

Caratterizzazione della radioattività ambientale attraverso spettroscopia gamma

CGT
Centro di GeoTecnologie

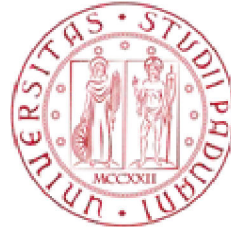
INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Legnaro



UNIVERSITÀ DI PISA



MATRAIA



**Fondazione**
Cassa di Risparmio di Padova e Rovigo

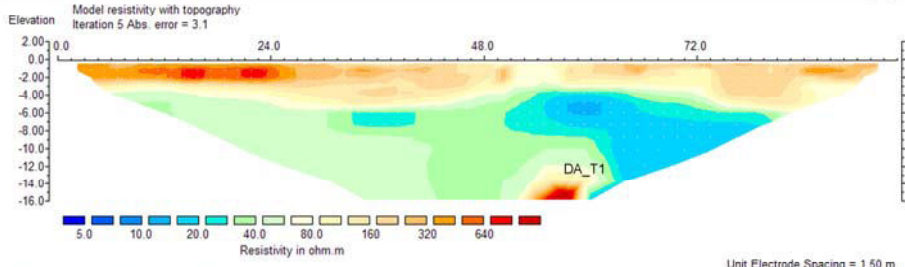
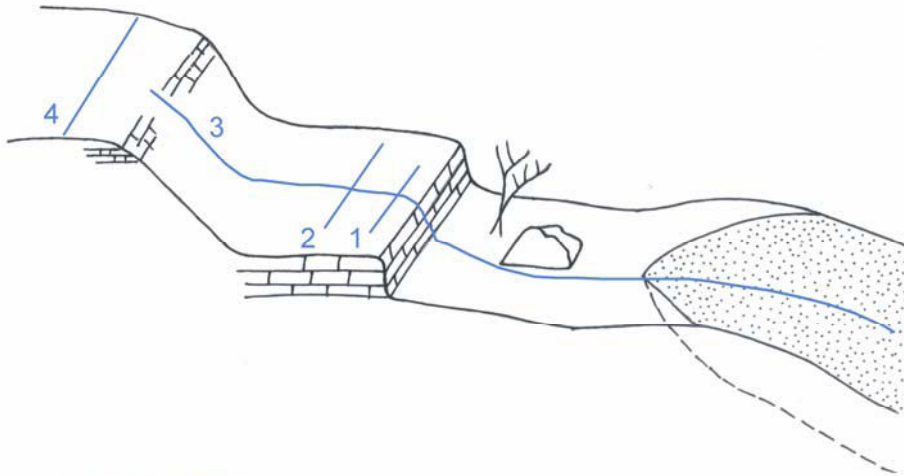
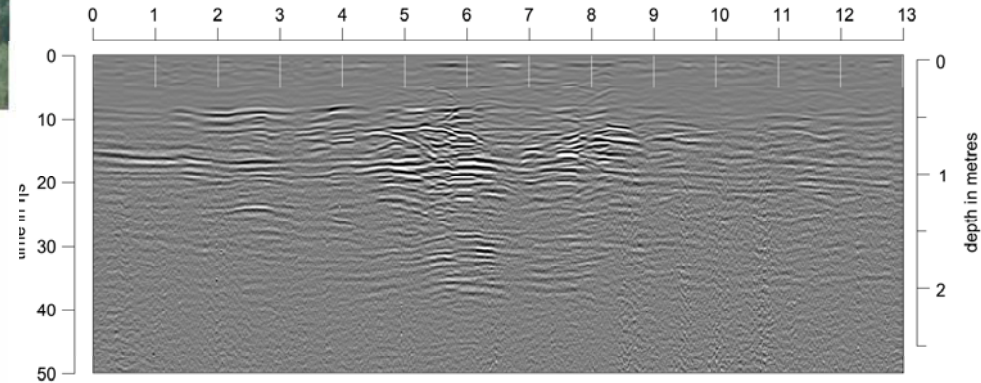
REGIONE
TOSCANA



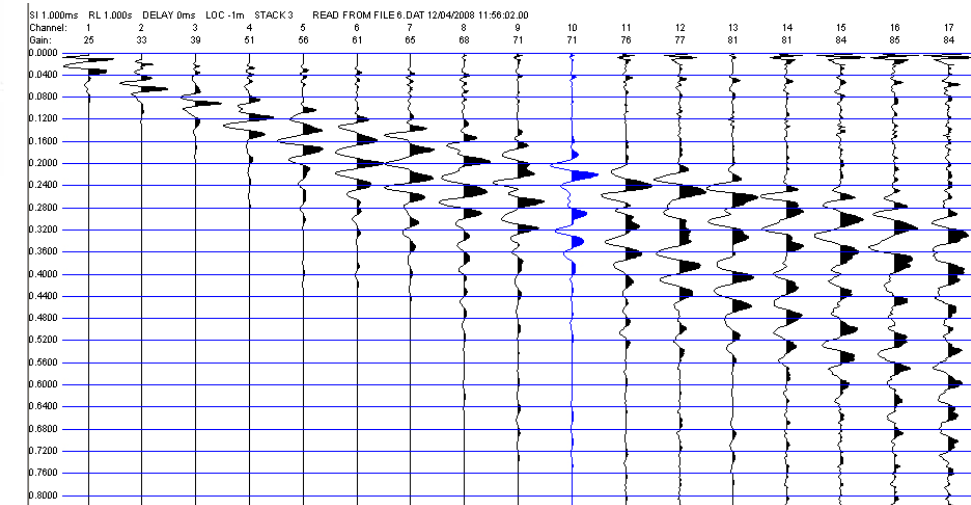
 università di ferrara

 **GLOBALMAP** by LITOGRAFIA *artistica* CARTOGRAFICA
geographical design solutions

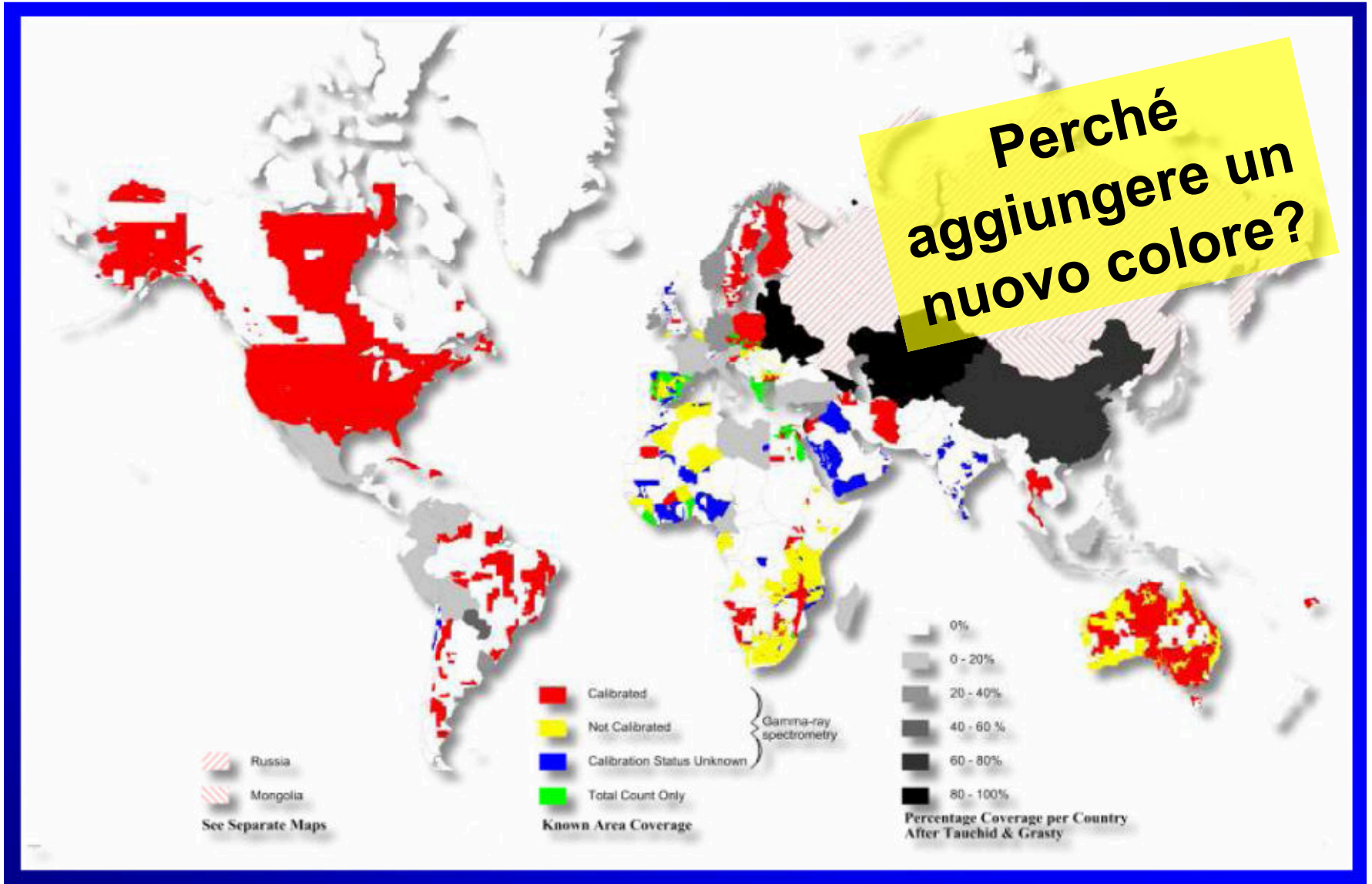
Il territorio visto con il “caleidoscopio” della geofisica...



Horizontal scale is 14.97 pixels per unit spacing
 Vertical exaggeration in model section display = 1.00
 First electrode is located at 0.0 m.
 Last electrode is located at 94.5 m.

