EU-NORM2
2014
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Performances of a lightweight collimated **γ**-ray spectrometer for in-situ surveys

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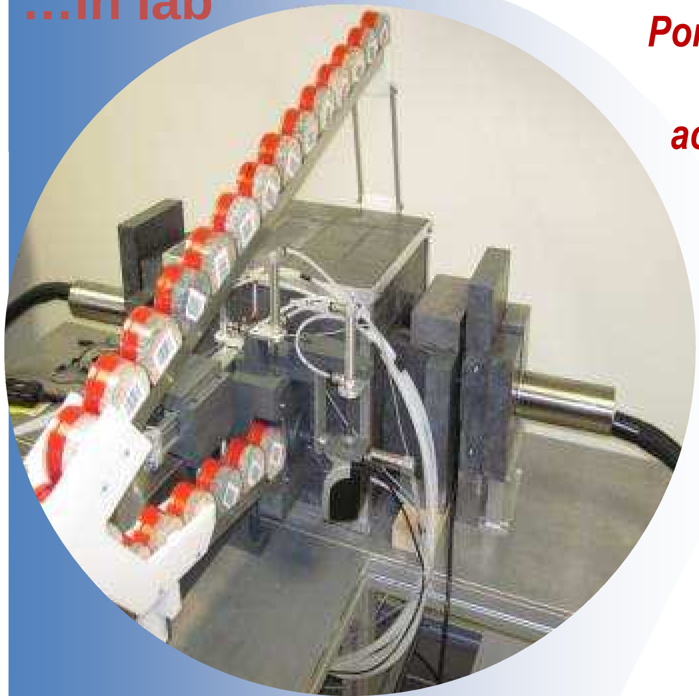
CGT Centro di GeoTecnologie

Dipartimento Scienze della natura e del territorio

R&D at our laboratories

Ad-hoc design, realization and testing of personalized instruments

…in lab



Fully-automated γ-ray spectrometer composed of two HPGe detectors, designed to measure up to 24 samples without human attendance.

- **Building material**
- **NORM residues**
- **Rock/soil baseline mapping**

Portable γ-ray spectrometer designed and realized to work in different acquisition configurations on-field.

- **Soil contamination**
- **Orphan source ID**
- **Quarry survey**

…in situ

…airborne

γ-ray
Thermal IR
NIR
VIS

Moduled airborne γ-ray spectrometer composed of four NaI(Tl) detectors, for a total volume of 16 Liters, ideal for large scale surveys

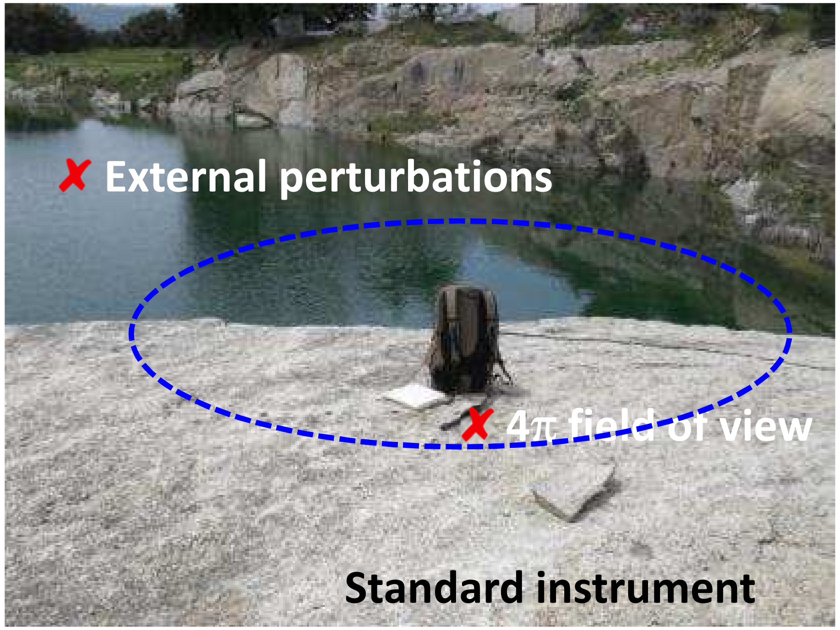
- **Mineral exploration**
- **Emergency response**
- **Precision agriculture**

http://fst.unife.it/ricerca/laboratori-1/laboratorio_radioattivita

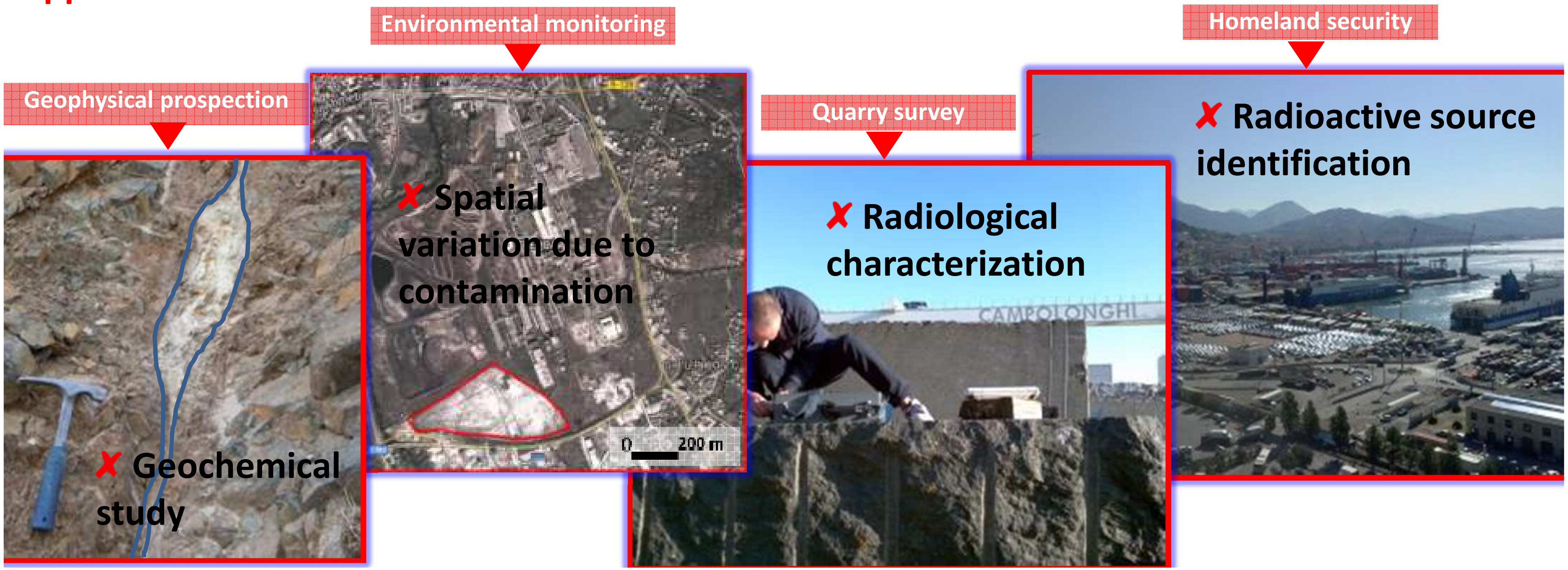
Scientific, technological & social motivations

Desired features for a customized instrument

- In-situ accurate identification and quantification of radionuclides
- Portable lightweight collimated instrument
- Quick response measurement on few cm^2 field of view

