HPGe Detectors Efficiency Calibration (ISOCS)

by S. Tarján

IAEA

International Atomic Energy Agency

Content

- Nuclear emergency
- Sources of radioactivity
- Exploration methods
  - Aerial
  - Surface
    - Quantitative
    - +Qualitative
    - Gamma dose rate

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Nuclear emergency

- **Accident of the**
  - Power reactor (fission and activation products)
  - Other nuclear facilities (any kind of radionuclides)

- **Radiation incident, accident** (transport, orphan sources)

- **Satellite re-entry**
  - Pu-238 (567 W/kg), Sr-90/Y-90, Tc-99
  - Fast reactor (HEU with Na coolant, 16-18) [NASA]

- **Application of nuclear weapon** (fission and activation products)

- **Terror attack** (similar to the nuclear weapon or single isotope)

NORM / TENORM

- Natural radioactive series and ^{40}K
  - ^{238}U, ^{235}U, ^{232}Th
    - In secular equilibrium
    - U surplus
    - Ra surplus
- Mining activity
- Naturally occurring anomaly
- Technological origin contamination

One interesting inventory estimation
(by the Colorado University):

Natural Radioactivity by the Square Mile, 1 Foot Deep			
Nuclide	Activity used in calculation	Mass of Nuclide	Activity found in the volume of soil
Uranium	0.7 pCi/g (25 Bq/kg)	2,200 kg	0.8 curies (31 GBq)
Thorium	1.1 pCi/g (40 Bq/kg)	12,000 kg	1.4 curies (52 GBq)
Potassium 40	11 pCi/g (400 Bq/kg)	2000 kg	13 curies (500 GBq)
Radium	1.3 pCi/g (48 Bq/kg)	1.7 g	1.7 curies (63 GBq)
Radon	0.17 pCi/g (10 kBq/m^3) soil	11 micro g	0.2 curies (7.4 GBq)
		Total:	>17 curies (>653 GBq)