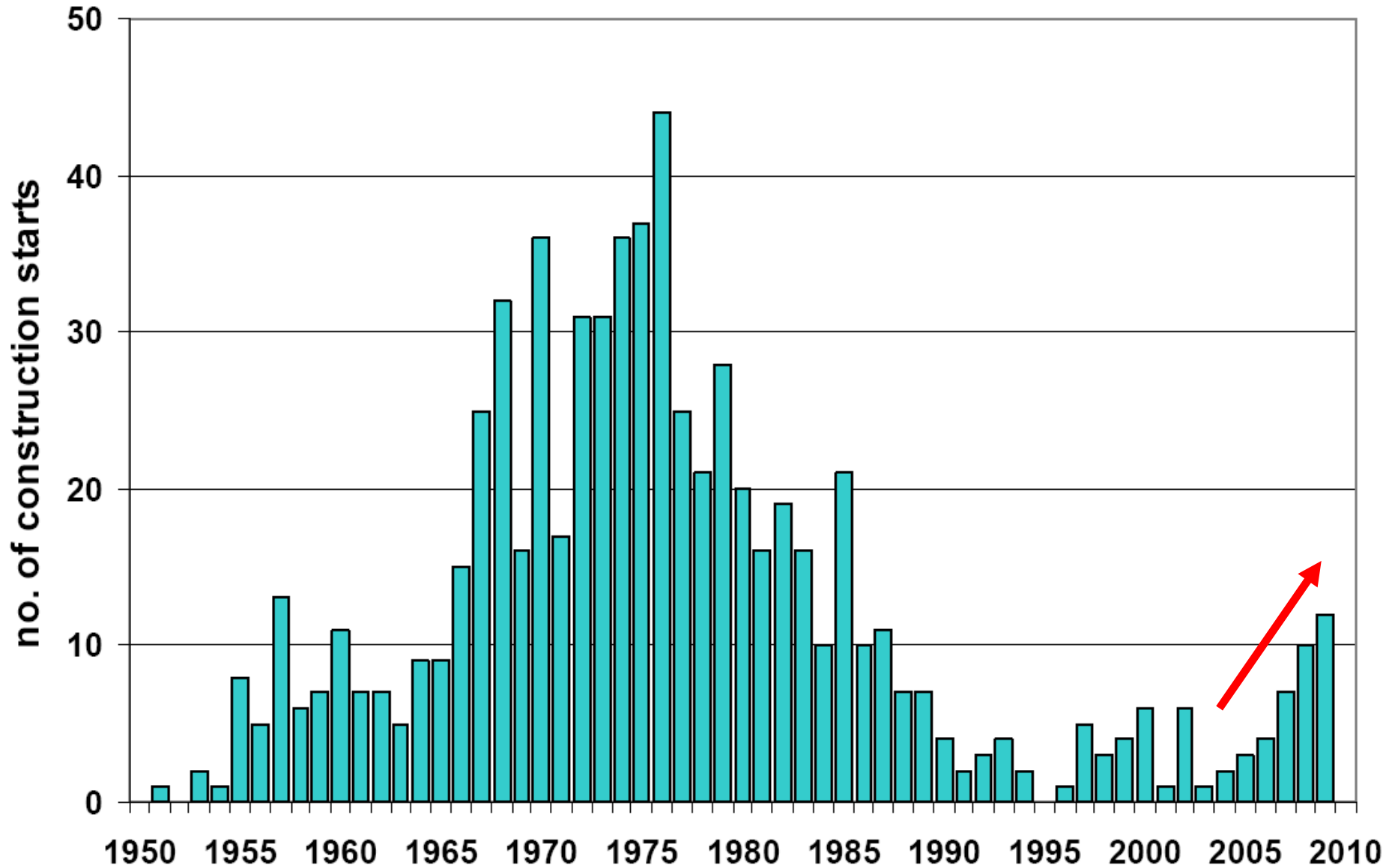


Mappatura della radioattività nel mondo



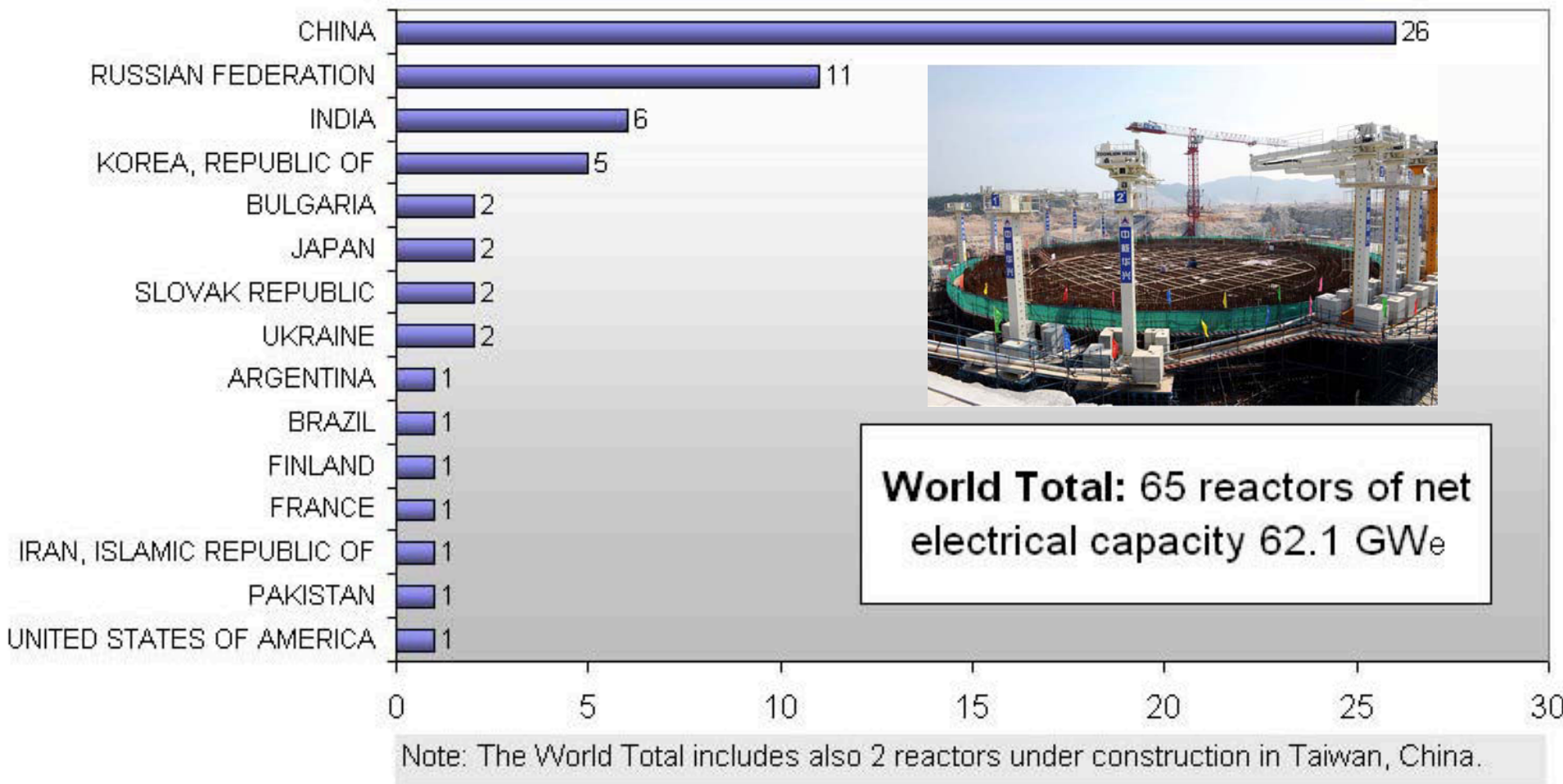
* Compiled by Sally Barritt, 2005 - Radioelement Mapping, IAEA.

Costruzione di nuovi impianti nucleari nel mondo*



* International Status and Prospects of Nuclear Power – IAEA – 2010

Numero di reattori in costruzione nel mondo¹

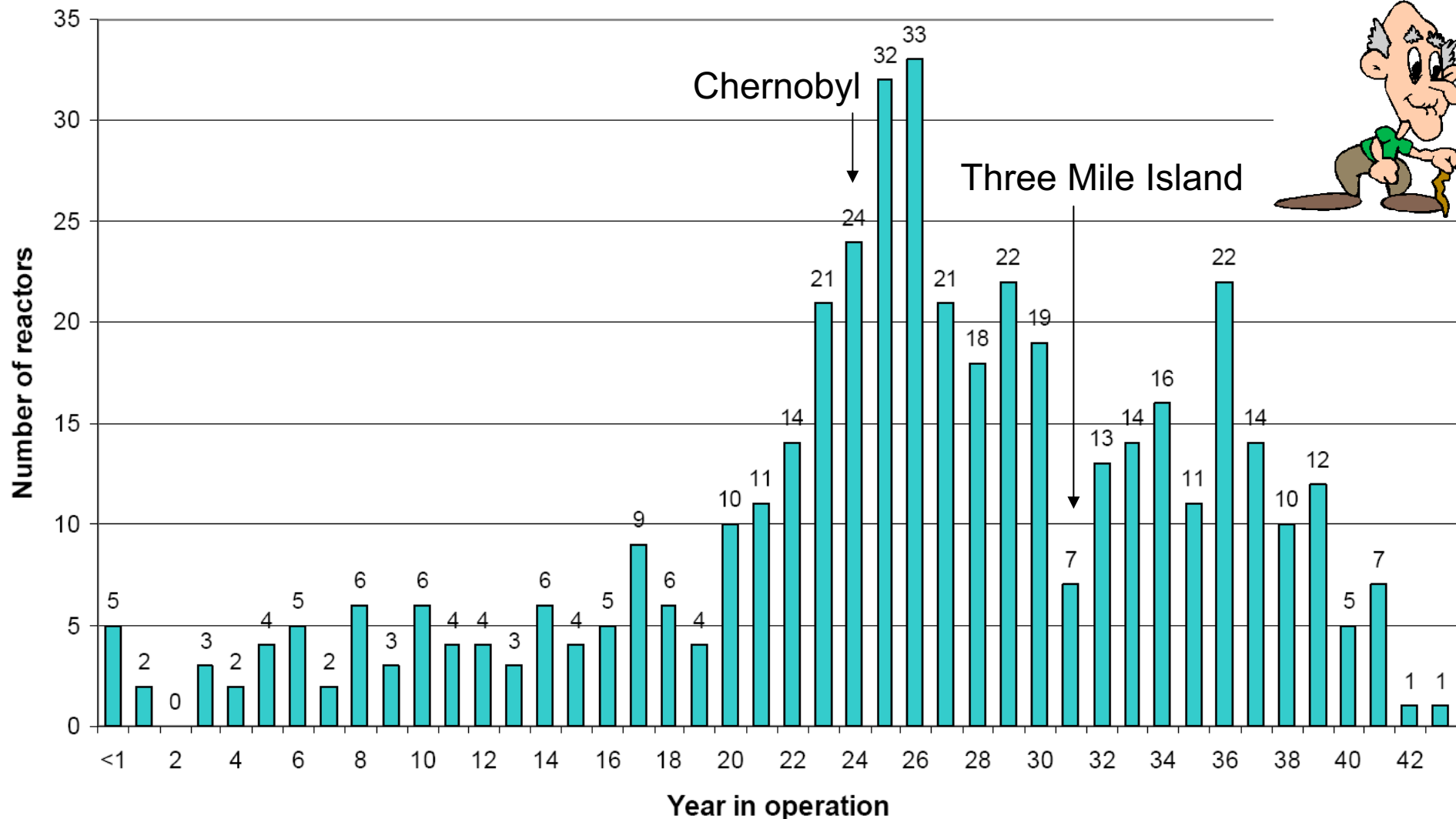


Attualmente sono operativi 441 impianti nucleari che producono 375 GW(e), ovvero il 14% dell'energia elettrica mondiale e il 5.7% dell'energia primaria totale².

¹ International Status and Prospects of Nuclear Power – IAEA – 2010

² IAEA PRIS (Power Reactor Information System) – Updated 2010

Età degli impianti nucleari nel mondo*



* International Status and Prospects of Nuclear Power – IAEA – 2010

La radioattività

La radioattività è un fenomeno fisico naturale che si verifica quando il nucleo di un atomo instabile raggiunge un nuovo stato di equilibrio emettendo radiazioni

1 Bq = 1 decadimento al secondo

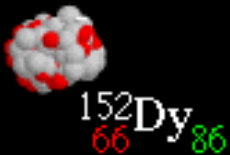
Decadimento Alfa



Decadimento Beta



Decadimento Gamma



La radioattività naturale terrestre

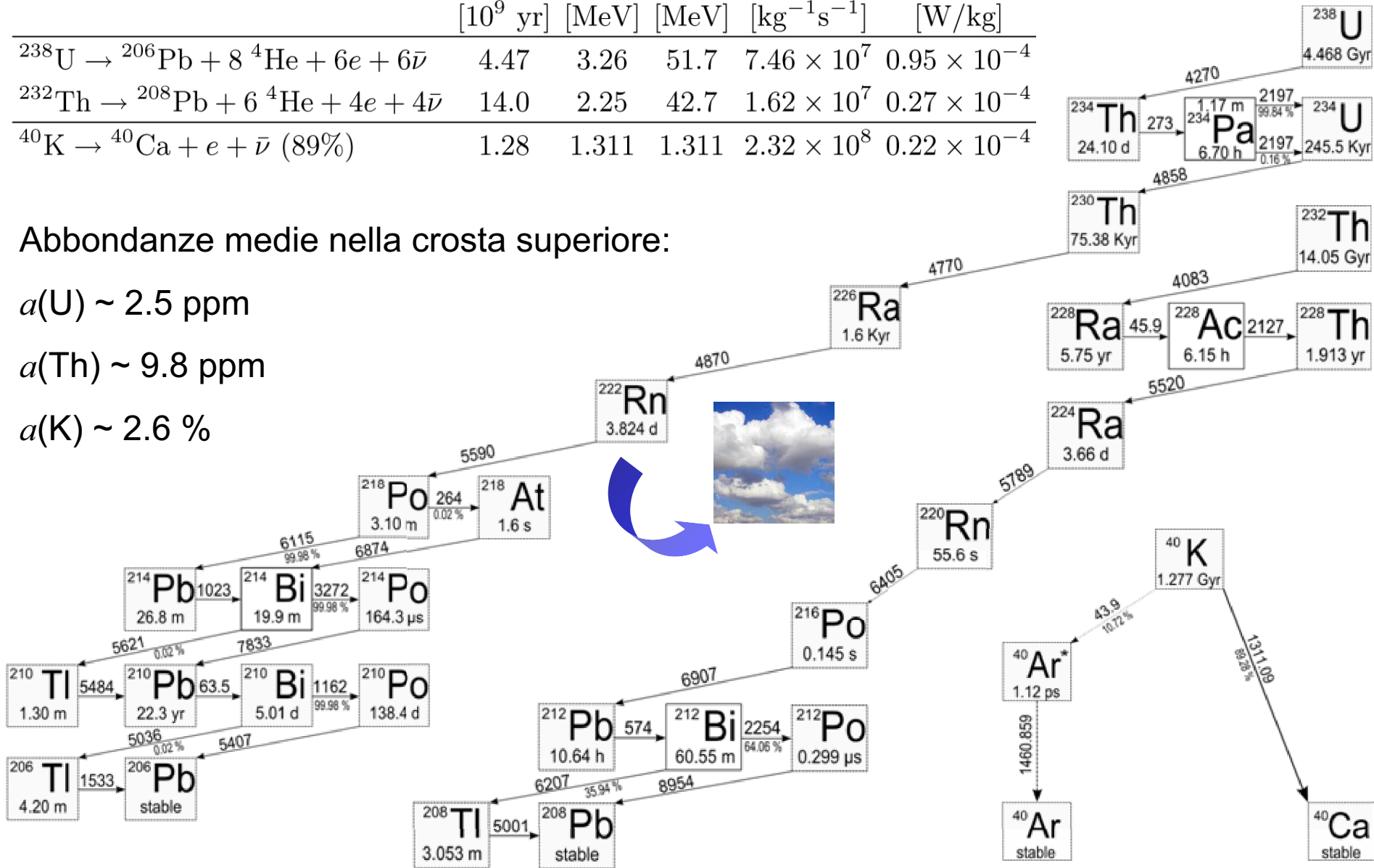
Decay	$T_{1/2}$ [10^9 yr]	E_{\max} [MeV]	Q [MeV]	$\epsilon_{\bar{\nu}}$ [$\text{kg}^{-1}\text{s}^{-1}$]	ϵ_H [W/kg]
$^{238}\text{U} \rightarrow ^{206}\text{Pb} + 8\ ^4\text{He} + 6e + 6\bar{\nu}$	4.47	3.26	51.7	7.46×10^7	0.95×10^{-4}
$^{232}\text{Th} \rightarrow ^{208}\text{Pb} + 6\ ^4\text{He} + 4e + 4\bar{\nu}$	14.0	2.25	42.7	1.62×10^7	0.27×10^{-4}
$^{40}\text{K} \rightarrow ^{40}\text{Ca} + e + \bar{\nu}$ (89%)	1.28	1.311	1.311	2.32×10^8	0.22×10^{-4}

