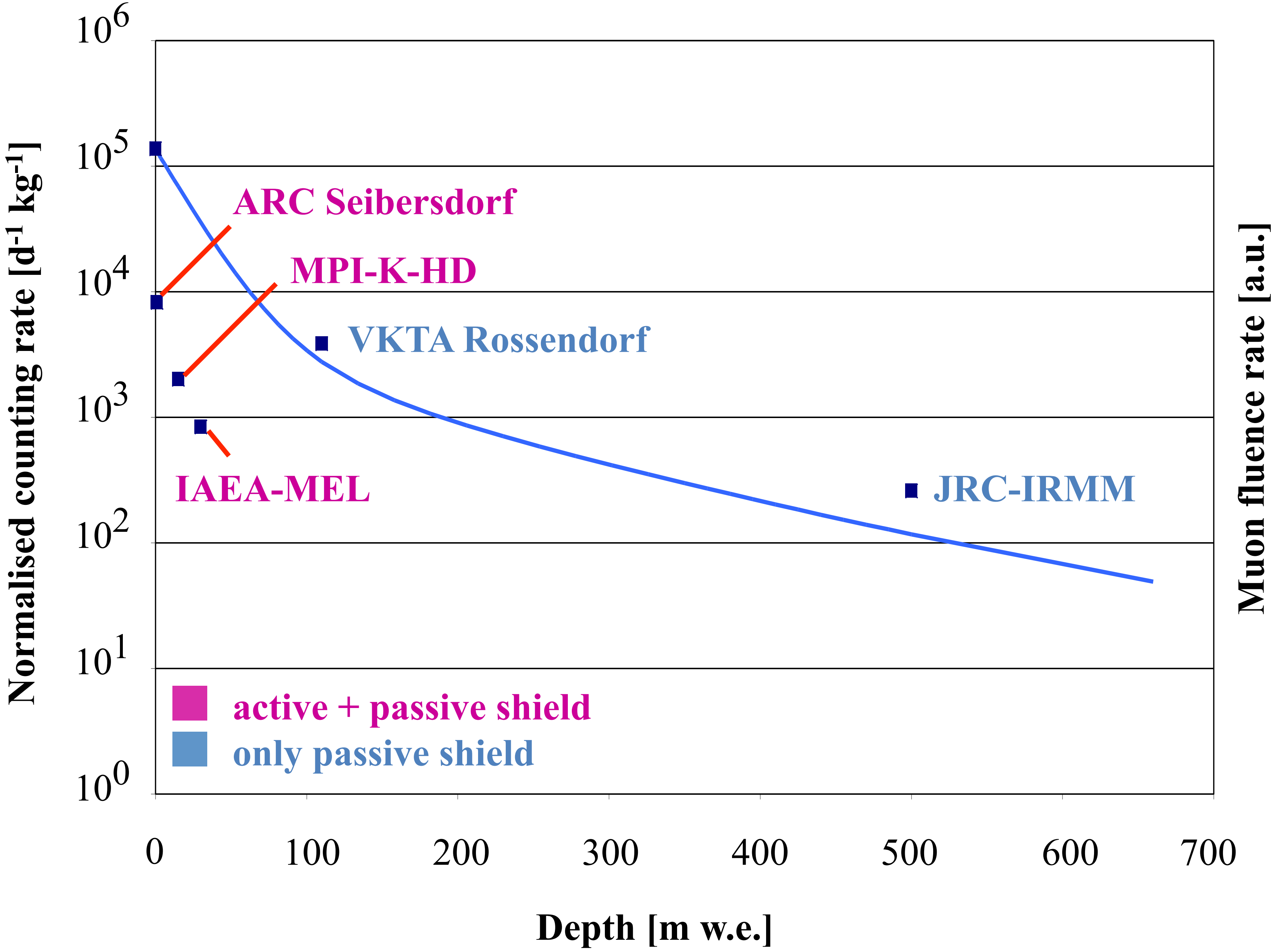
Collaboration of **E**uropean **L**ow-level **underground** **LA**bo**R**atories


LSCE
IRMM
PTB
Physikalisch-Technische Bundesanstalt
IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE
VKTA
Dresden
LSC
Laboratorio Subterráneo de Canfranc
MPI-K
Max-Planck-Institut für Kernphysik
LEGOS
IFIN-HH
IAEA-MEL
LSM
LNGS
Boulby
STFC
Boulby Underground Laboratory