1 sq mile in 1 foot deep ≈ 1.24×10^9 kg soil

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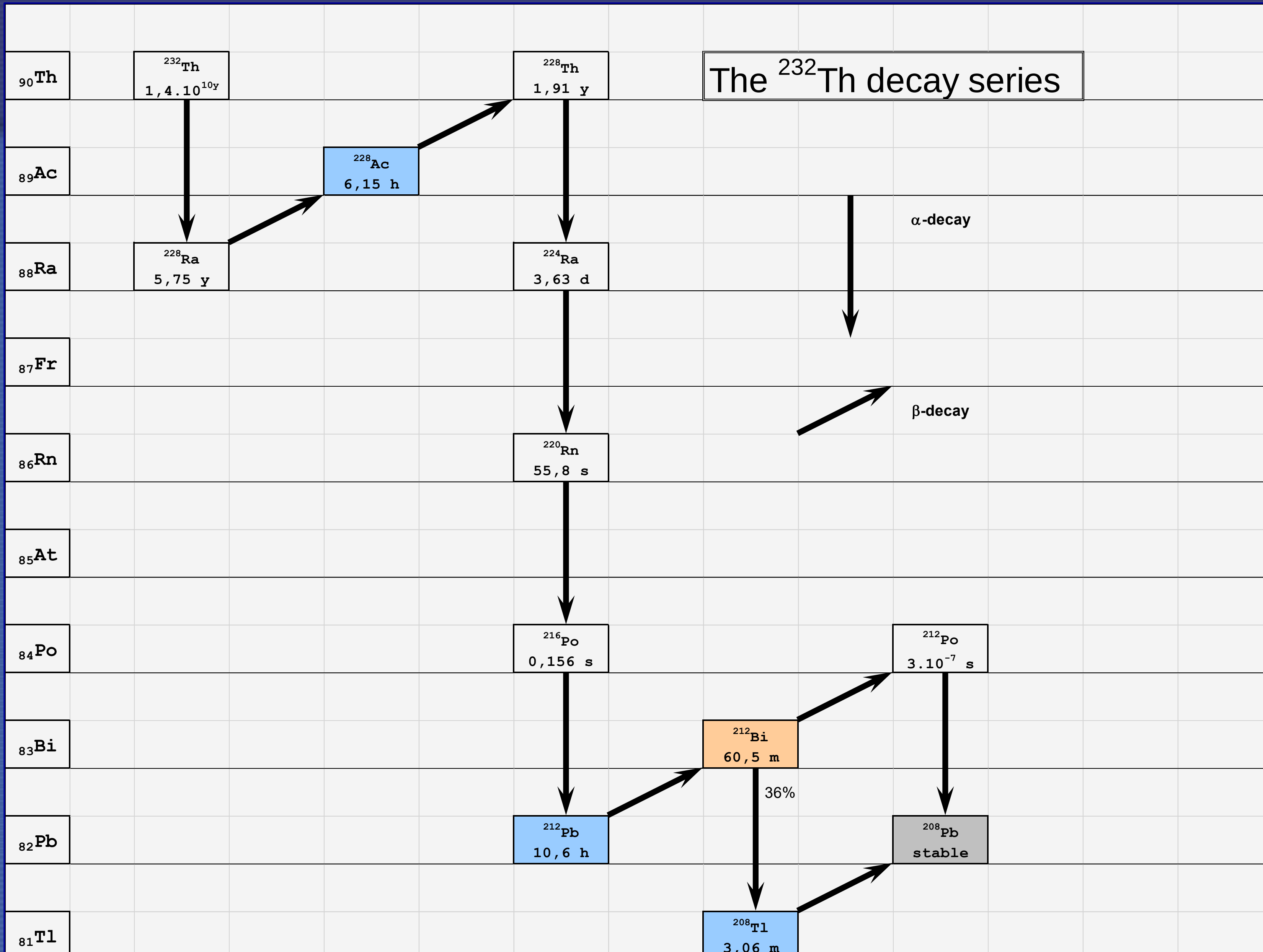
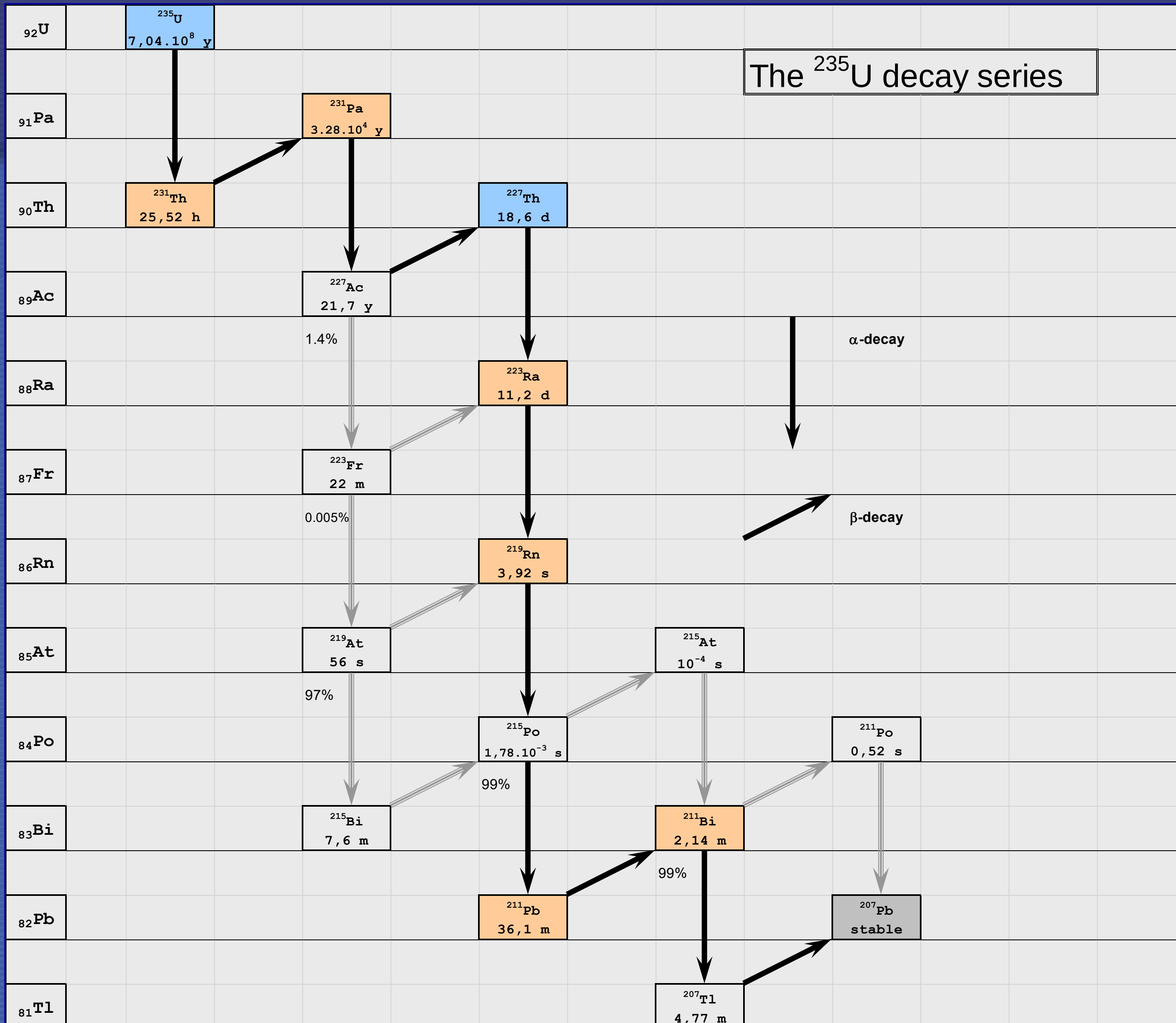
The ^{232}Th decay series





