Gamma-ray spectrometry 225 m underground – *Developments, possibilities and applications*

+ Status of GERDA

Mikael Hult

IRMM - Institute for Reference Materials and Measurements

Geel - Belgium

http://irmm.jrc.ec.europa.eu/

http://www.jrc.ec.europa.eu/

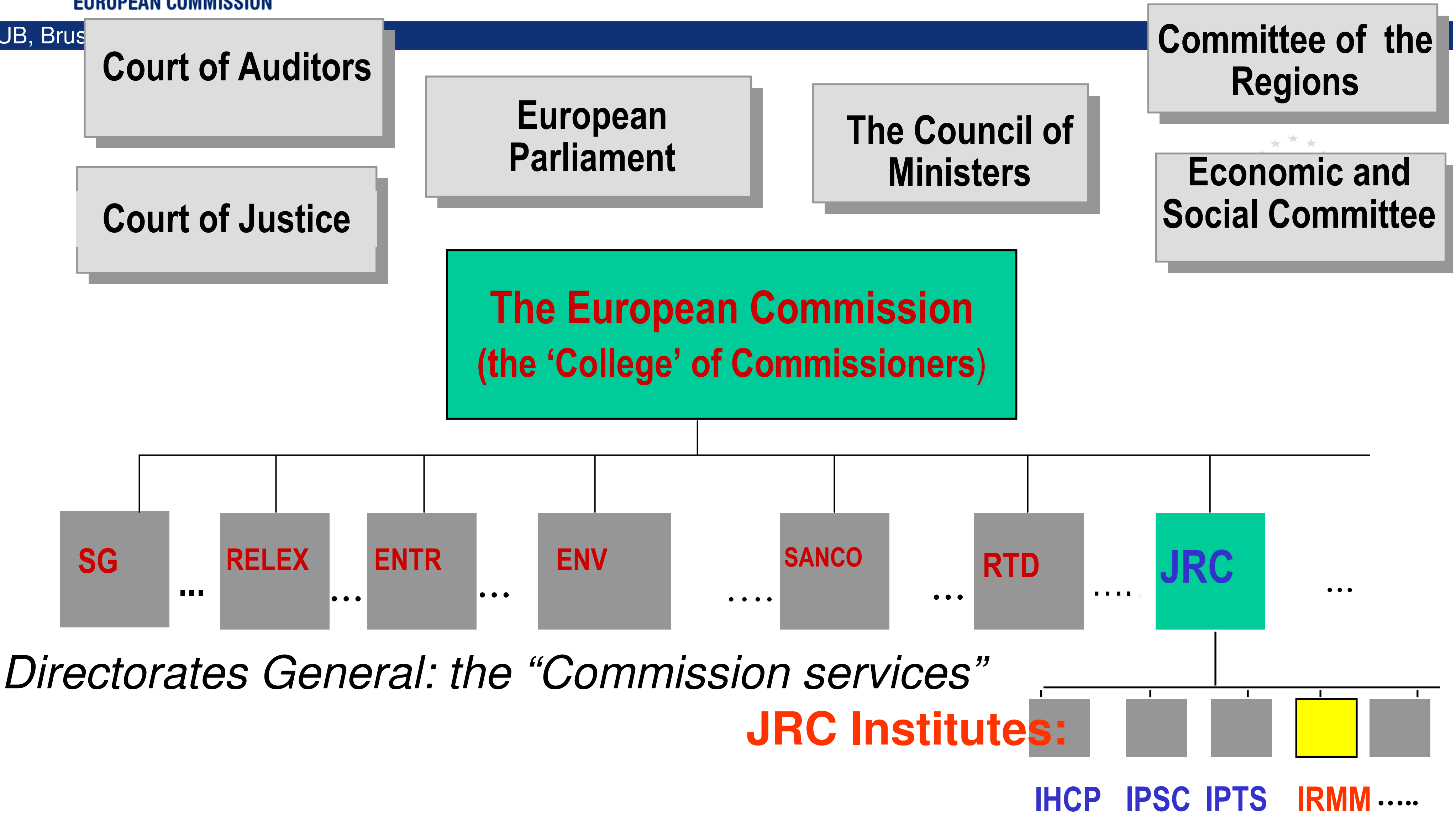
NEW TECHNOLOGIES

- **IRMM was/is (1992 - present) a pioneering laboratory for underground gamma-ray spectrometry**

- **Reduction of muon flux a factor 10,000 open up for low-level radioactivity measurements in many fields. Radioecology, specific processes in nature and industry, rare decays, safeguards etc.**

- **IRMM is making use of this new technology to support EU-policies in a wide range of projects (200).**

The EU Institutions



JRC can apply for funding from DG RTD like any other institution. The only restriction is that JRC persons are not allowed to co-ordinate indirect actions

Structure of the DG-JRC

7 Institutes in 5 Member States

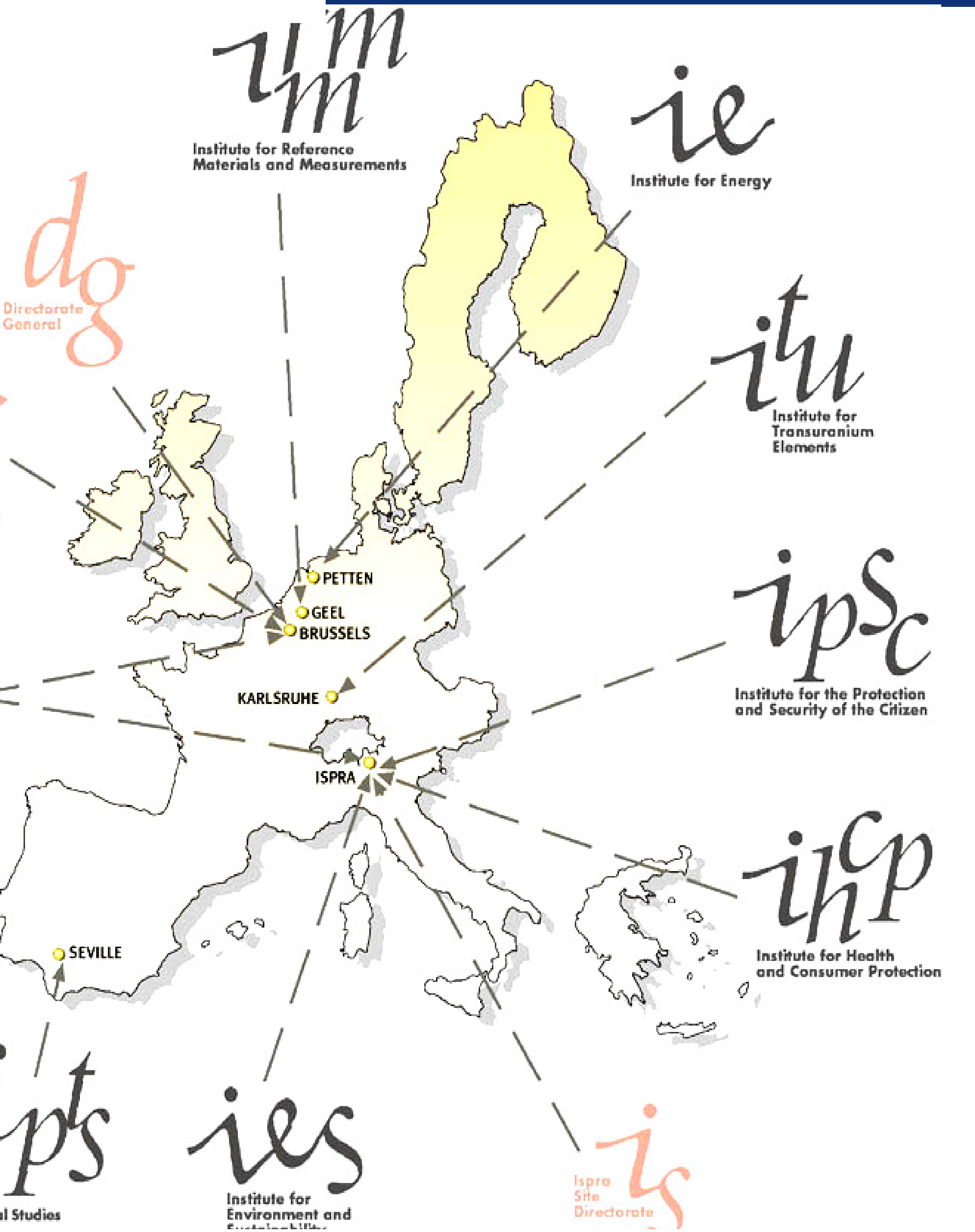
IRMM – Geel, Belgium
- Institute for Reference Materials and Measurements
Staff: ≅ 250

IE – Petten, The Netherlands
- Institute for Energy
Staff: ≅ *180*

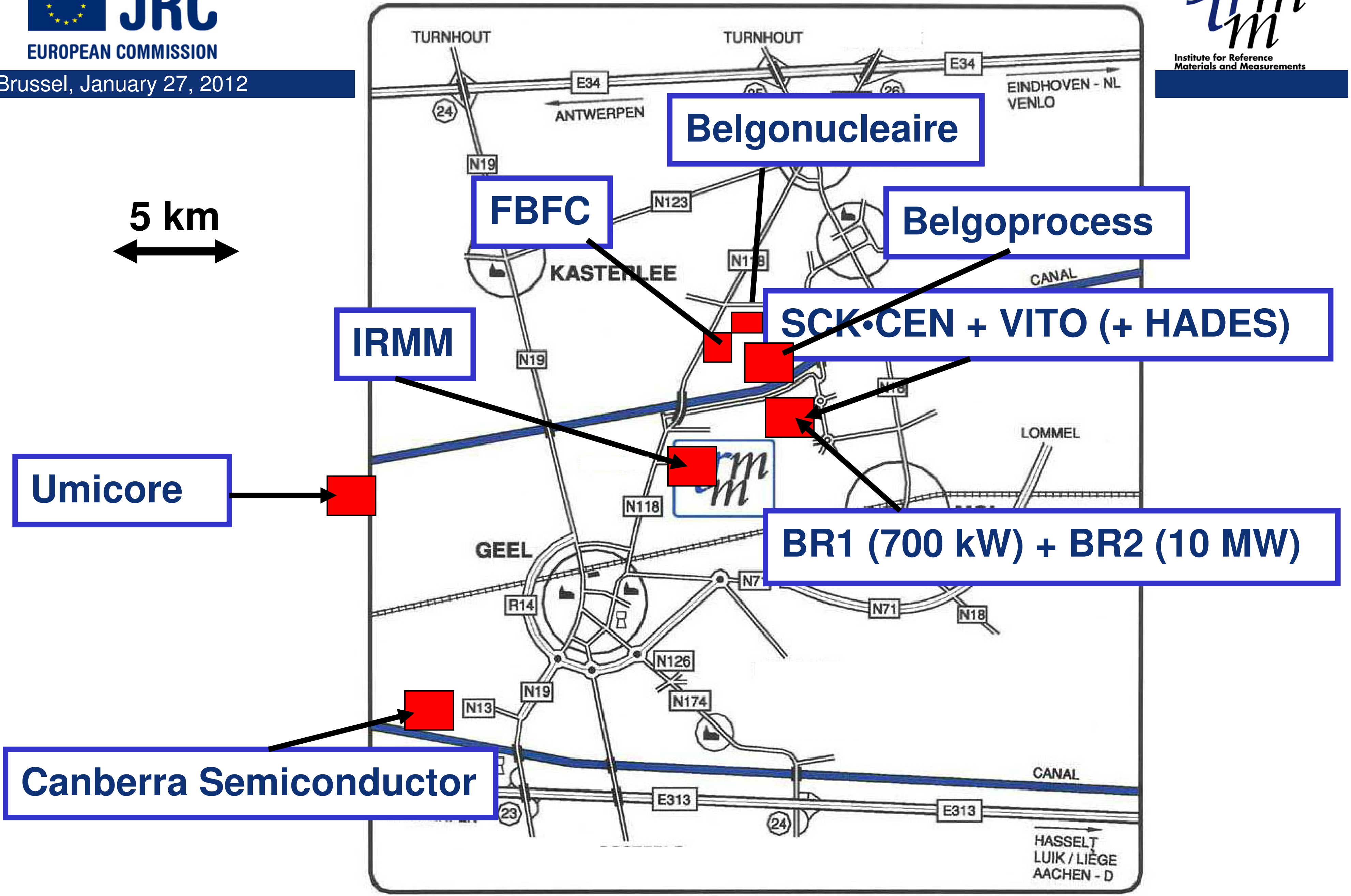
ITU – Karlsruhe, Germany
- Institute for Transuranium elements
Staff: ≅ 250

IPSC - IHCP - IES – Ispra, Italy
- Institute for the Protection and the Security of the Citizen
- Institute for Health and Consumer Protection
- Institute for Environment and Sustainability
Staff: ≅ 350, 250, 370

IPTS – Seville, Spain
- Institute for Prospective Technological Studies
Staff: ≅ 100



Total staff: ~ 2200 people


5 km
Umicore
Canberra Semiconductor
IRMM
FBFC
Belgonucleaire
Belgoprocess
SCK•CEN + VITO (+ HADES)
BR1 (700 kW) + BR2 (10 MW)
TURNHOUT
TURNHOUT
E34
E34
ANTWERPEN
EINDHOVEN - NL
VENLO
N19
N123
KASTERLEE
CANAL
LOMMEL
GEEL
N118
R14
N71
N18
N126
N174
N13
N19
CANAL
E313
E313
HASSELT
LUIK / LIÈGE
AACHEN - D

Nuclear Physics Unit

Linac (GELINA)
100 MeV white spec.

