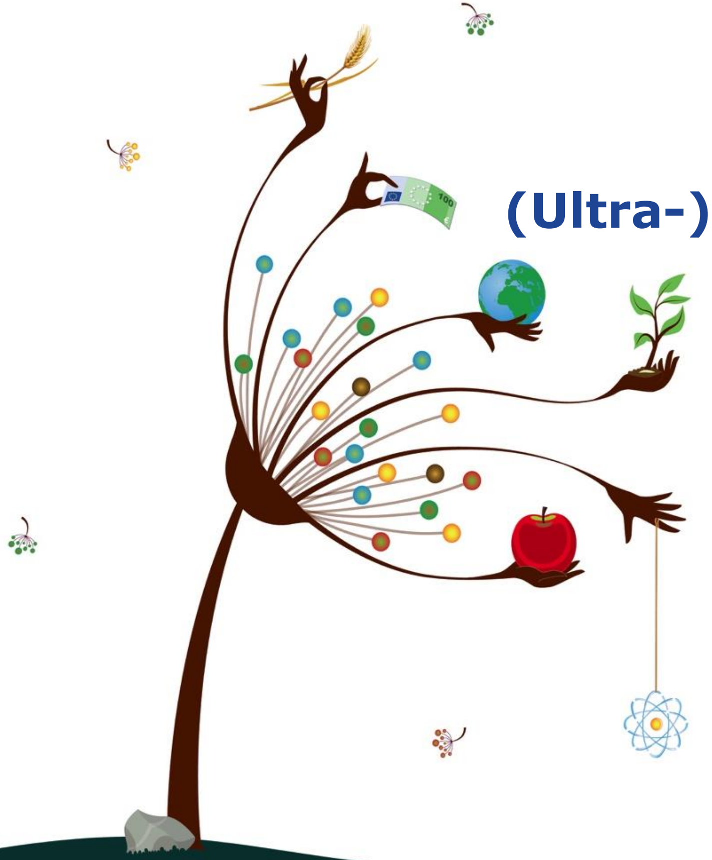
The European Commission's science and knowledge service

Joint Research Centre



(Ultra-)Low Background Gamma-ray Spectrometry

Mikael Hult

European Commission – Joint Research Centre – Directorate for Nuclear Safety and security, JRC-Geel

Nordic Nuclear Safety Research, NKS-B Gamma Spec, Risö, Sept. 19-20, 2017

European Commission

Outline

- The JRC
- Low background in gamma-ray spectrometry
  (brief extract from courses)
- Point contact detectors
- Top deadlayer characterisation
- Examples of applications
- Upcoming meetings:
  - Radioactivity in feed workshop+training
    Jan. 30 – Feb. 2, 2018 (at JRC-Geel)

Joint Research Centre

- JRC is the European Commission's in-house science service. It provides the science for policy decisions,

- One of the Directorate Generals of the European Commission

- **Mission…** is to provide customer-driven scientific and technical support to Union policies.

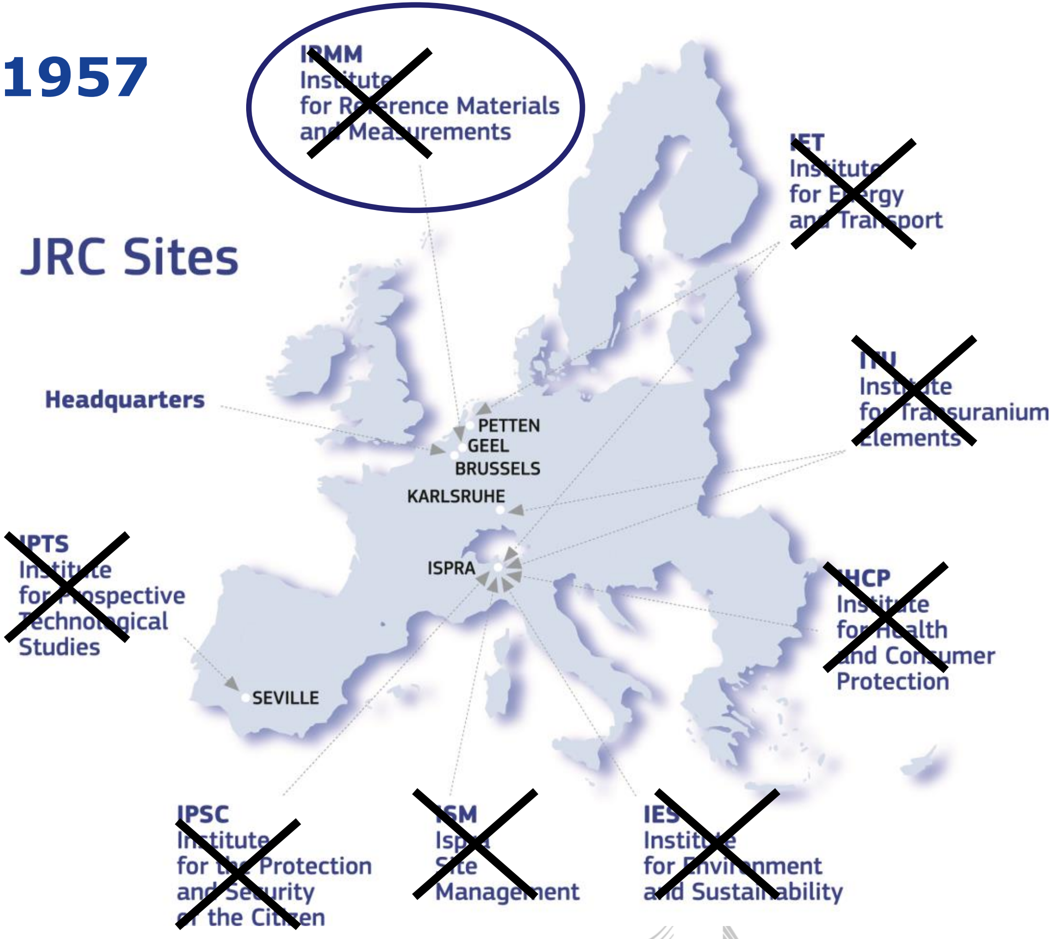
- **Dir. G.:** To implement the JRC Euratom research and training programme, to maintain nuclear competences in Europe to serve both "nuclear" and "non-nuclear" Member States. ….

Euratom treaty signed in 1957
⇒ creation of the J(N)RC

Since 2016 New names of sites:

JRC-Geel
JRC-Petten
JRC-Karlsruhe
JRC-Ispra
JRC-Seville
JRC-Brussels

..and work conducted in directorates encompassing several sites.



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External access scheme - EUFRAT

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

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EU SCIENCE HUB

The European Commission's science and knowledge service

European Commission > EU Science Hub > EUFRAT – European facility for nuclear reaction and decay data measurements

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- **Call for Proposal**
- **How to apply**
- **Programme Advisory Committee**
- **Before you start**
- **Accepted proposals**
- **Contacts**
- **Forms**

EUFRAT

EUFRAT – European facility for nuclear reaction and decay data measurements

Transnational Access of external users to JRC nuclear facilities

The unit Standards for Nuclear Safety, Security and Safeguards (SN3S unit) of the Directorate for Nuclear Safety and Security of the Joint Research Centre (JRC) in Geel, Belgium, operates a unique nuclear research infrastructure dedicated to the measurement of accurate nuclear reaction and decay data. These measurements serve the needs of safe operation of nuclear reactors, safe handling of nuclear waste and the radiological protection of the safety of the citizen and the environment.

Related Publications

- Search for the decay of nature's rarest isotope 180mTa
- Variation of natural radionuclides in non-ferrous fayalite slags during a one-month production period
- Radiological characterization and evaluation of high volume bauxite residue alkali activated concretes
- Nuclear activities of the Joint Research Centre. European Atomic Energy Community (Euratom) Research Infrastructure

External access scheme - EUFRAT

Via the transnational access programme EUFRAT, JRC offers external researchers from the EU Member States and 3rd countries experimental possibilities at its nuclear facilities. There is a permanent call for proposals for experiments. Selection of experiments is based on peer review by international experts representing the stakeholder community.

The eufrat-facilities of JRC Geel encompass:

- a 150 MeV linear electron accelerator (GELINA) with a high-resolution neutron time-of-flight (TOF) facility;
- a 7 MV Van de Graaff facility for the production of continuous and pulsed proton-, deuteron- and helium ion beams which is serving as a source of well characterised quasi-monoenergetic neutrons;
- a broad set of experimental set-ups used for nuclear decay measurements, the Radionuclide metrology laboratories;
- a low-level radioactivity laboratory in the deep-underground facility HADES;
- a unit for the preparation and characterisation of actinide and stable targets needed for nuclear data measurements.

External researchers from the EU Member states and 3rd countries can propose an experiment at these facilities, provided JRC experimental infrastructure can offer a significant added value to the project proposal. JRC launches a permanent Call for Proposals. Proposals are peer reviewed by a Programme Advisory Committee (PAC).

More >

Events

JUL 06 2017	**Geel (BE)** 7th EUFRAT Program Advisory Committee meeting
JUL 05 2016	**Geel (BE)** EUFRAT Program Advisory Committee meeting

Related Facilities & Laboratories

HADES underground laboratory

Linear electron accelerator facility

Radionuclide metrology laboratories

Van de Graaff accelerator

https://ec.europa.eu/jrc/en/research-facility/open-access

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The European Commission's science and knowledge service

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Google: "JRC, open access, infrastructure"

About us   Research   Knowledge   Working with us   Procurement   News & Events   Our Communities

Research

- **Commission priorities**
- **Science areas**
- **Research topics**
- **Centre for Advanced Studies**
- **Laboratories & facilities**
- Open Access of JRC Research Infrastructures
  - Framework for Access
  - About
- **Crosscutting activities**

Open access to JRC Research Infrastructures

The European Commission's Joint Research Centre (JRC) opens its scientific laboratories and facilities to people working in academia and research organisations, industry, small and medium enterprises (SMEs), and more in general to the public and private sector.

The JRC offers access to its non-nuclear facilities to researchers and scientists from EU Member States, candidate countries and countries associated to the EU Research Programme Horizon 2020. For nuclear facilities, the JRC will open to EU Member States, candidate countries (on the conditions established in the relevant agreement or decision) and countries associated to the Euratom Research Programme

Offering access to visiting researchers is part of JRC's strategy to:

- enhance dissemination of scientific knowledge;
- boost competiveness;
- bridge the gap between research and industry.

Or… email to Mikael.hult@ec.europa.eu

Euratom Treaty, ARTICLE 6:

To encourage the carrying out of research programmes communicated to it the Commission may:

.....

(c) place installations, equipment or expert assistance at the disposal of Member States, persons or undertakings, either free of charge or against payment;

Euratom Treaty, ARTICLE 8:

……the Commission shall establish a Joint Nuclear Research Centre.

This Centre shall ensure that the research programmes and other tasks assigned to it by the Commission are carried out.

It shall also ensure that a uniform nuclear terminology and a standard system of measurements are established.

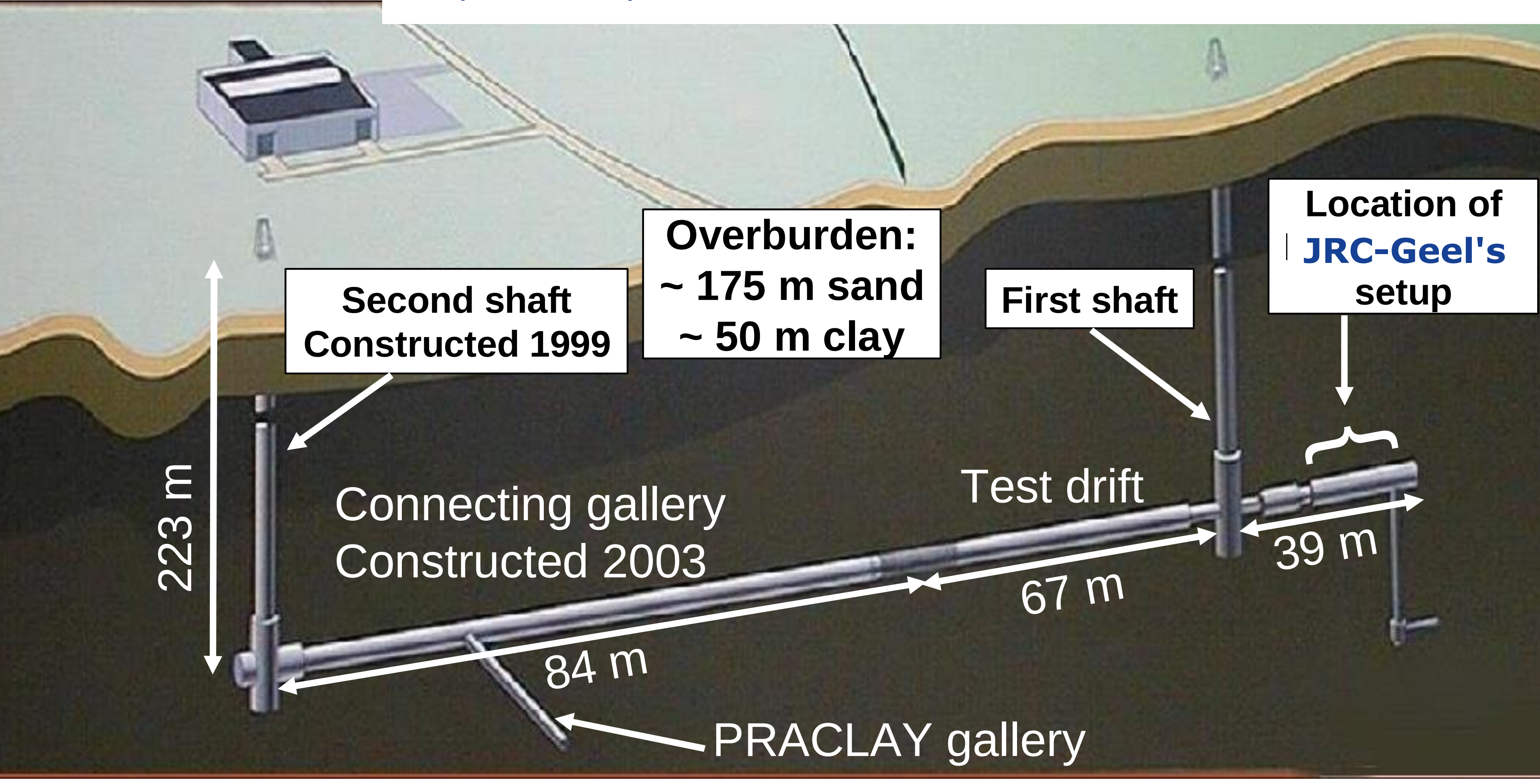
It shall set up a central bureau for nuclear measurements. (CBNM)