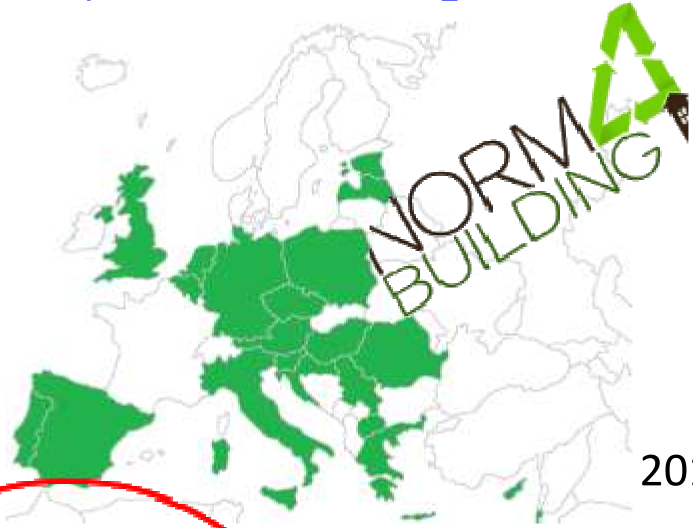


Applications:



NORM4BUILDING COST TU1301

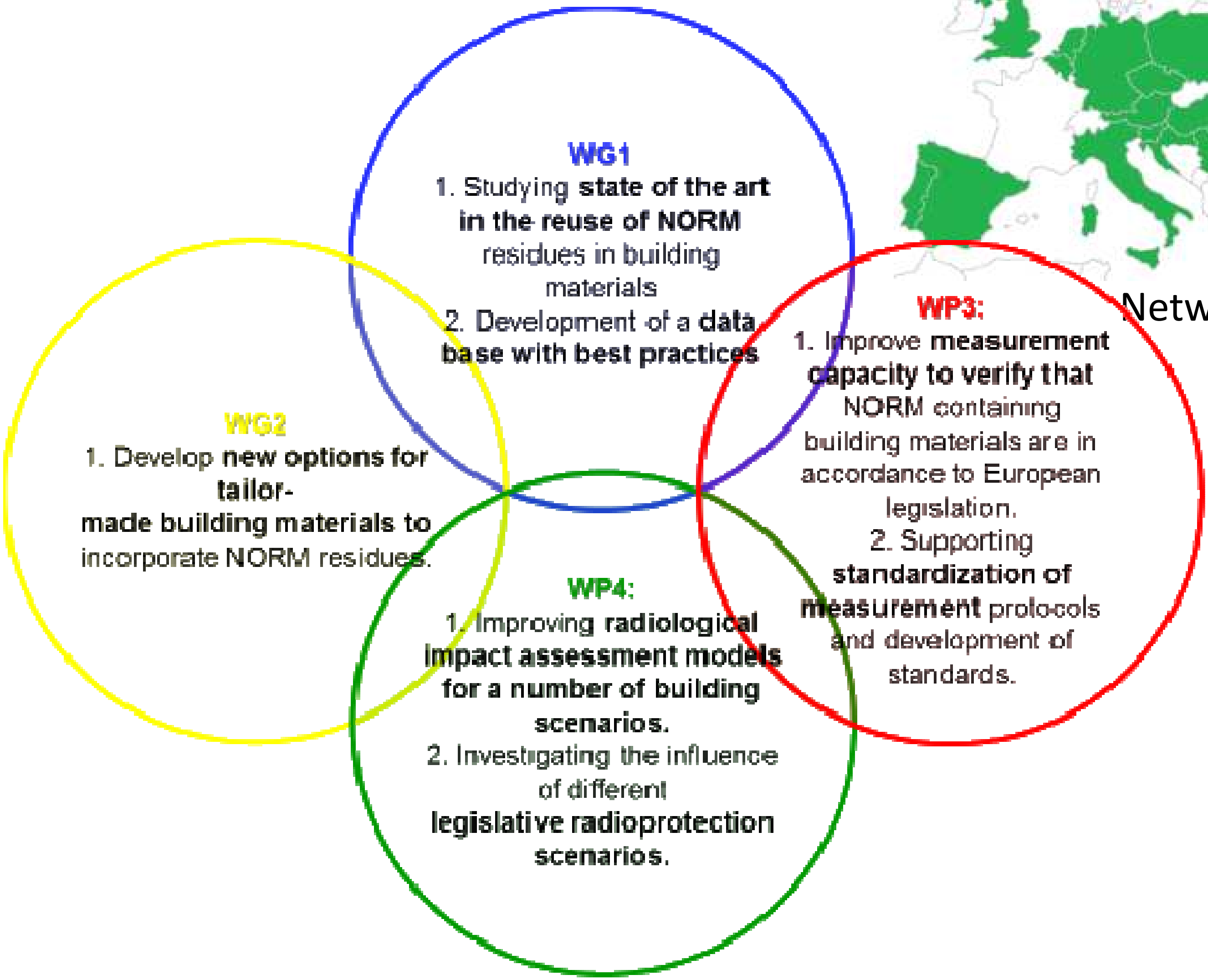
http://www.cost.eu/domains_actions/tud/Actions/TU1301



2014 - 2017

Network involving 21 countries

(Last update May 2014)

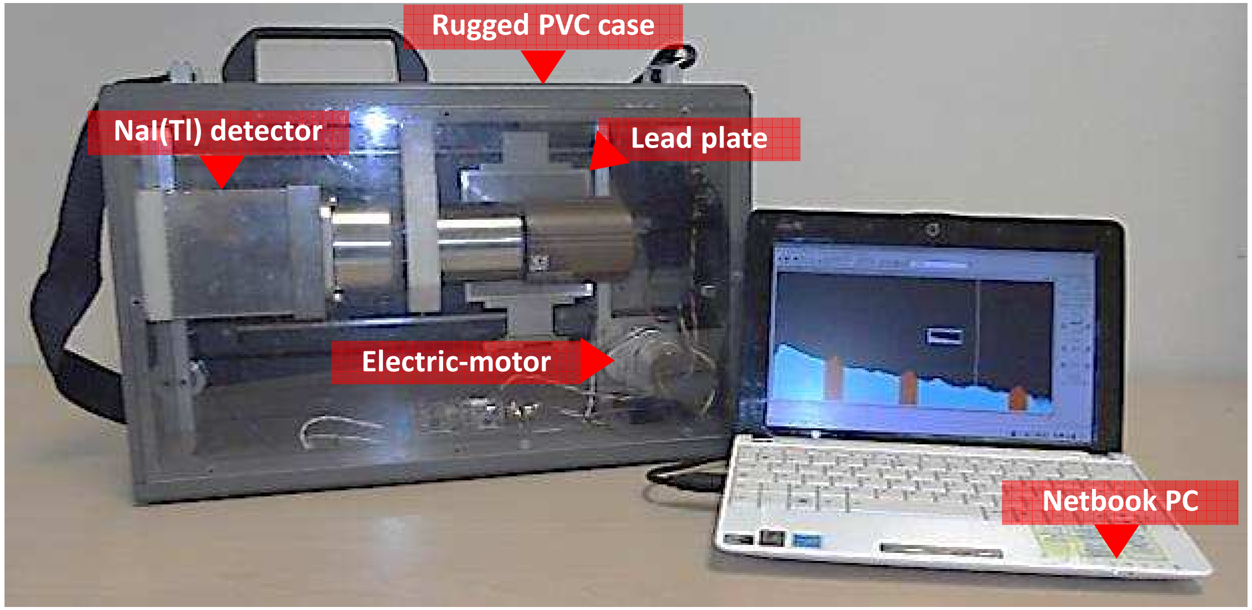


http://norm4building.org/

Cava-rad system: design

Physical parameters
- Dimensions (L 43.0 cm x H 27.0 cm x W 13.5 cm)
- Weight 8.0 kg