The 235U decay series
92U
91Pa
90Th
89Ac
88Ra
87Fr
86Rn
85At
84Po
83Bi
82Pb
81Tl
235U
7,04.10^8 y
231Pa
3.28.10^4 y
231Th
25,52 h
227Th
18,6 d
227Ac
21,7 y
1.4%
223Ra
11,2 d
223Fr
22 m
0.005%
219Rn
3,92 s
219At
56 s
215At
10^-4 s
97%
215Po
1,78.10^-3 s
211Po
0,52 s
99%
215Bi
7,6 m
211Bi
2,14 m
99%
211Pb
36,1 m
207Pb
stable
207Tl
4,77 m
α-decay
β-decay
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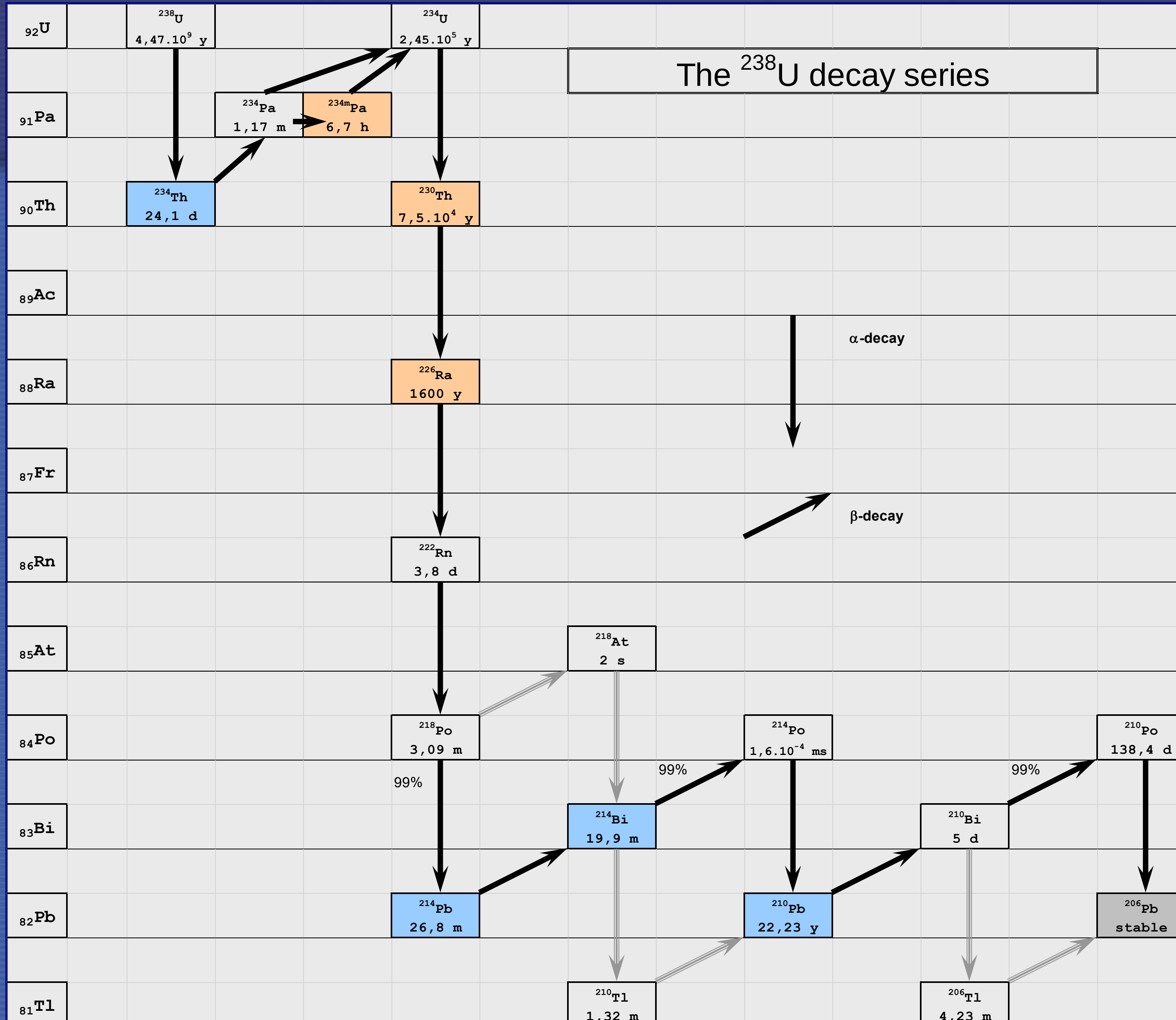
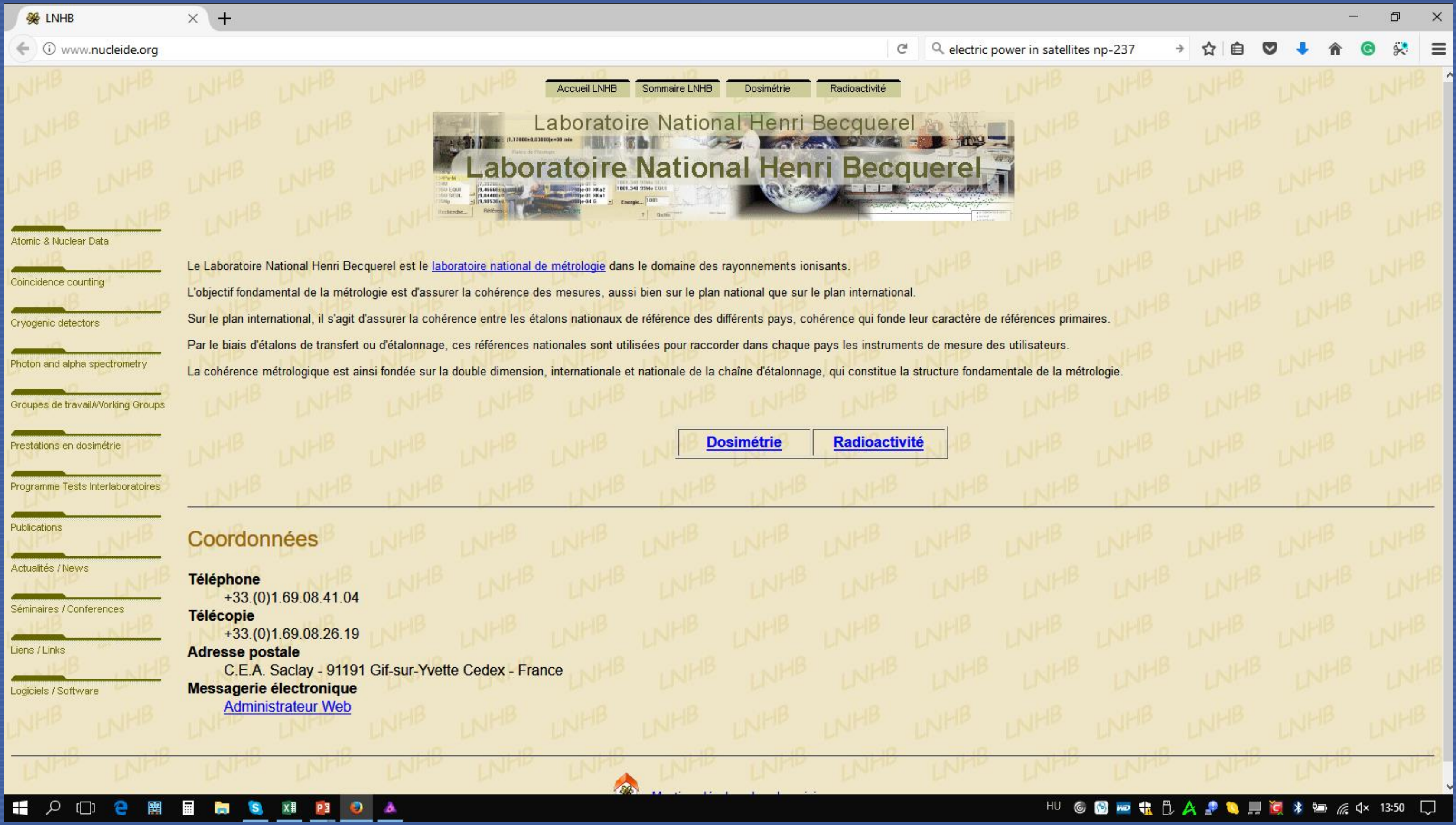
The ^{238}U decay series