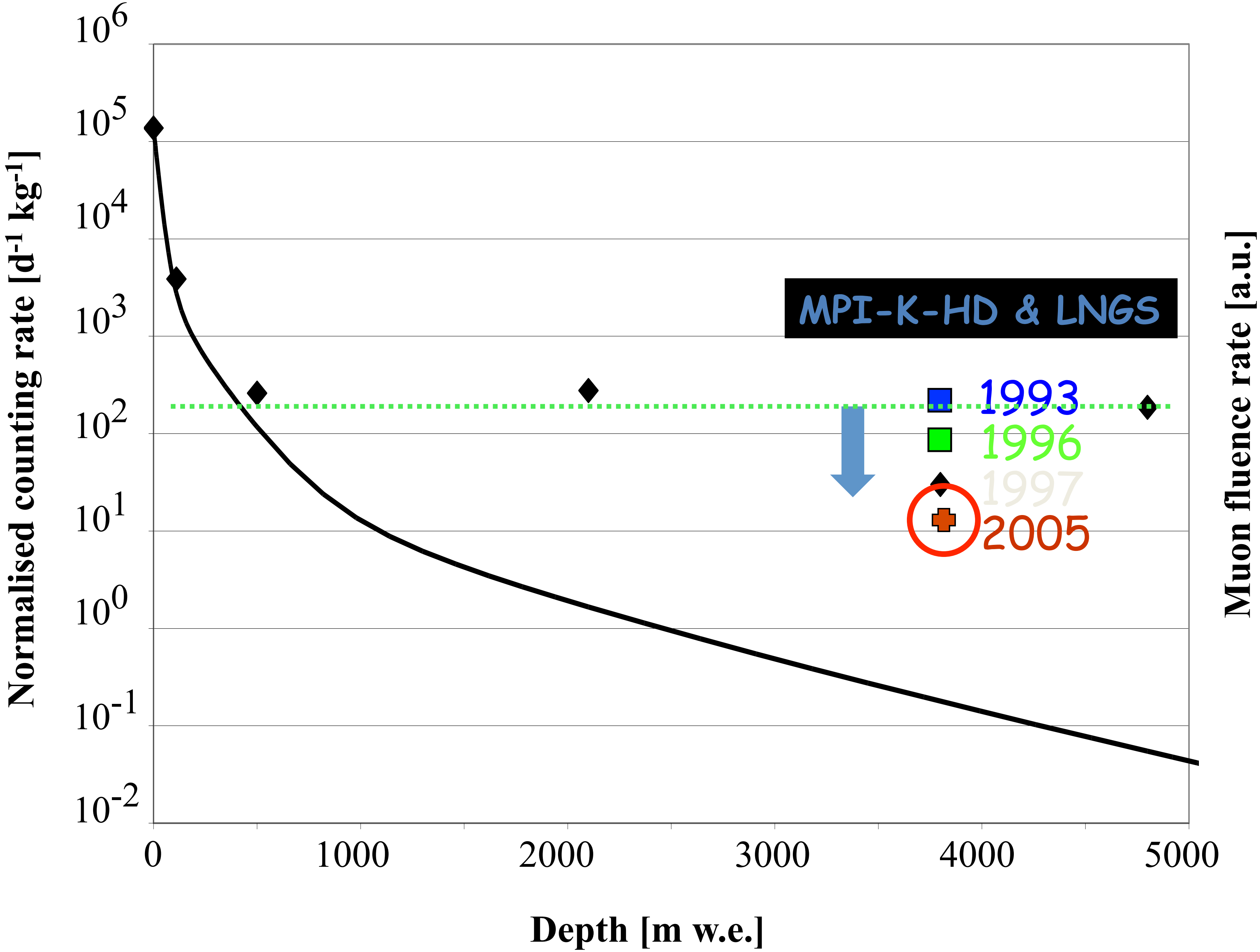
EUFRAT – European facility for nuclear reaction and decay data measurements

Transnational Access of external users to JRC-IRMM nuclear facilities

https://ec.europa.eu/jrc/en/eufrat



Normalised counting rate [d-1 kg-1]
Muon fluence rate [a.u.]
Depth [m w.e.]
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0
100
200
300
400
500
600
700
ARC Seibersdorf
MPI-K-HD
VKTA Rossendorf
IAEA-MEL
JRC-IRMM
active + passive shield
only passive shield



Normalised counting rate [d-1 kg-1]
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
MPI-K-HD & LNGS
1993
1996
1997
2005
0
1000
2000
3000
4000
5000
Depth [m w.e.]
Muon fluence rate [a.u.]

Conclusions

- For future more sensitive screening is needed, especially for gamma-ray spectrometry, if secular equilibrium has to be tested.
- Advanced screening techniques are needed, whatever this means.
- Surface contamination screening is needed with the required sensitivity (see e.g. Bi-Po detector).