VdG (MONET)
7 MV monoenergetic

Radionuclide Metrology

- **Interlaboratory comparisons**
  Euratom obligation check MS
- **Primary Standardisation**
  - Harmonisation
  - Equivalence
  - Decay data
- **Low-level measurements**

Radionuclide Metrology – 2012 Key projects

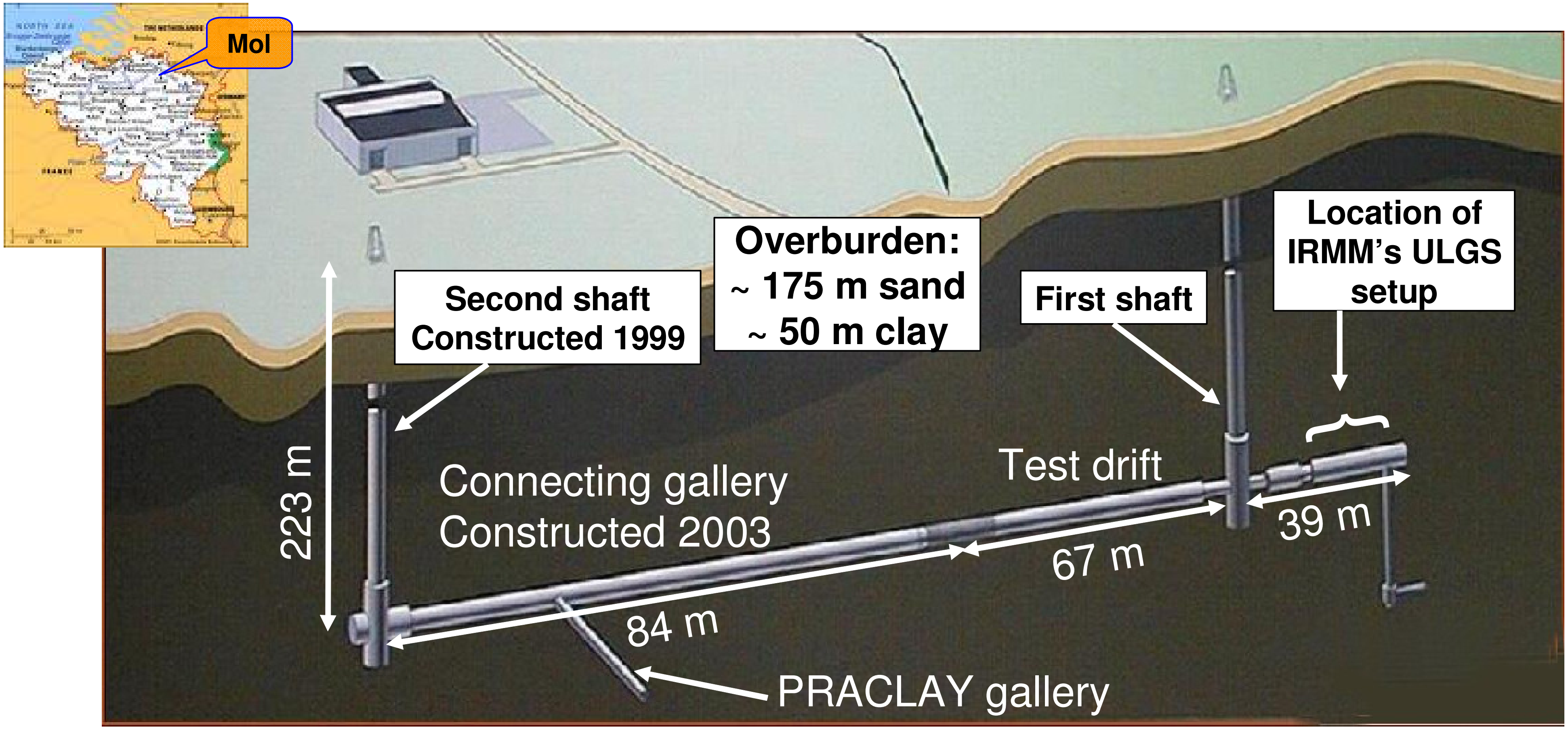
- **Training (Turkey, pre-accession)**
- **Security: ITRAP Calibration of Portal Monitors**
- **REM (Euratom obligation)**
- **Fukushima support**
- **EMRP – Euramet (European Metrology Projects)**
  - **Rad. Waste Management**
  - **Metro-Fission**
  - **Metro-Metal Scrap**

GERDA?
Not key project but essential to develop state-or-the-art instrumentation!
Also an essential partner due to former EU actions.

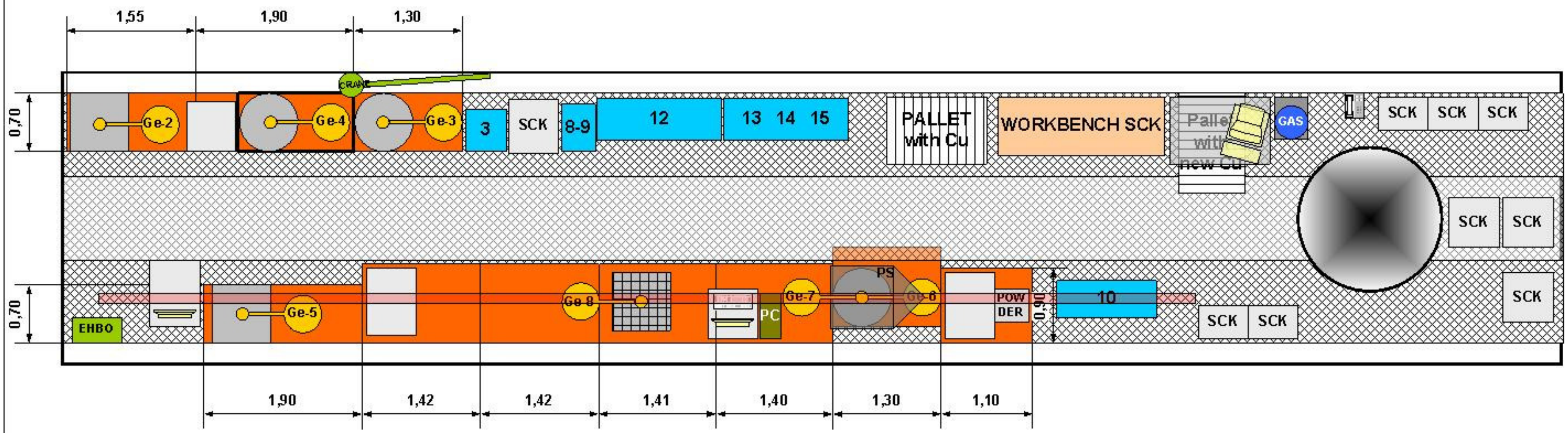
HADES

HADES = High Activity Disposal Experimental Site
– Operated by EURIDICE* and located at SCK•CEN in Mol

***European Underground Research Infrastructure for Disposal of nuclear waste In Clay Environment**



HADES



HADES= 0.05 muons/m^{2}s

	Detector
	Detectorshield
	Cupboard
	Electronics rack
	Platform
PS	Plastic Scintillator
UPS	Battery

SCALE: 1/50
1.0 m

10 HPGe detectors

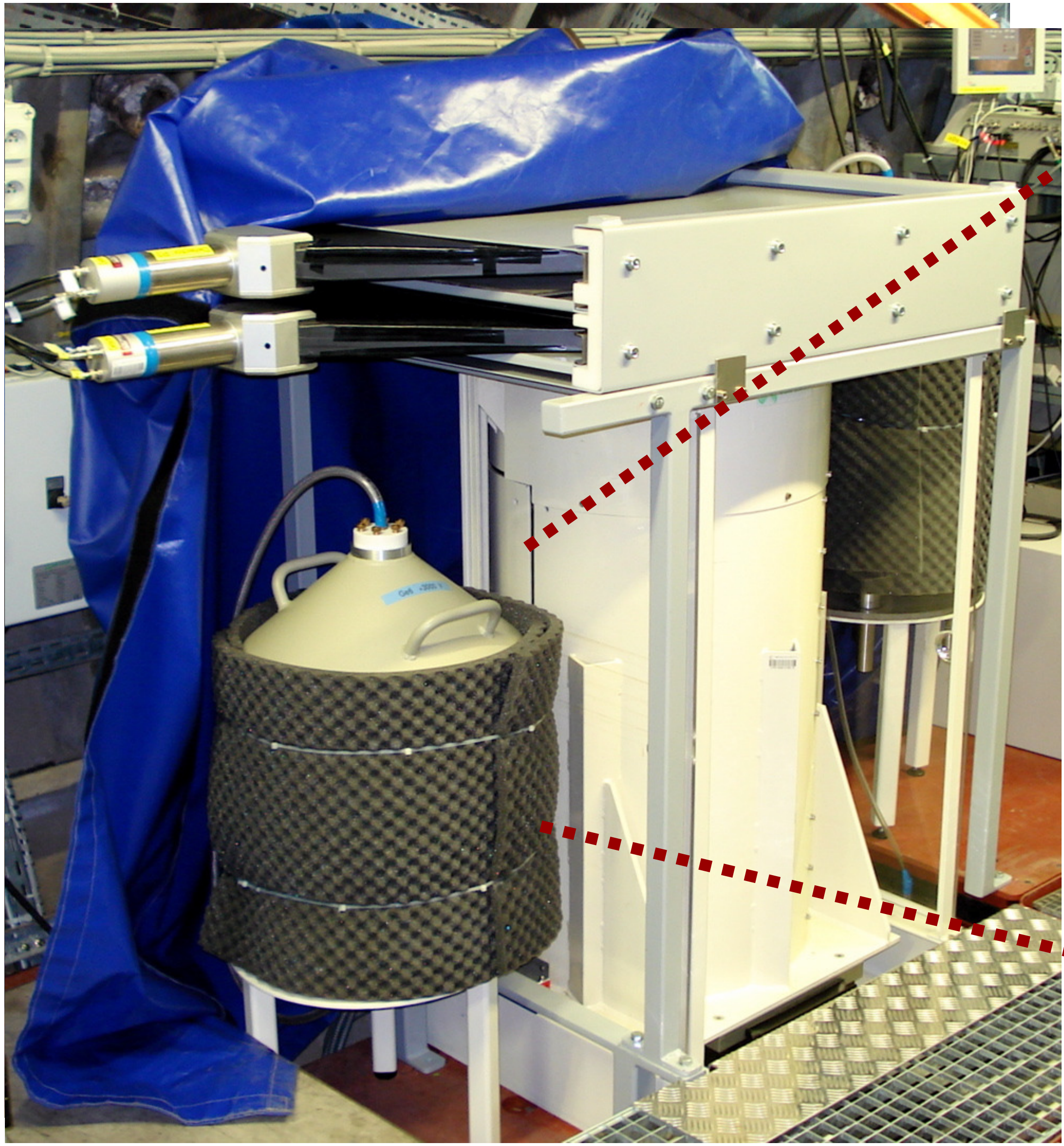
(soon 11, maybe 12)