Environmental parameters
- Temperature -10 to +50 °C
- Humidity 85%



Detector

Gamma-ray detector
- NaI(Tl) scintillation detector of 0.3 L volume

Energy resolution
- 7.3 % at 662 keV (^{137}Cs)
- 5.2 % at 1172 and 1332 keV (^{60}Co)

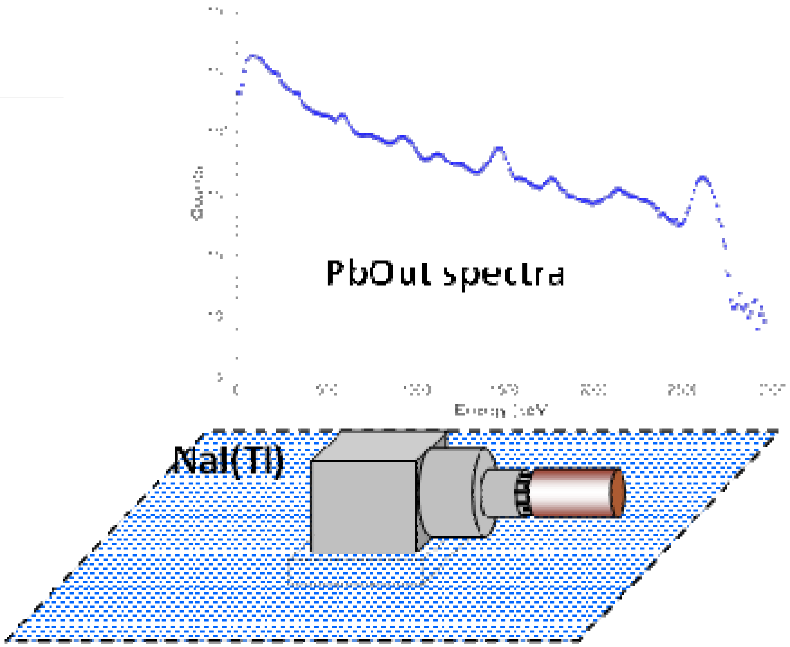
Physical parameters
- Dimensions (L 7.62 cm x H 7.62 cm x W 7.62 cm)
- Weight ~2 kg

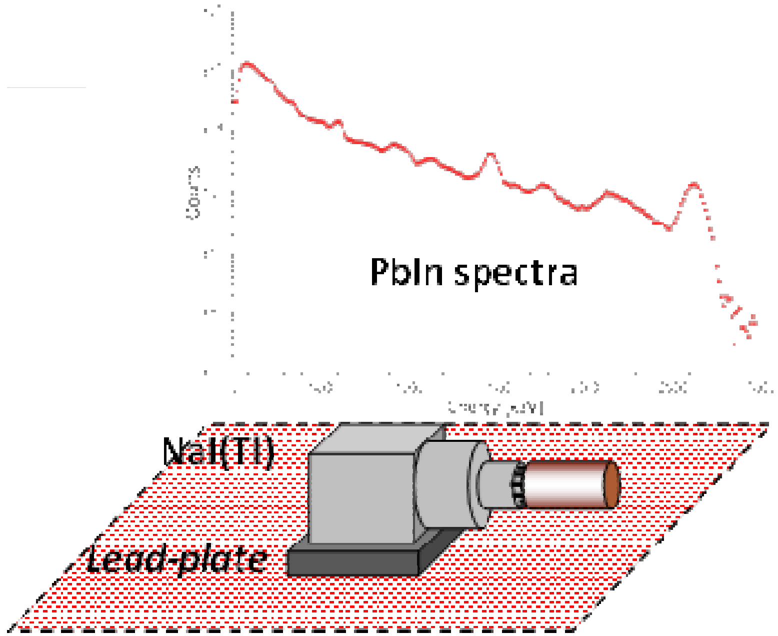
Collimator

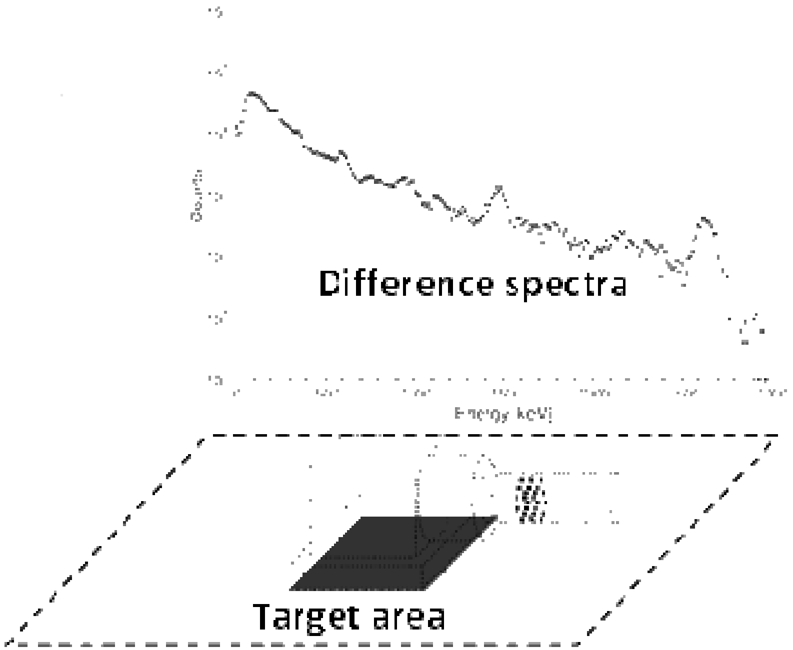
Collimation configuration
- Lead-plate method