- Primary standardisation of activity
- Decay data
- Realisation of the unit Bq

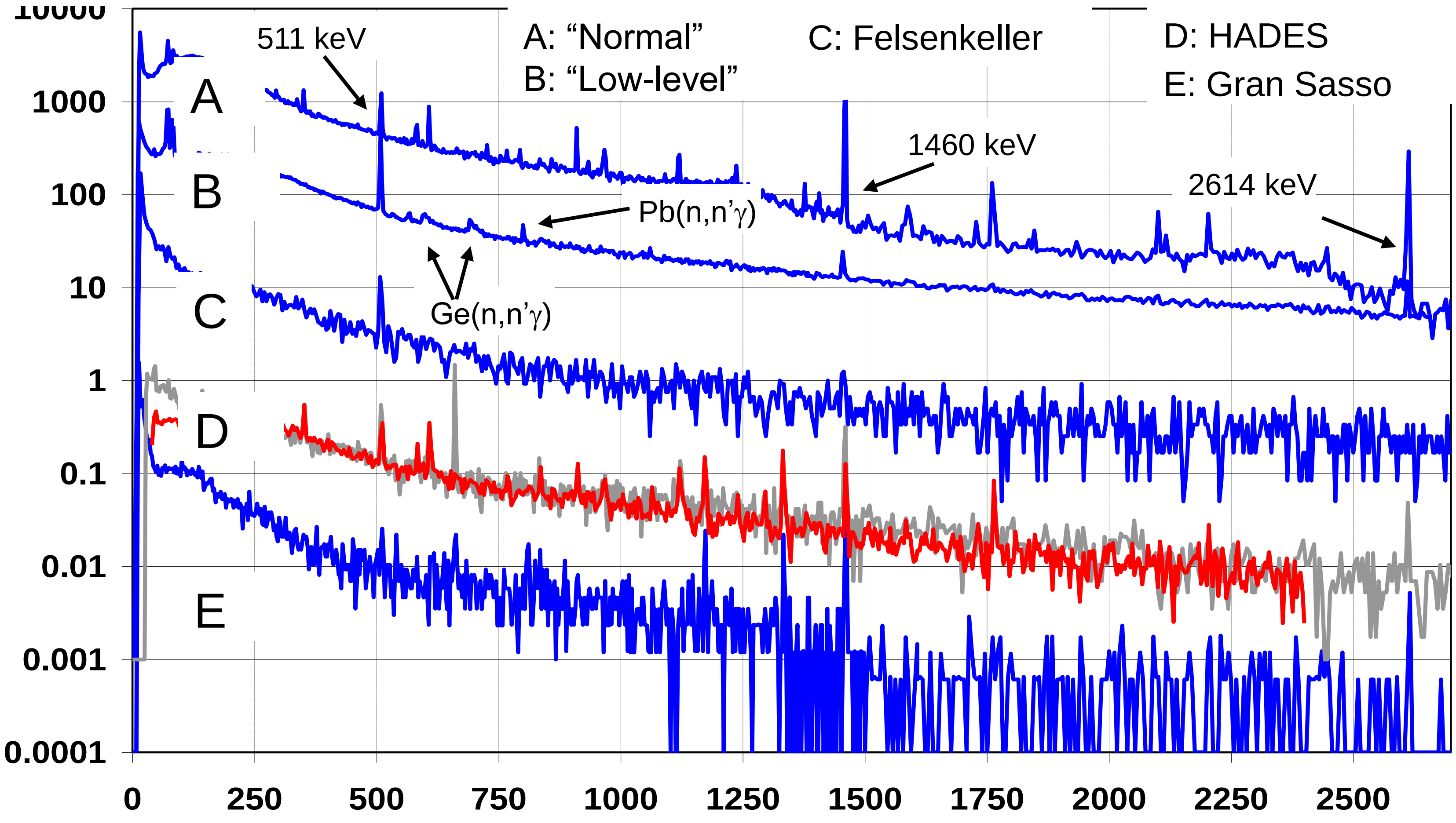
JRC-Geel

HADES

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



Background Comparison – Gamma-ray spectrometry



The simplified Basic Equation for gamma-ray spectrometry

$$C = AP_{\gamma}t\varepsilon$$

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

Peak Count

Gamma-ray emission probability

FEP (Full Energy Peak) efficiency

Measurement time
(live time)

The (almost) complete basic equation for gamma-ray spectrometry

$$A = \frac{C_{TOT} - C_{Peak}^{Bkg} - C_{Continuum}}{\varepsilon_{REF}^{Exp} \dfrac{\varepsilon_{Sample}^{MC}}{\varepsilon_{REF}^{MC}} P_{\gamma}} e^{\lambda t_d} \frac{\lambda}{(1 - e^{-\lambda t_m})} K_1 K_2 K_3$$

Measured (Exp) Reference sample (Ref)

Correction factor from calculation or Monte Carlo code (MC)

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

Also deadtime correction!

Combine activities from several gamma-rays from one radionuclide

Combine activities from several daughters into one activity for the mother (like for ^{226}Ra and the ^{222}Rn-daughters)

Ge-detectors

- **The workhorse of modern radiometric laboratories**

- **Li-drifting first described in 1960 (Pell)**

- **First Ge-detector in 1963 (Tavendale):**

  1 cm^3, same resolution as a NaI detector.

- **Improved detection limits if FoM is maximised (important for low-level measurements)**

$$\mathrm{FoM} = \frac{\varepsilon(E)}{\sqrt{R(E)B(E)}} = \frac{\text{efficiency}}{(\text{FWHM} \times \text{background})^{1/2}}$$

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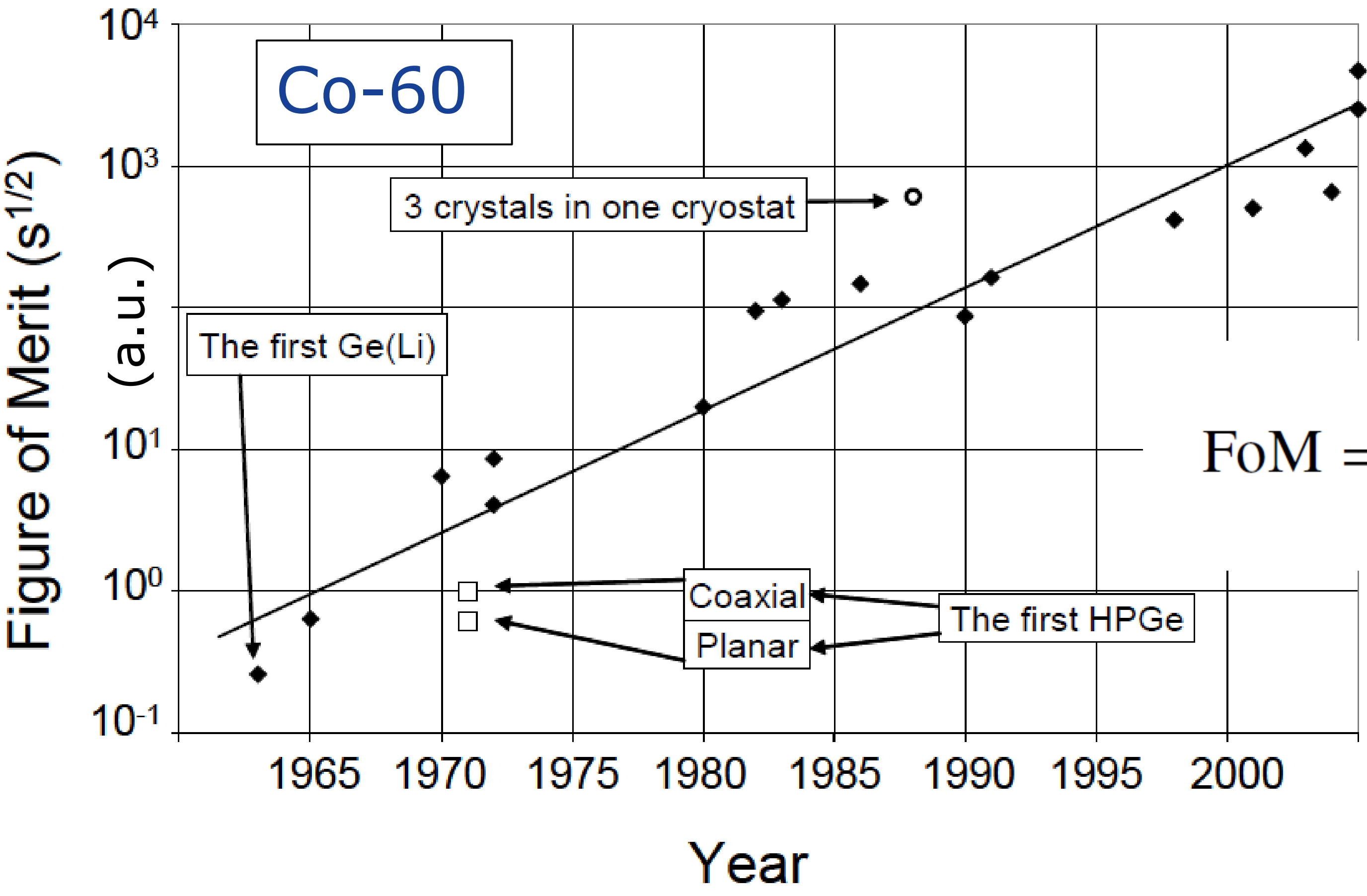

$$\mathrm{FoM} = \frac{\varepsilon(E)}{\sqrt{R(E)B(E)}}$$

Ge-detectors

- **Different types needed for:**
  - **Low/high energy**
  - **Small/big sample**

- **Don't buy bigger crystal than necessary!**

- **Small samples benefit from well-detectors (high ε)**

……..at least when it comes to single gamma-rays emitters like Pb-210, Am-241, Cs-137, etc.

And for double beta decay!!!   (bigger than BeGe-detectors)

- **Low detection limits for massic activity (μBq/kg) requires big samples**

How long measurement time can you afford?

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

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Low background

Low level Gamma-ray Spectrometry (LGS) =
Gamma-ray spectrometry using a detector and shield built from selected radiopure materials

Ultra Low level Gamma-ray Spectrometry (ULGS) =
LGS with additional measures such as placement in an underground laboratory or use of a muon shield.

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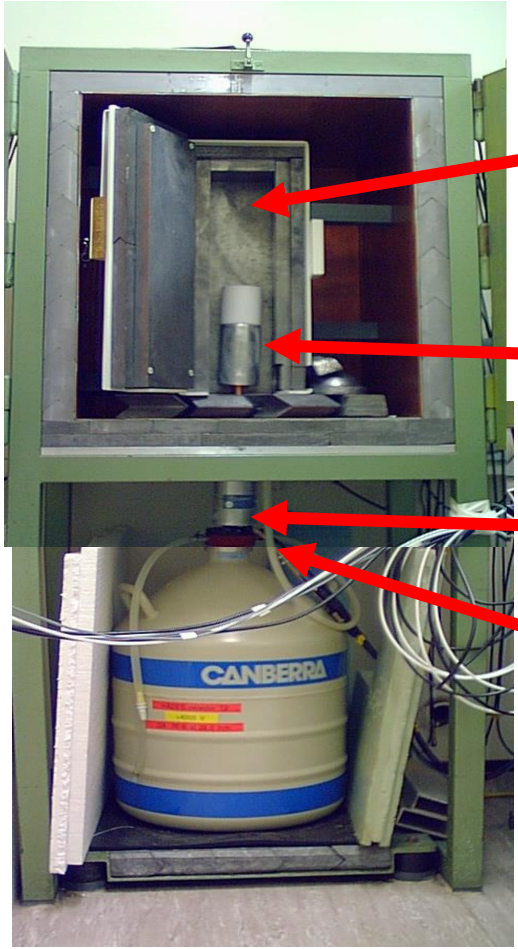
Example of a Low Background Detector



Inner 2.5 cm from ULB lead (2 Bq/kg)

Endcap, cryostat and front-end-electronics from selected radiopure materials

Pre-amp outside lead shield

Tube for nitrogen “flushing”

The background in gamma-ray spectrometry

- **Important to know accurately both for qualitative as well as quantitative analysis!**
- **May vary with time** (decay, contamination, natural variation, noise)
- **Understanding of the sources is important in order to properly correct for the background as well as to improve it!**

The background in gamma-ray spectrometry

1. Primordial
2. Anthropogenic (man-made)
3. Cosmogenic

Primordial radionuclides

(natural, existing since the formation of the earth)

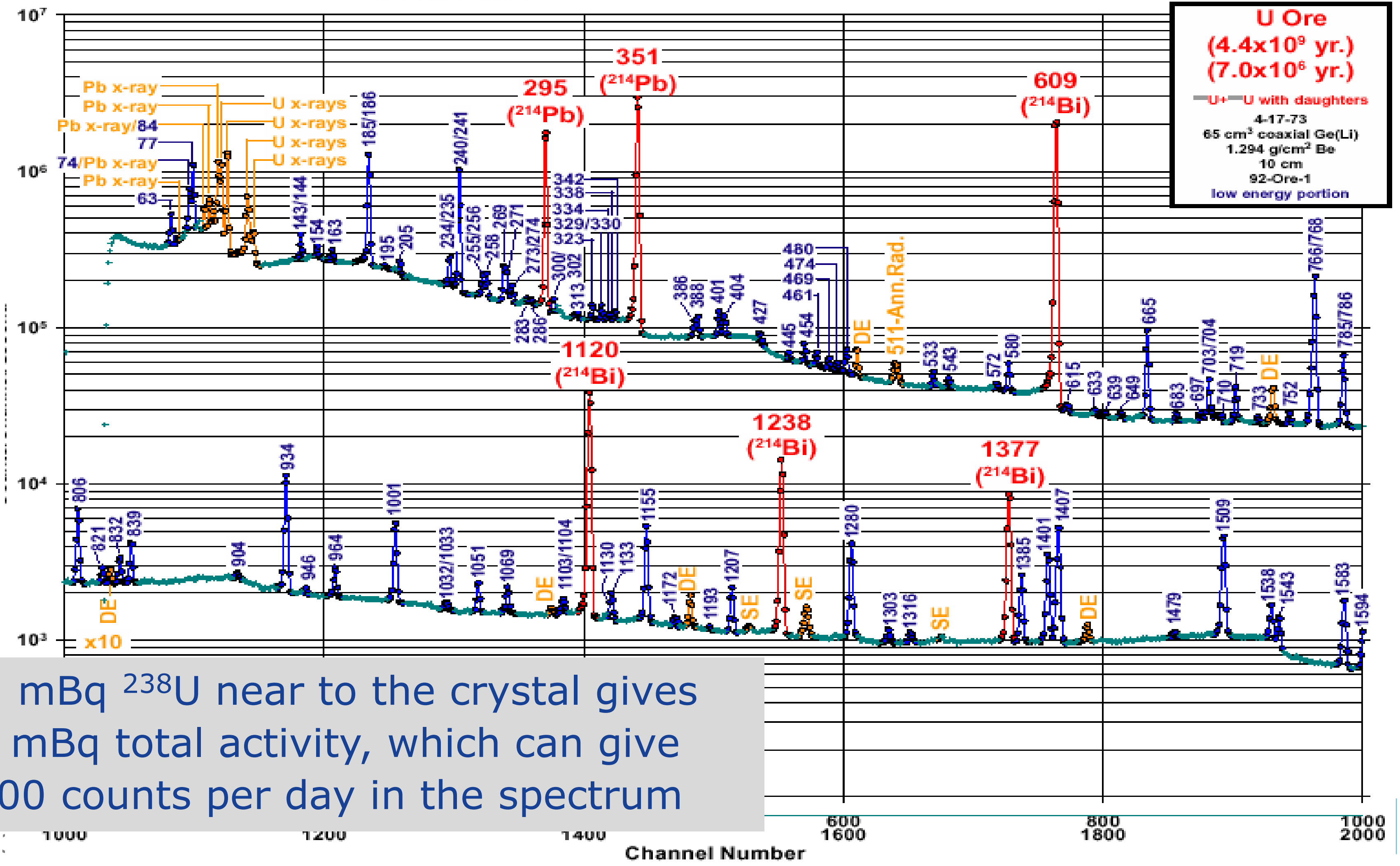
Earth is about $4.5 \cdot 10^9$ years

^{238}U, $T_{½}$ = $4.5 \cdot 10^9$ years
^{235}U, $T_{½}$ = $0.7 \cdot 10^9$ years
^{232}Th, $T_{½}$ = $14 \cdot 10^9$ years
^{40}K, $T_{½}$ = $1.3 \cdot 10^9$ years

Decays to

radium-226, radon-222,

polonium-210, lead-210 etc.