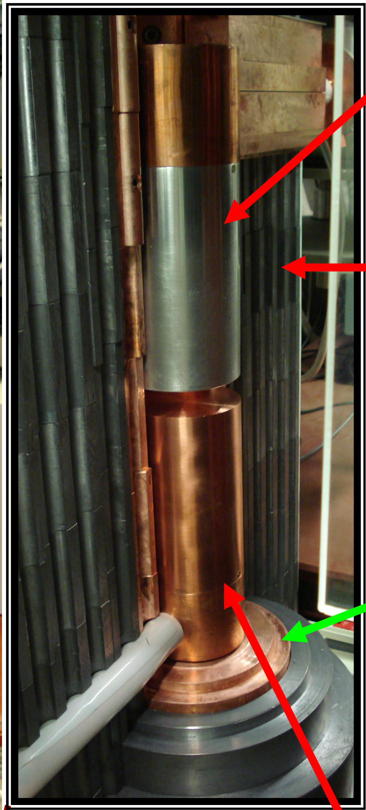
+3 NaI + 4 PS

AIR LUCHT
BRGM

The Sandwich Spectrometer

Increased solid angle





Ge-7

Pb shield = radiopure lead, 4 cm, 2.5 Bq/kg

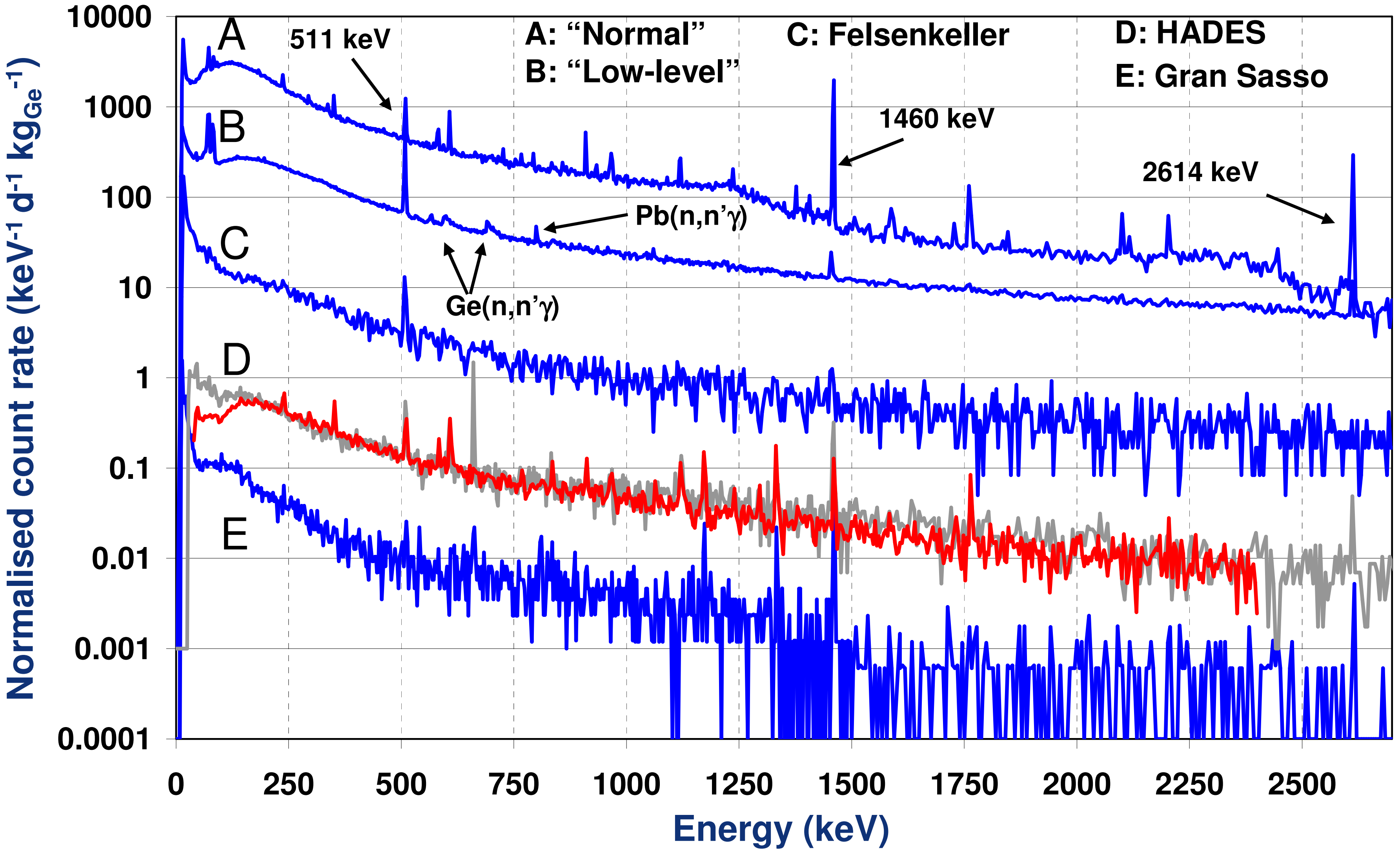
+14.5 cm lead, 20 Bq/kg

Cu lining = radiopure copper, 3.5 cm

Ge-6

Detector mass ~ 1.9 kg each

Background Comparison – Gamma-ray spectrometry



$$A = \frac{C}{t_m P_\gamma \varepsilon}$$

Simplified formula

A = Activity (Bq)

C = Net peak counts

t_m = Measurement time (s)

$P\gamma$ = Gamma-ray emission probability

ε = detection efficiency

Activity calculations with correction factors

Equilibrium?

$$A=\frac{C_{TOT}-C_{Peak}^{Bkg}-C_{Continuum}}{\varepsilon_{REF}^{Exp}\dfrac{\varepsilon_{Sample}^{MC}}{\varepsilon_{REF}^{MC}}P_{\gamma}}e^{\lambda t_d}\frac{\lambda}{(1-e^{-\lambda t_m})}K_1K_2K_3$$

Reference sample similar (sum corrected?)

Correction factor from e.g. MonteCarlo code

K_1 = summing correction

K_2 = Branching correction

K_3 = Equilibrium correction

t_d = decay time (to a reference date)
t_m = measurement live time

Combined activities from several gamma-rays to activity for one radionuclide

Combined activities from several daughters to one parent

Ex.: ^{226}Ra from ^{214}Bi and ^{214}Pb

Minimum Detectable Activity

$$MDA \propto \frac{\sqrt{CR_{Bkg}}}{\sqrt{t_m}} \cdot \frac{1}{\varepsilon}$$

MDA = Minimum Detectable Activity (Bq)
CR_{Bkg}= Background Count Rate (s^{-1})
t_m = Measurement time (s)
ε = detection efficiency

Improving MDA

$$MDA \propto \frac{\sqrt{CR_{Bkg}}}{\sqrt{t_m}} \cdot \frac{1}{\varepsilon}$$

ε: Increasing detector size will also increase background

ε: Increasing sample size may also increase background

t_m : "only" scales with square root

∴

It is worth while spending efforts to reduce background in order to obtain better MDAs

Interference free detection limits for a 7-day measurement

	Air filter mBq	Water 2L Marinelli mBq/L	Water on filter* Ba Co-prec. mBq/L
^{140}Ba	0.2	6	-
^{137}Cs	0.1	2	**
^{226}Ra	0.2	4	0.5

**Depends on amount of water used. Here 2 L.*

*** Plan for Fukushima project 0.5 mBq/m^3*

How long measurement time can you afford?

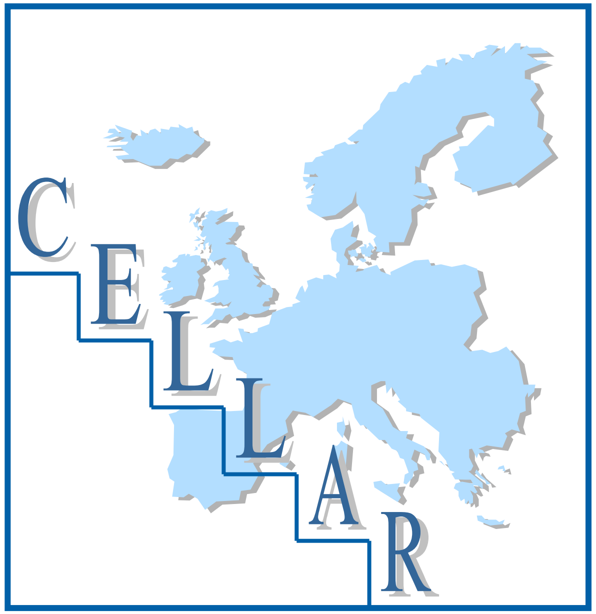
1 mBq ~ decay per hour
1 μBq ~ decay per week

⇒To carry out big projects and measurement of numerous samples, <u>networking is essential</u>

Collaboration of European Low-level underground LAboRatories

CELLAR

Collaboration of European Low-level underground LAboRatories

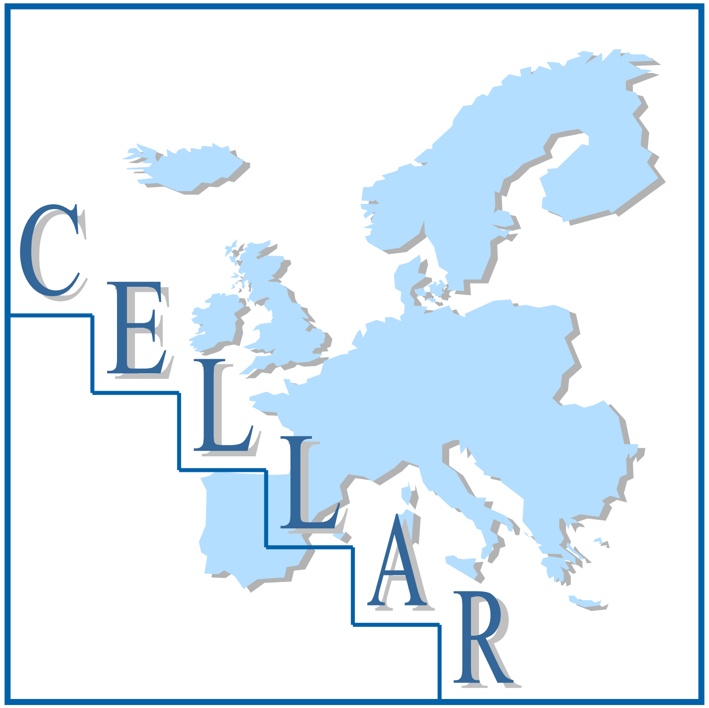


Mission: **To promote higher quality and sensitivity in ultra low-level radioactivity measurements for the improvement of crisis management, environment, health and consumer protection standards of Europe.**

CELLAR-labs

- Modane - France (-2200 m)
- Gran Sasso - Italy (-1700 m)
- Asse/PTB - Germany (-415 m)
- HADES – EU/Belgium (-225 m)
- Unirea, Romania (-208 m)
- University of Iceland (-165 m)
- Baradello Hill, Italy (- 100 m)
- Ferrière (LEGOS)-France (-80 m)
- Felsenkeller - Germany (-50 m)
- CAVE – Monaco (-15 m)
- MPI-Heidelberg - Germany (-10 m)

+ associated partners
e.g. Solotvina salt mine (Ukraine)



Not all partner institutes are in the list!

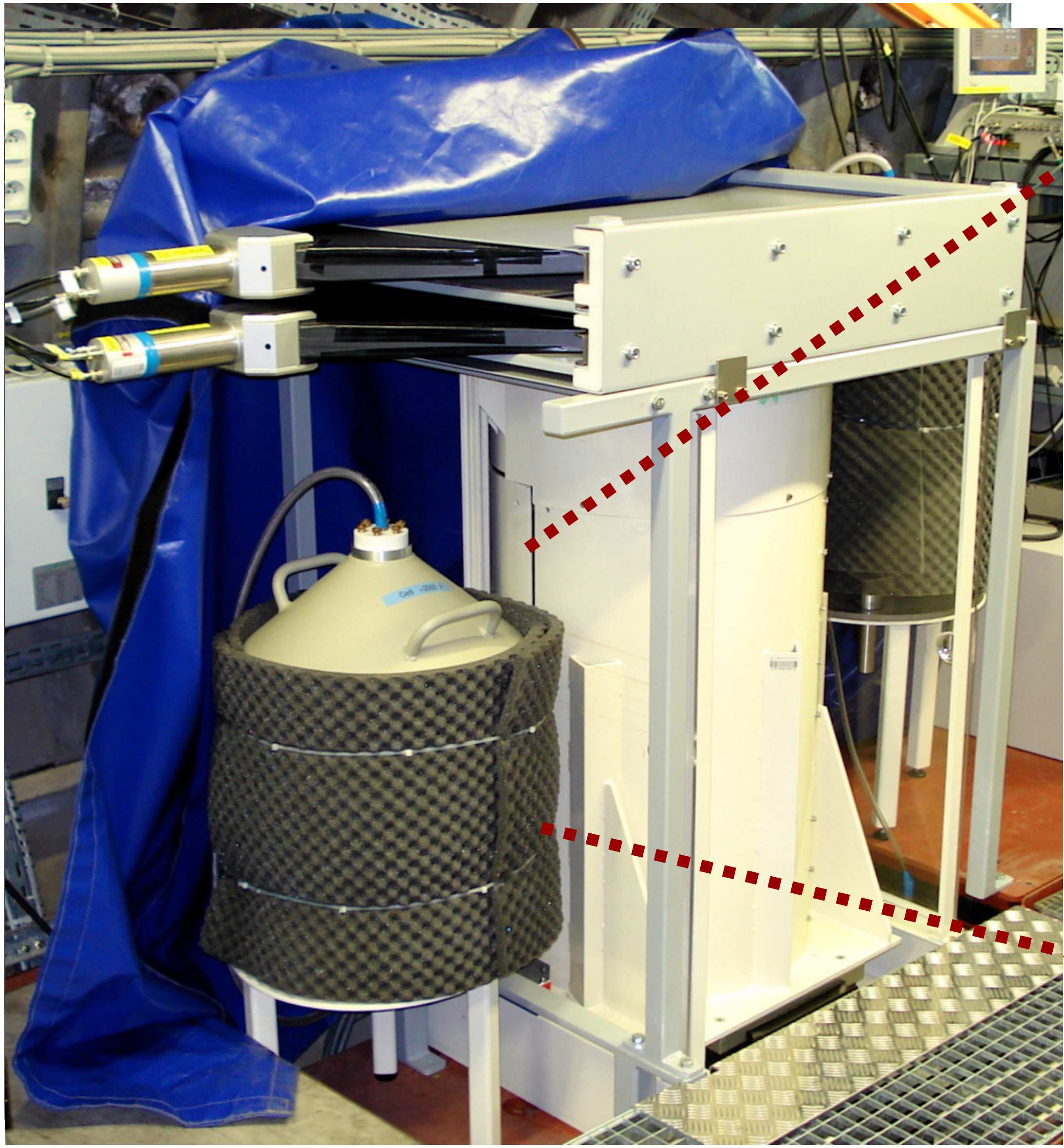
Detectors in HADES

Detector name	Manufacturer	Crystal type	Relative efficiency (%)	Year installed
Ge-2	Eurisys	n-type semiplanar	8	1995
Ge-3	Eurisys	p-type coaxial	60	1997
Ge-4	Canberra	p-type coaxial (XTRa)	106	2000
Ge-5	Canberra	p-type planar (BEGe)	50	2001
Ge-6	Canberra / Ortec	p-type coaxial	80	2004
Ge-7	Canberra	p-type coaxial (XTRa) with inverted head	80	2005
Ge-8	Canberra	p-type planar (BEGe)	38	2006
Ge-9	Canberra	$BE^{dep}Ge$	~45	2010
Ge-10	Canberra	n-type	60	2011
Ge-11	Baltic Instr.	p-type coaxial	100	2011
Ge-12	?	well-type	~100	2012 (expected)

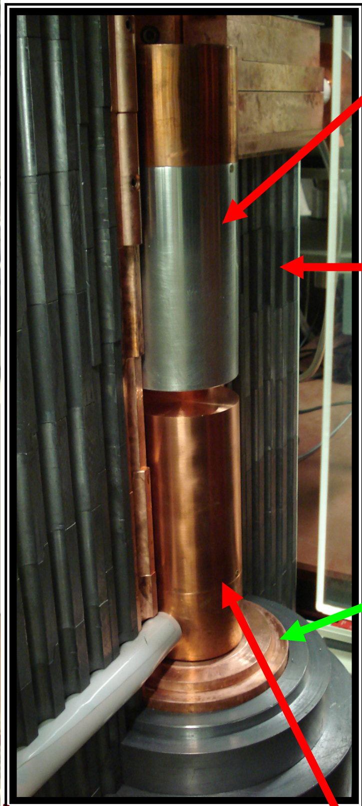
Ge-6 + Ge-7 => Sandwich

Ge-10 + Ge-11 =>Pacman (possibility for NaI –shield)

The Sandwich Spectrometer



Increased solid angle



Ge-7

Pb shield = radiopure lead, 4 cm, 2.5 Bq/kg

+14.5 cm lead, 20 Bq/kg

Cu lining = radiopure copper, 3.5 cm

Ge-6

Detector mass ~ 1.9 kg each

Low-level measurements – a growing field!