Abbondanze medie nella crosta superiore:

$a(\text{U}) \sim 2.5$ ppm

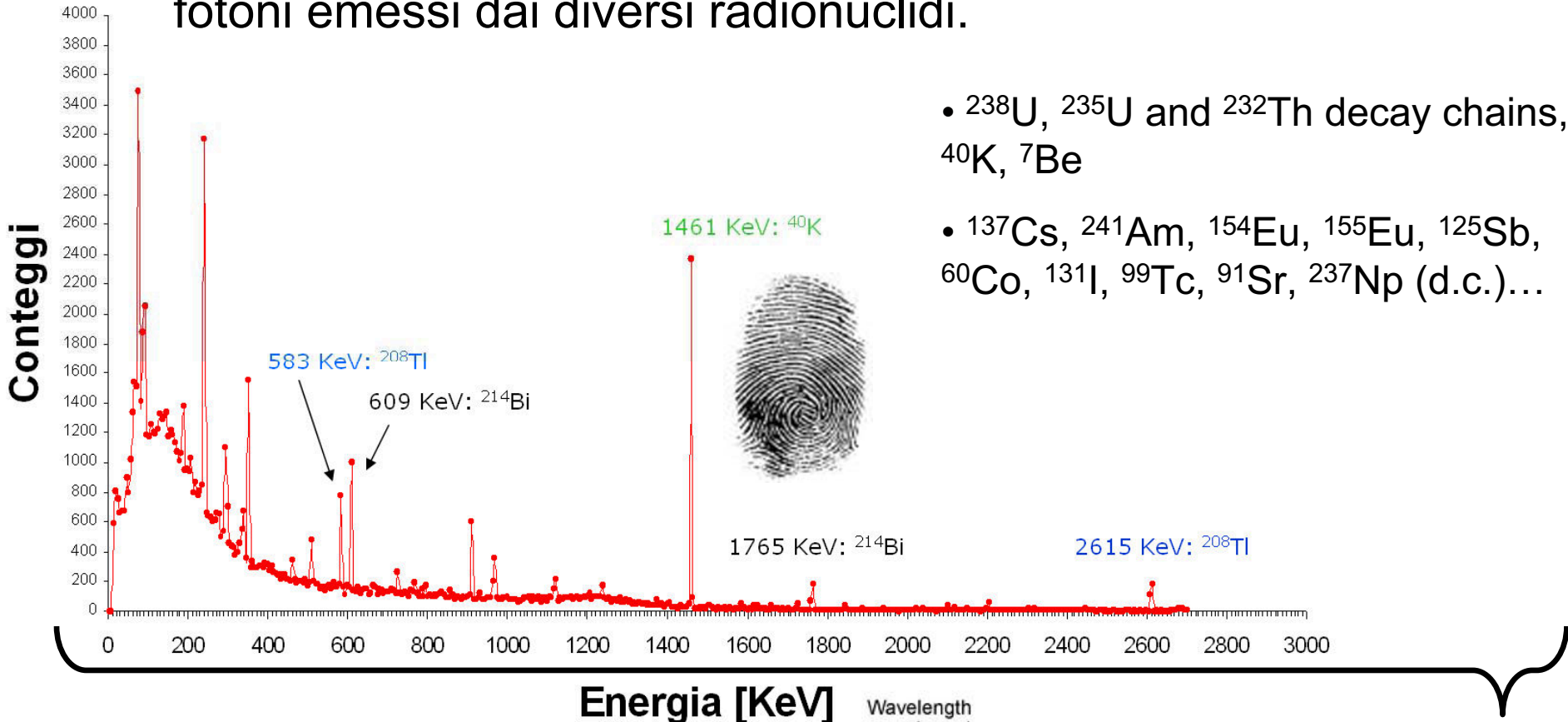
$a(\text{Th}) \sim 9.8$ ppm

$a(\text{K}) \sim 2.6$ %

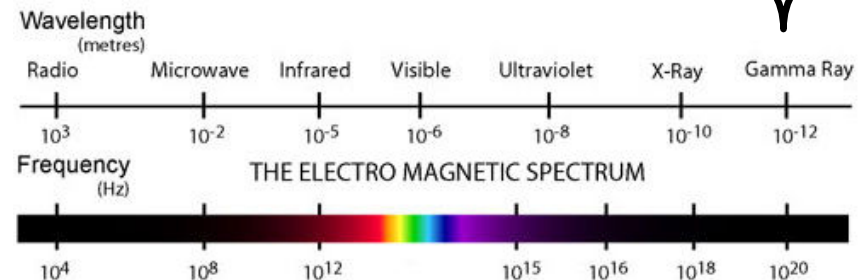


La spettroscopia gamma

La spettroscopia gamma è una tecnica spettroscopica in grado di misurare non solo l'attività specifica, ma anche l'energia dei fotoni emessi dai diversi radionuclidi.



- ^{238}U , ^{235}U and ^{232}Th decay chains, ^{40}K , ^7Be
- ^{137}Cs , ^{241}Am , ^{154}Eu , ^{155}Eu , ^{125}Sb , ^{60}Co , ^{131}I , ^{99}Tc , ^{91}Sr , ^{237}Np (d.c.)...



Spettroscopia gamma a diverse scale

... in laboratorio



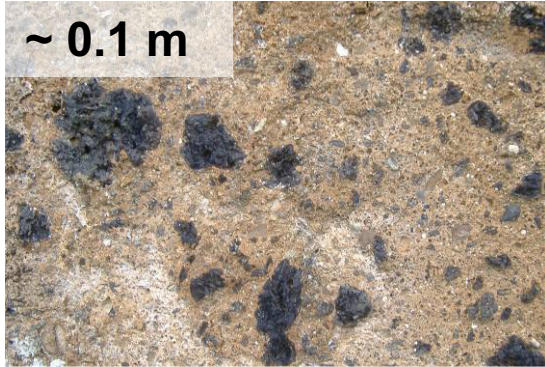
... in situ



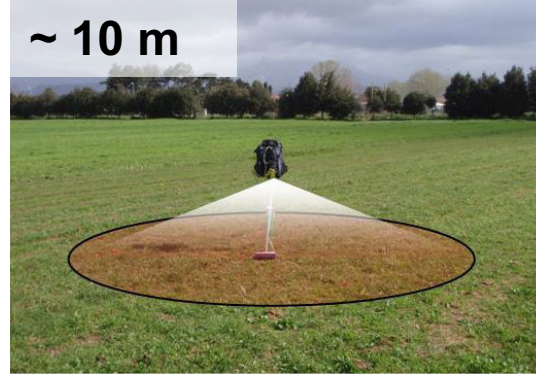
... in volo



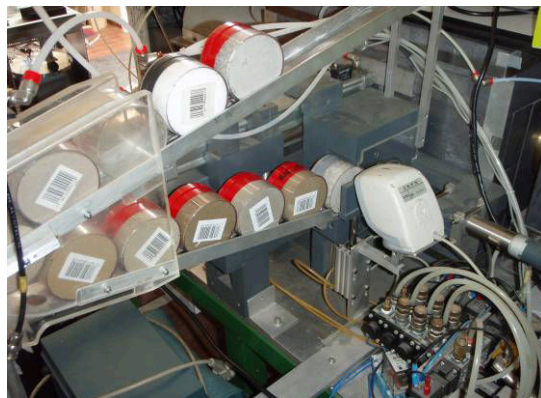
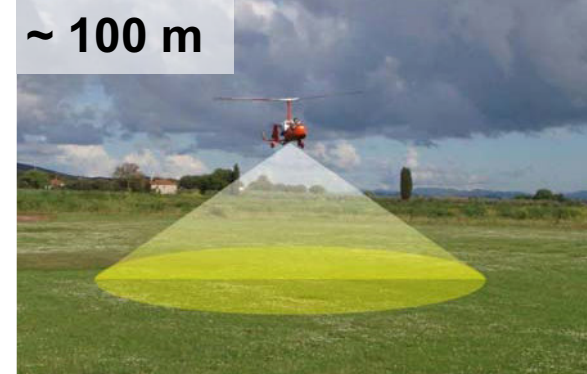
~ 0.1 m



~ 10 m



~ 100 m

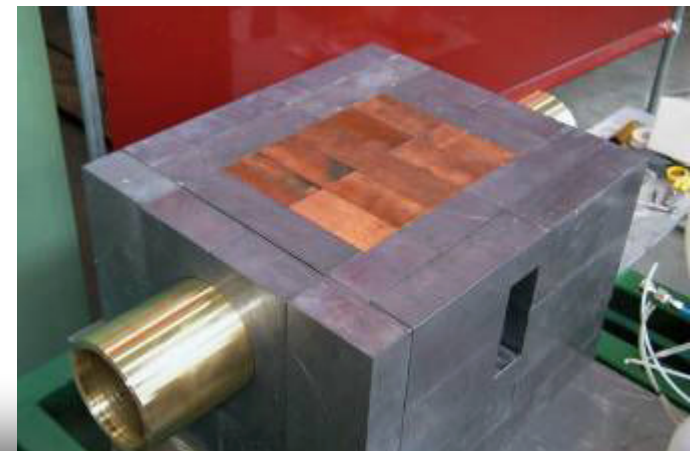


Misure in laboratorio: MCA_Rad system

- Detectors: 2 HPGe (Rel. Eff. 80%)
- Risoluzione Energetica: 2.02 keV at 1.33 MeV
- Temperatura di funzionamento: ~ -190 °C
- Schermatura: Cu, Pb
- Volume del campione: 200 cc
- Durata misura standard: ~ 1 h
- Errore sistematico sulla misura dell'attività assoluta: $< 5\%$
- Grado di automazione: 38 campioni con lettore di codice a barre
- Conforme alle linee guida IAEA¹ e alla norma ANSI N42²

¹ Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363, 2003.

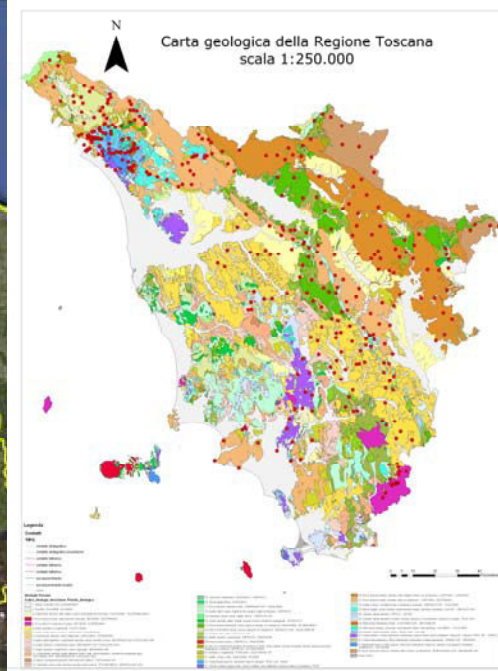
² American National Standard for calibration and use of Germanium Spectrometers for the measurement of Gamma-Ray emission rates of radionuclides. ANSI N42.14-1999.