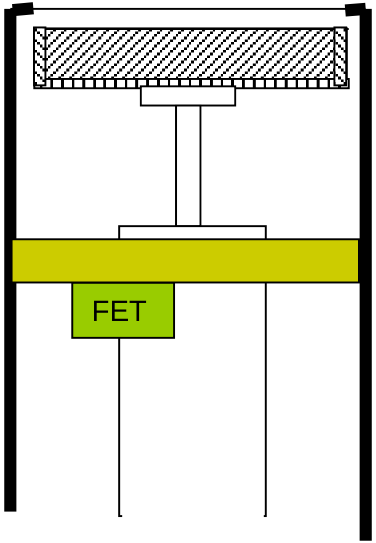


~1 mBq ^{238}U near to the crystal gives
10 mBq total activity, which can give
1000 counts per day in the spectrum

Electronics outside the shield

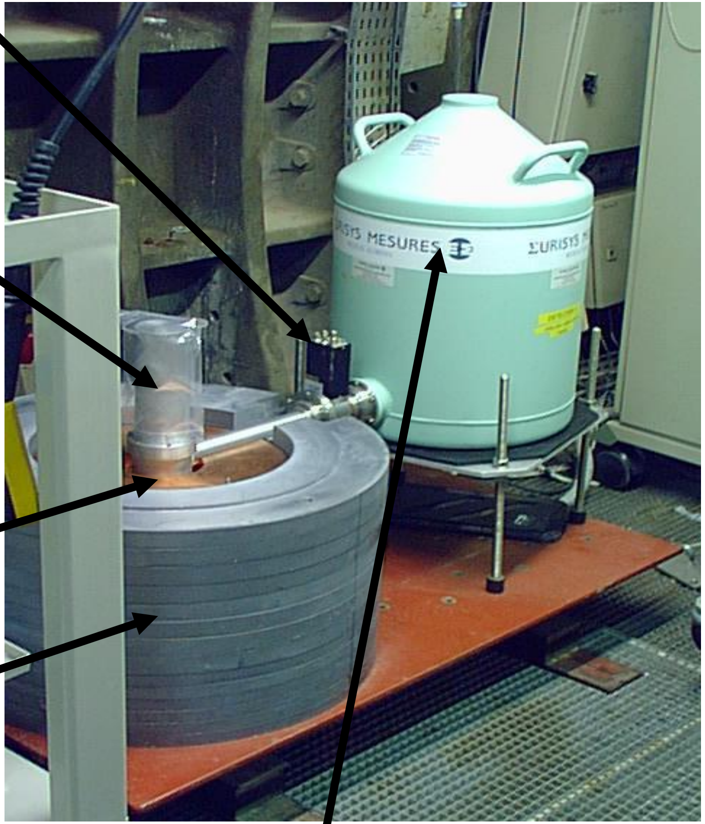
Cryostat, solder, wires from selected materials

Al, Cu, Mg, Si, plastics



Electrolytic copper

Old lead



Molecular sieve not seen by Ge-crystal

Bad materials:

Very often: electronics, printed circuit boards, FET etc.

Rubber, silicone foam, normal Al, Be, molecular sieve, aluminized Mylar

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Solder: Contains Pb and other stuff
Solution: Use pure tin

Teflon: Not good above ground due to neutron interactions with F - Good underground

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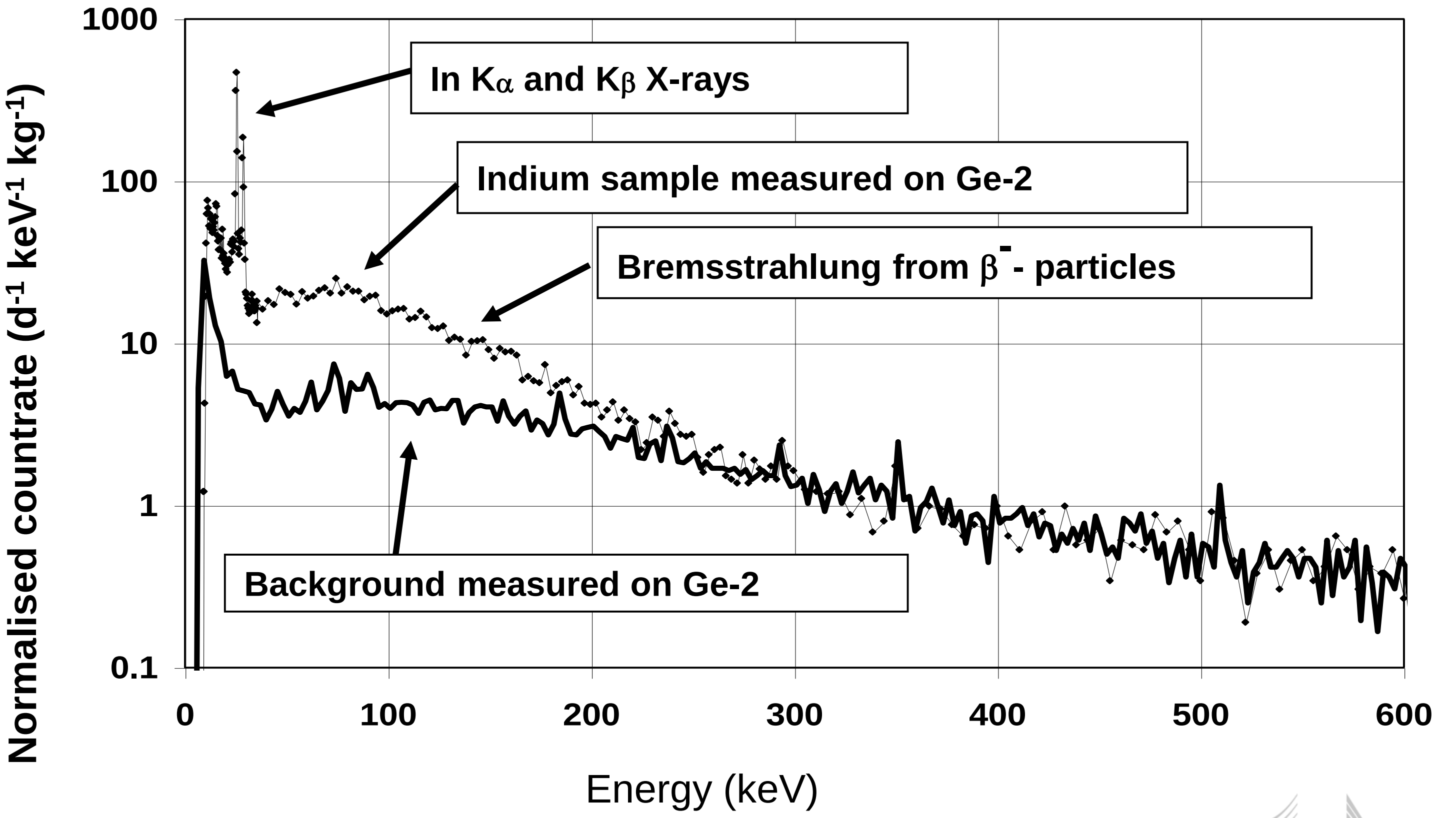
Plastics etc.: Generally radiopure. Can be prone to accumulate radon gas

Indium – radioactive? Yes



Point-contact Ge-detectors

Since ~10 year: Point contact detectors
Canberra: BEGe (Broad Energy Germanium)

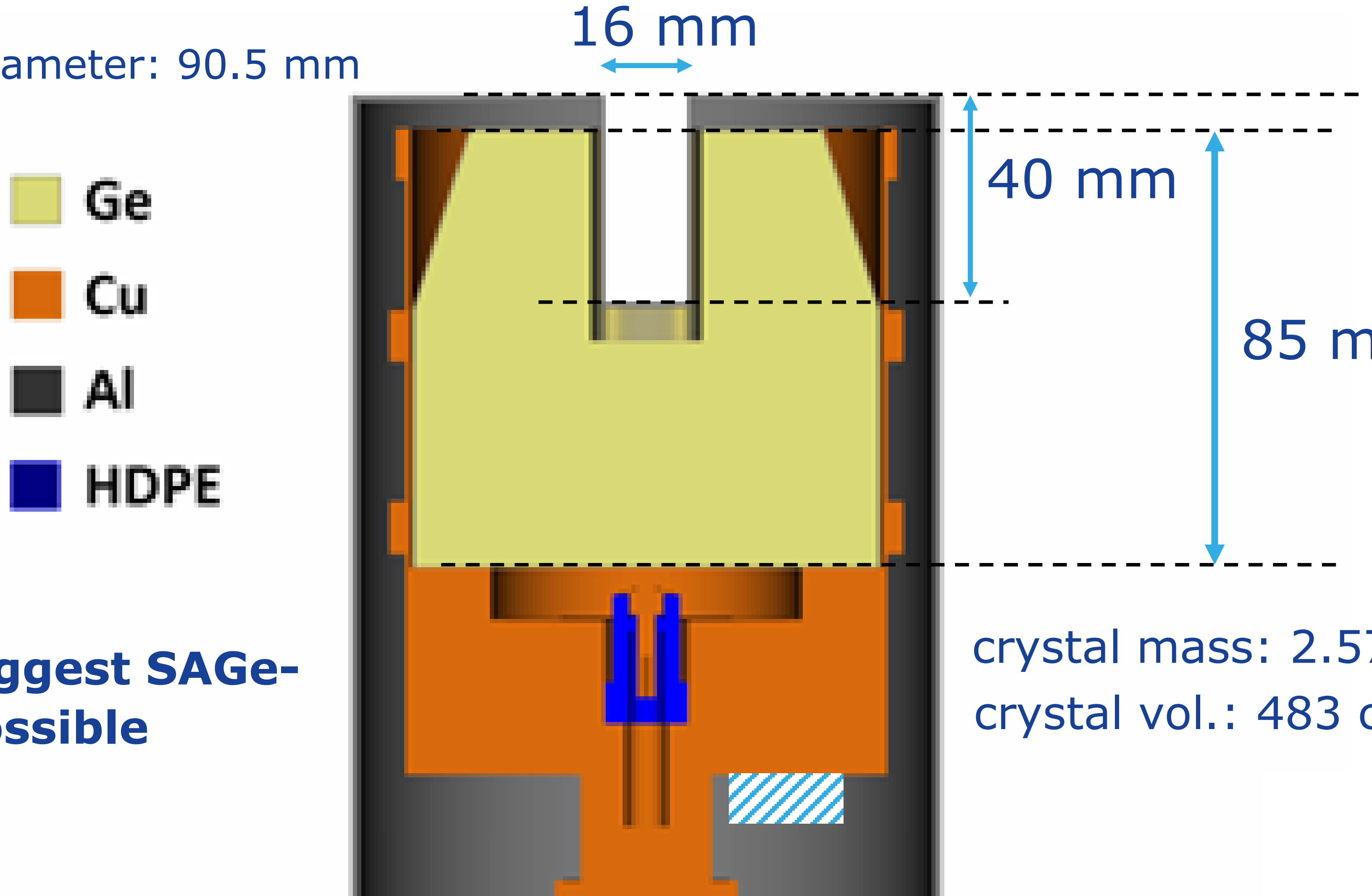
Small anode ⇒ low capacitance ⇒ reduced noise ⇒ good resolution

Since ~2 years: Point contact detectors in well-configuration
Canberra: SAGe (Small Anode Germanium)

David Radford (ORNL) (Majorana, Gammasphere, Gretina,..)

Interest from LEGEND (~GERDA Phase III)