Isotopic fingerprints

Hiroshima

JET

Tokai-mura

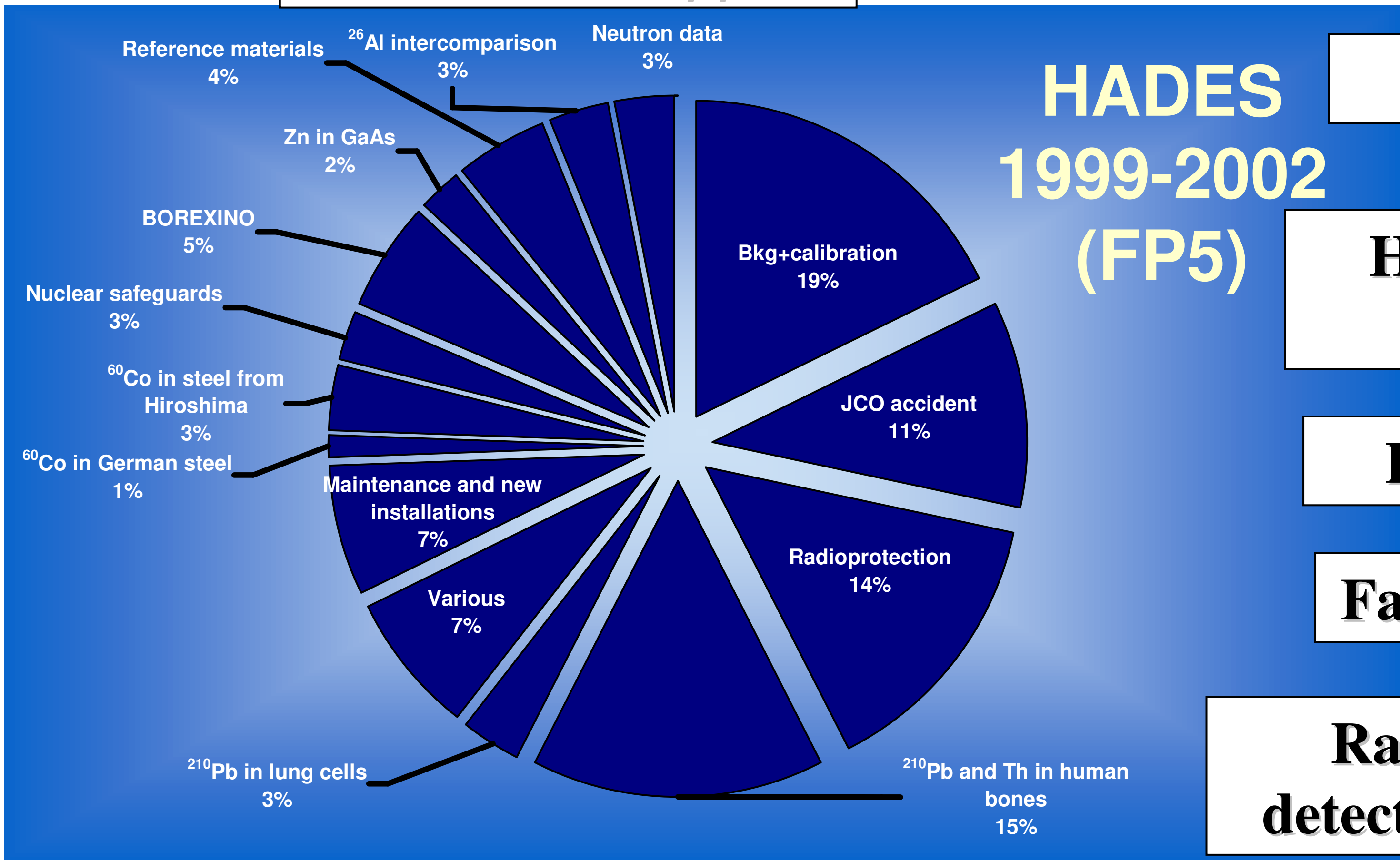
Ref.measurements

Decay data

Safeguards

Radiation Protection

Neutrinos / ββ



Small samples

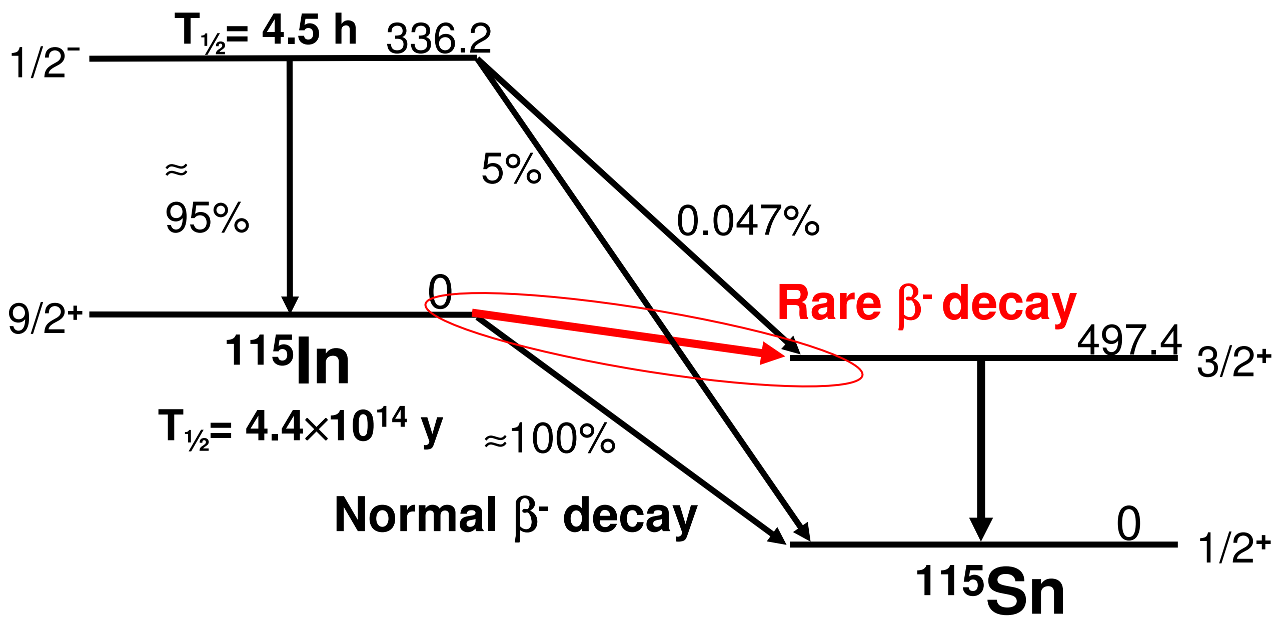
High temporal resolution

Benchmarking

Fast measurements

Radiopurity for detector construction

The rare β⁻ decay $^{115}In \rightarrow {}^{115}Sn$

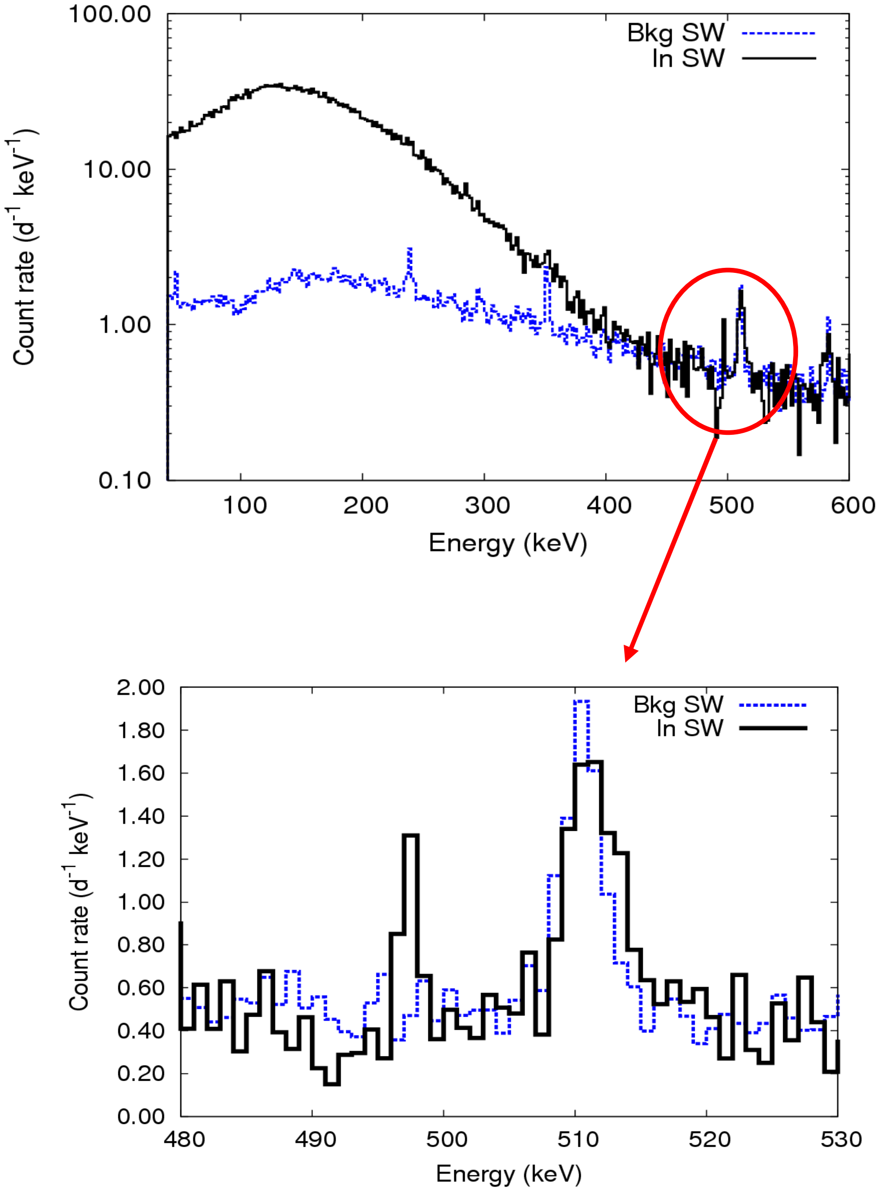


At present: Decay energy of ^{115}In(9/2+) → ^{115}Sn(3/2+) 1.7±4.0 keV (Δm =499 keV)

*Audi, Wapstra, 2003. Nucl. Phys A729.