Nuclear parameters for evaluation of measurement results



www.nucleide.org

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In situ „characterisation" process

Speed

Details

Aerial

- Large scale, rapid
- Approximately location and quantity
- Some limitation

Route m

- More precise location (qualitative information)
- Opportunity to mark the borders
- Precise dose rate mapping

In situ GSP

- Qualitative and quantitative information
- Inventory assessment, more reliable data service

Sampling and laboratory analysis

Aerial exploration

- Spatial distribution large scale overview
- Weak quality information
- Acceptable quantity information (more or less)
- Gamma dose rate conversion to the surface (1m height)
- Metrological aspect: traceability cannot be established

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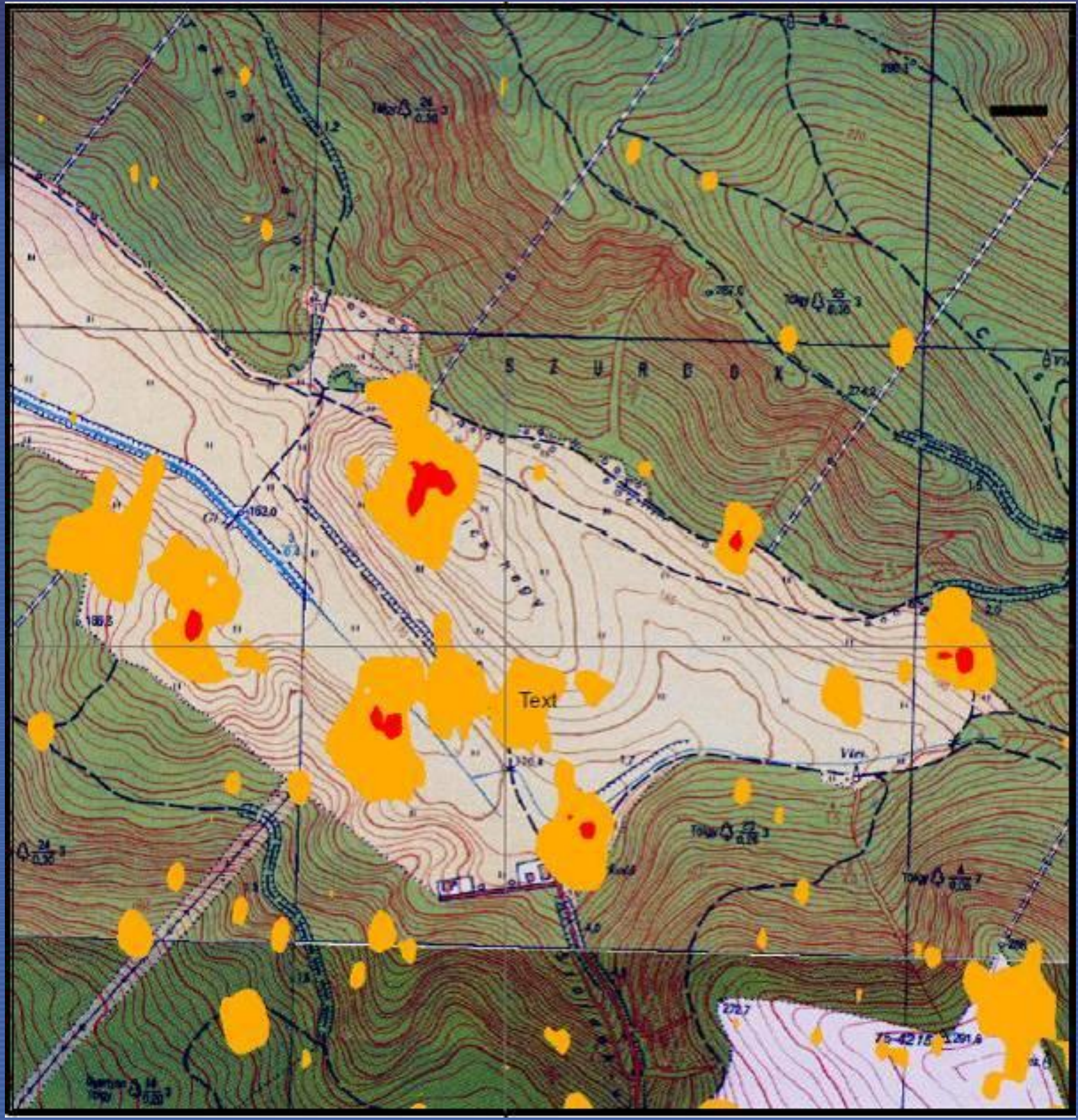
Large volume NaI(Tl) detector with active cosmic ray shield