Diameter: 90.5 mm

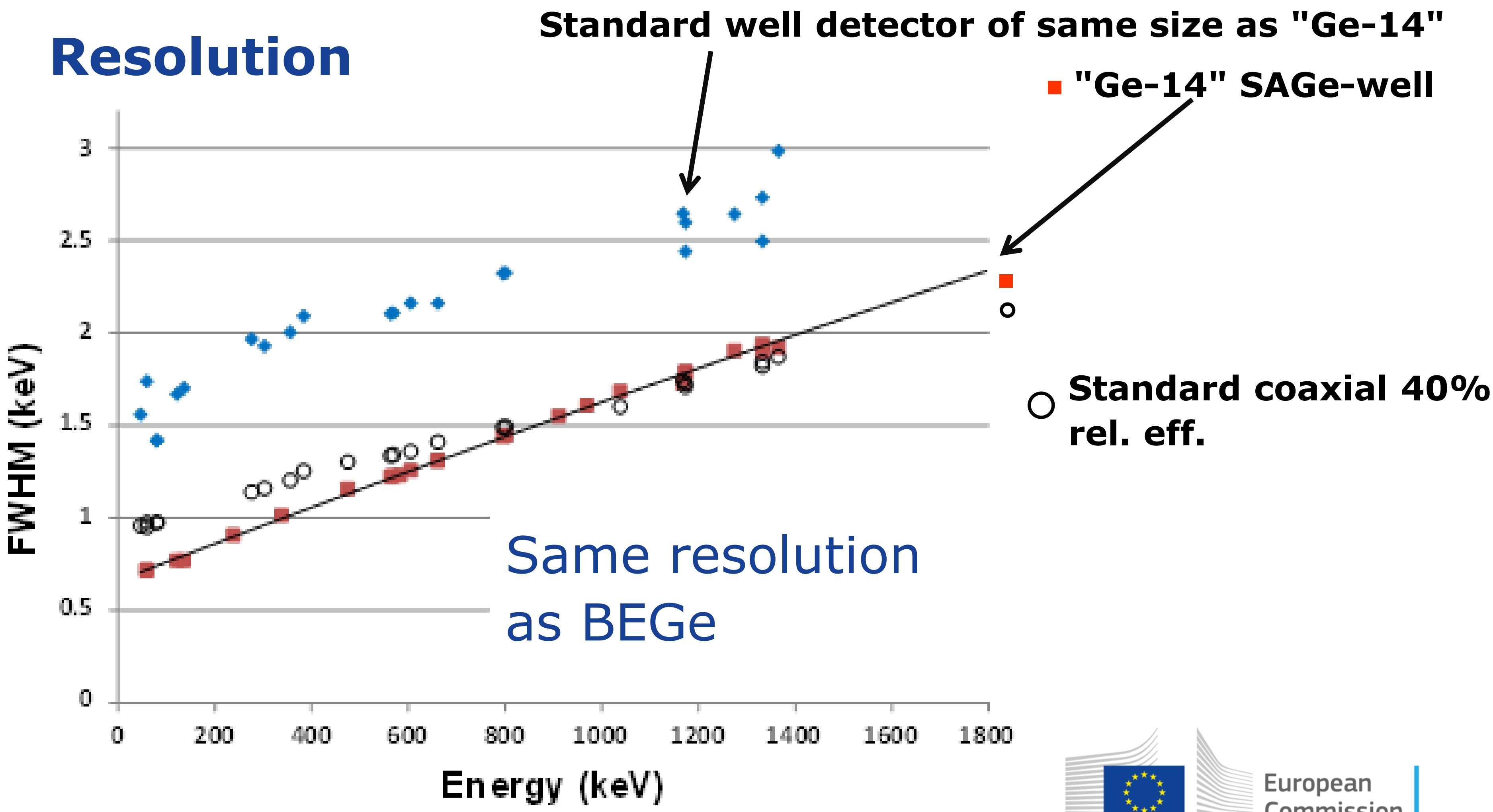


Biggest SAGe-possible

crystal mass: 2.57 kg

crystal vol.: 483 cm^3

Resolution



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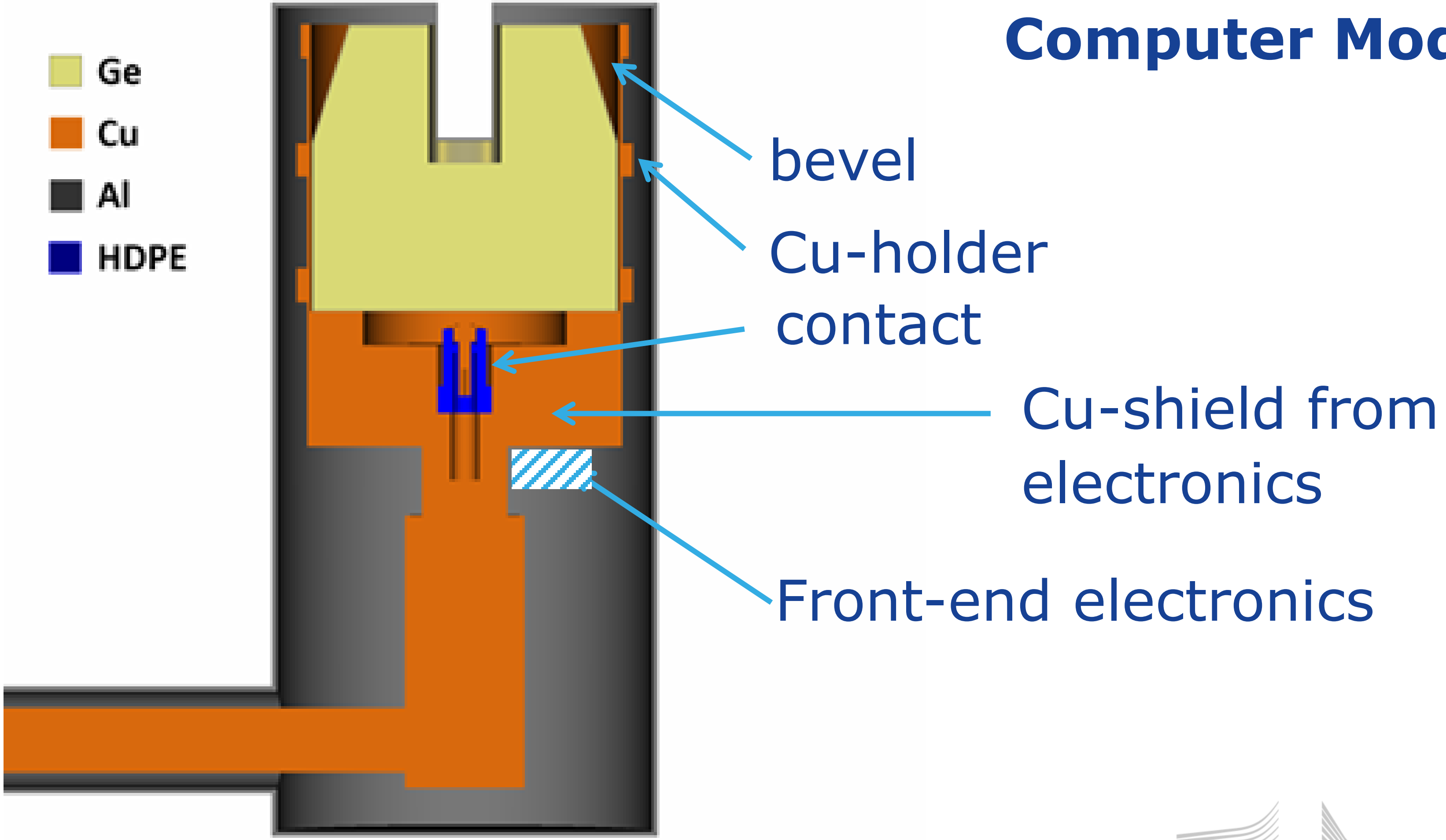
Computer Model



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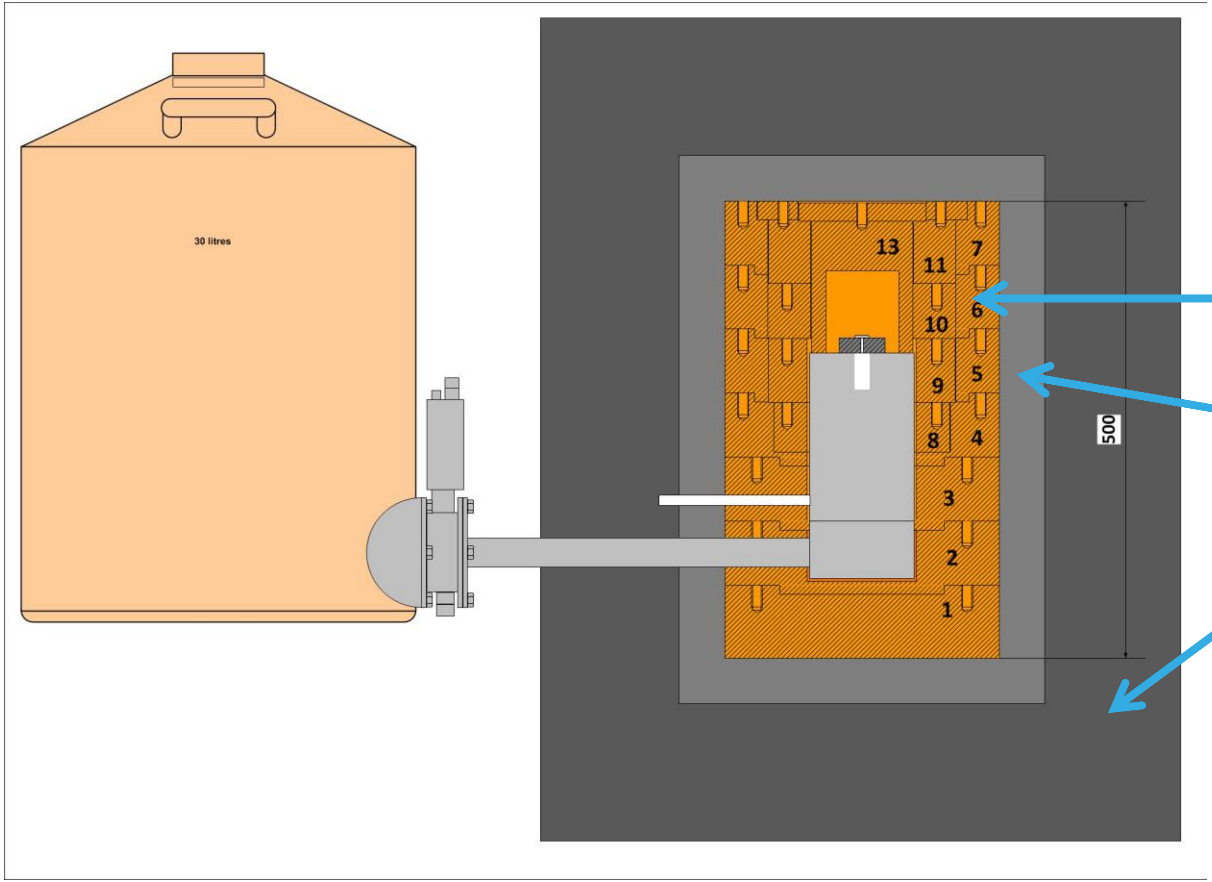
Detector Ge-14 in final shield in HADES

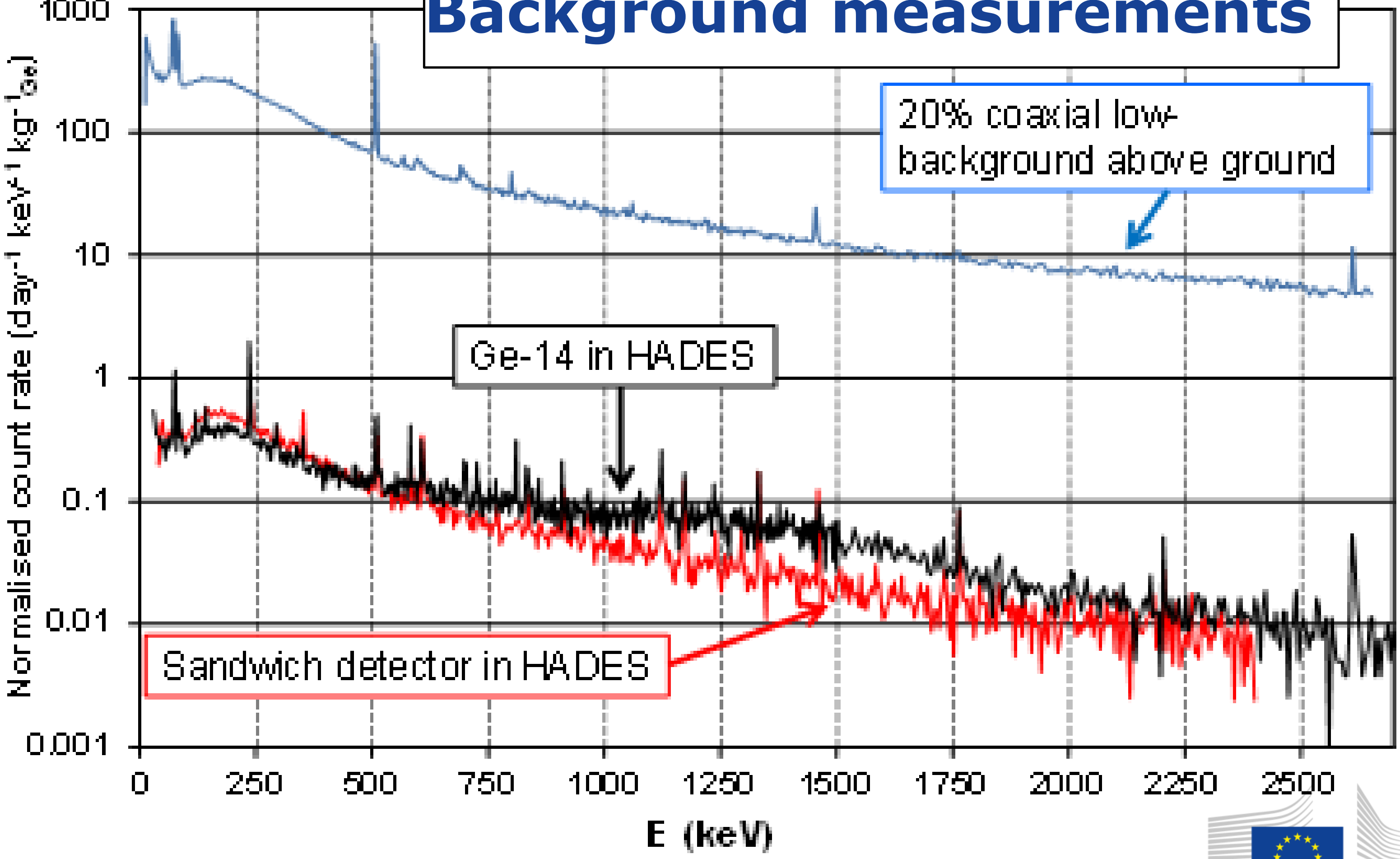


9 cm Cu

5 cm Pb (2 Bq/kg)

15 cm Pb (50 Bq/kg)

Background measurements



Background count-rate (selected lines)

	Ge-14	Ge-3 60% rel. eff coaxial	Ge-7 90% rel. eff. Coaxial (XtRa)
Peak/interval	Installed 2015	Installed 1997	Installed 2006
(keV)	(d^{-1})	(d^{-1})	(d^{-1})
46.5	0.45±0.20	1.28±0.25	1.3±0.2
186	< 0.6	<0.40	1.11±0.19
238	18±1	0.87±0.20	2.9±0.3
352	1.2±0.3	0.72±0.15	2.2±0.2
911	1.03±0.23	0.45±0.10	0.83±0.12
1332	1.34±0.25	< 0.05	0.60±0.10
1460	0.54±0.21	0.62±0.09	1.13±0.12
1764	1.04±0.20	< 0.07	0.67±0.09
2614	1.20±0.17	< 0.05	0.78±0.09

Background count-rate for selected intervals

	Ge-14	Ge-3 60% rel. eff coaxial	Ge-7 90% rel. eff. Coaxial (XtRa)
Peak/interval	Installed 2015	Installed 1997	Installed 2006
(keV)	(d^{-1})	(d^{-1})	(d^{-1})
40-1500	612±8	325±2	410±2
1500-2700	95±3	11±0.4	32±0.5
40-2700	707±8	336±2	442±2
40-2700 divided by Ge-mass in kg	275±2	250±2	245±1

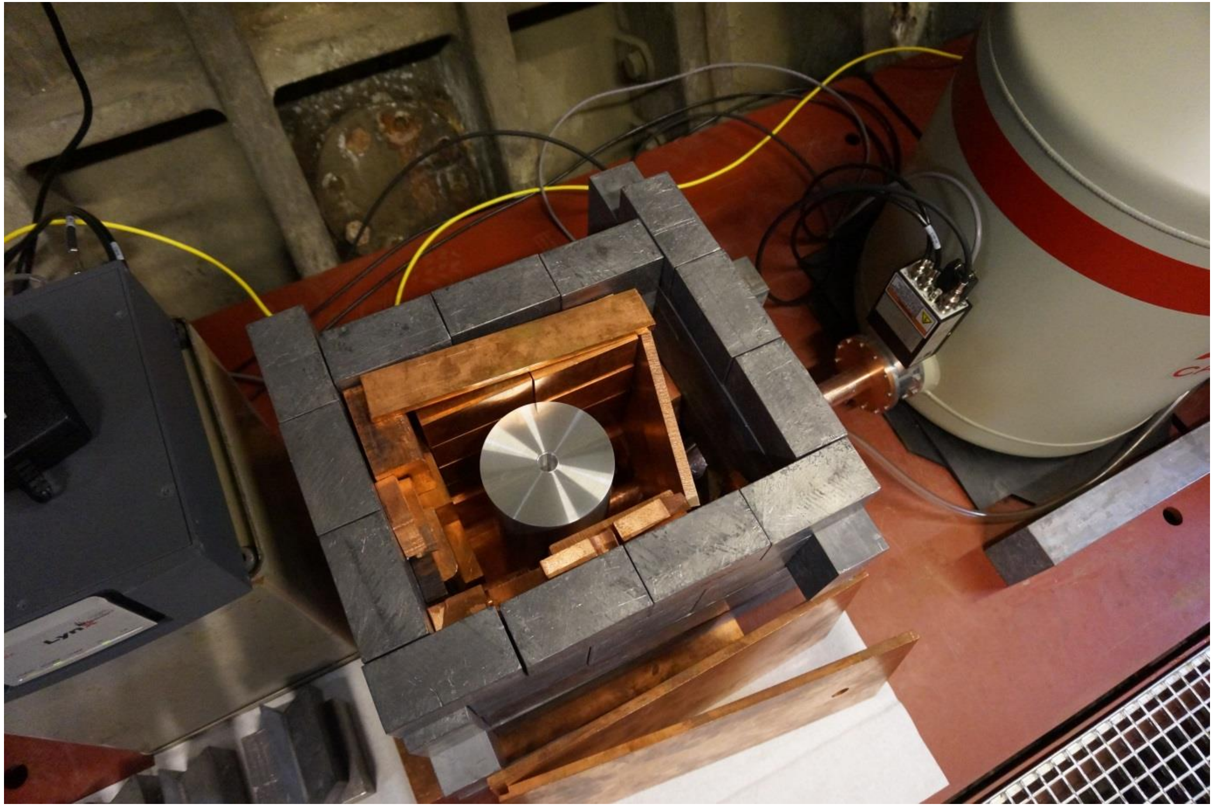
237 d^{-1} with muon shield

Activity of Components (mBq/g)

Radionuclide*	Capacitor	Al-endcap	contacts	Epoxy glue
^{238}U	2.9±0.7	< 0.021	19±9	1.89±0.17
^{226}Ra	24.5±1.0	< 0.012	< 0.4	1.26±0.06
^{210}Pb	22±4	< 0.03	< 0.14	1.5±0.3
^{228}Ra	6.9±0.5	< 0.005	0.18±0.03	0.16±0.02
^{228}Th	4.0±0.3	< 0.007	0.24±0.03	0.17±0.02
^{40}K	1.4±0.4	< 0.022	0.38±0.14	2.7±0.2

Pb-212/Th-228? Thoron from a surface??