Physical parameters
- Dimensions (L 9.0 cm x H 9.0 cm x W 3.0 cm)
- Weight ~3 kg

Cava-rad system: operation





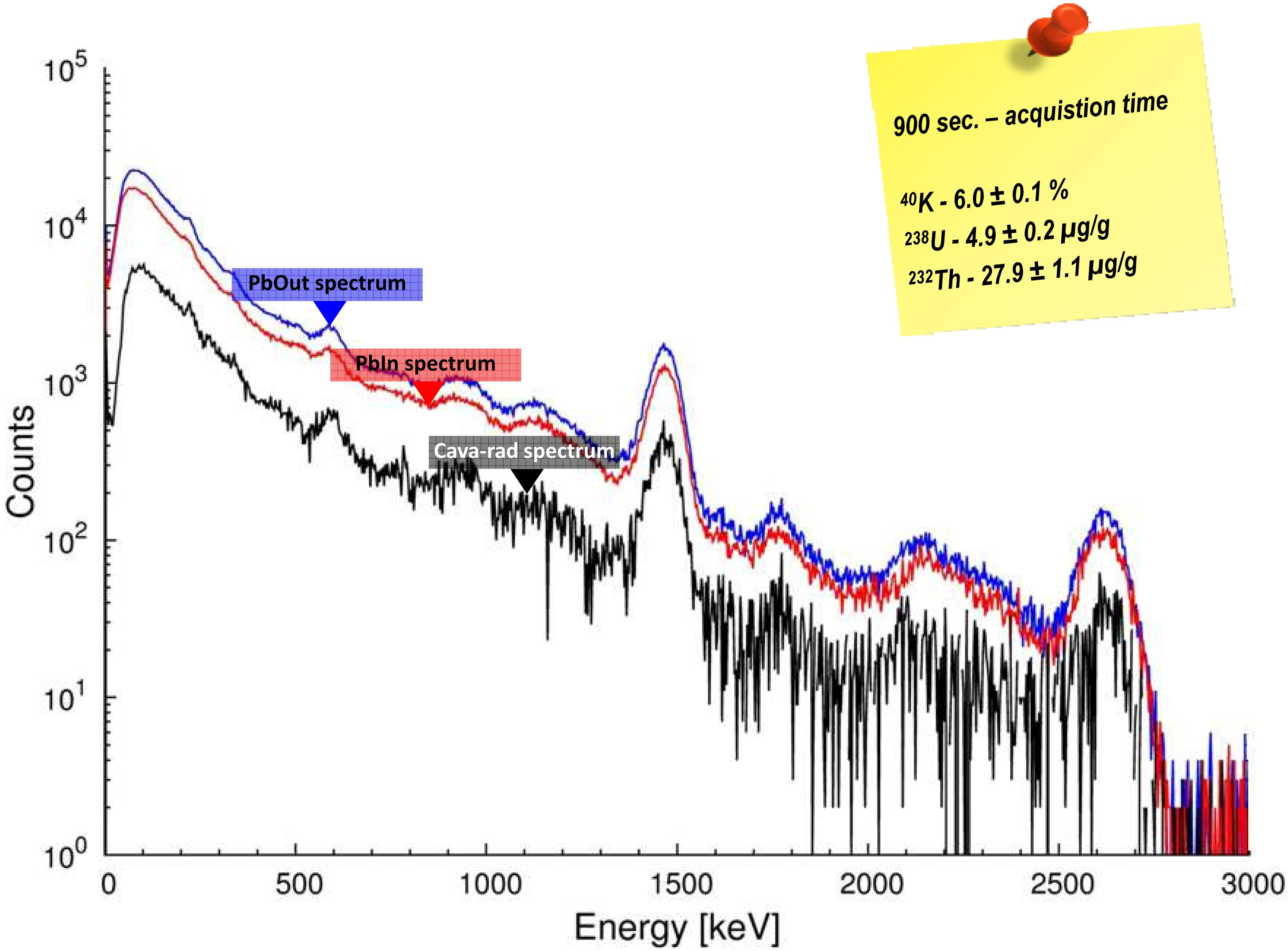


	^{40}K 1.46 MeV	^{214}Bi 1.76 MeV	^{208}Tl 2.61 MeV	Total 0.3 – 2.9 MeV
Counts	60783	9147	7082	1932745
	45484	7107	5441	1471222

$$bias_{rel.} = \frac{(Pb_{out} - Pb_{in})}{Pb_{out}} \times 100\%$$

Bias$_{rel.}$	25%	22%	23%	24%

Typical cava-rad spectra



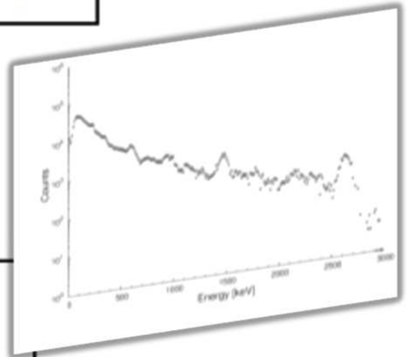
Calibration process: flowchart scheme

PbOut spectra → Manual energy calibration

PbIn spectra → Manual energy calibration

0 offset
12 keV/channel

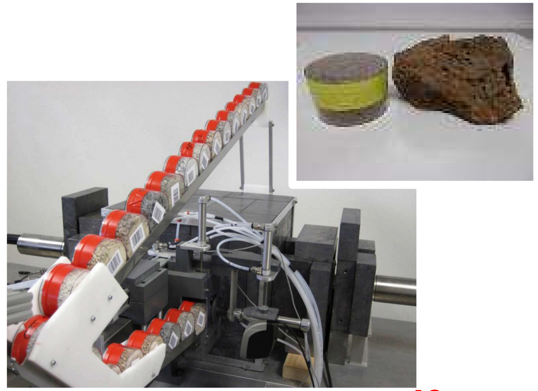
Difference spectra (DS) = PbOut spectra - PbIn spectra



Full Spectrum Analysis with
Non-negative Least Square constraints

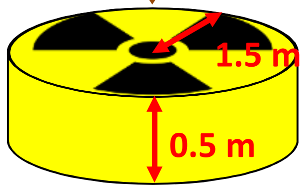
FSA-NNLS algorithm with χ2 minimization (Caciolli et al. 2012) including the input concentration measured in laboratory

Cava-rad standard spectra



^{40}K
^{238}U
^{232}Th
^{137}Cs

calibration pads



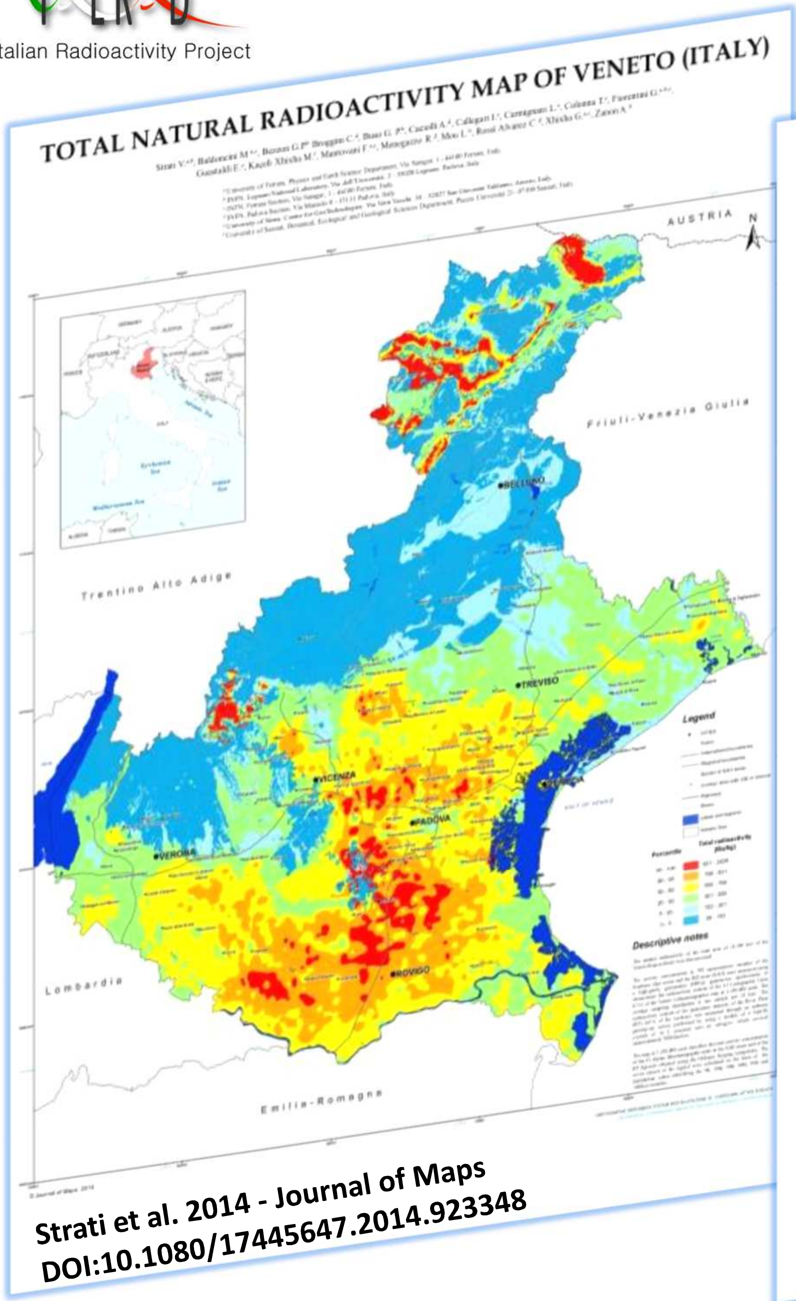
Stripping Ratios or
Windows Analysis method