Misure su campioni di roccia e suolo...










Alcuni risultati preliminari delle misure su campioni di roccia



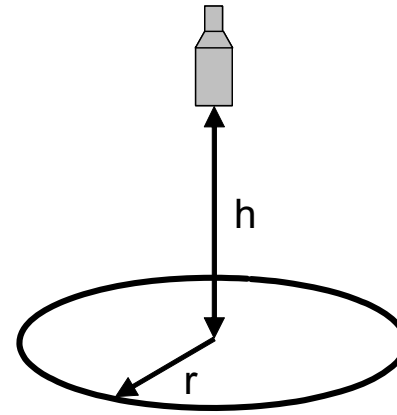
<i>Classe litologica</i>	N. camp.	$K \pm \sigma_k$ [%]	$eU \pm \sigma_U$ [ppm]	$eTh \pm \sigma_{Th}$ [ppm]
Sedimentarie (SiO_4)	187	2.1 ± 0.7	2.5 ± 0.9	10.5 ± 3.1
Carbonatiche ($CaCO_3$)	85	0.5 ± 0.4	1.2 ± 0.9	2.6 ± 2.2
Metamorfiche	17	0.4 ± 0.6	0.8 ± 1.0	2.3 ± 3.9
Vulcaniche	21	5.5 ± 1.7	11.9 ± 7.7	68.2 ± 30.2

Misure in situ: Za_Nal

Lo Za_Nal è uno strumento portatile dedicato alla determinazione quantitativa in situ della radioattività gamma di origine naturale ed antropica.

Richieste	Soluzioni	Strumento
Portatile	0.3L NaI(Tl) detector ~ 4 kg zaino 	
Veloce	Standard acquisition time: 5 - 10 min 	
Lunga autonomia	Elettronica integrata USB Digibase (1024 channel) Power Aut.: 6 hours 	
Risposta in real time	Laptop EeePC Asus Software Maestro 	
Sensori accessori	USB GPS antenna, USB Temp&Humidity sensor 	
Risoluzione energetica	Energetic resolution 12.5% (662 keV ¹³⁷ Cs), 15% (122 keV ⁵⁷ Co)	

Za_Nal: alcuni dettagli

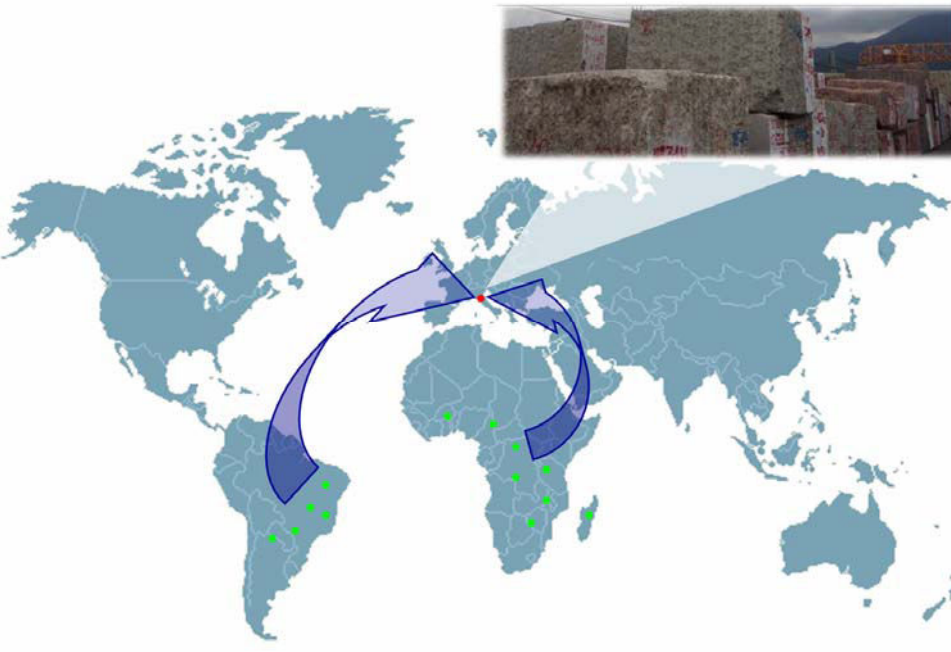
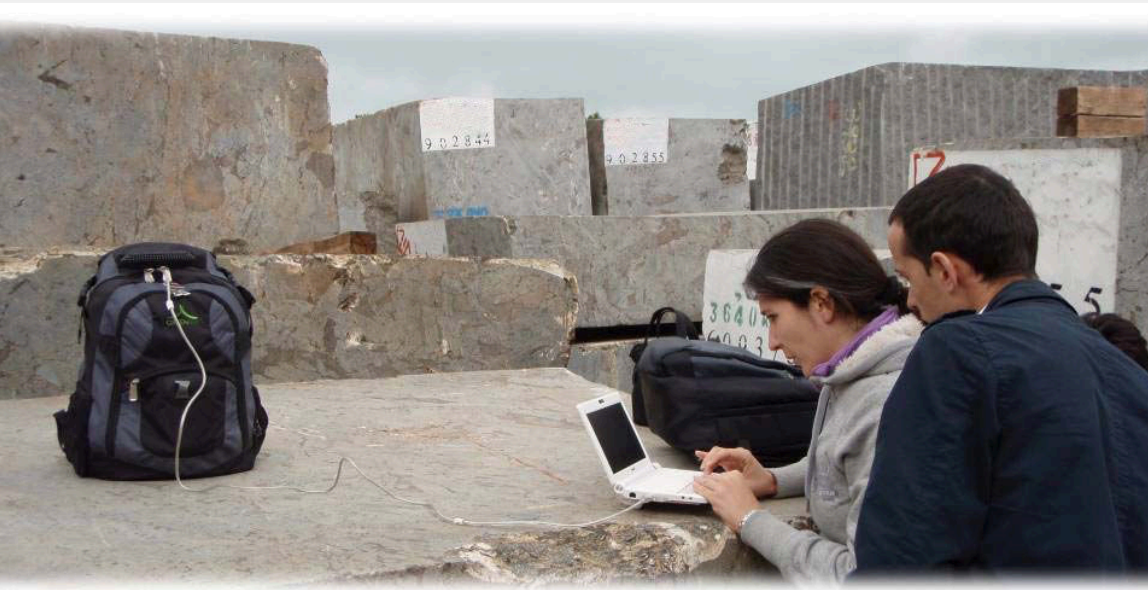


Per il detector posto ad un'altezza h , il 90% del segnale non scatterato avente $E = 2614$ keV) viene da un'area circolare omogenea di raggio r

h (m)	0.1	0.3	0.5	0.8	1.0
r (m)	0.7	2.2	3.5	6	7.5



Applicazioni sui materiali lapidei...

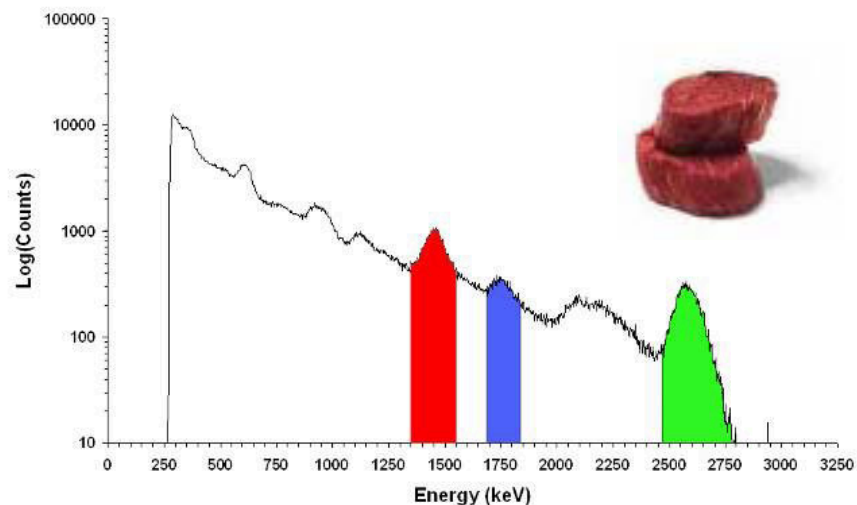
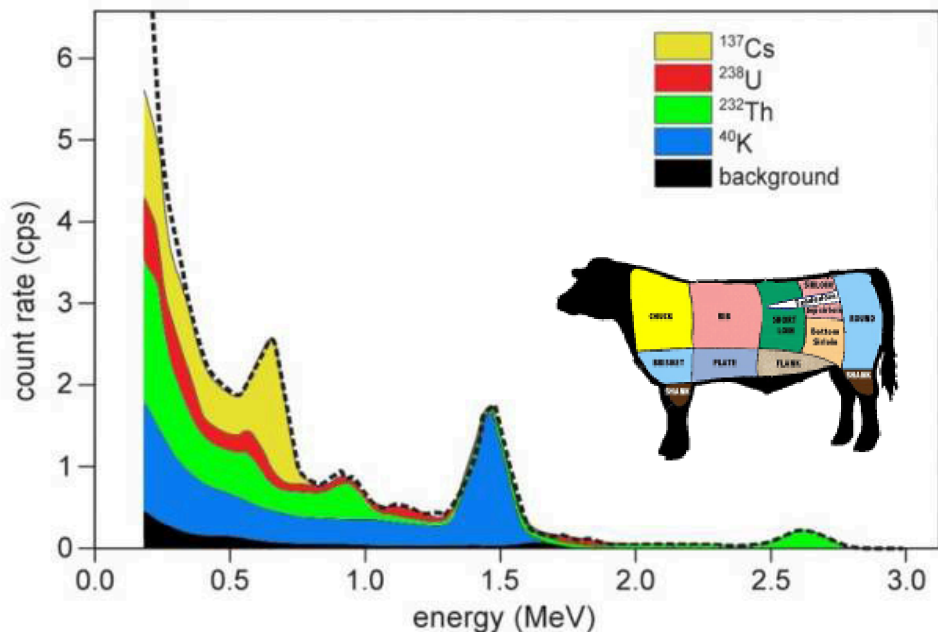


Sviluppo di nuove tecniche d'analisi

The Window Analysis Method (WAM)

The conventional approach¹ to the acquisition and processing of gamma ray spectrometric data is to monitor three or four relatively broad **spectral windows**, corresponding to the main photopeaks.

Radioisotope	Energy (keV)	Energy windows (keV)
⁴⁰ K	1460	1370-1570
²¹⁴ Bi	1765	1660-1860
²⁰⁸ Tl	2614	2410-2810