"Ge-14" in temporary shield



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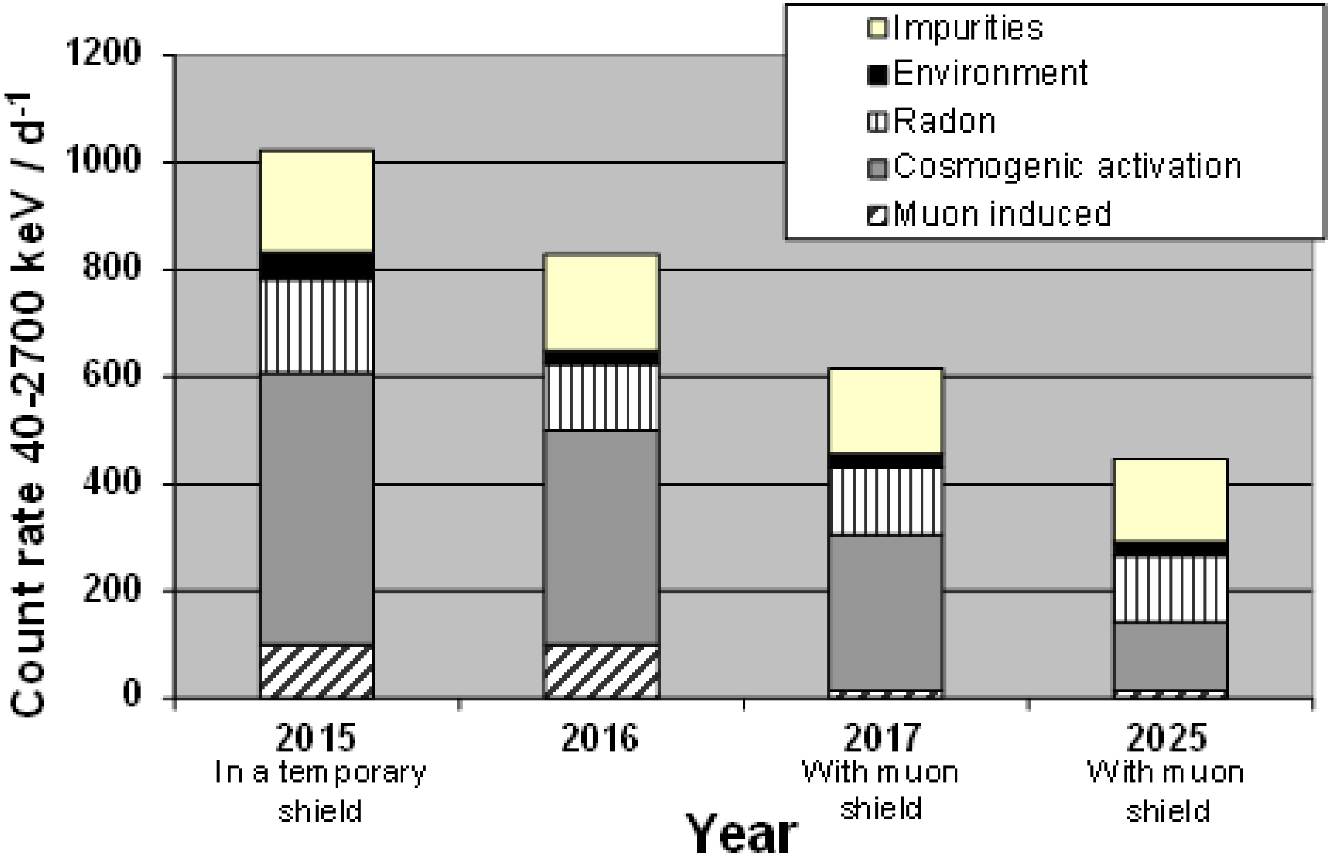
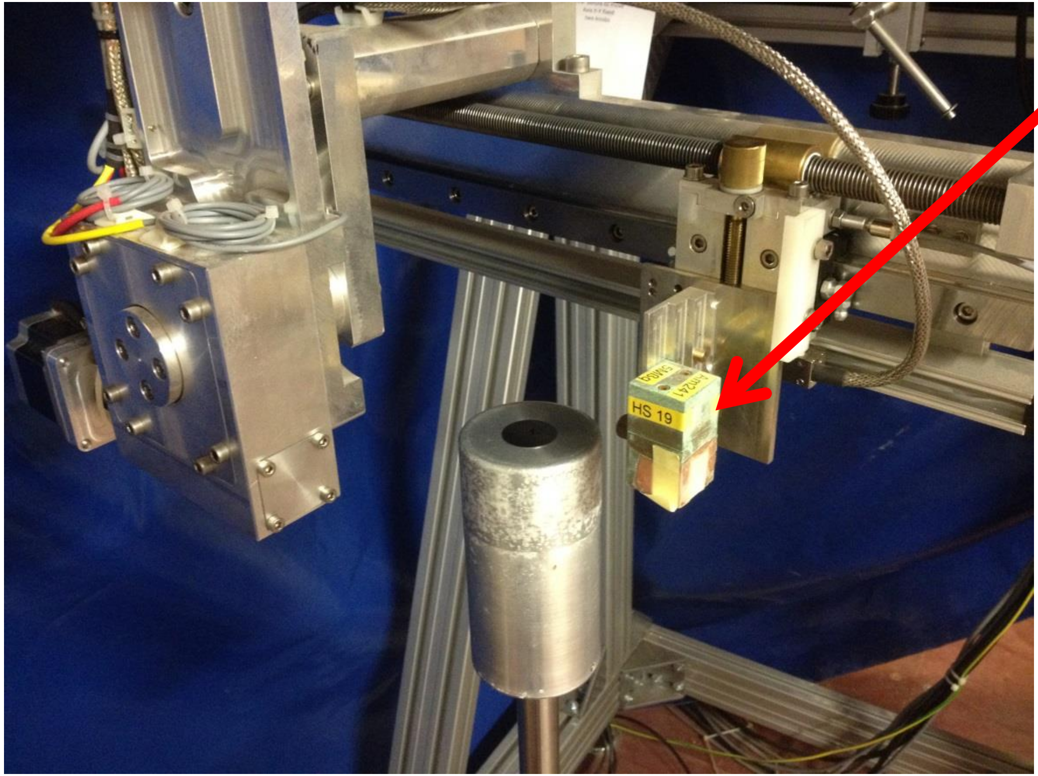
Location of background sources



The JRC-Geel scanning station



Contains a 5 MBq Am-241 source

The JRC-Geel scanning station

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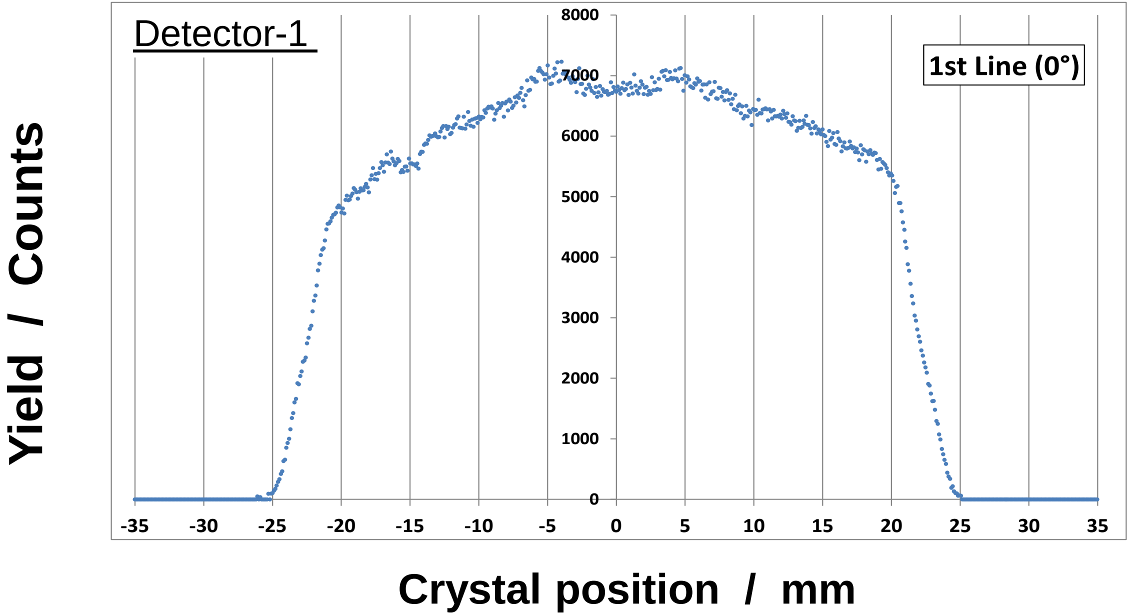
Top line scan of 21 y old detector

- Kept "warm" for > 10 years



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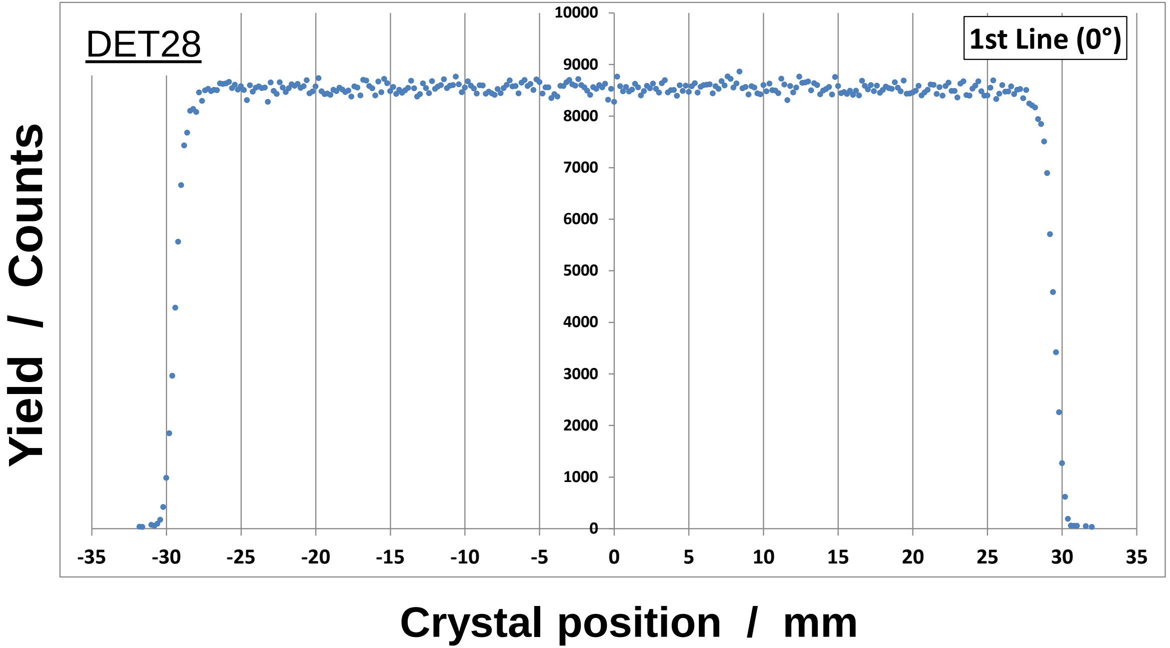
Top line scan of 13 y old detector

- Kept "warm" for ~ 2 months



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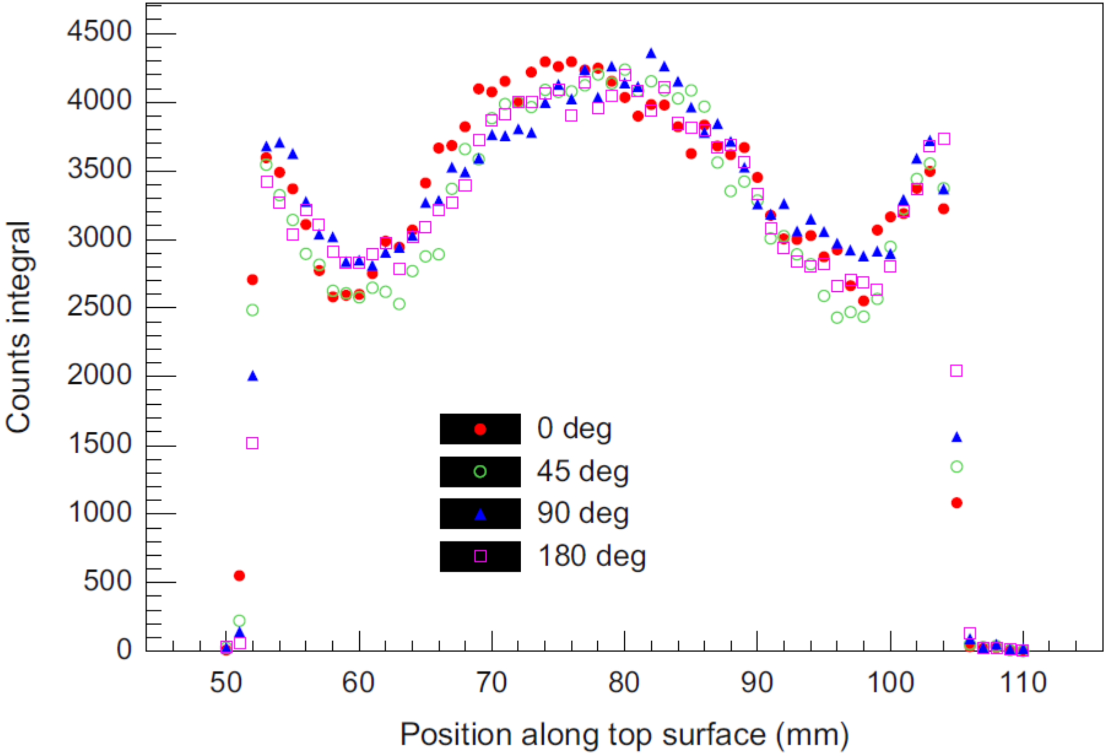
Top line scan of 35 y old detector