Pad\Isotope	K (%)	eU (µg/g)	eTh (µg/g)
K-pad	8	0	0
U-pad	0	50	0
Th-pad	0	0	125
Blank	0	0	0

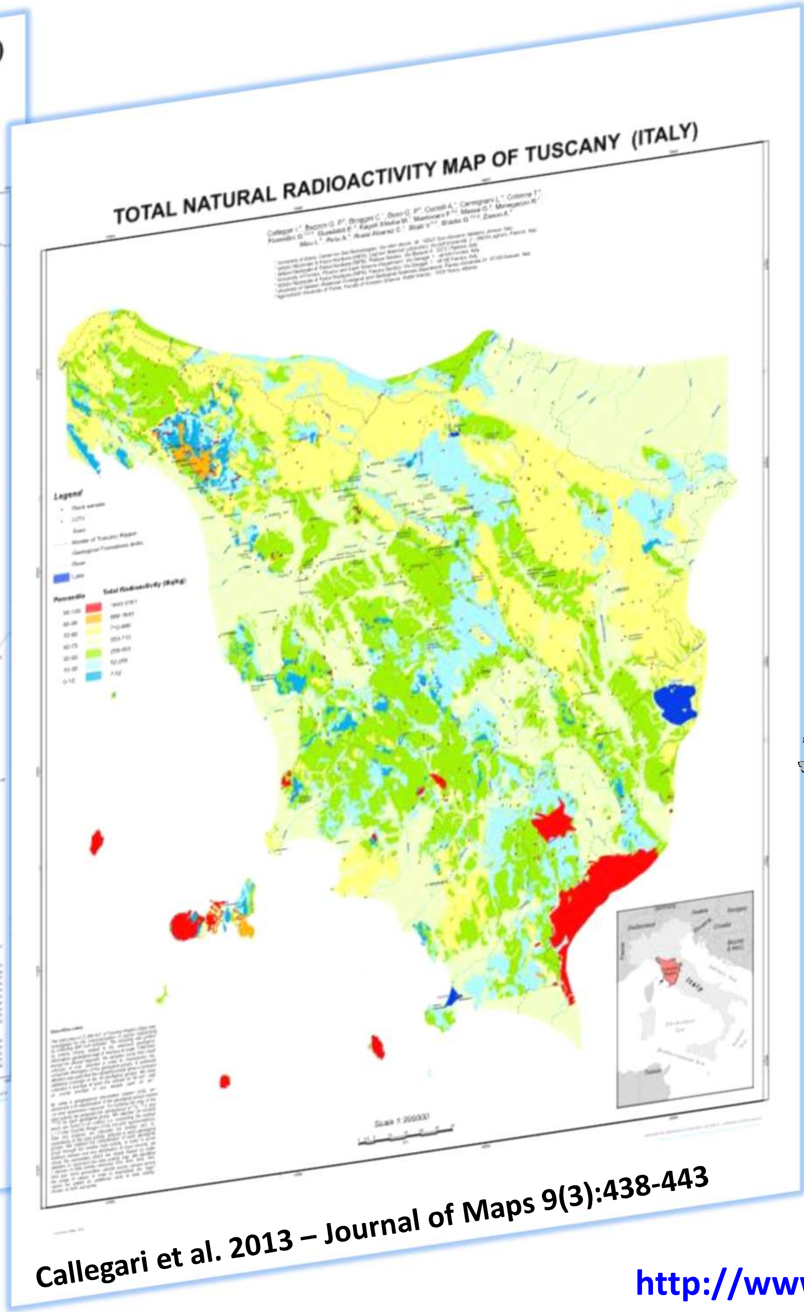
IAEA-TECDOC-1363, July 2003

Italian Radioactivity Project

ITALian RADioactivity project



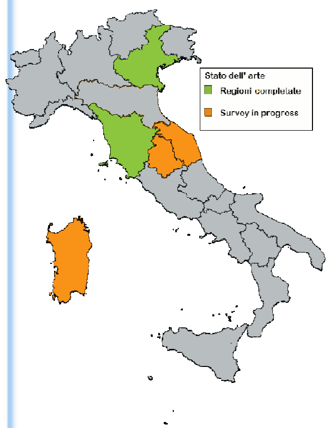
Strati et al. 2014 - Journal of Maps
DOI:10.1080/17445647.2014.923348



Callegari et al. 2013 – Journal of Maps 9(3):438-443

2000 samples measured in laboratory

200 hours of flight using AGRS

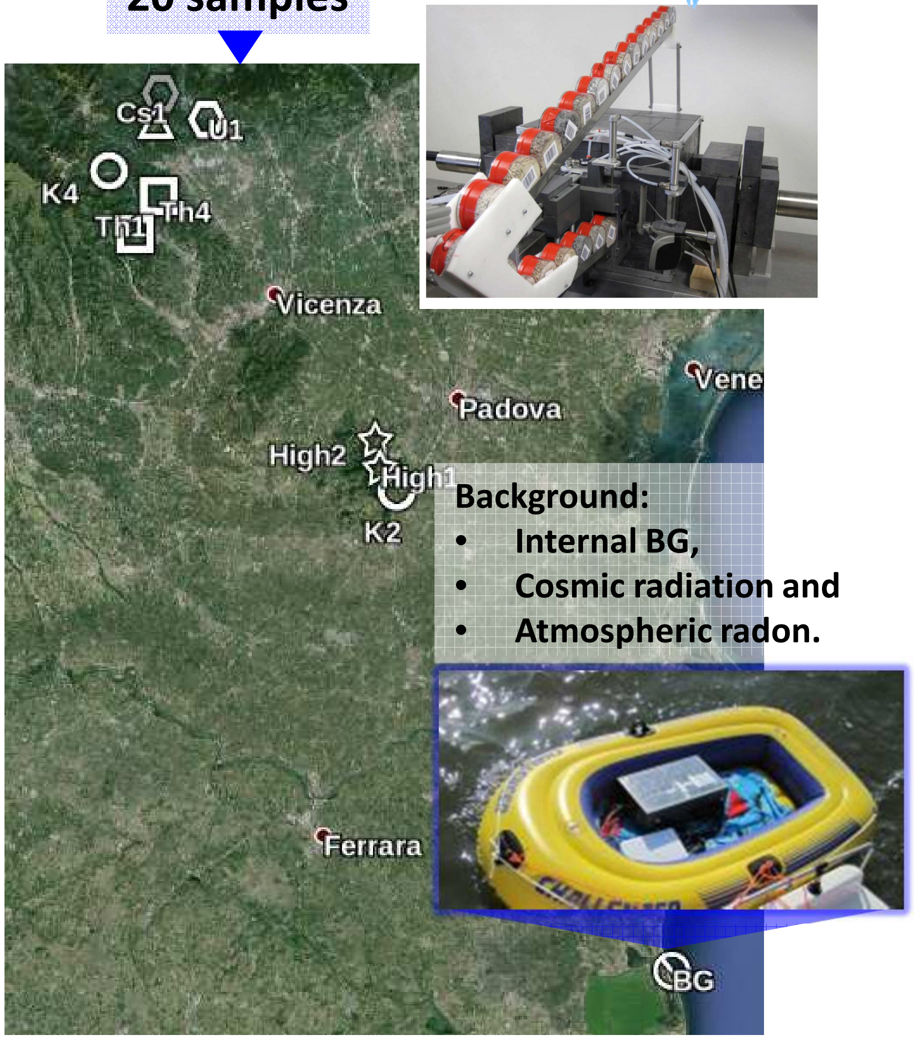


http://www.fe.infn.it/italrad/

Calibration ‘natural pads’

The radioactivity content of calibration “natural sites” used for calibration of Cava_Rad is measured in laboratory by using HPGe detectors.