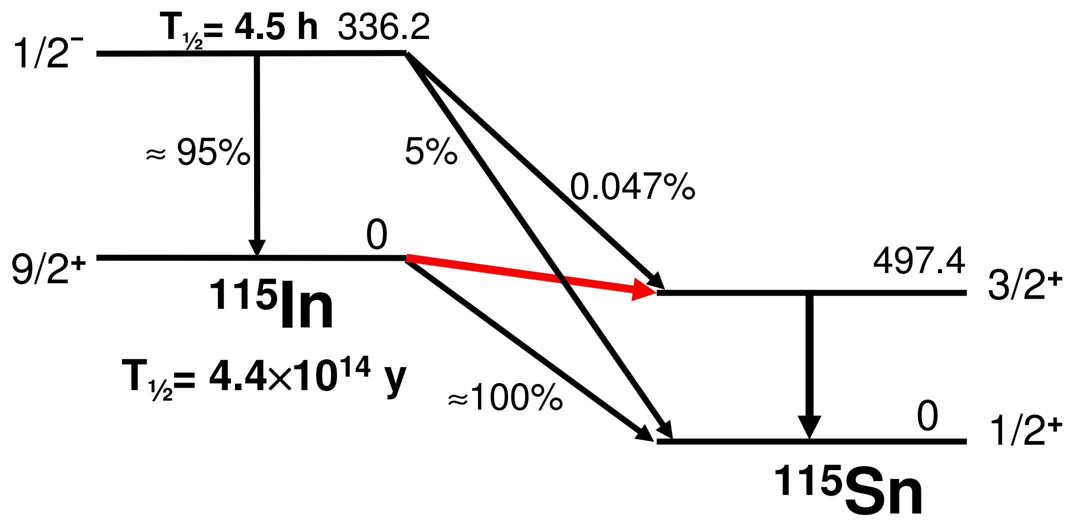
⇒ Not for sure if it is energetically possible or not

Lowest decay energy known to man

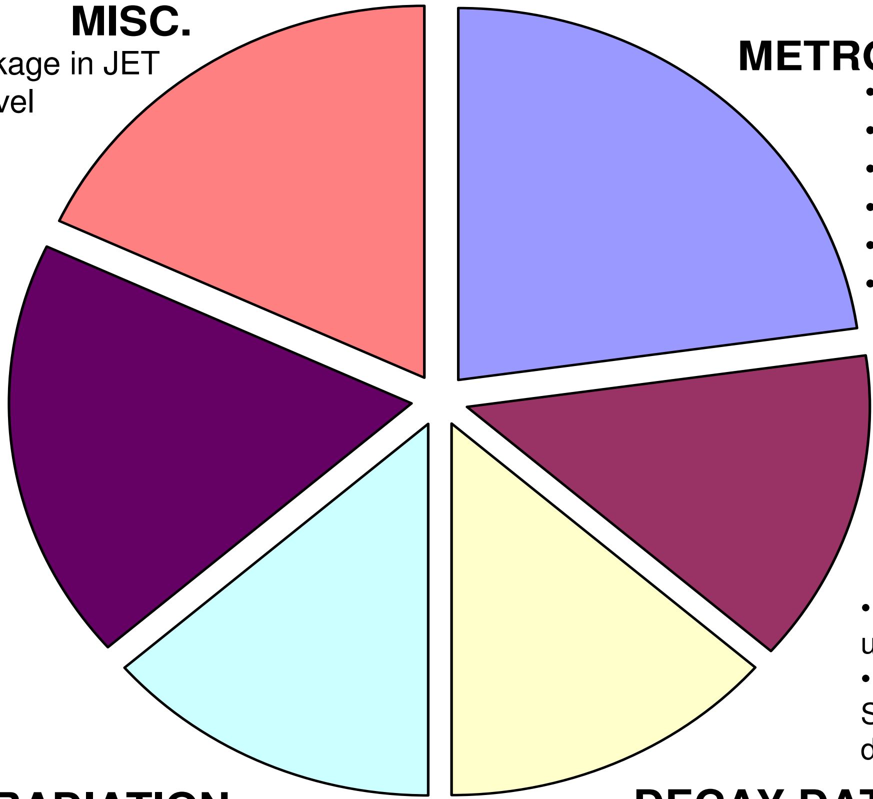


Half-life: 4.1×10^{20} years

Decay energy: 155 eV



HADES 2004-2009



MISC.

- Fusion plasma: Study of charged particle leakage in JET
- CELLAR – Collaboration of European Low-level underground LAboRatories
- Emergency support l'Aquila/Gran Sasso
- ILIAS

METROLOGY

- Efficiency calculations
- Reviews
- Monte Carlo work
- Background analyses
- New detector concepts
- Improvement of existing detectors

ENVIRONMENTAL RADIOACTIVITY

- Organic vs. Conventional farming
- Reference materials (Berries, mushroom, sediments, soil)
- Pb-210 in bones

NEUTRON PHYSICS

- DONA – Dosimetry and Spectroscopy using Neutron activation
- NAXSUN – Neutron Activation Cross Sections Curve measurements using deconvolution technique

RADIATION PROTECTION

- Hiroshima II
- Support to SHES

DECAY DATA

- Ta-180m (nature's rarest isotope)
- In-115 (lowest decay energy known to man)
- GERDA – double beta decay of Ge-76
- Double beta decay in tin ($^{112, 122, 124}Sn$)

GERDA

EUROPEAN CO

Low-level measurements – a growing field!

Isotopic fingerprints

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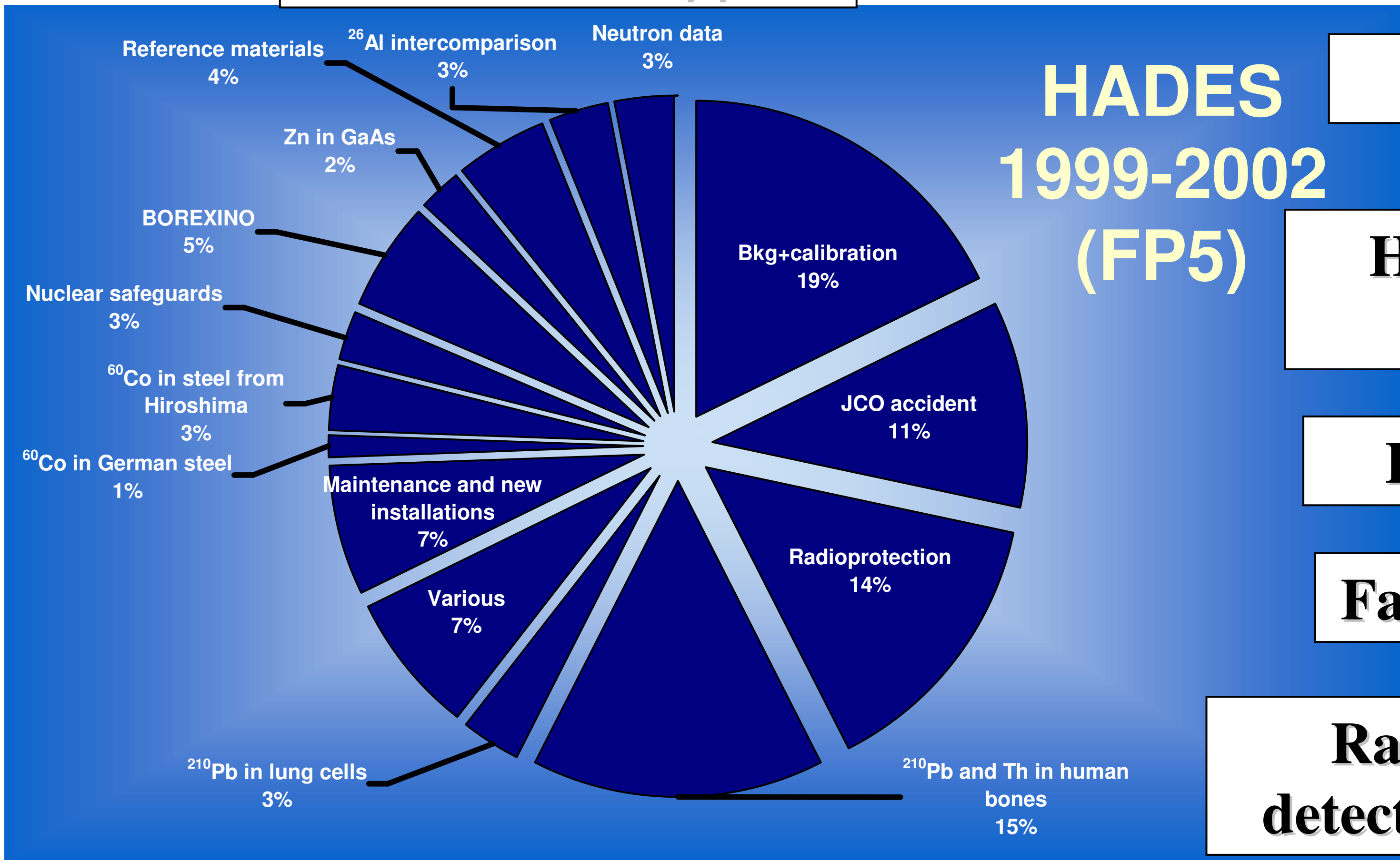