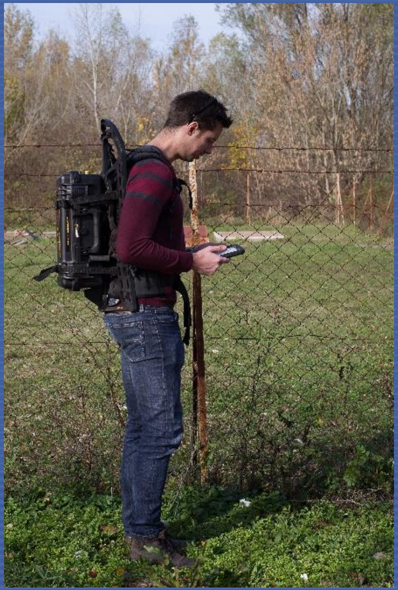
Results of the aerial scanning

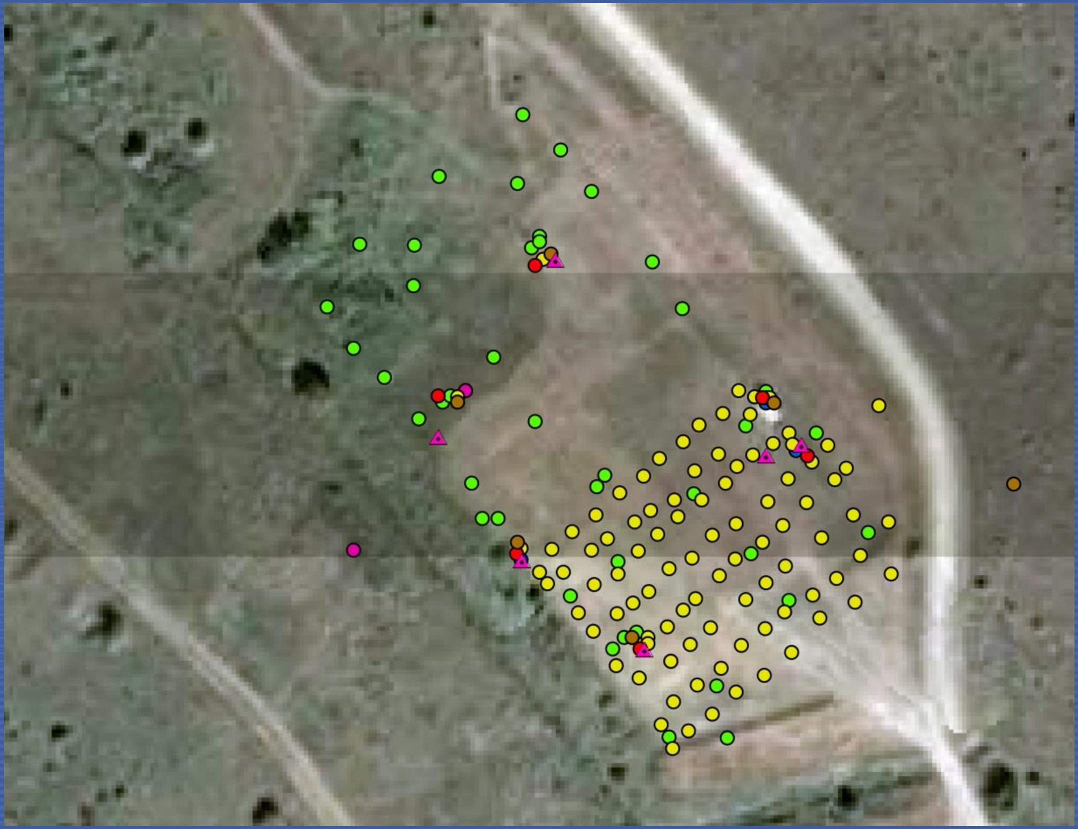
- 40 m elevation
- Gamma intensity map
- No any nuclide specific information



Surface exploration

- Two detector systems
  - sensitive but short time constant (for searching) 3"x3"NaI, LaBr, plastic (gross gamma information)
  - gamma dose rate measurement (non paralysable equipment)
- GPS, GIS
- (Sampling tools)





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Metrological aspect: traceability can be established partly

In situ gamma-ray spectrometry

General task:

Identification of isotopes
Inventory estimation

- HPGe detector system
  - fast electronics
  - 25-40 % relative efficiency
  - 180-3600 sec counting time
  - 1 m above the surface
- Prerequisite
  - calibrated detector
  - check list (system parts, battery, GPS, documentation tools) **handheld radiation monitors** (surface contamination monitor, gamma dose rate monitor, personal dosimeter)
  - decontamination tools
  - Map and task description