20 samples

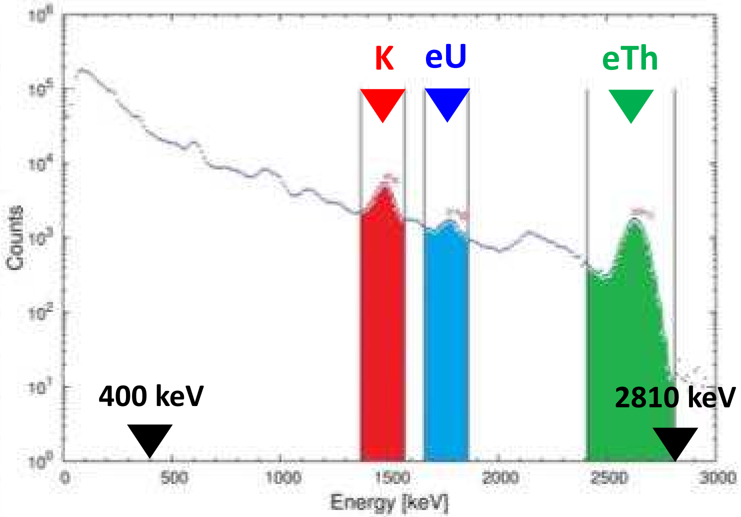


Background:

- **Internal BG,**
- **Cosmic radiation and**
- **Atmospheric radon.**

ID	^{40}K ± σ (%)	^{238}U ± σ (μg/g)	^{232}Th ± σ (μg/g)	^{137}Cs ± σ (Bq/kg)	Th/U	K/U × 10^3
K2	**6.0 ± 0.1**	4.9 ± 0.2	27.9 ± 1.1	10.2 ± 1.1	5.5	1.2
K4	**2.8 ± 0.1**	2.5 ± 0.3	13.4 ± 0.8	6.5 ± 0.8	5.4	1.1
U1	< 0.04	**7.4 ± 0.2**	<1.0	2.0 ± 0.6	-	-
U3	0.05 ± 0.01	**7.5 ± 0.2**	<1.0	< 1.4	-	0.006
Th1	2.1 ± 0.1	0.9 ± 0.1	**4.2 ± 0.6**	< 1.6	4.7	2.3
Th	2.3 ± 0.1	25.6 ± 0.5	**360.7 ± 3.3**	< 3.2	14.1	0.08
Cs1	0.5 ± 0.1	1.2 ± 0.2	< 3.9	**1496 ± 13**	-	0.4
H1	4.2 ± 0.1	12.3 ± 0.3	55.9 ± 1.5	< 2.8	4.6	0.3
H2	4.1 ± 0.1	8.0 ± 0.2	36.8 ± 1.3	< 2.6	4.6	0.5
Bckg1	n/a	n/a	n/a	n/a	-	-

Windows Analysis vs. Full Spectrum Analysis



The count rates registered in the K, eU and eTh energetic windows are linearly related to the corresponding concentration in the pad.

$$\mathbf{N} = \mathbf{S} \cdot \mathbf{C}$$

N – column vector of background corrected count rates;
S – 3 x 3 matrix of sensitivities;
C – column vector of concentrations.

This method includes the estimation of:

Background radiation,
Stripping ratios, and
Sensitivity constants

$$S_{IAEA}^{\ 1} = \begin{pmatrix} 3.360 & 0.250 & 0.062 \\ 0.000 & 0.325 & 0.075 \\ 0.000 & 0.011 & 0.128 \end{pmatrix} \quad \Rightarrow \quad \mathbf{C} = \mathbf{S}^{-1} \cdot \mathbf{N}$$

IAEA-TECDOC-1363, July 2003

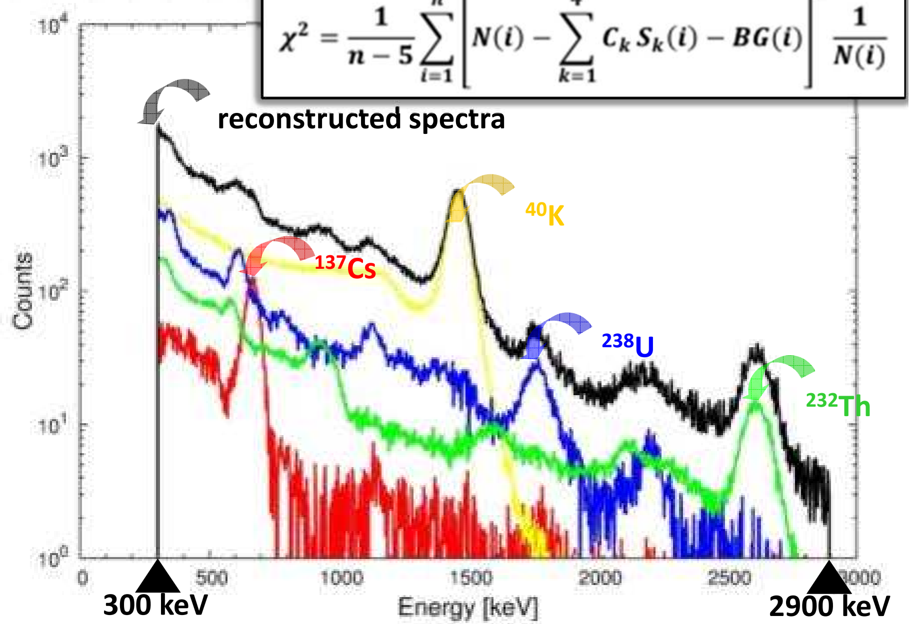
The FSA reconstructs the total spectrum as a linear combination of standard spectra (K, eU, eTh, Cs) with weights equal to the corresponding isotope concentration, plus a background spectrum

$$N(i) = S_K(i)C_K + S_U(i)C_U + S_{Th}(i)C_{Th} + S_{Cs}(i)C_{Cs} + BG(i)$$

N(i) – measured spectra,
S_j – standard spectra,
C_j – activity concentrations, and
BG – background spectra