Small samples

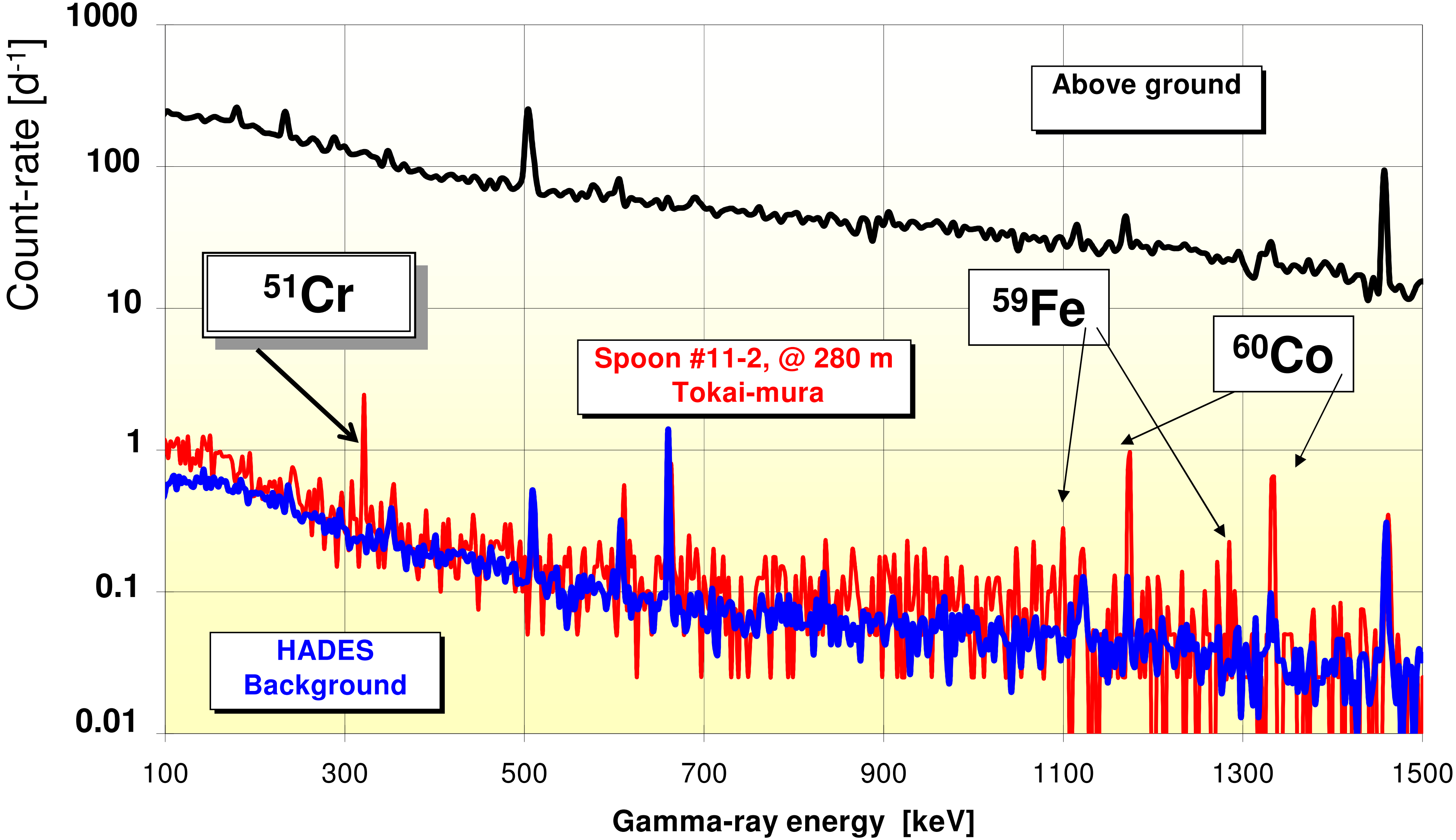
High temporal resolution

Benchmarking

Fast measurements

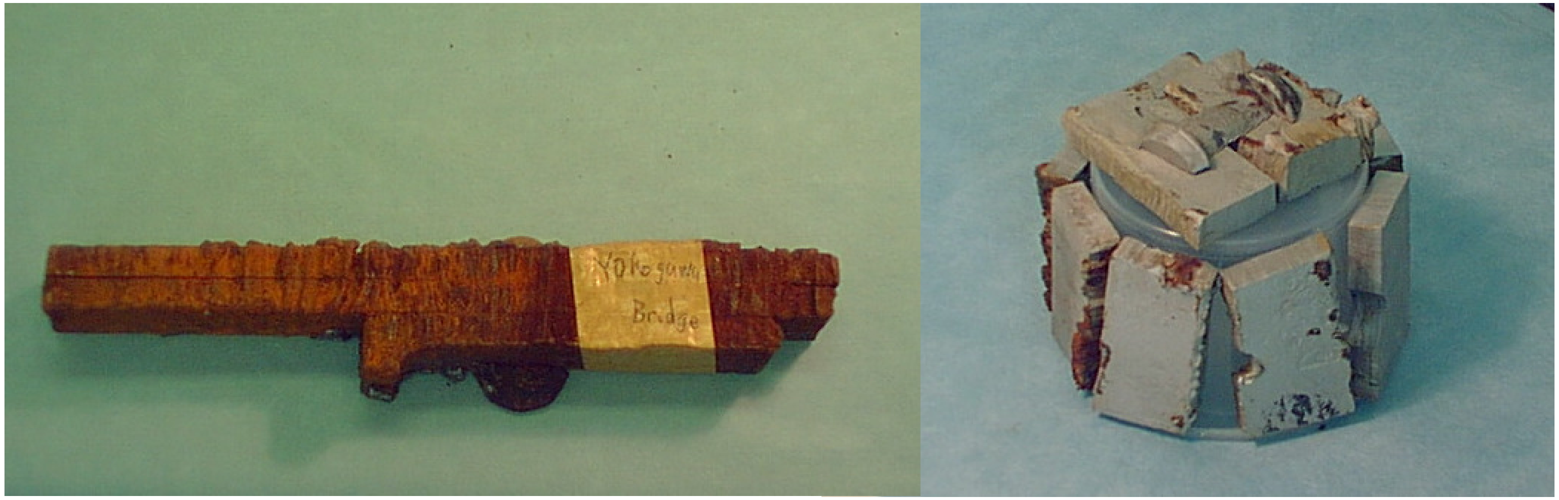
Radiopurity for detector construction

Tokai-mura, 1999

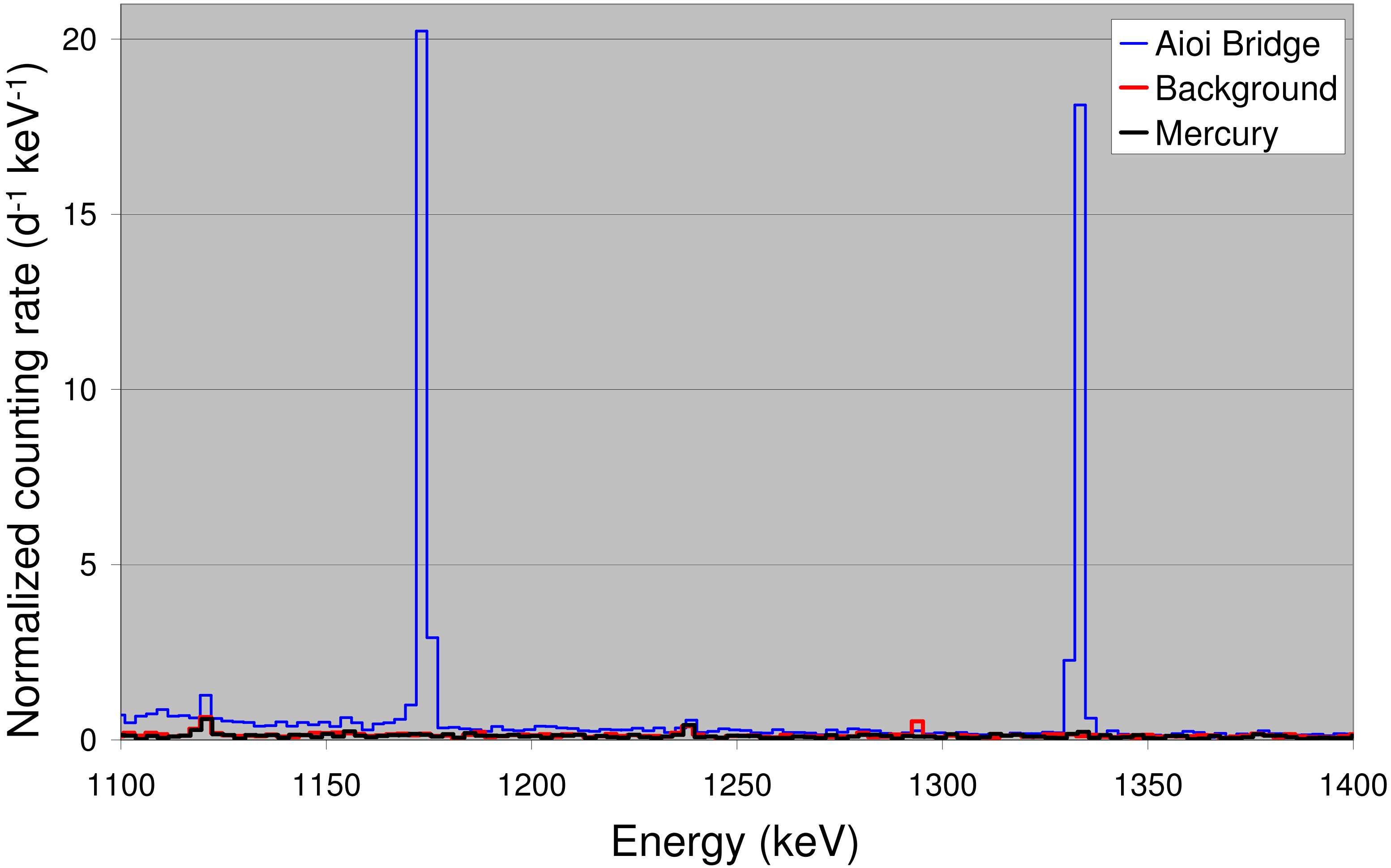


Gamma-ray spectrum of one of the spoons measured in HADES (red) and background above ground (black) and in HADES (blue)