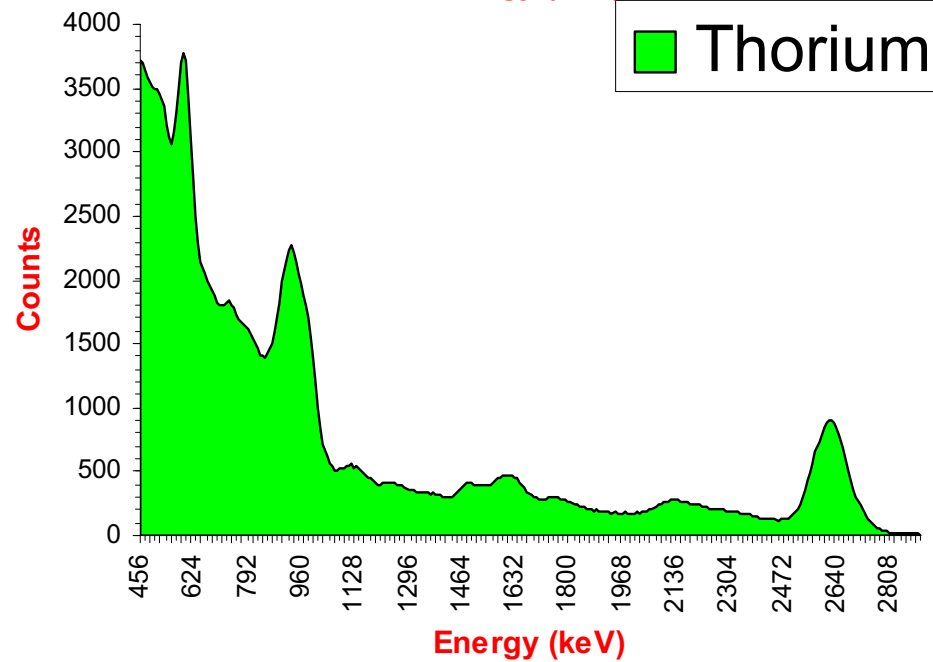
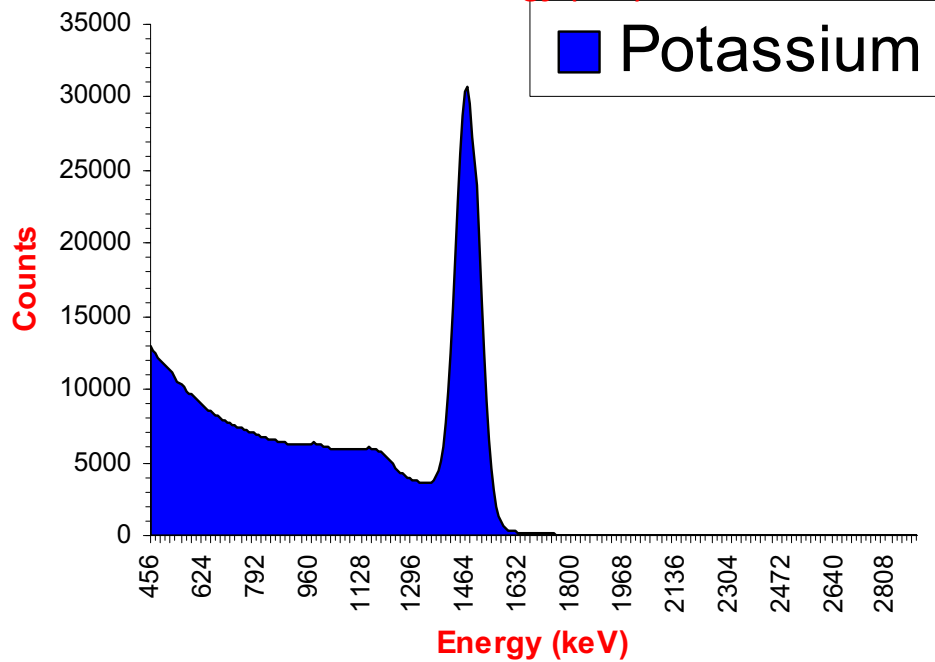
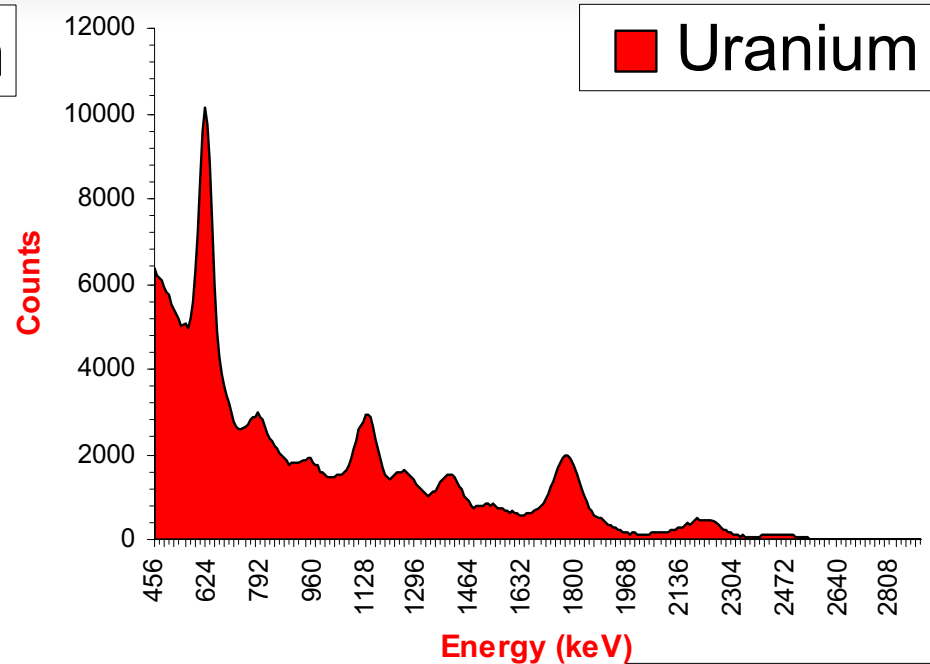
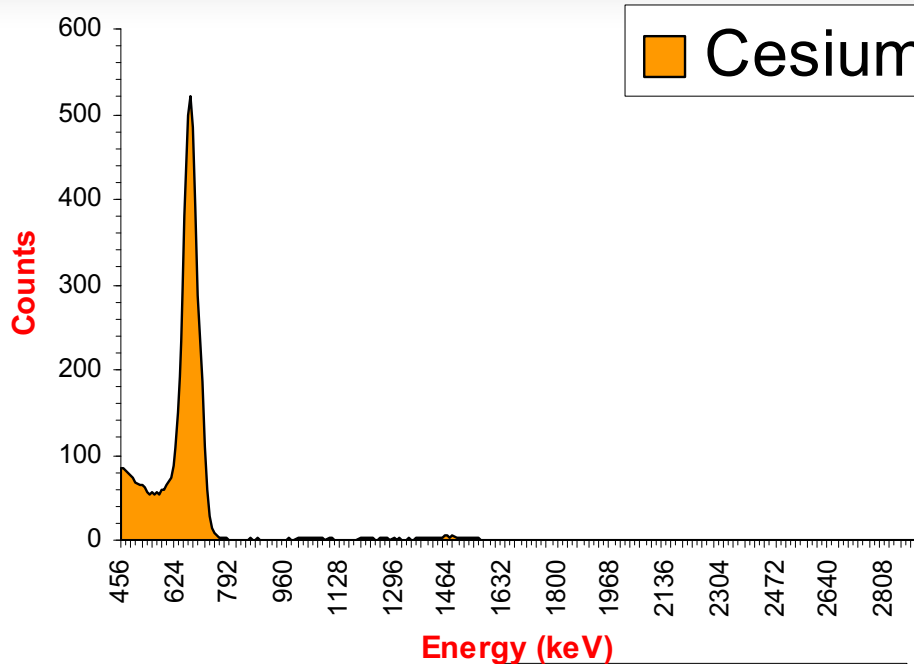


Full-Spectrum Analysis method (FSA)

In FSA method the shape of the total spectrum is taken into account and is 'unfolded' into the spectra for the individual radionuclides (**standard spectra**) and a background spectrum.

¹ Guidelines for radioelement mapping using gamma ray spectrometry data, IAEA-TECDOC-1363, 2003.

Gli spettri standard



Studio di correlazione tra misure in situ e misure su campione



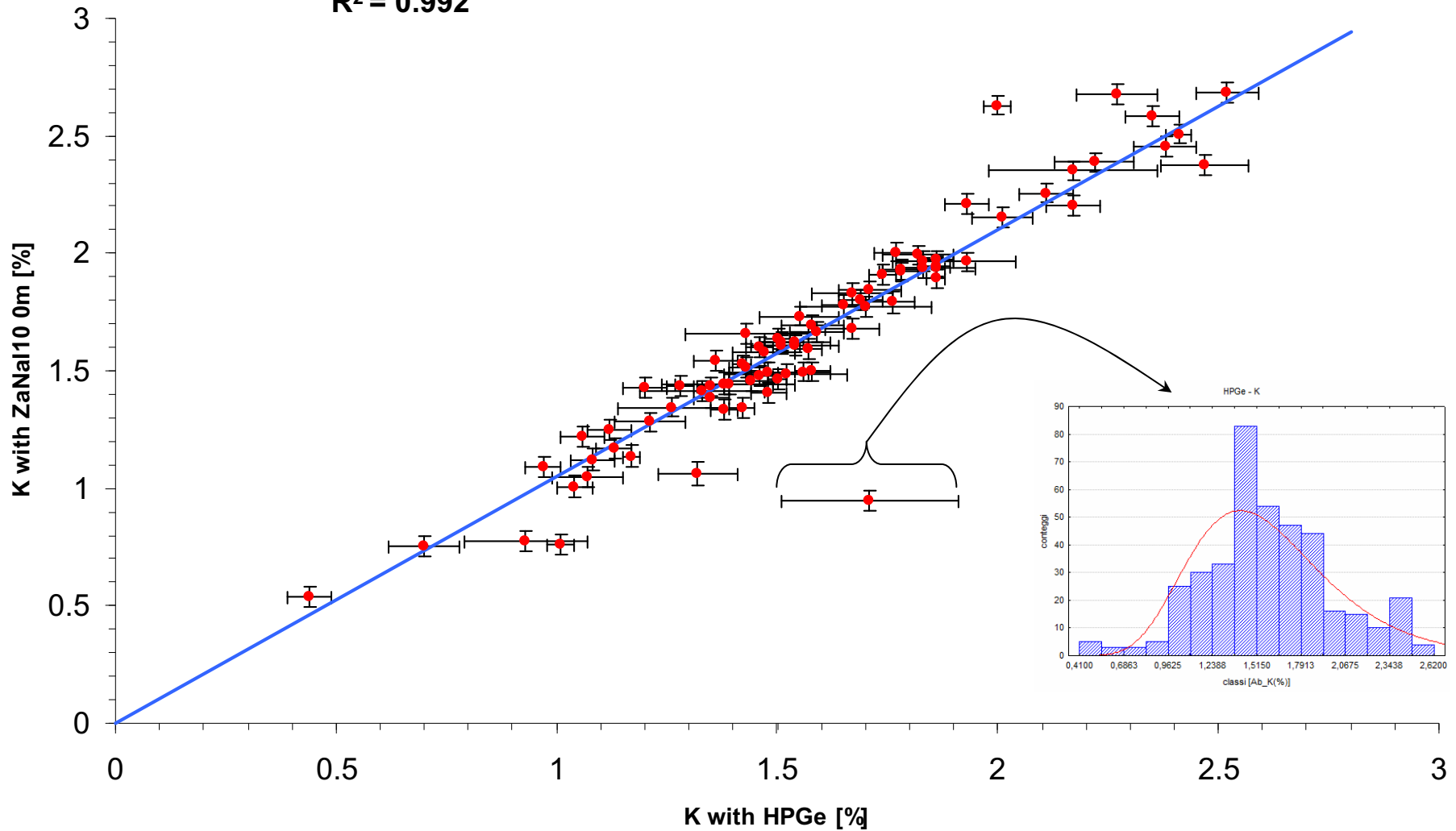
- $80 \times 5 = 400$ campioni analizzati in laboratorio
- 80 misure con zaino a 0 m
- 80 misure con zaino a 1 m