- Kept warm for 28 years



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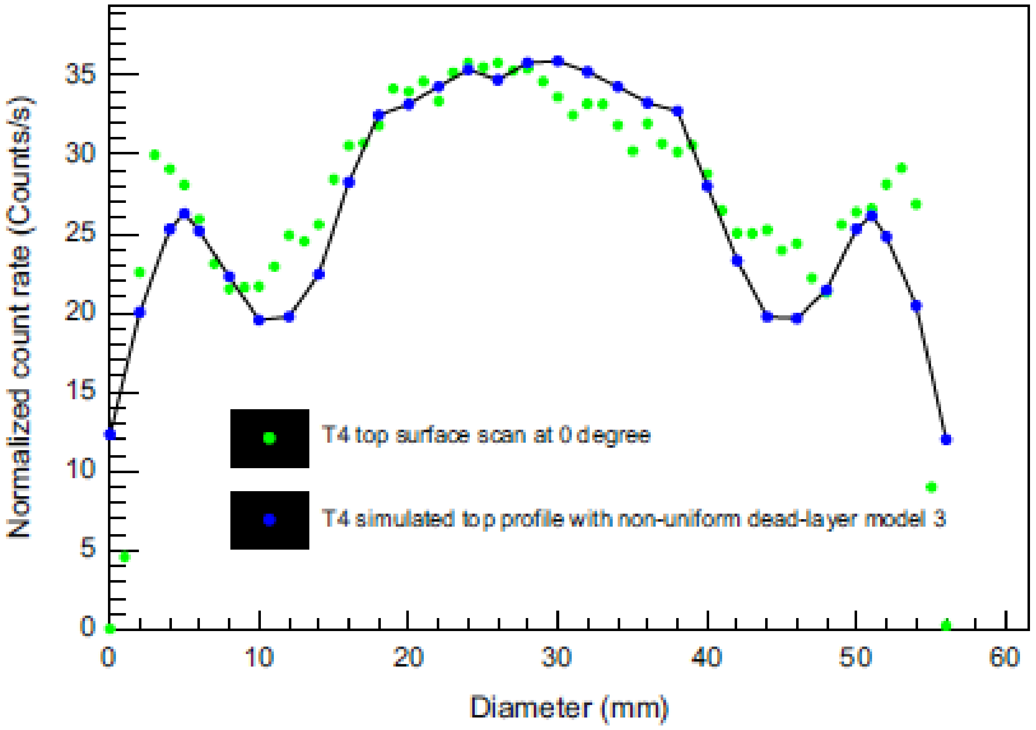
Computer model with "adjusted" deadlayer



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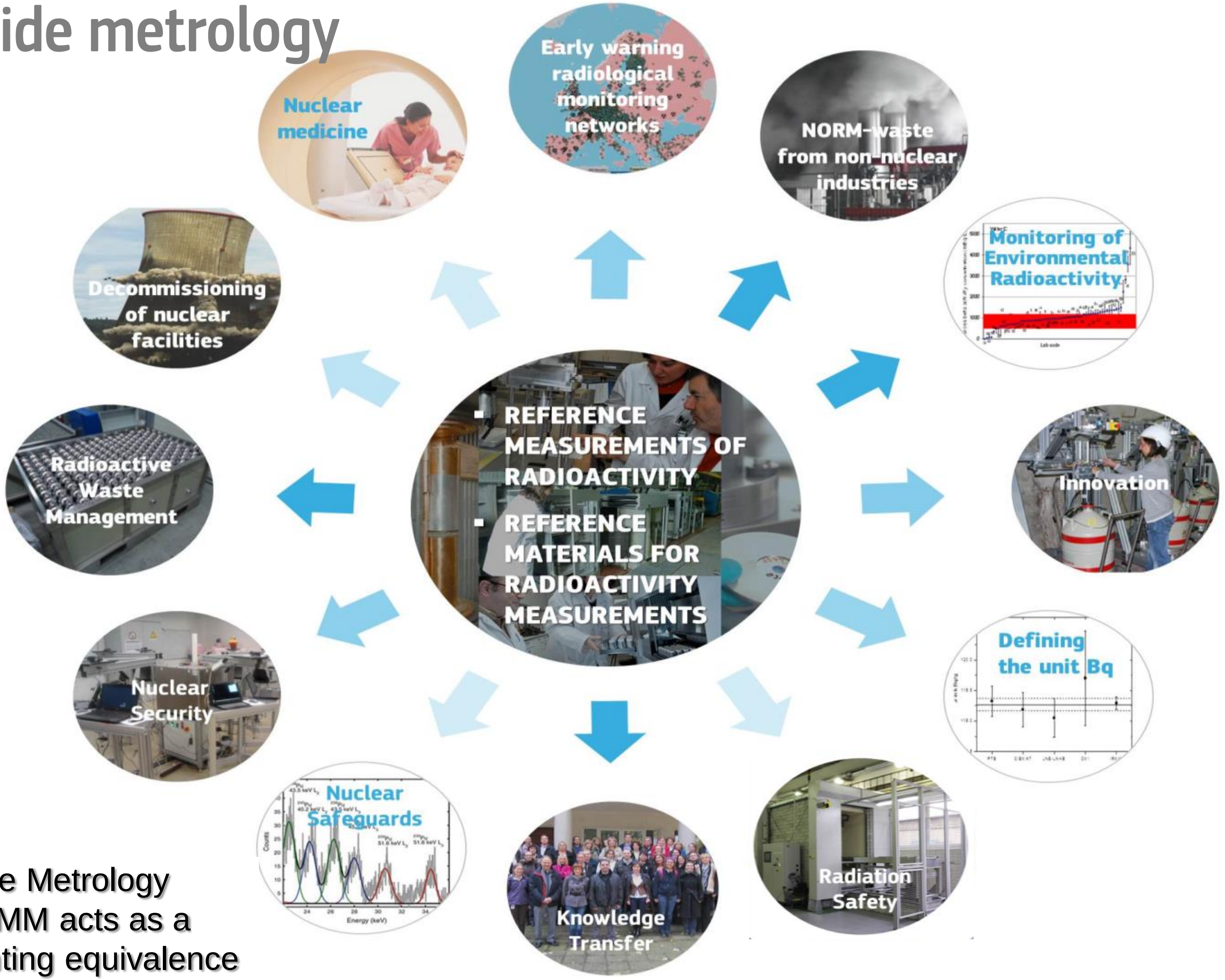
Take good care of your Ge-detector

- Important to try to keep cold at all times

Radionuclide metrology



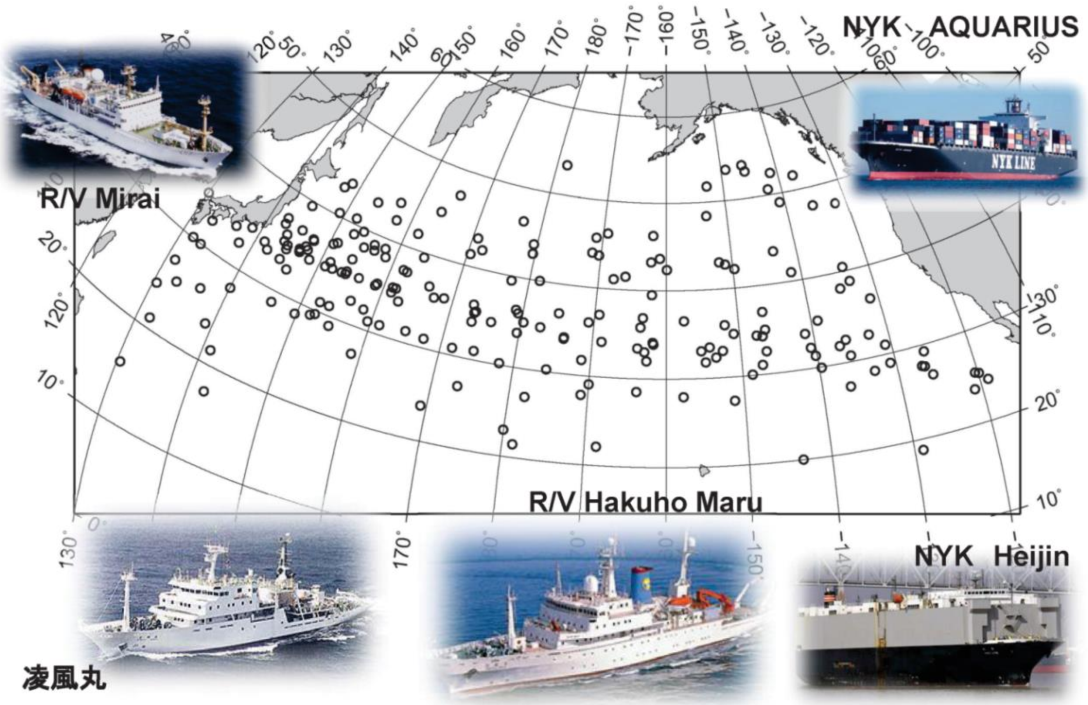
The Radionuclide Metrology Team of JRC-IRMM acts as a hub in implementing equivalence and harmonisation of radioactivity

uropean
ommission

Measurements Matter
Meten is Weten

Tracer studies. Using radioactivity from Fukushima

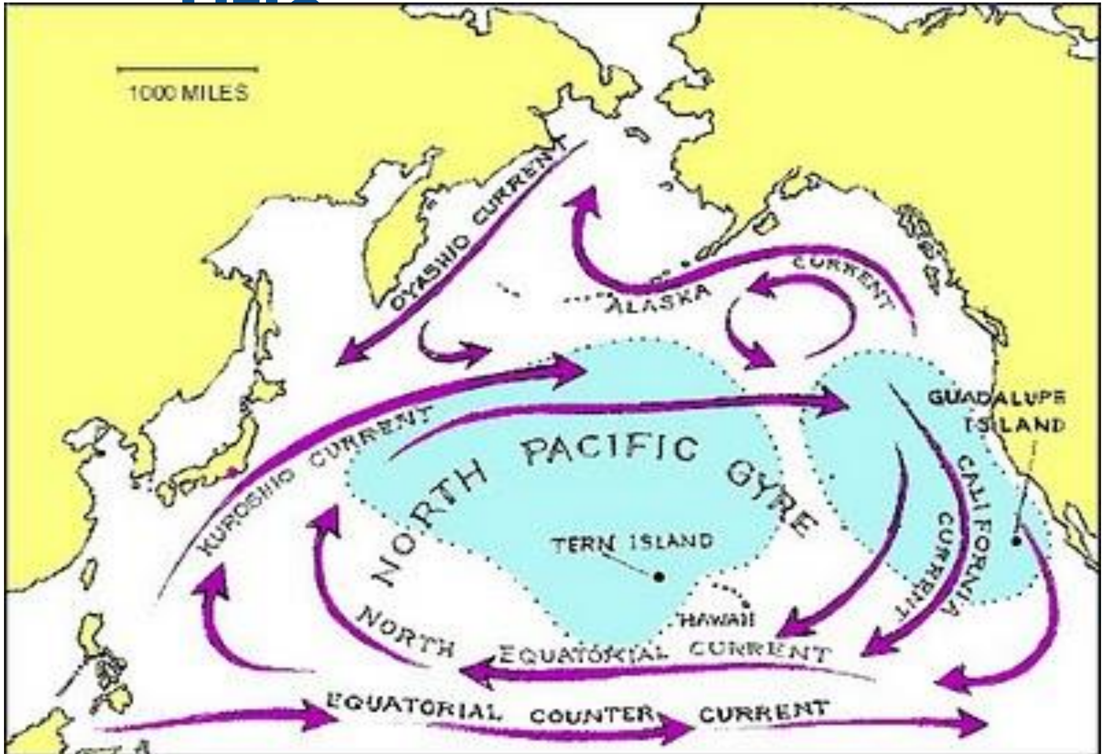
Sampling locations during the period from March 2011 to Oct. 2012



Dr. Michio Aoyama
Meteorological Research Institute,

Fukushima University Japan

- ^{134}Cs and ^{137}Cs (also Ag-110m + search for others) (~ mBq/L)
- **sea-water, plankton and suspended particles**
- Collaboration with (i) Oceanographic Society of Japan, (ii) Fukushima University and (iii) Woods Hole Oceanographic Institute (USA).



Important for models on climate change

input to the IPCC work

European Commission

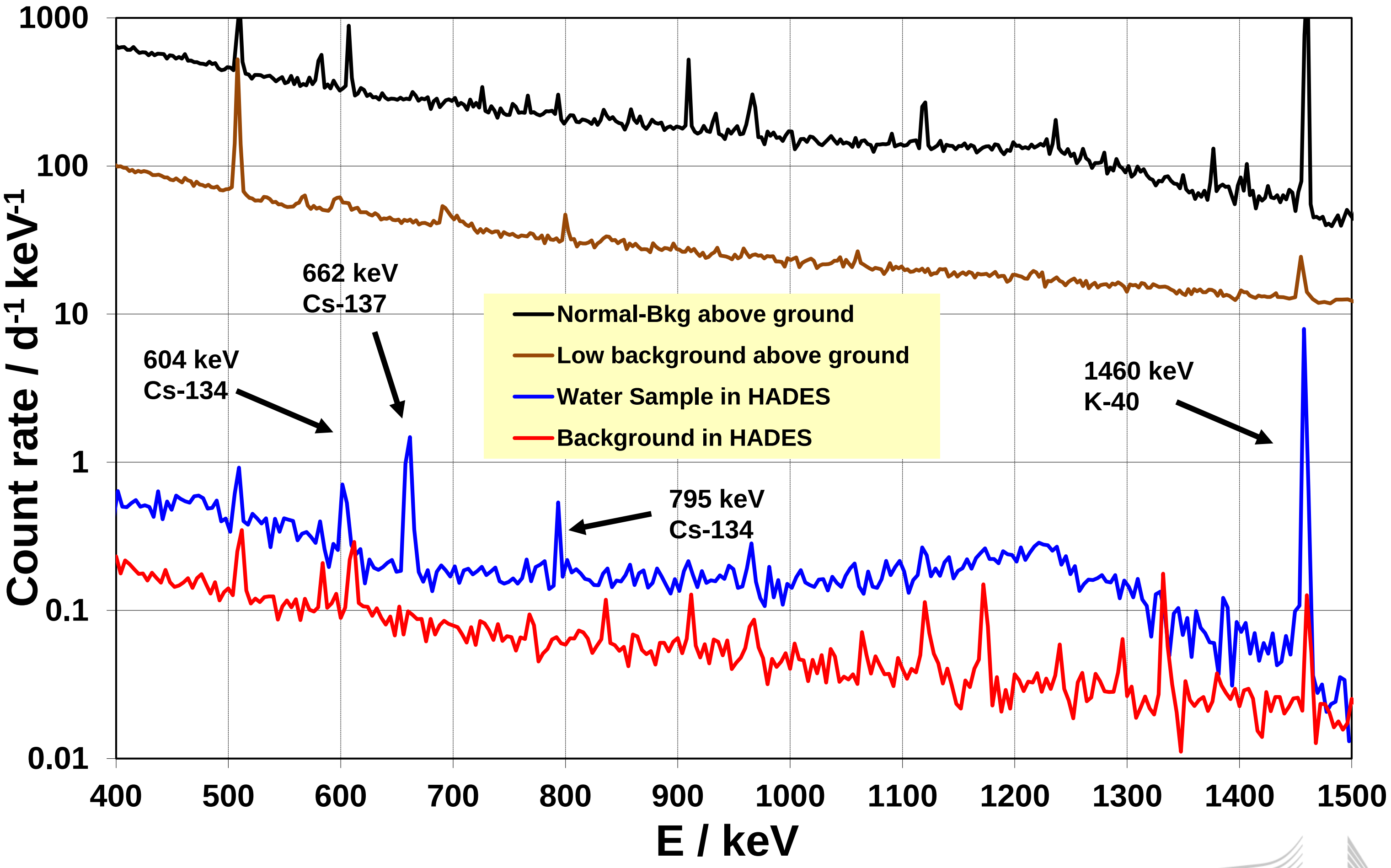
Water precipitate (AMP)

Filter w. phyto-plankton and particulate matter

Freeze dried zoo-plankton

Samples from the Northern Pacific

European Commission



Spectrum from a 4 g pacific Sea water precipitate

REFERENCE MATERIALS (CRM, PT, testing,..)