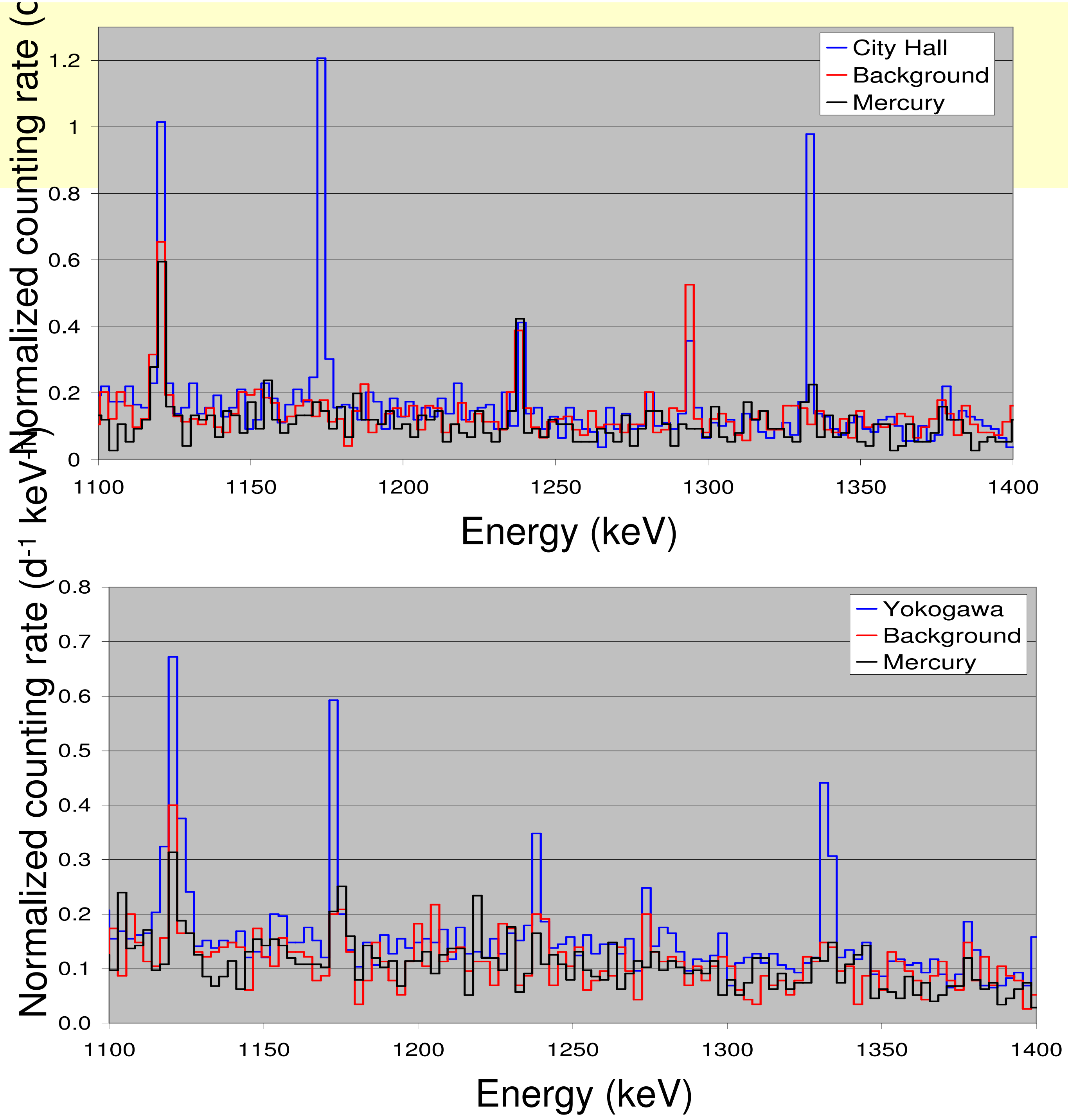
Retrospective Hiroshima Dosimetry



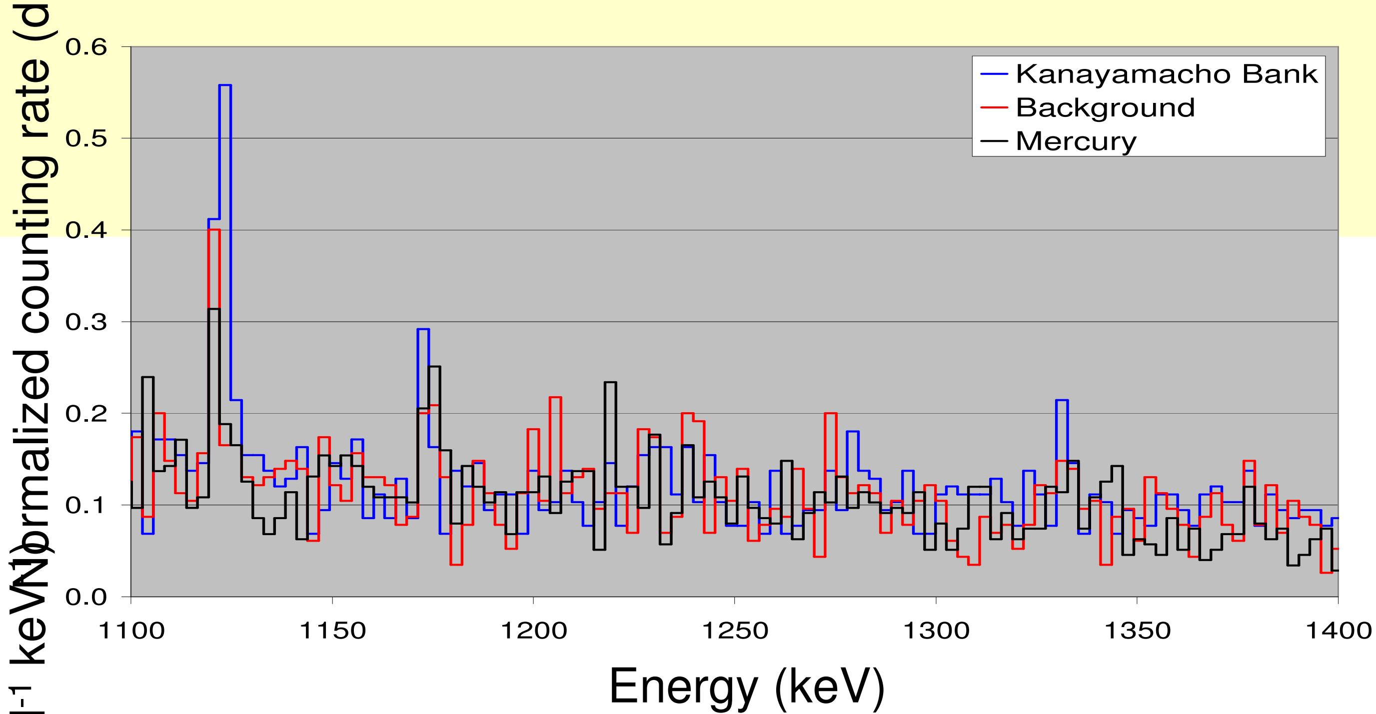
Steel from Yokogawa Bridge

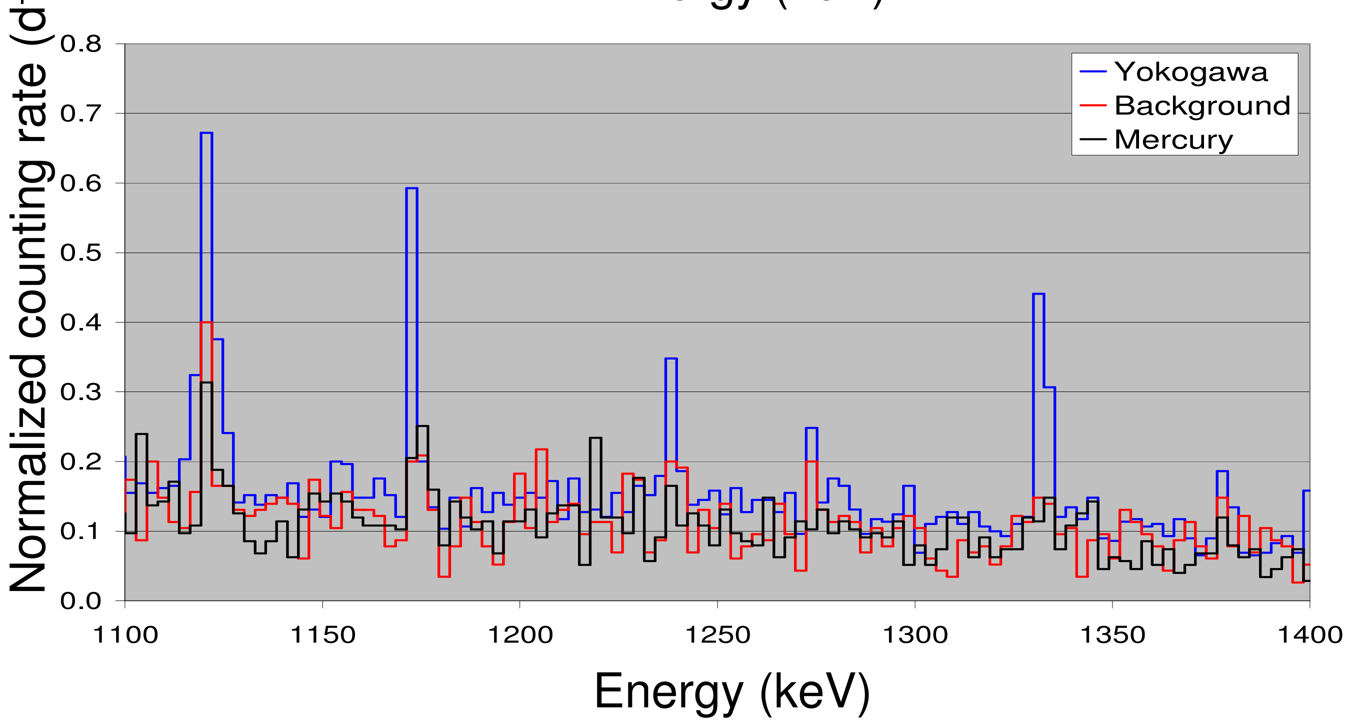


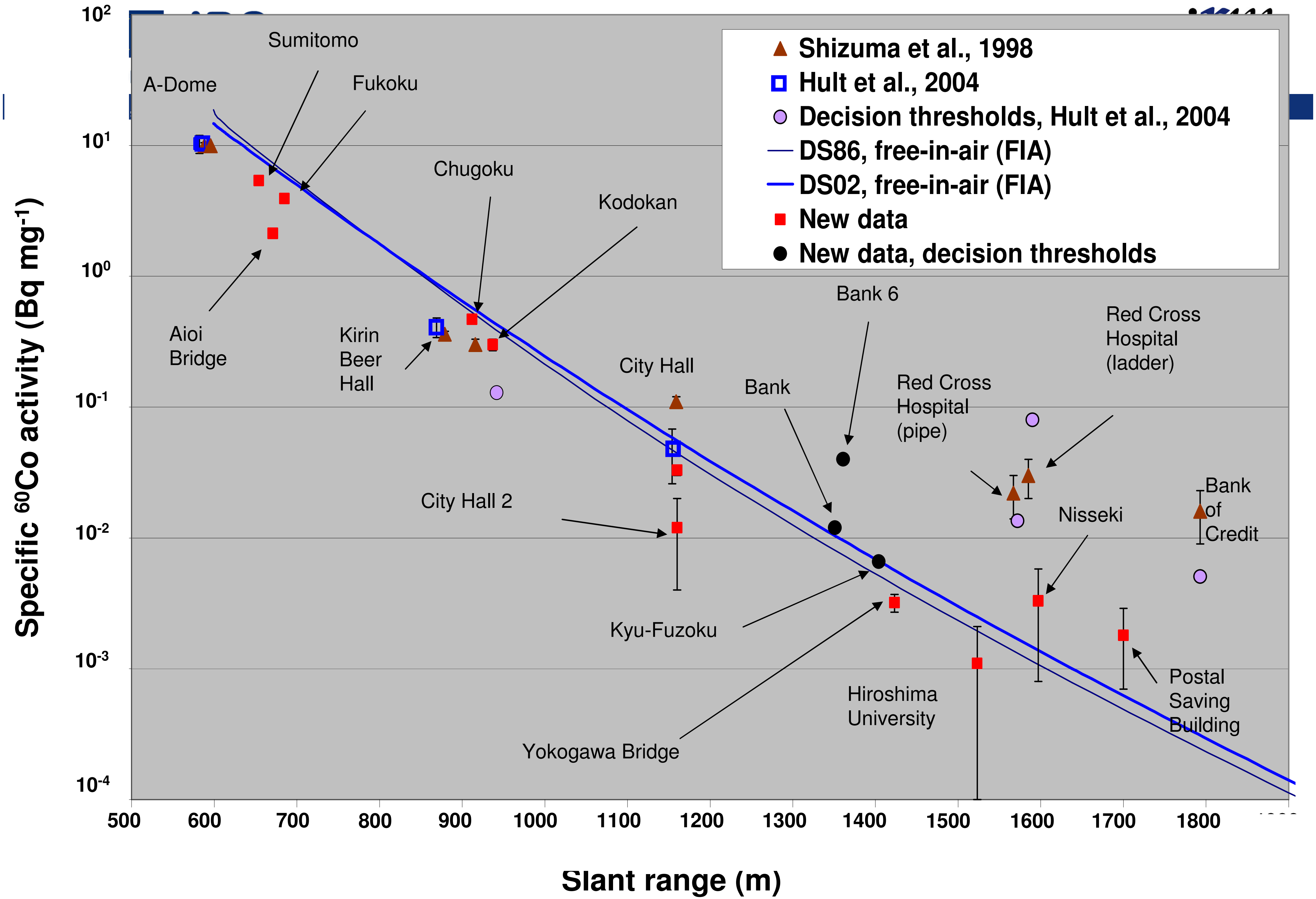
Aioi bridge – very near to epicenter



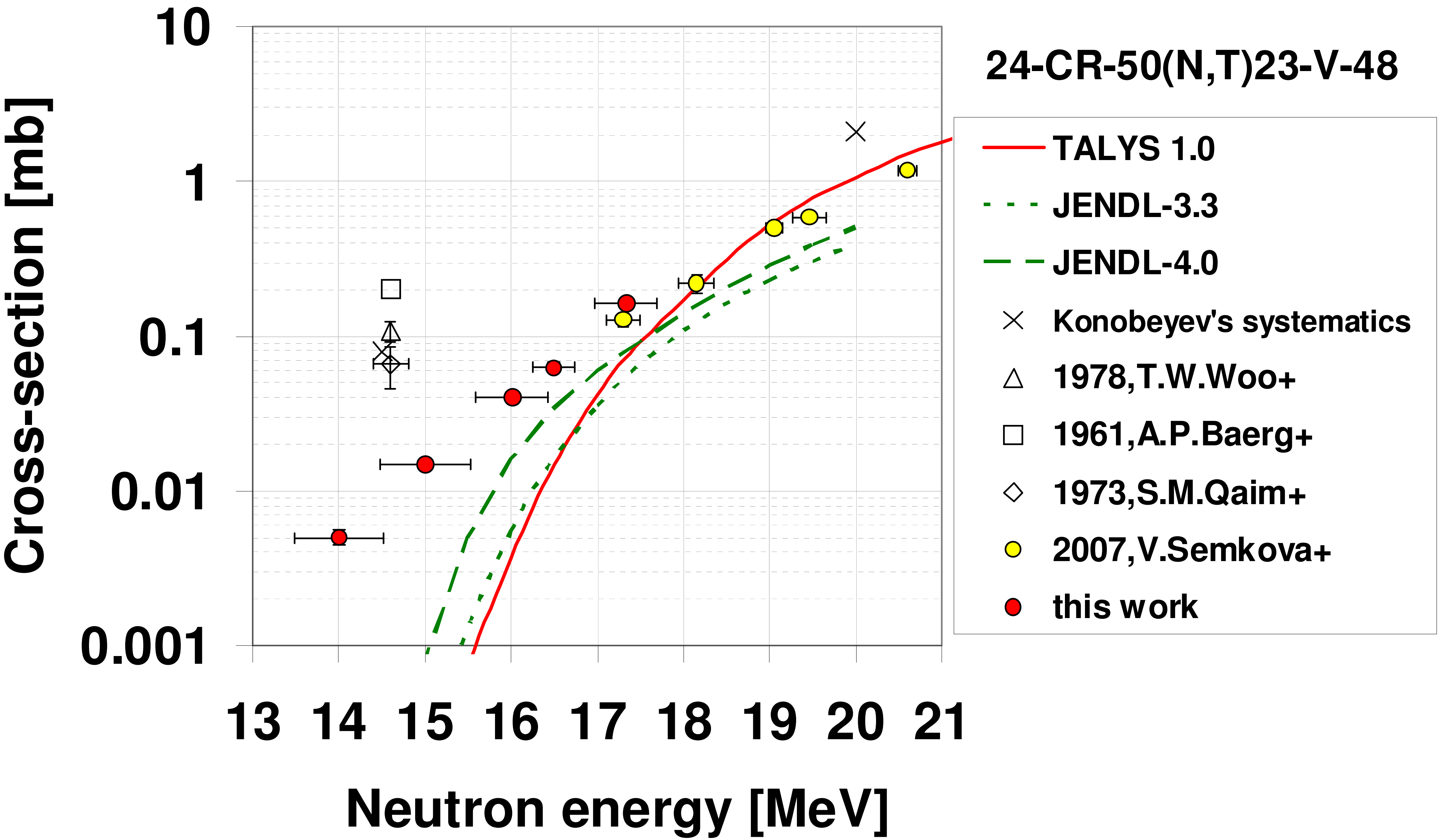
City Hall
Background
Mercury
Yokogawa
Background
Mercury
Normalized counting rate (d-1 keV-1)
Energy (keV)
Energy (keV)


Normalized counting rate (d-1 keV-1)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1100
1150
1200
1250
1300
1350
1400
Energy (keV)
Kanayamacho Bank
Background
Mercury


Normalized counting rate (d-1 keV-1)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1100
1150
1200
1250
1300
1350
1400
Energy (keV)
Yokogawa
Background
Mercury


Shizuma et al., 1998
Hult et al., 2004
Decision thresholds, Hult et al., 2004
DS86, free-in-air (FIA)
DS02, free-in-air (FIA)
New data
New data, decision thresholds
A-Dome
Sumitomo
Fukoku
Chugoku
Kodokan
Aioi Bridge
Kirin Beer Hall
City Hall
City Hall 2
Bank
Bank 6
Red Cross Hospital (pipe)
Red Cross Hospital (ladder)
Nisseki
Bank of Credit
Kyu-Fuzoku
Yokogawa Bridge
Hiroshima University
Postal Saving Building
Specific ^{60}Co activity (Bq mg^{-1})
Slant range (m)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

$^{50}Cr(n,t)^{48}V$ – our results



Why Gamma-ray Spectrometry?

- Easy sample preparation
- Non destructive
- Low running cost

Why Ultra Low-level Gamma-ray Spectrometry?

In addition to above:………

- Low detection limits (improvement: 10-300 times)
- More robust
- Potentially faster
- Potential to achieve higher temporal resolution
- Potential to sample small volumes

$\Rightarrow$ More interesting applications are feasible

“Reference” for other methods

- **No sample preparation!**
  Direct measurement; Non-Destructive

- **There is a need to check methods that require sample preparation**

Radiochemical methods **Mass spectrometry methods**

Some examples

^{40}K in water (ICP-MS), ^{26}Al in meteorites (AMS)

Zn in GaAs (ERS and GDMS), ^{60}Co (radiochemistry)

Checking of neutron detectors

International collaborations

To compare radioactivity measured in different laboratories one need to ascertain correct measurements

- reliable and comparable measurement results are based on their traceability to measurement units
- participation in Proficiency Testing schemes to confirm

IRMM is organising Proficiency Testing for nominated European laboratories monitoring radioactivity in the environment

- ^{137}Cs in air filters (2007)
- ^{137}Cs, ^{40}K, ^{90}Sr in milk powder (2008)
- ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U in mineral waters (2010)
- run at present: radionuclides in soil, among them several NORM

IRMM approach to these comparisons

- EU member states nominate monitoring laboratories to participate in European comparisons (Treaty obligation)
- IRMM provides comparison samples, carrying reference values traceable to SI and SIR
- example: in anticipation of a new European directive on drinking water quality, IRMM organised a water comparison to see where monitoring laboratories stand