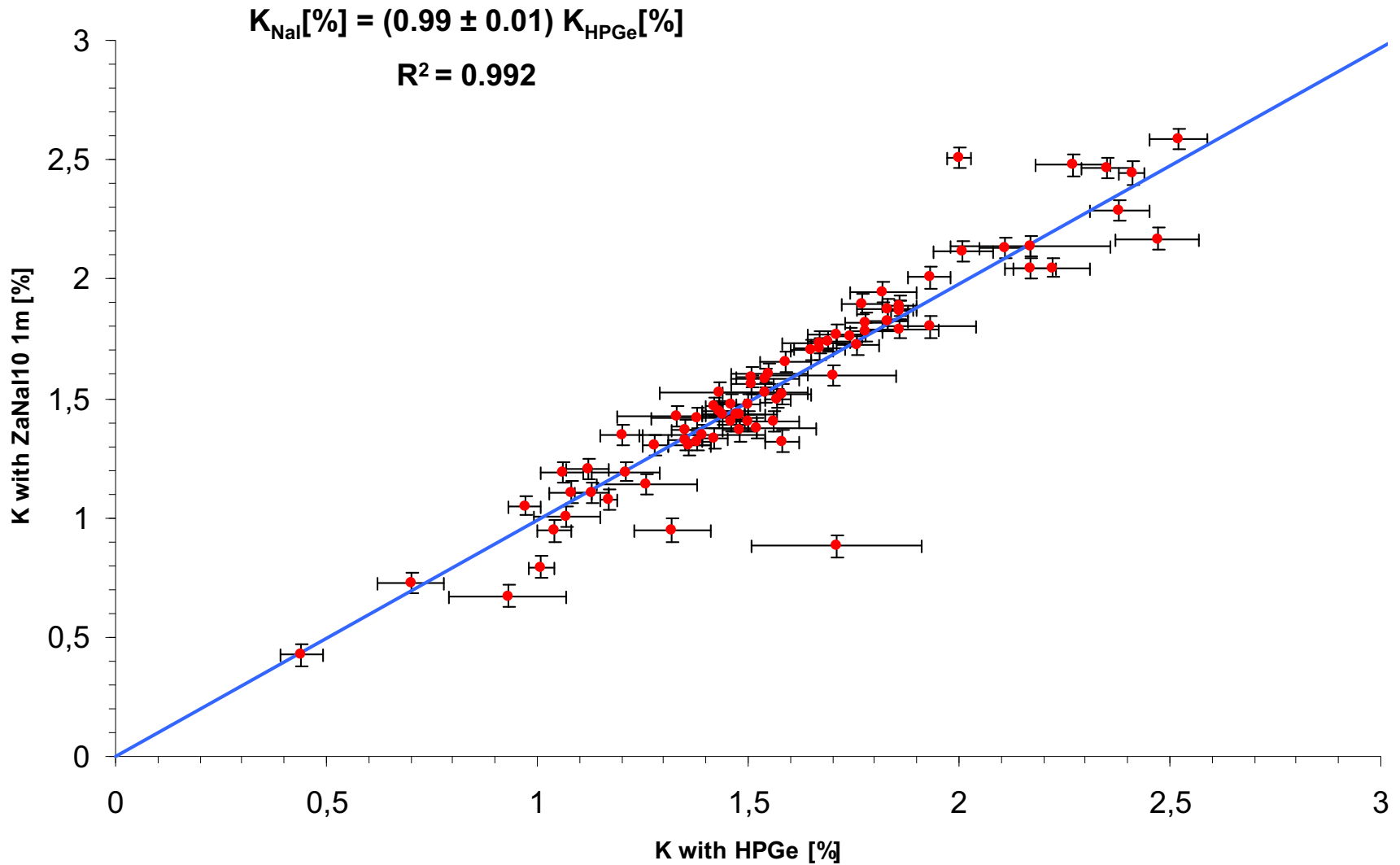
Potassio: Za_NaI (0 metri) vs HPGe

$$K_{\text{NaI}}[\%] = (1.05 \pm 0.01) K_{\text{HPGe}}[\%]$$

$$R^2 = 0.992$$



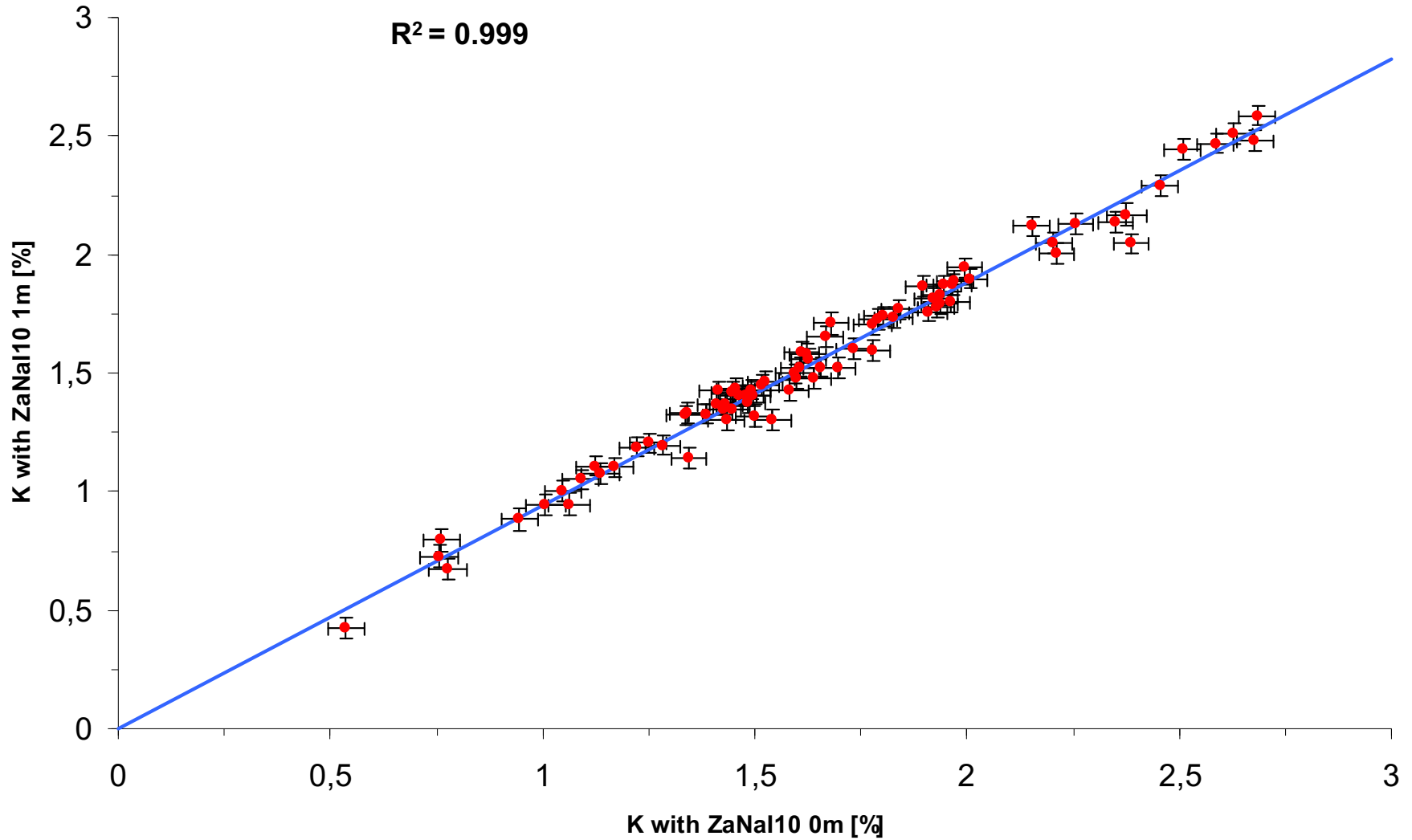
Potassio: Za_NaI (1 metri) vs HPGe



Potassio: Za_NaI (1 m) vs Za_NaI (0 m)

$$K_{\text{NaI}}[\%] = (0.943 \pm 0.004) K_{\text{HPGe}}[\%]$$

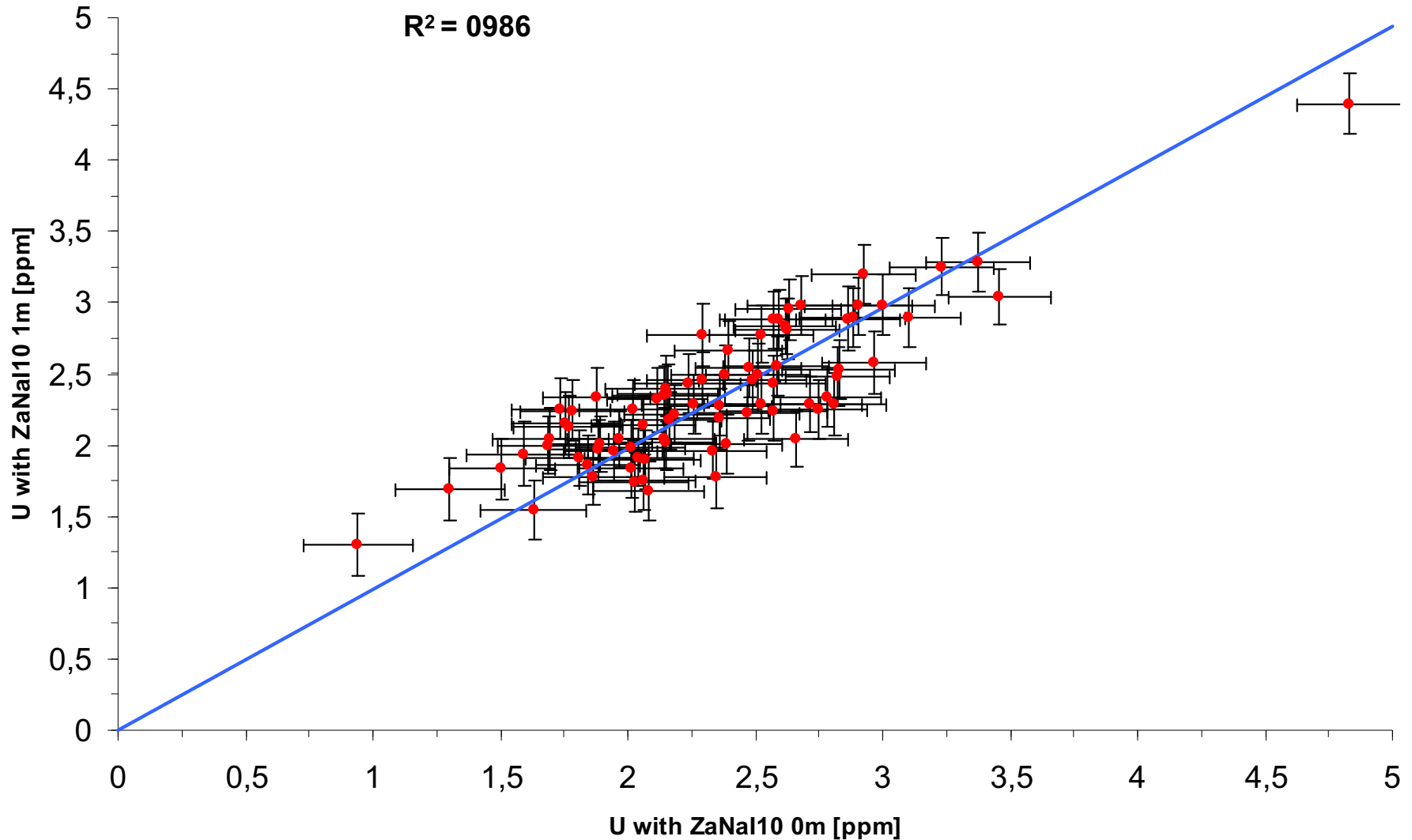
$$R^2 = 0.999$$



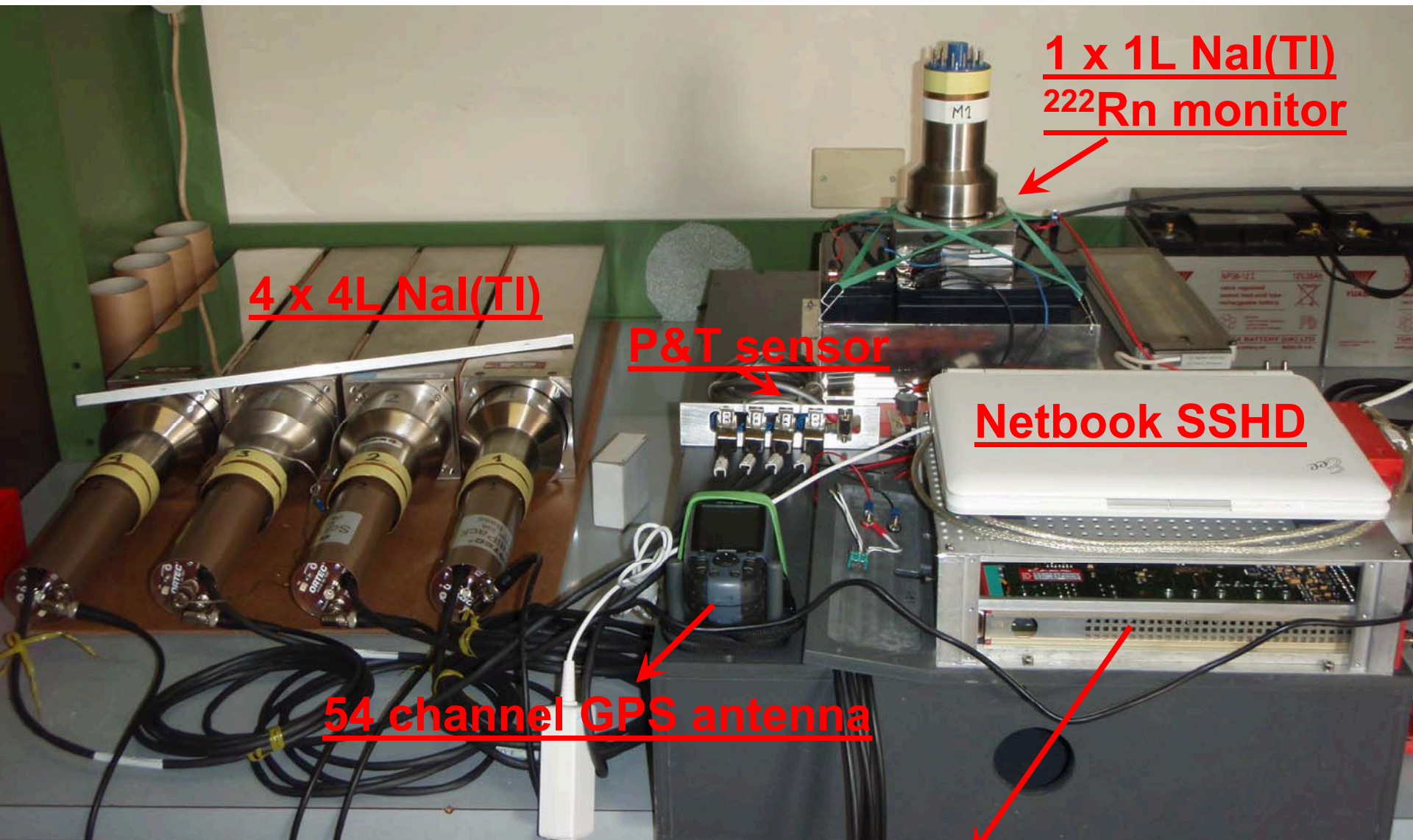
Uranio: Za_NaI (1 m) vs Za_NaI (0 m)

$$U_{\text{NaI}}[\text{ppm}] = (0.989 \pm 0.013) U_{\text{HPGe}}[\text{ppm}]$$

$R^2 = 0.986$



Misure airborne: AGRS_16



4 x 4L NaI(Tl)