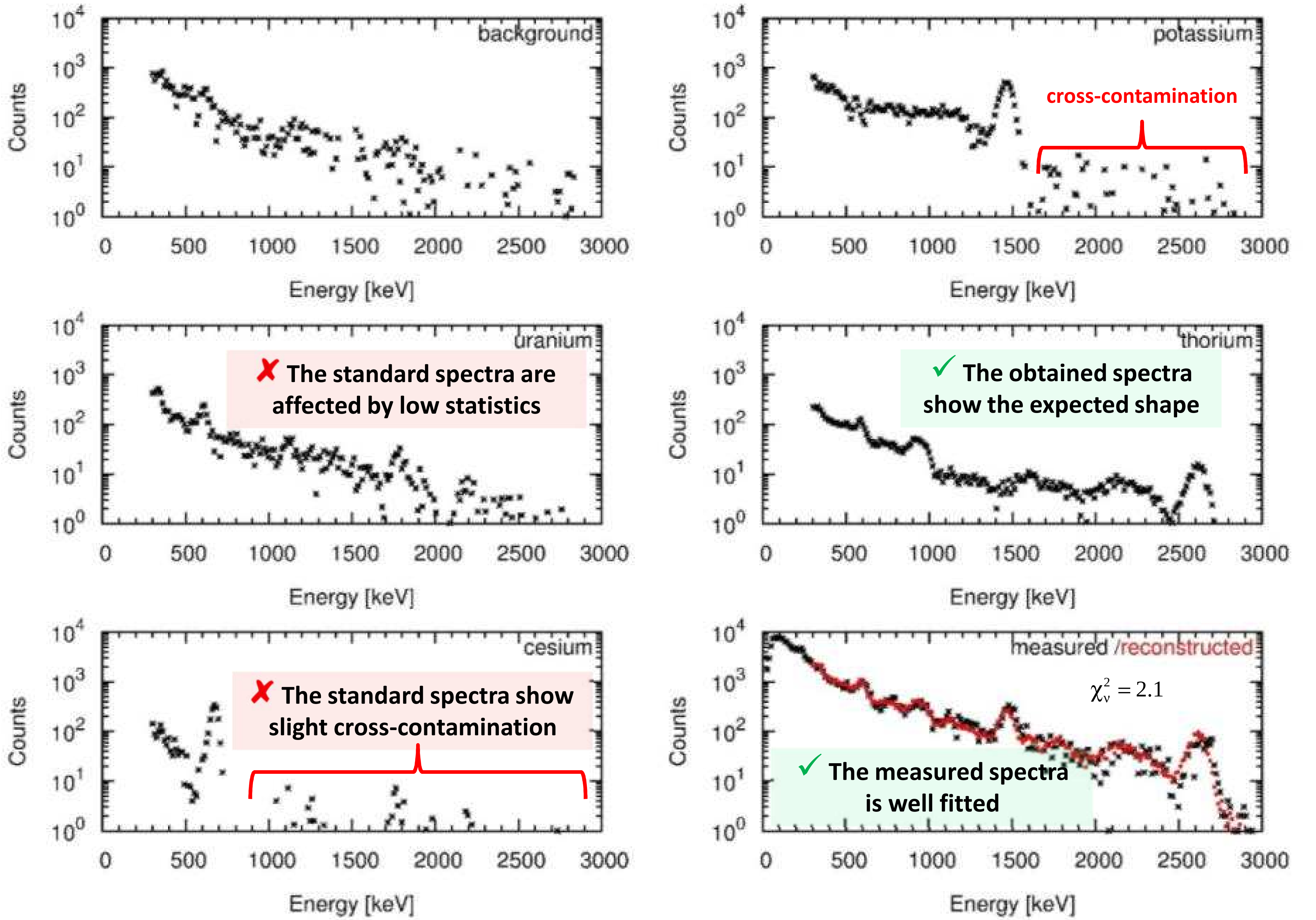
$$N(i) = \sum_{j=1}^{M} C_j S_j(i) - BG(i)$$

$$\chi^2 = \frac{1}{n-5} \sum_{i=1}^{n} \left[N(i) - \sum_{k=1}^{4} C_k S_k(i) - BG(i) \right]^2 \frac{1}{N(i)}$$



A. Caciolli et al. 2012. Science of the Total Environment 414:639–645

Fundamendal spectra



Validation of the results: sites description

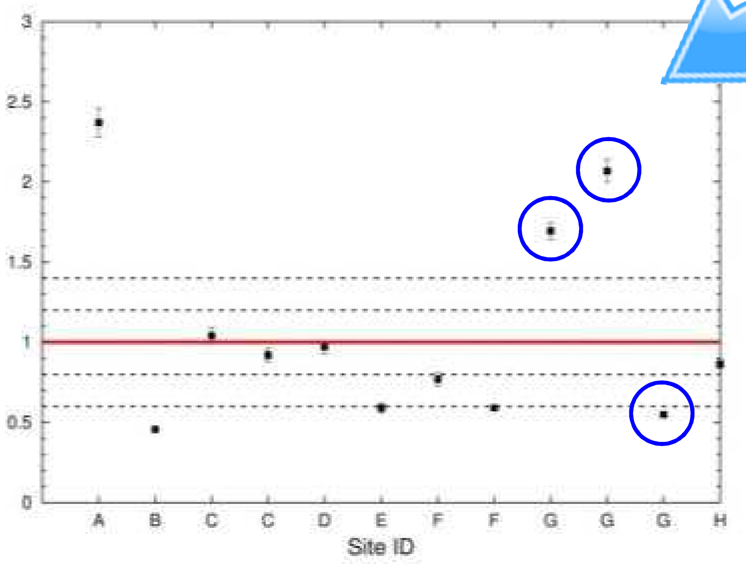
Monti Vulsini (south Tuscany)
Deposits of different pyroclastic rocks due to volcanic activity (~300.000 years ago).

Euganean Hills (Veneto)
Homogeneous outcrops of acid effusive rocks.

In-situ:
- PbOut and PbIn measurements
- Acquisition time: 5 or 10 minutes

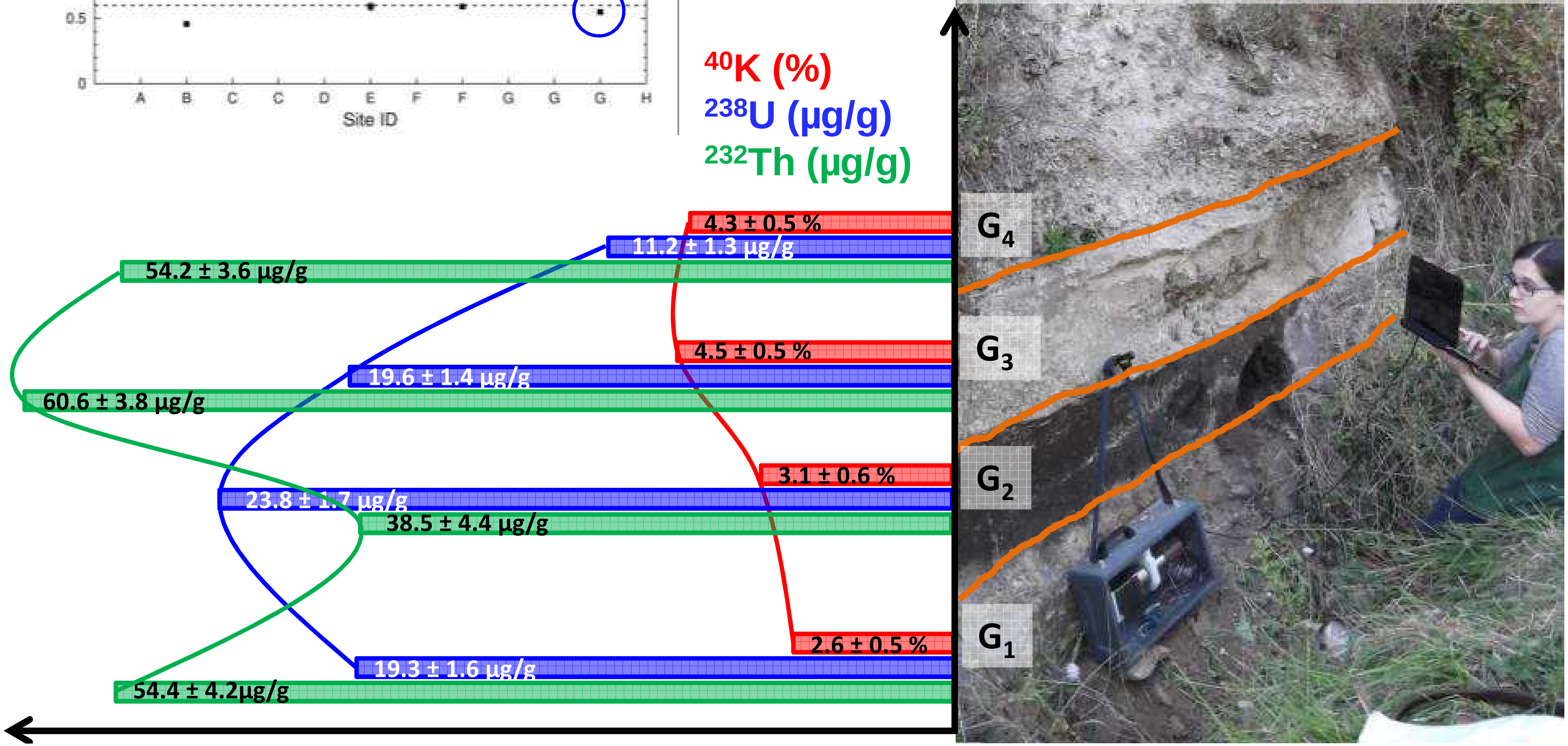
In-laboratory:
- Sample collection, under the detector
- Analysis in laboratory (MCA_Rad)