Calibration standards for free release measurements

Metal disks

certified (low) ^{60}Co-activity

Homogeneity verified in HADES

Production ready
Certification ongoing: 2017-2018.
Planned CRM release: 2019.

Reference Materials

Metrological tools for nuclear decommissioning

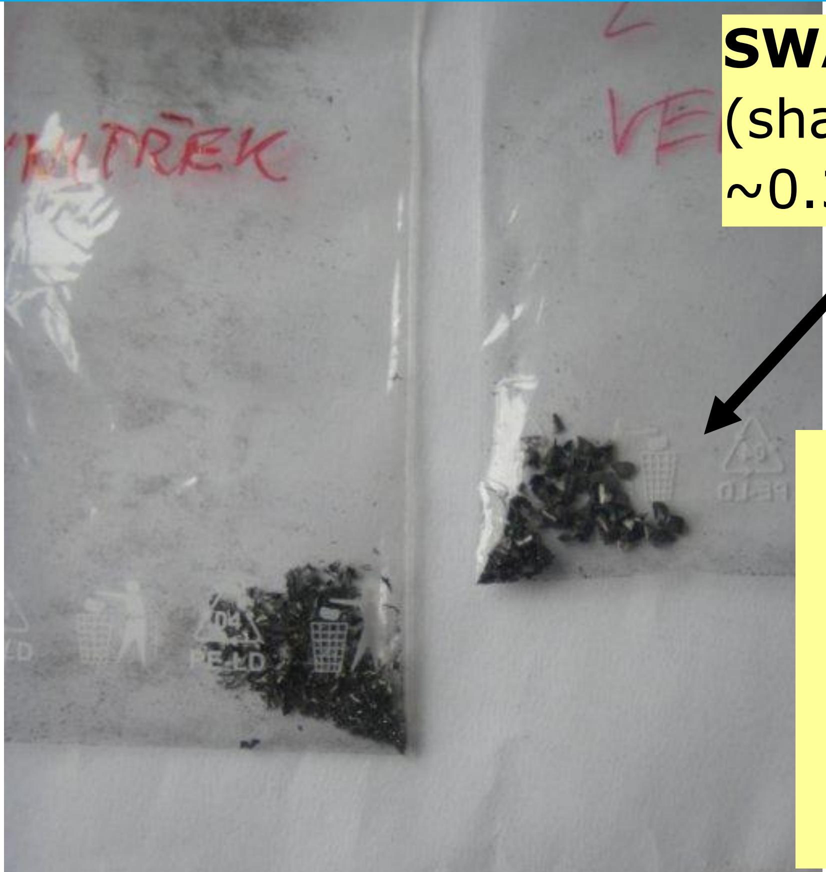
Calibration standards for **free release** measurements

Spectrometer for free release
(CMI/Envinet, Czech Rep.)

Metal tubes
certified (low) activity
^{60}Co, ^{108m}Ag

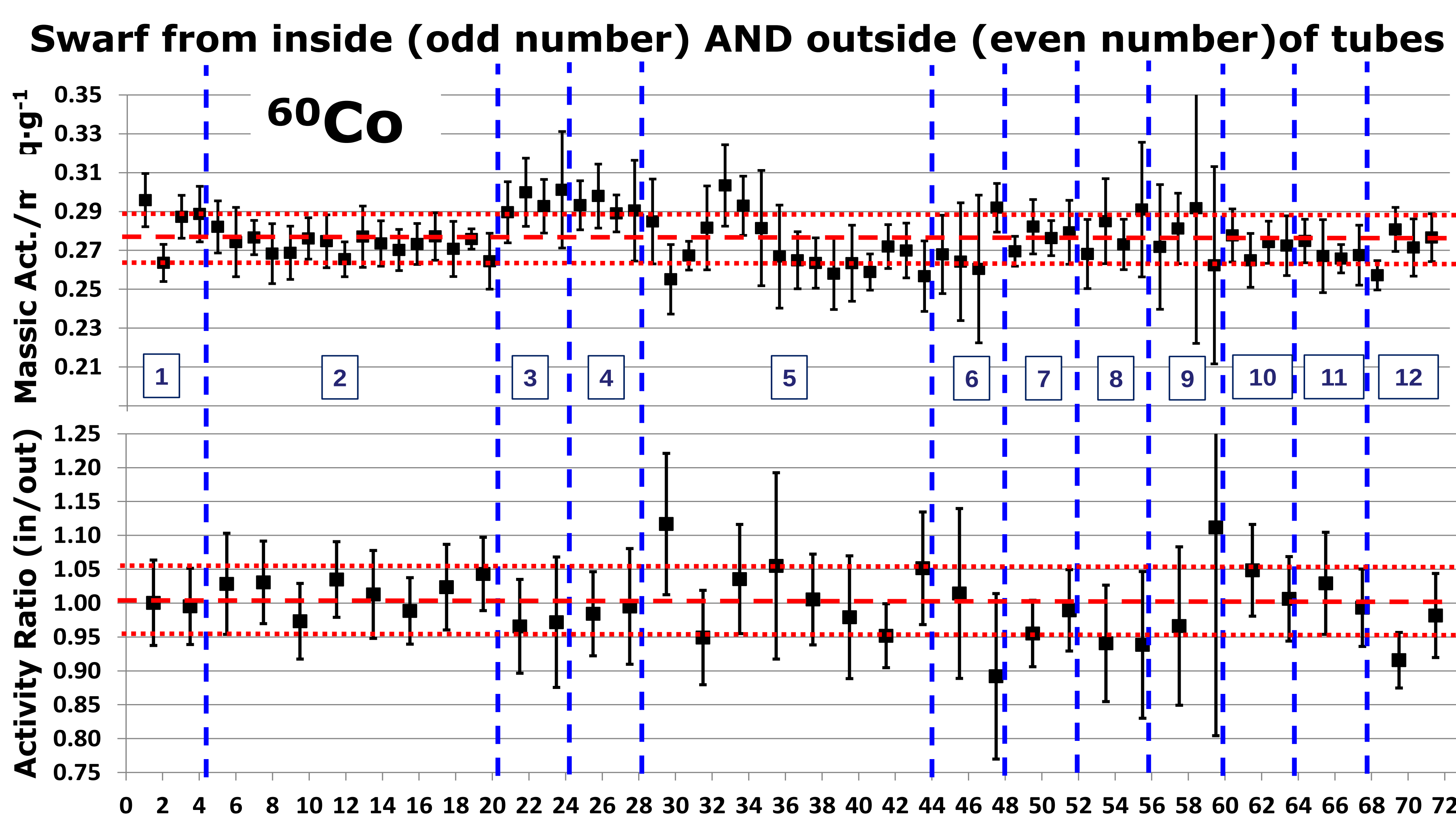
Tubes produced in 2016. Certification (partly in HADES) during 2017.

Determining the distribution of ^{60}Co and $^{110m/108m}Ag$ in cast iron tubes



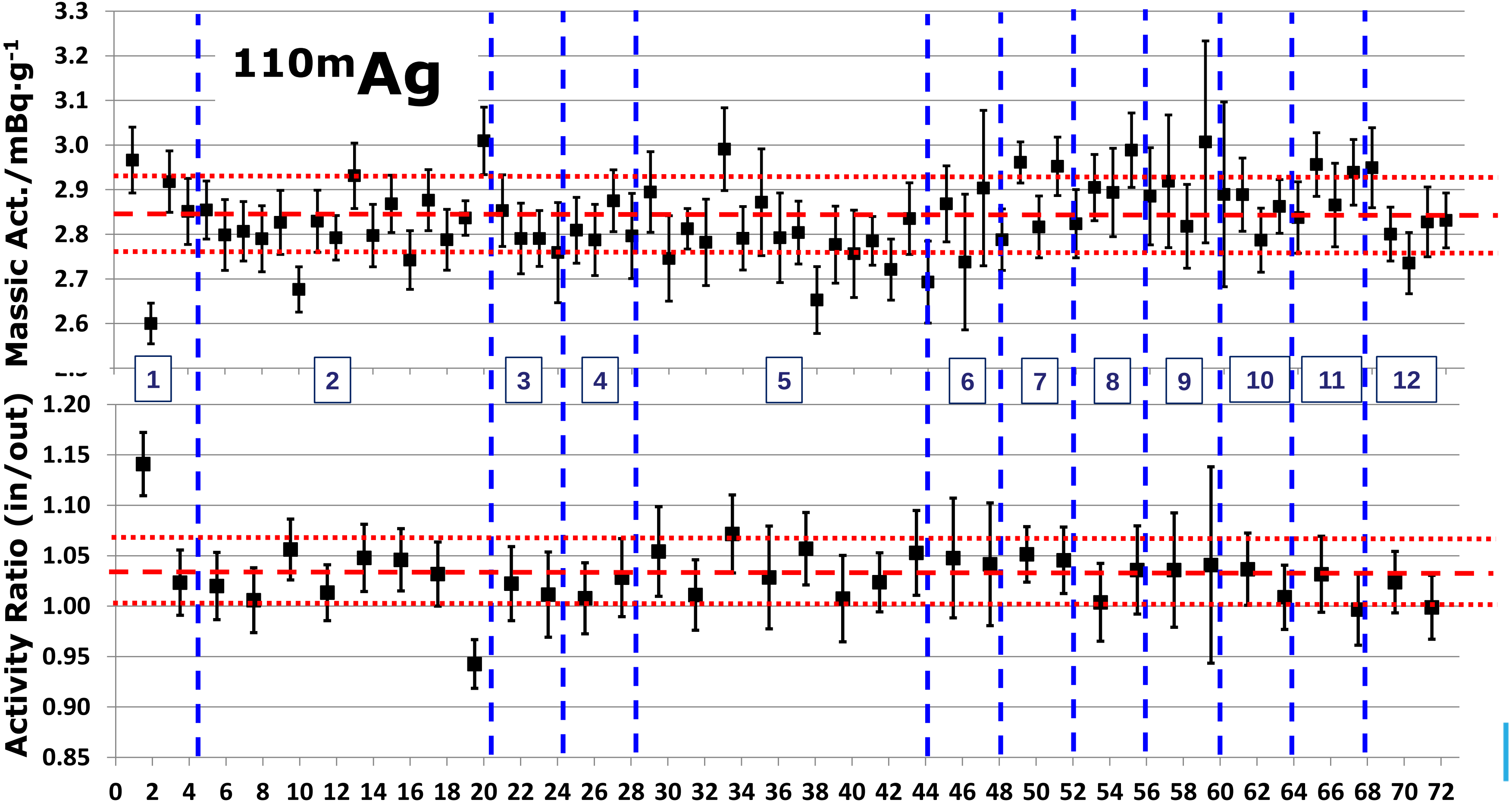
SWARF
(shavings)
~0.3 g / sample

In total 108 samples were measured in HADES



Swarf from inside (odd number) AND outside (even number)of tubes
^{60}Co
Massic Act./mq·g-1
Activity Ratio (in/out)
1
2
3
4
5
6
7
8
9
10
11
12

Swarf from inside (odd number) AND outside (even number)of tubes



Calibration standards for radioactive waste management.

Employed at Free-Release Measurement Facility in Prague.

Euratom Treaty, Chapter 3 – Health & Safety

ARTICLE 39:

The commission shall set up within the framework of the JRC…… a health & safety documentation study section….. and assisting the Commission in carrying out the tasks assigned to it in Chapter 3.

European Commission

Euratom Treaty, Chapter 3, ARTICLE 35 + 36:

Article 35

Each Member State shall ….. carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards*. The Commission shall have the right of access to such facilities; it may verify their operation and efficiency.

JRC-Geel

*see Article 31

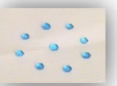
JRC-Ispra

Article 36

The appropriate authorities shall periodically communicate information …… so that the Commission is kept informed of the level of radioactivity to which the public is exposed.

Proficiency Tests in support of Article 35 (since 2003)

Year	Matrix	Radionuclide(s)
2010	Soil	^{40}K, ^{137}Cs, $^{212/214}$Bi, $^{212/214}$Pb, ^{226}Ra, $^{230/232}$Th, $^{234/235/238}$U, $^{238/239/240}$Pu, ^{90}Sr
2011	Bilberry	^{90}Sr, ^{137}Cs, ^{40}K
2012	Water	Total α / ß activity
2014	Air filter	^{137}Cs
2017	Maize	^{134}Cs, ^{137}Cs, ^{131}I
2018	Water	Radon
2019	Water	Total α / ß activity
2020	Air filter	^{134}Cs, ^{137}Cs, ^{131}I







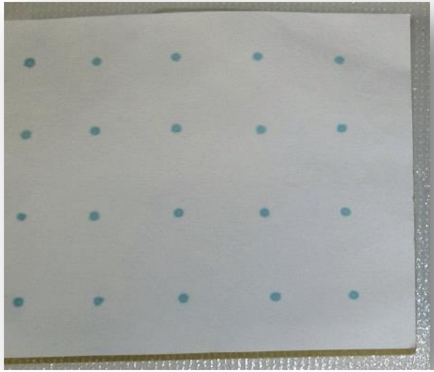
2015-2016 Air filter ^{134,137}Cs, ^{131}I (MetroERM project)