1 x 1L NaI(Tl)
222Rn monitor

P&T sensor

Netbook SSHD

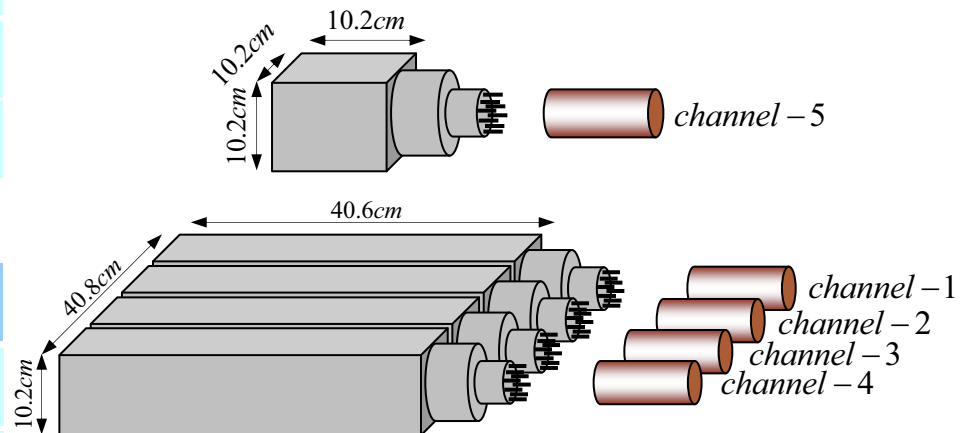
54 channel GPS antenna

4 channel ADC with MCA CAEN module

Specifiche tecniche

Aircraft	
Weight capacity	~120 kg
Survey speed	100 km/h
Autogyro costs	500 € / h
AGRS system	
Channel	16000
Detector NaI(Tl)	4 x 4L + 1 x 1L
Weight	117 kg
ADC and MCA	individual
Output	list mode
Altimeter	P&T sensor
Power supply	battery
Route manager	Co-pilot monitor
Data processing	
Isotope ID	^{40}K , eU, eTh, ^{137}Cs
Spectra analysis	FSA with NNLS

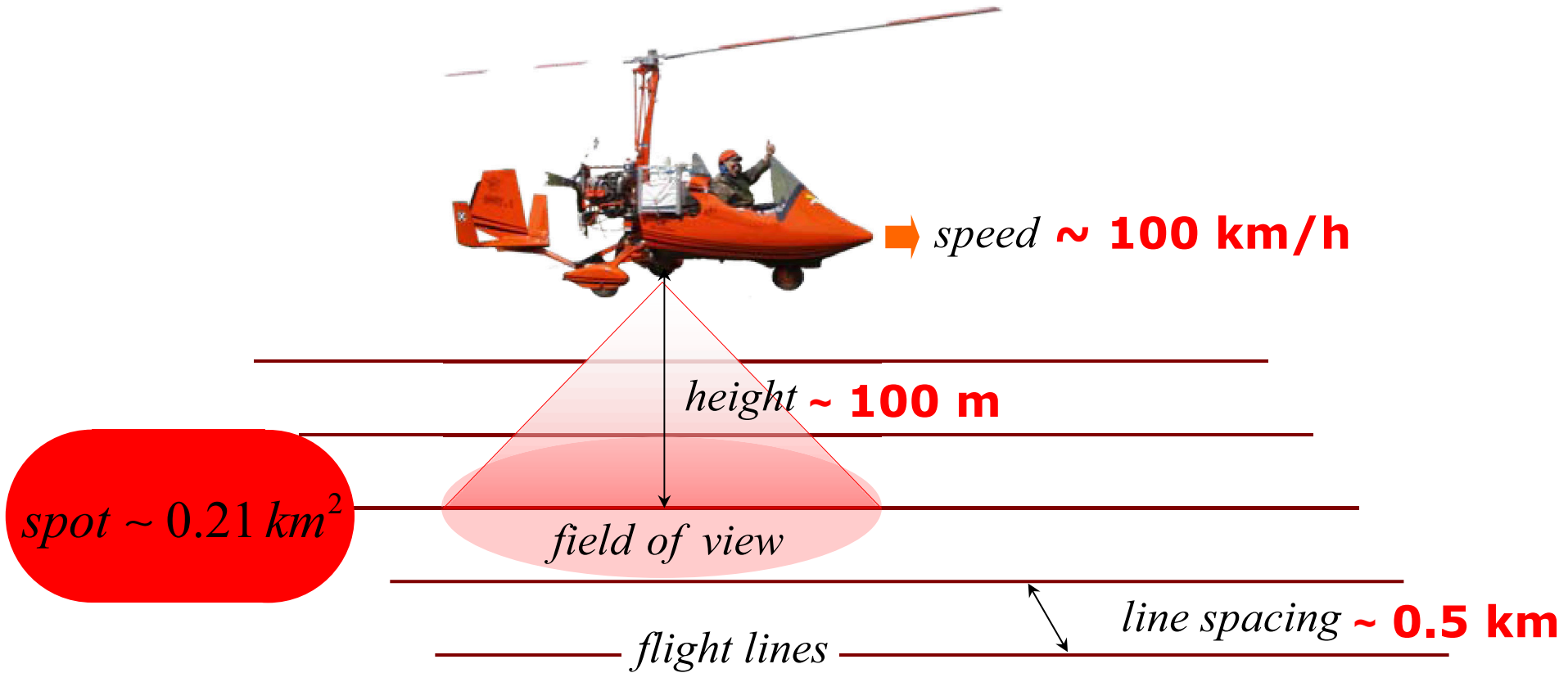
Autogyro





AGRS survey: parametri di volo

Following the Technical Reports of IAEA we adopted the same flight parameters: it permits a comparison between different international experiences.



The aircraft has to follow the morphology of the territory.



ASSOXI SPEED

ITALIA

PISA
AERO CLUB

107834

Microflight





Telemetria del sistema (quota, posizione, spettri gamma, sensori di pressione e temperatura): collegamento wireless fino a pochi istanti prima del decollo.



A typical AGRS_16.0L measurement

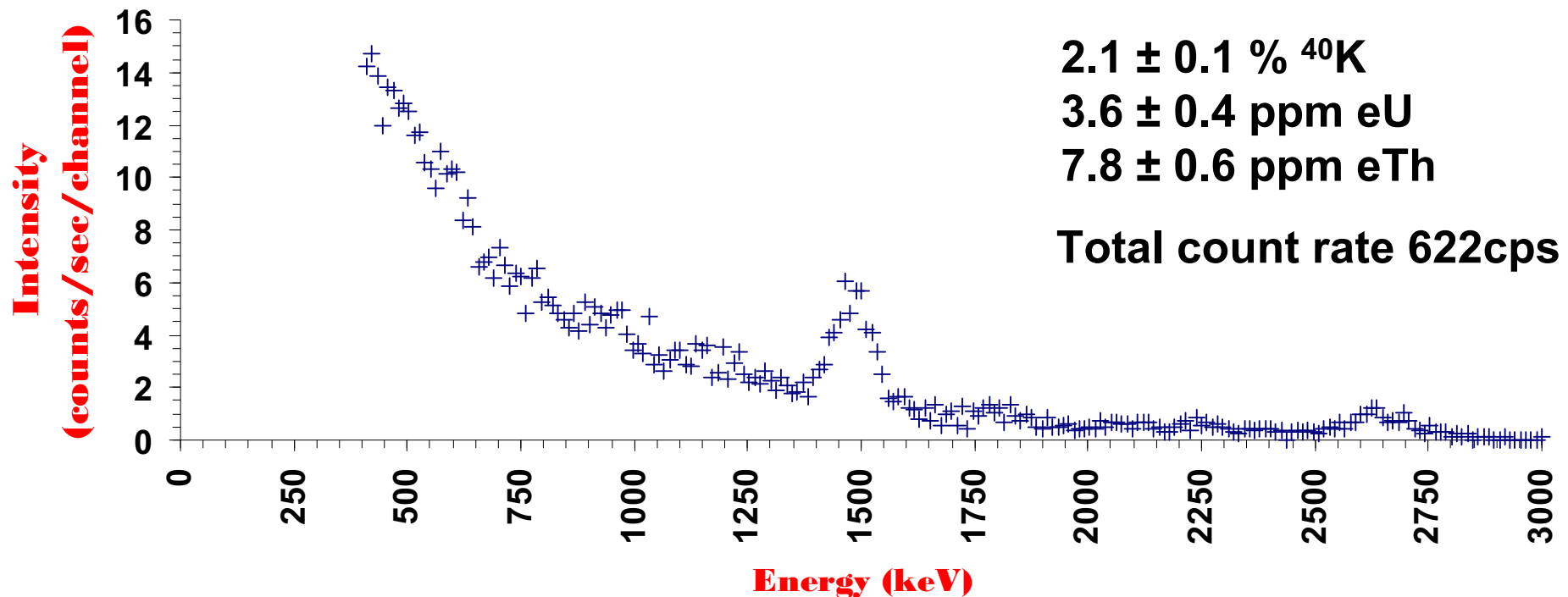
1 Hz sampling rate per channel in each 4L detector

50 mHz sampling rate per spectra for the radon monitor detector

0.5 Hz sampling rate of GPS antenna acquisition

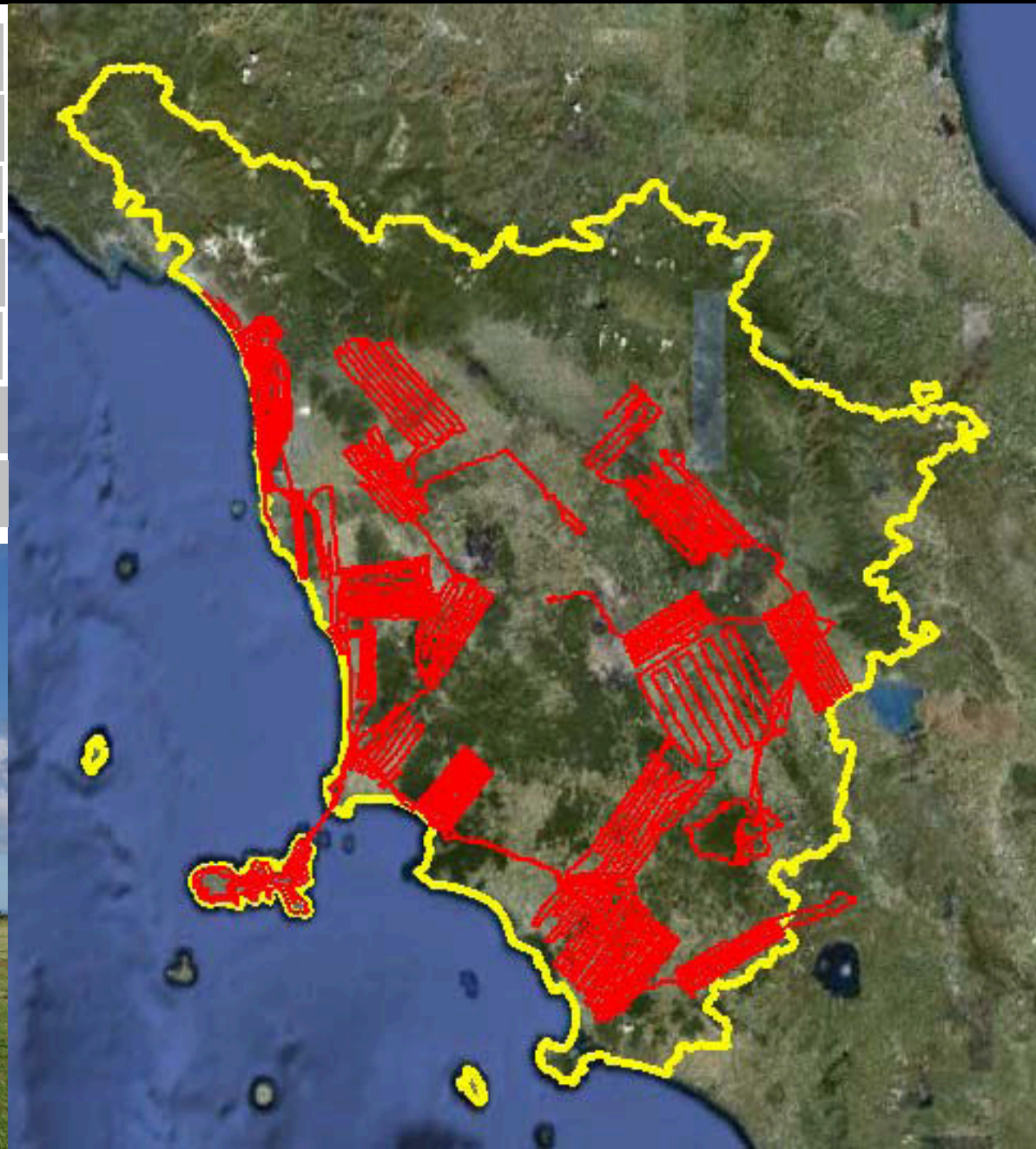
0.5 Hz sampling rate of pressure & temperature sensor acquisition