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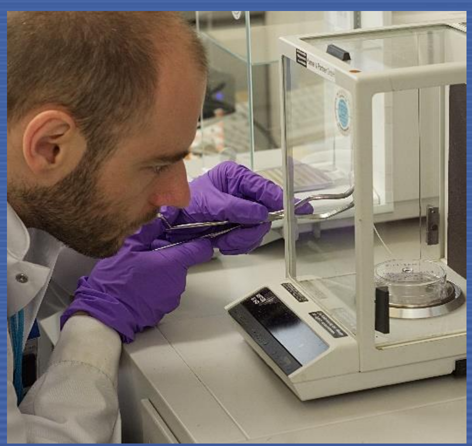
In situ gamma-ray spectrometry (2)

Metrological aspects (traceability):

Detector efficiency	+
Angular correction factor	+
Φ/A	model calculation only

In some cases, method validation can be achieved!

Large surface mosaic source for flat geometry



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Most frequently used detectors

- **For in-situ gamma-ray spectrometry**
  - NaI(Tl) scintillation detector
  - $LaBr_3$(Ce) scintillation detector
  - CZT (for high count rate)
  - HPGe detector

- **Surface exploration**
  - Plastic scintillator (large volume, on vehicle)
  - NaI(Tl), $LaBr_3$(Ce) scintillation detector
  - Gas ionising detectors (GM tube, gas-proportional detector)

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NaI(Tl)- HPGe detector

- NaI(Tl)
  - +
    - Excellent quantum efficiency
    - Relatively simple electronics
    - Working without cooling
    - Moderate price
    - Low background
  - –
    - Low resolution (7.5% at 661.67keV)
    - Sensitive for the high voltage drift
    - Thermic drift
    - Nonlinearity in energy scale

- HPGe
  - +
    - Excellent energy resolution
    - Linear energy scale (10^{-8})
    - Suitable for isotope identification
    - Low background
  - –
    - Less efficiency
    - Mechanical sensitivity
    - The price is not user friendly
    - Cooling required (LN_2 or electronic)

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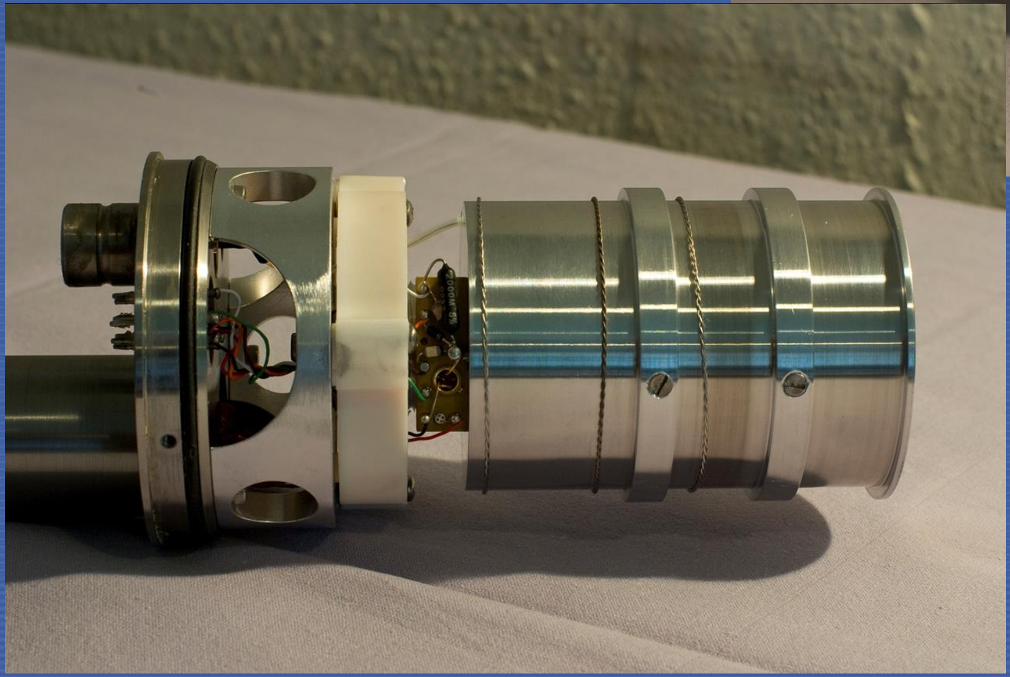
n-type HPGe detector