Metology approach to being correct and accepted by other laboratories

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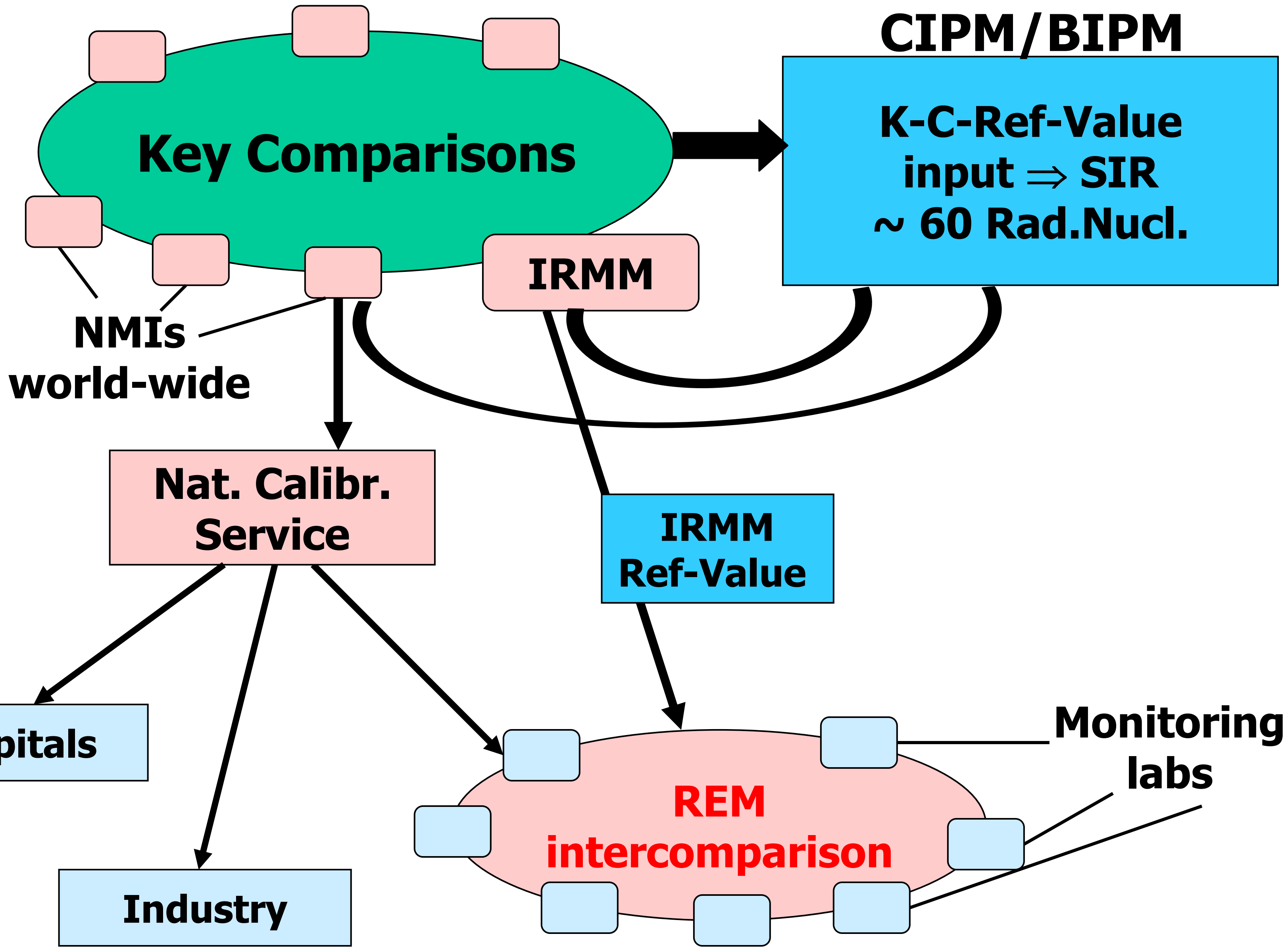
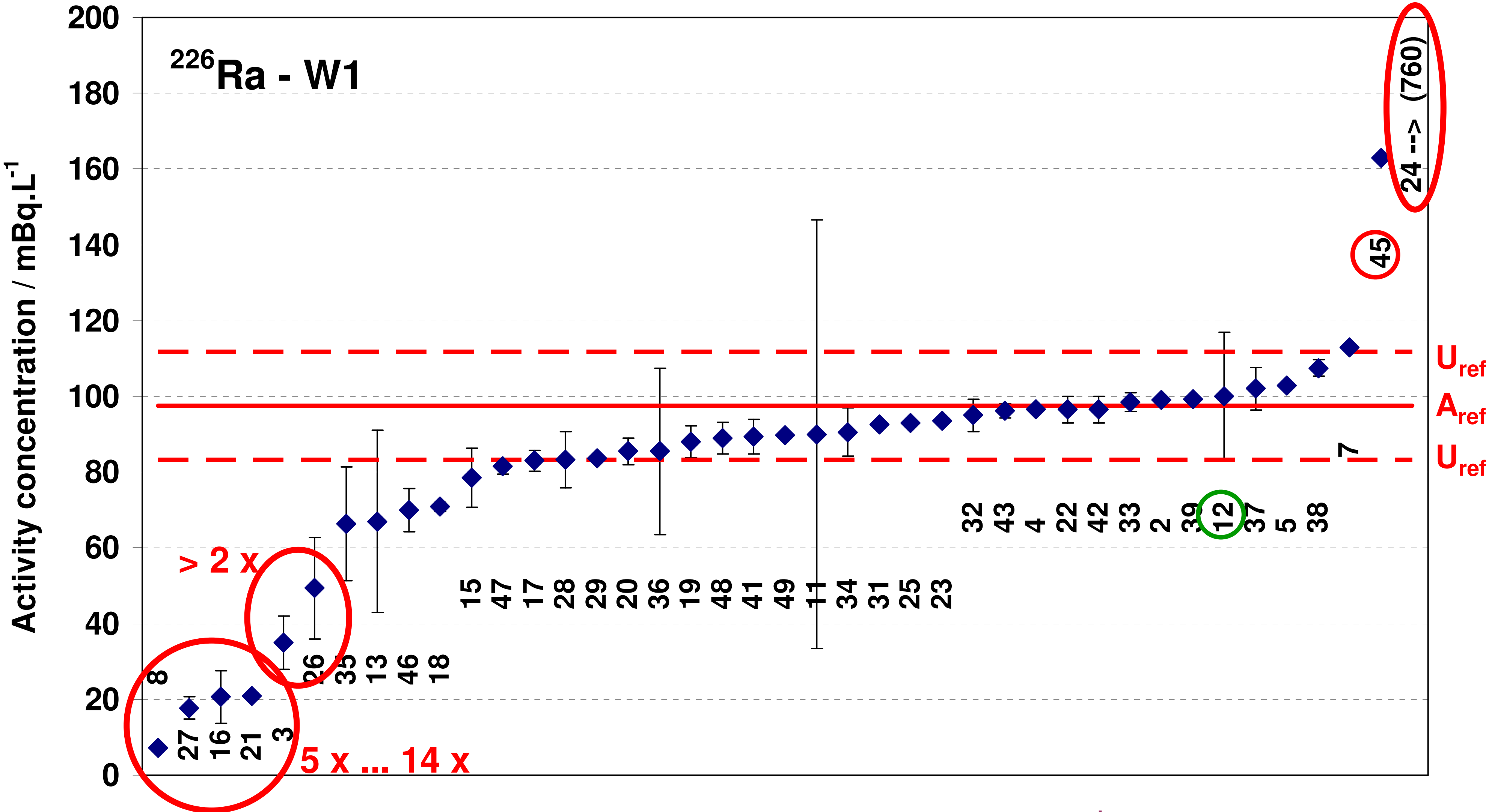
- allows realistic estimate of accuracy under routine conditions
- reliable monitoring results are necessary to assess the exposure of the population as a whole (done by DG ENER of the European Commission)

Key comparisons and traceability

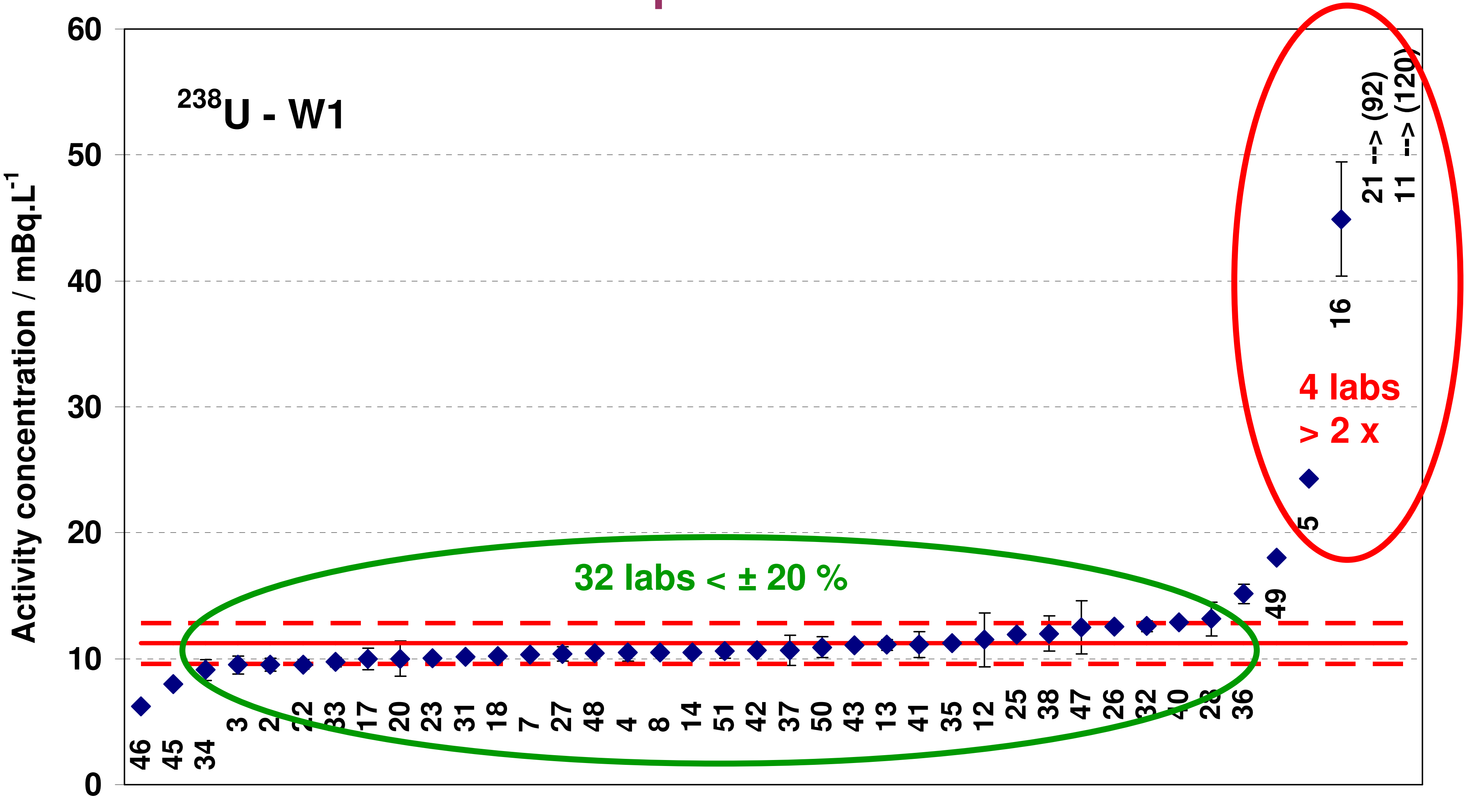


Lab means* compared with reference value $A_{ref} \pm U_{ref}$



* 41 submitted results

Lab means* compared with reference value

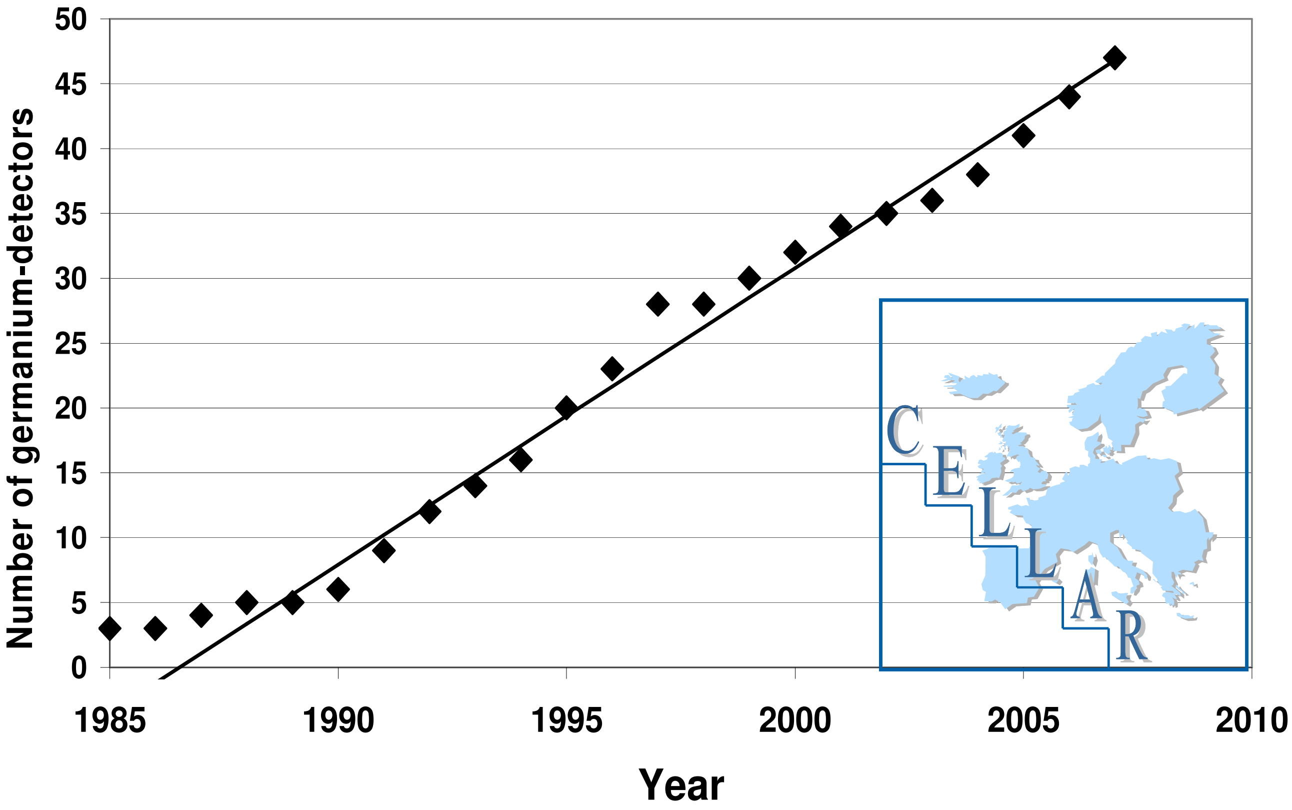


* 40 submitted results

Not always necessary for obtaining the lowest detection limits

Much better control of background components than above ground ⇒ more robust measurements ⇒ Important for better QC of reference samples.

…a growing field of science, engineering and metrology




Thank you
for your attention!