**A typical 1s spectrum acquisition with AGRS_16.0L at 100 m of height.
The spectra is recorded in 256 channels in the energy reange 0-3 MeV.**



Summary of airborne survey

Region	Tuscany
Regional area	23 10 ³ km ²
Surveyed area	~ 20%
N. Eff. flights	33
Total hours	~ 100
Data amount	~ 30 GB
Period	Apr.-Jun. 10



Isola d'Elba survey

Flight realized at 3 June 2010

Flight's duration: ~2.2 h

Surveyed area: ~225 km²

Weather conditions: cloudy

Data acquisition: complete



Isola d'Elba: attività totale misurata su campioni

4 Rocce intrusive acide, subvulcaniche e filoniane.
NEOGENE-QUATERNARIO

33 Marne, argilliti, calcari nodulari, calcari selciferi, diaspri, calcilutiti e calcareniti, Calcari ad angulati, Rosso ammonitico, Calcare selcifero di Limano, Marne a *Posidonomya*, Calcare selcifero della Val di Lima, Diaspri, Calcari ad aptici, Maiolica.
LIAS INF. - CRETACICO INF.

20 Ofioliti: peridotiti, gabbri, basalti, oficalciti e breccie ofiolitiche, plagiograniti; (presenti anche come masse disarticolate all'interno delle formazioni del Dominio Ligure Esterno).
GIURASSICO

17 Flysch arenacei: arenarie e siltiti. Arenarie di M. Gottero, Arenarie di Montecatini, Flysch dell'Elba, F.ne di Marina di Campo, Arenarie di Ghiaieto.
CAMPANIANO SUP.-PALEOCENE

**Total activity
(Bq/kg)**

2700 ± 52

**Total activity
(Bq/kg)**

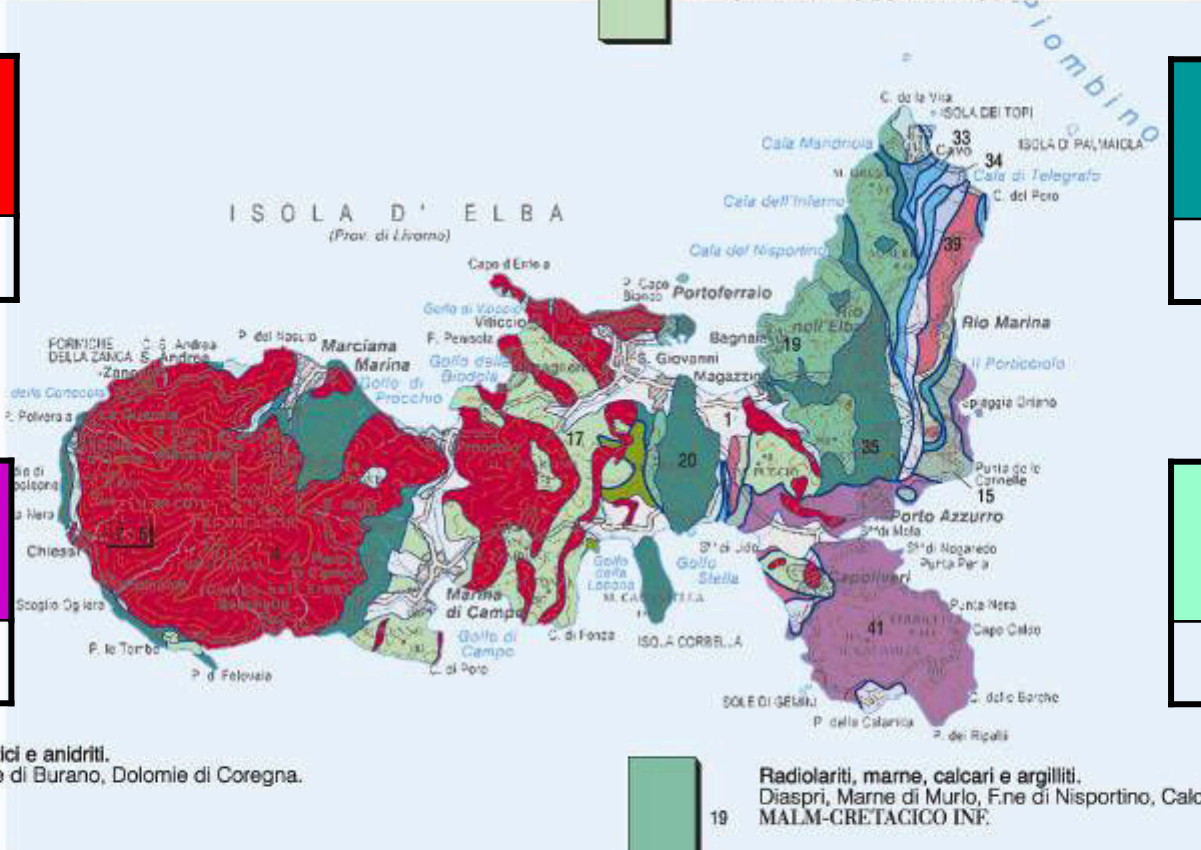
38 ± 6

**Total activity
(Bq/kg)**

1080 ± 33

**Total activity
(Bq/kg)**

186 ± 14



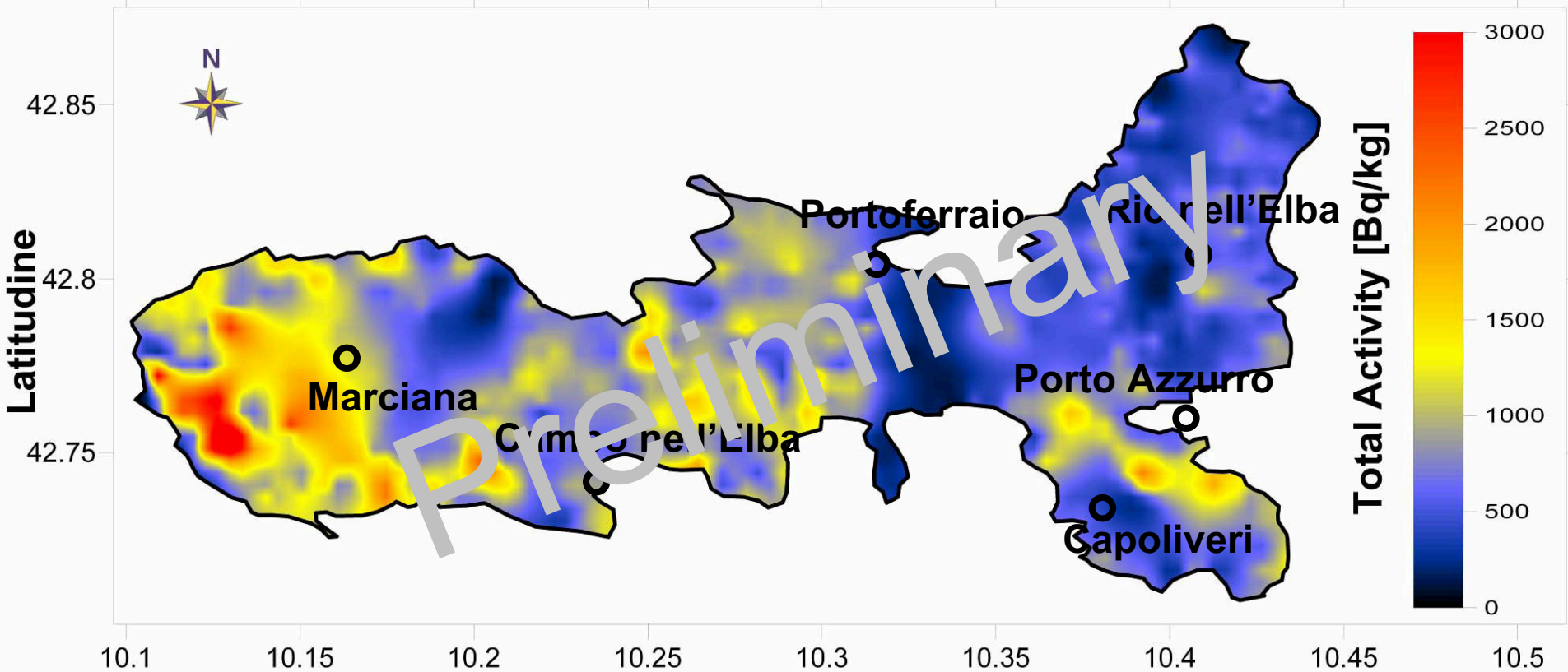
35 Dolomie, calcari dolomitici e anidriti. Calcare cavernoso, F.ne di Burano, Dolomie di Coregna.
TRIAS SUP.

19 Radiolariti, marne, calcari e argilliti. Diaspri, Marne di Murlo, F.ne di Nisportino, Calcari a Calpionelle.
MALM-CRETACICO INF.

41 Basamento ercinico: filladi, quarziti, calcescisti, metacalcari, metarose, dolomie, scisti grafitosi, metabasiti. Filladi inferiori, Filladi e quarziti di Buti, Scisti di Ortano, Gneiss del Calamita, Porfiroidi e scisti porfirici, Quarziti e filladi superiori, Scisti a Graptoliti, F.ne di Risanguigno, Dolomie a *Orthoceras*.
CAMBRIANO? - DEVONIANO

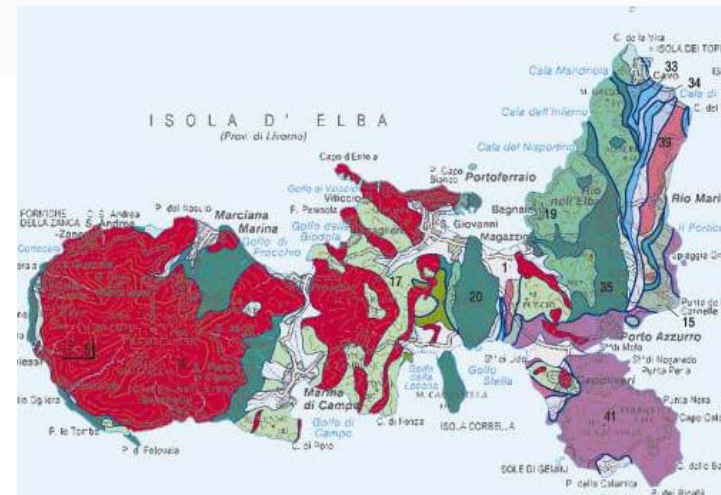
1 Sabbie, ciottolami e limi (depositi alluvionali, eolici, lacustri, palustri, lagunari e di spiaggia).
QUATERNARIO

Attività totale (Bq/kg) ottenuta da AGRS survey



Total activity (Bq/kg)	Total activity (Bq/kg)
2700 ± 52	38 ± 6
Total activity (Bq/kg)	Total activity (Bq/kg)
1080 ± 33	186 ± 14

Longitudine



Grazie al team!



Bellotti Enrico, Bezzon Pietro, Boggini Carlo, Buso Paolo, Callegari Ivan, Carmignani Luigi, Colonna Tommaso, Di Carlo Giuseppe, Fantozzi Piero, Fiorentini Giovanni, Guastaldi Enrico, Mantovani Fabio, Mariani Sara, Massa Giovanni, Rossi Alvarez Carlos, Xhixha Gerti, Shyti Manjola, Claudio Pagotto, Mauro Antongiovanni, Antonio Cacioli, Liliana Mou