Request for: > 1 per year, >200 participants

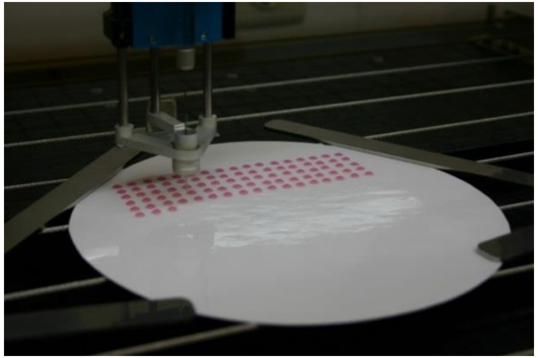
European Commission

New developments

Precision pattern **robot dispenser** developed and tested

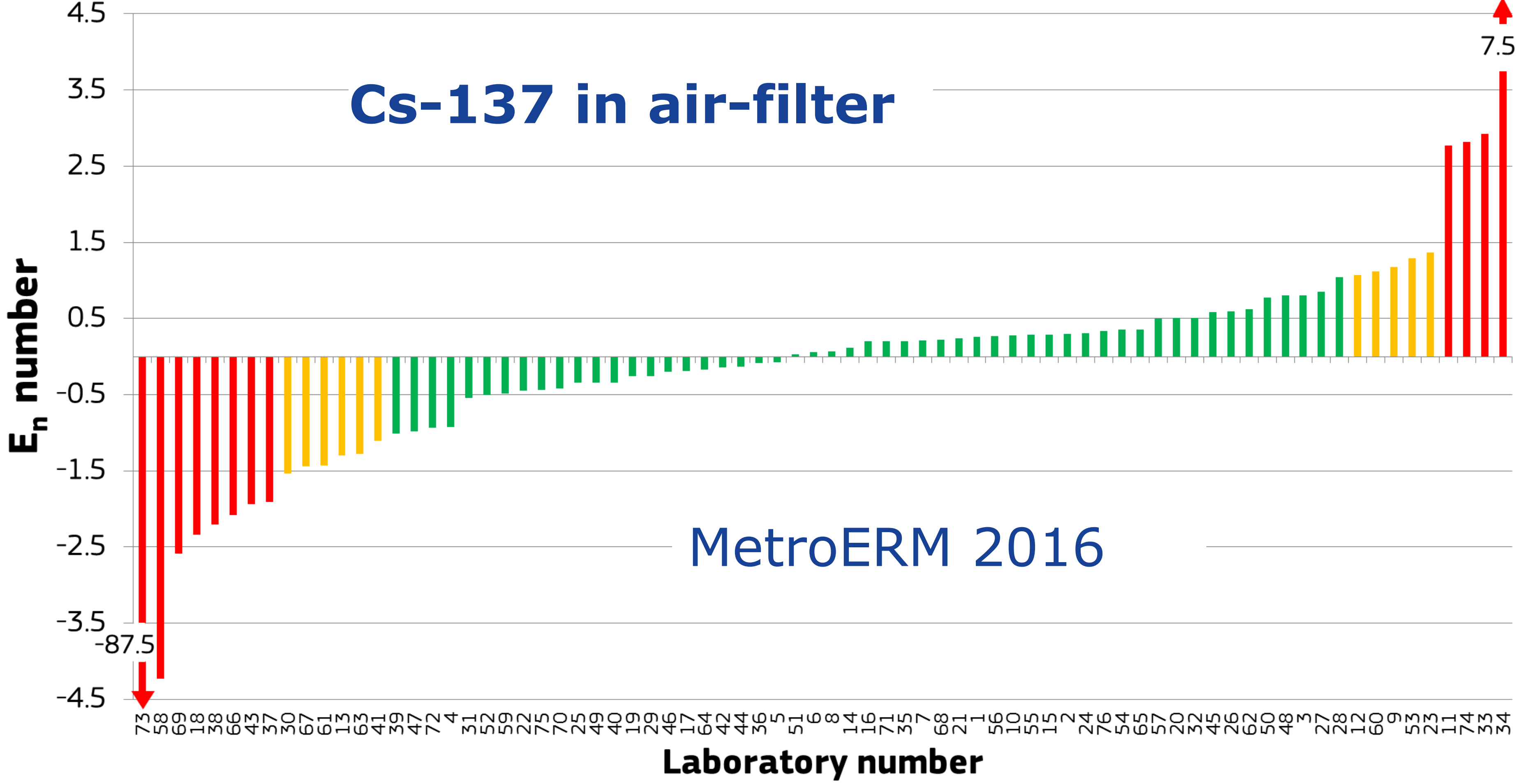


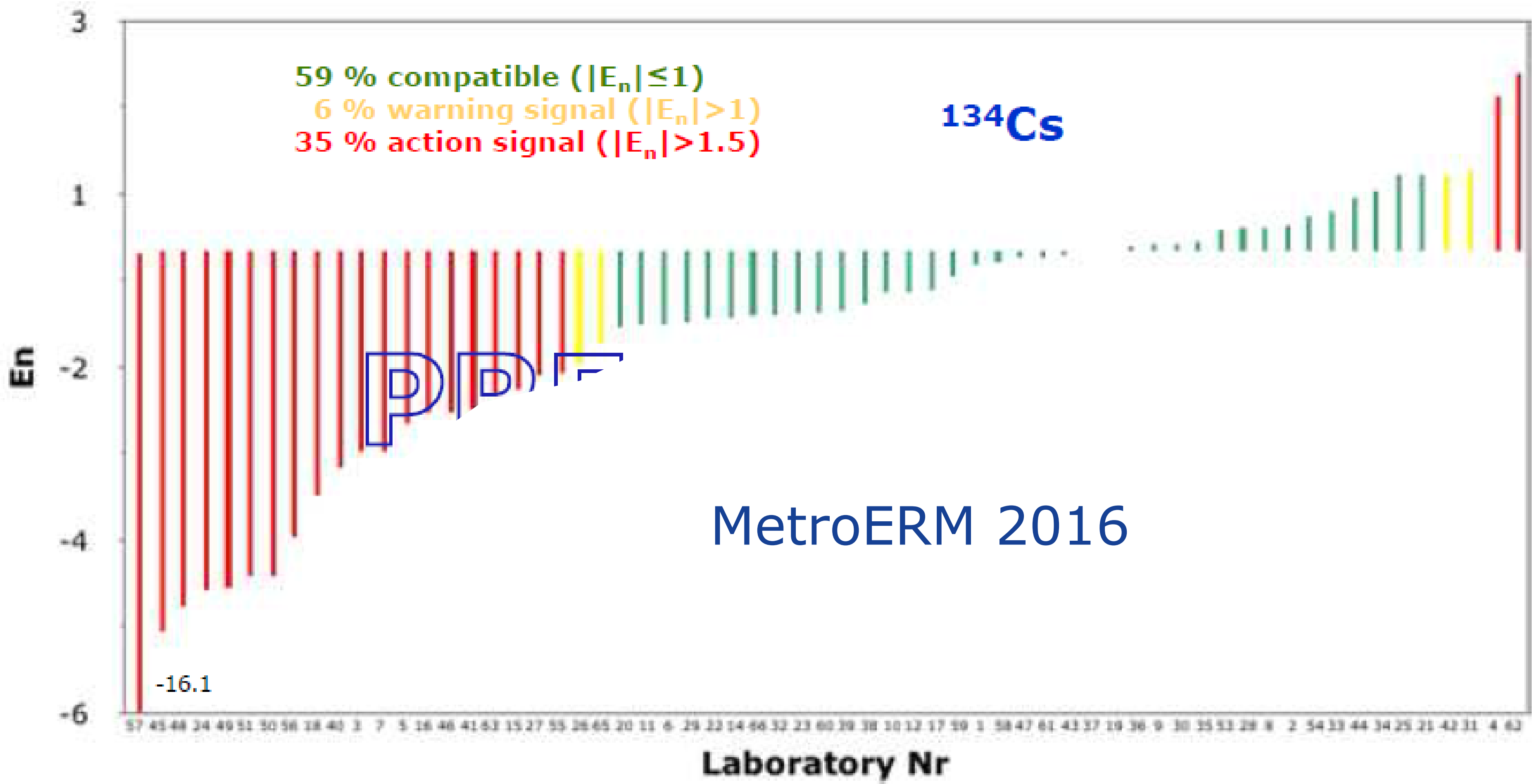
Dispenses from 20 µl to 4 ml in various patterns and geometries



Old pattern (manual)

New automated pattern


Cs-137 in air-filter
MetroERM 2016
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5
7.5
-87.5
E_n number
73 58 69 18 38 66 43 37 30 67 61 13 63 41 39 47 72 4 31 52 59 22 75 70 25 49 40 19 29 46 17 64 42 44 36 5 51 6 8 14 16 71 35 7 68 21 1 56 10 55 15 2 24 76 54 65 57 20 32 45 26 62 50 48 3 27 28 12 60 9 53 23 11 74 33 34
Laboratory number

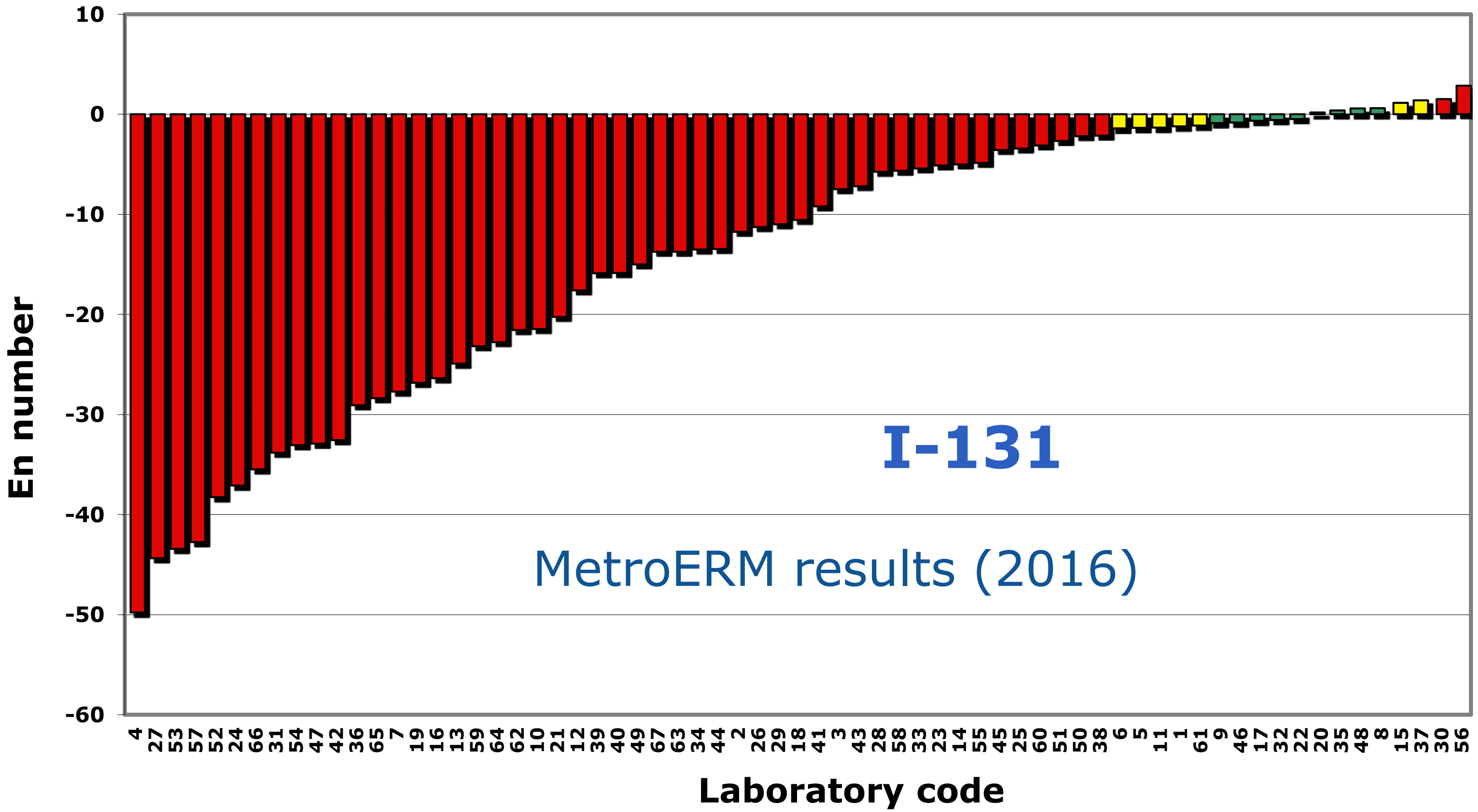


$$E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}}$$

where

x participant's result

The laboratory numbers have no correlation with the



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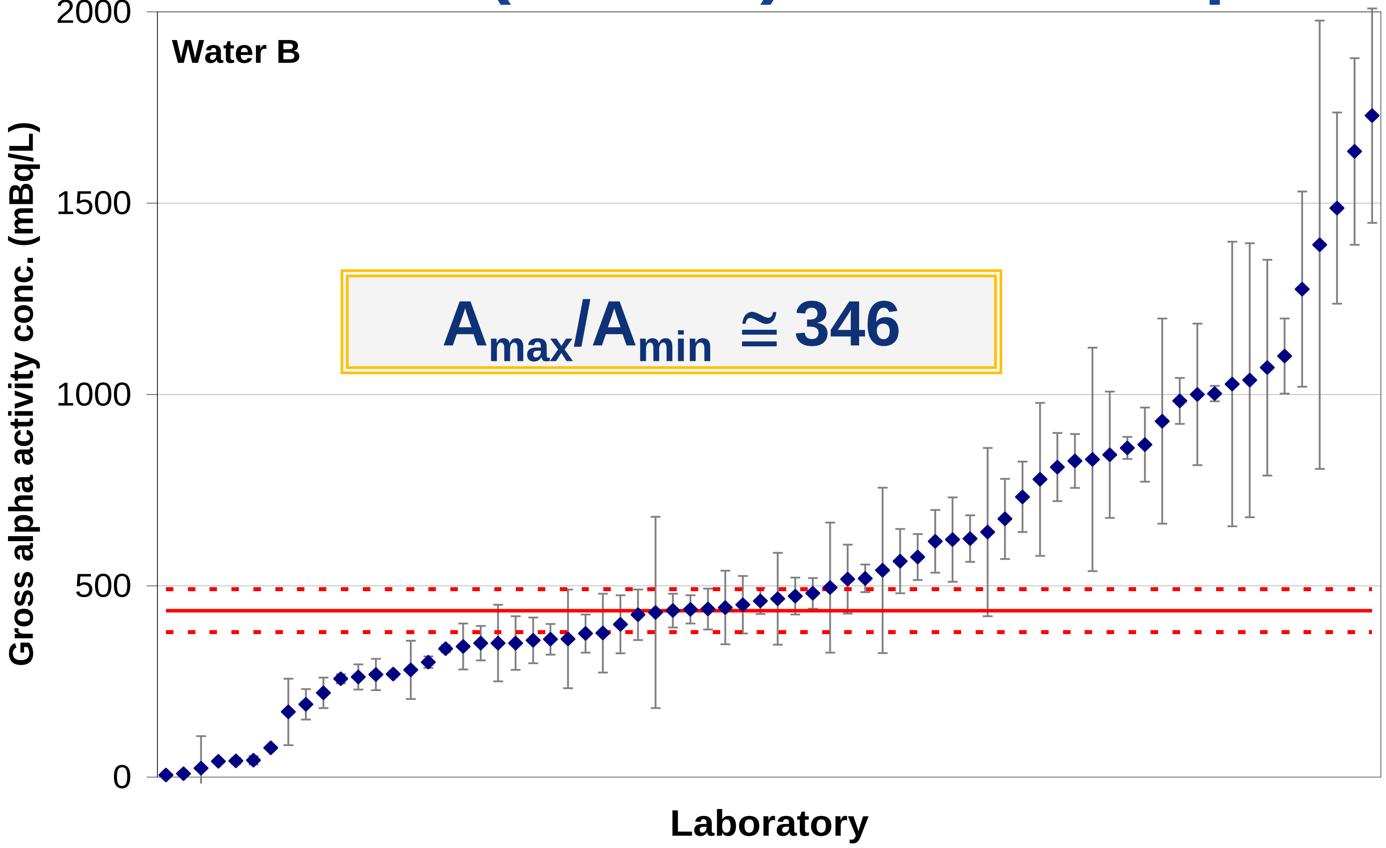
Important to identify and address "gaps"

- **Training course** & **workshop** on gamma-spec. of air-filters
- …of particular importance for **non-nuclear Member States**
- **Enables** a correct **response** to sudden discharges of radioiodine!

- Every PT is now followed by a workshop and training

Water B (natural) Gross alpha



Reference Materials for feed

Hay & maize

- PT for Article 35 finalised. Workshop January 31, 2018.

Project Leader: Kasia Sobiech-Matura

- Submitted first draft **CEN standard** on measuring ^{131}I, ^{134}Cs and ^{137}Cs in feed
- Two reference materials for **method validation**, maize and hay from Chernobyl
- **Questionnaire** to MS for food & feed measurement methods (requested by Article 35 Experts)

Upcoming meetings/conferences

- CELLAR meeting – Bucharest Nov 22-23, 2017 Romulus Margineanu romulus@ifin.nipne.ro
- Maize - Participants workshop+training Geel, 30/1-2/2, 2018 (petya.malo@ec.europa.eu)
- ICRM conference – Salamanca May/June 2019 (Begoña Quintana-Arnes)
- ICRM-Low-level Radioactivity Measurements Techniques (Sept.?) 2020, Gran Sasso, Italy (Matthias Laubenstein)
- EUFRAT Users' Meeting, 4-7 December 2017, JRC-Geel

Acknowledgement

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The HADES team at SCK•CEN (EURIDICE).

European Commission

Thanks you for your attention !

We are not the only ones digging tunnels in Mol.

Stay in touch

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LinkedIn: ***Joint Research Centre***

YouTube: ***EU Science Hub***

European Commission

Collaboration of European Low-level underground LAboRatories

CELLAR

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.**