Validation of the results: cava-rad results

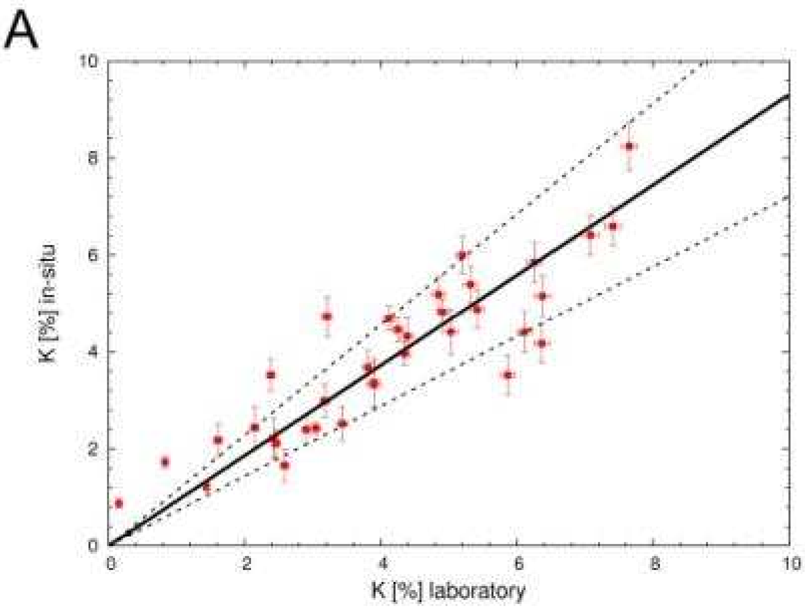


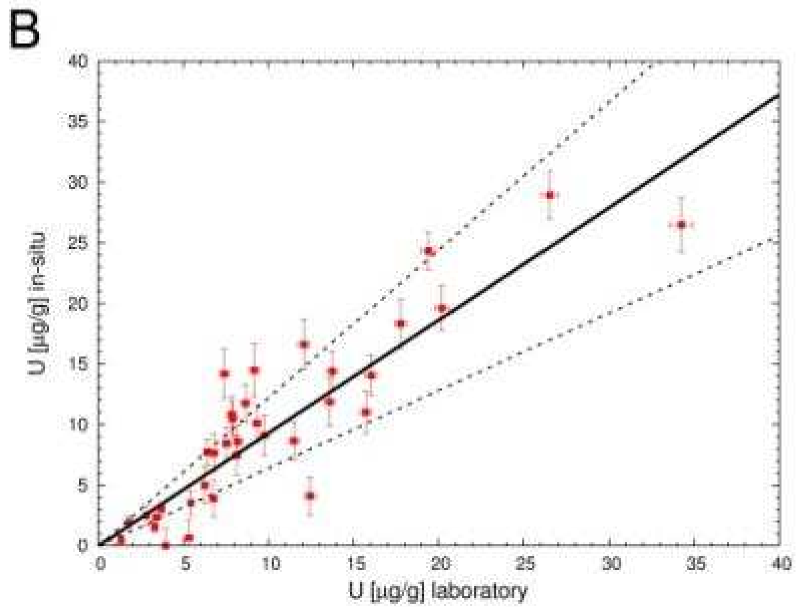
The variability (relative bias) of U abundance measured by HPGe detectors.

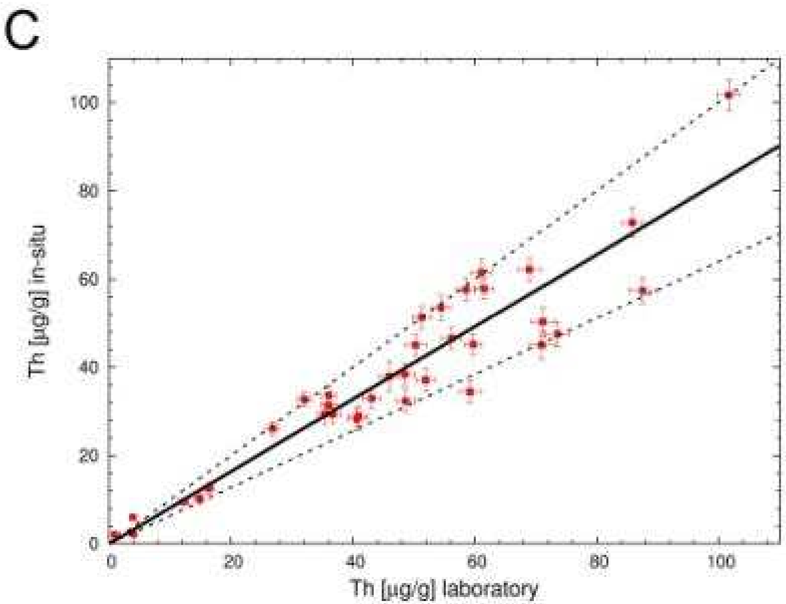
Two consecutive layers (e.g. G_1 and G_2) correspond to different eruptions.



Correlation between laboratory and in situ results







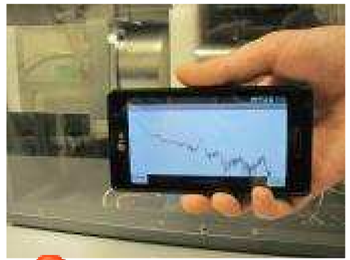
Comparison in-situ vs. laboratory measurements	
^{40}K [%]	$K_{in\text{-}situ} = (0.93 \pm 0.21)\ K_{lab}$
eU [µg/g]	$eU_{in\text{-}situ} = (0.93 \pm 0.29)\ eU_{lab}$
eTh [µg/g]	$eTh_{in\text{-}situ} = (0.84 \pm 0.18)\ eTh_{lab}$

Conclusions & Perspectives

- The Cava-rad sytem was **designed and realized** aiming at optimizing weights, acquisition time and counting statistics;
    - Technological improvements are foreseen:

      - *GammaSTREAM* – All-in-one digital MCA tube base for gamma spectrometry.

      - ***Wireless connection*** to Tablet & Smartphone for spectrum analysis.

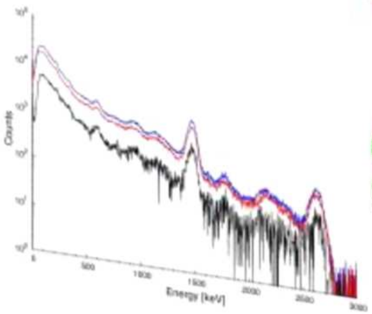


- The ***calibration*** was performed based on FSA-NNLS method and standard spectra of K, U, Th, Cs and Bckg were obtained.
    - Improvements are expected by:

      - Increasing ***counting statistics*** and

      - Construction of ***calibration pads*** facility.

- In-situ and laboratory measurements are ***compatible at 1σ level*** (counting uncertainty of ~20%) and the instrument is ***sensitive to the spatial variability*** of radioactivity content.



Thank you

for your attention…