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$LaBr_3(Ce)$ detector

- +
  - Good energy resolution
    - 2.8% at 661.67keV
  - Efficiency (better than NaI(Tl))
  - Moderate price
  - Fast decay time
- -
  - Considerable background
  - Thermic drift
  - Nonlinearity in energy scale (10^{-5})

- Background
  - The naturally occuring ^{138}La radioactive ($T_{1/2}=103.6 *10^9$)
  - +^{227}Ac as a contamination
  - (0.5% Ce)

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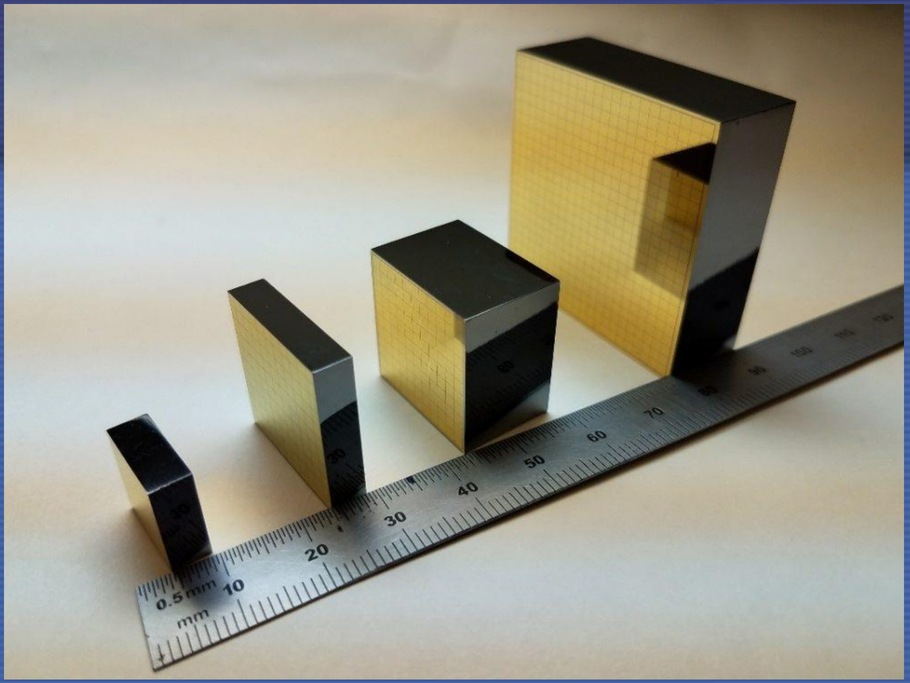
CZT detector

- Cadmium-Zink-Tellurid



- +
  - Good energy resolution
    - 1.3% (8.7 keV) at 661.67keV
  - Room temperature operation
  - High effective Z number
  - Efficiency is good, however the size is limited
- –
  - Long decay (fall) time
  - (rise time is 600 ns, fall time 700 micros)
  - Sensitive for the orientation
  - Price is about 2000 USD/cm^3

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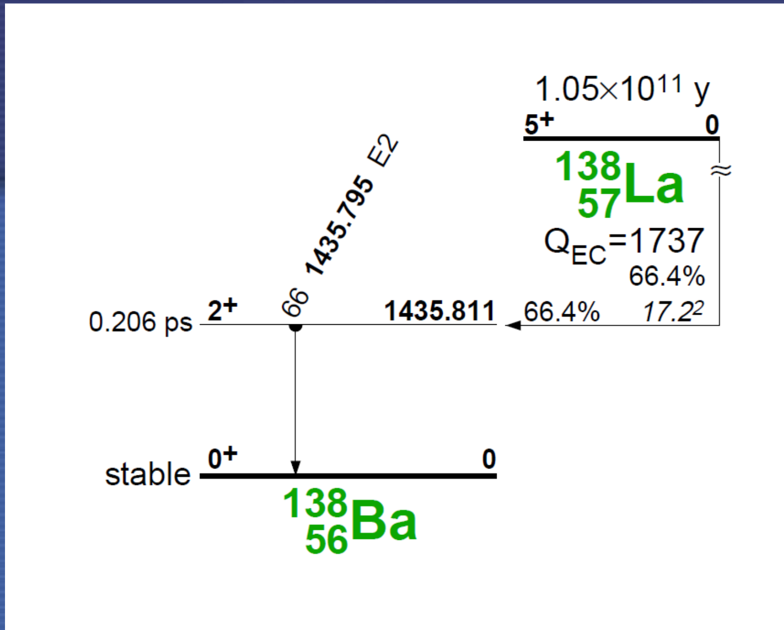
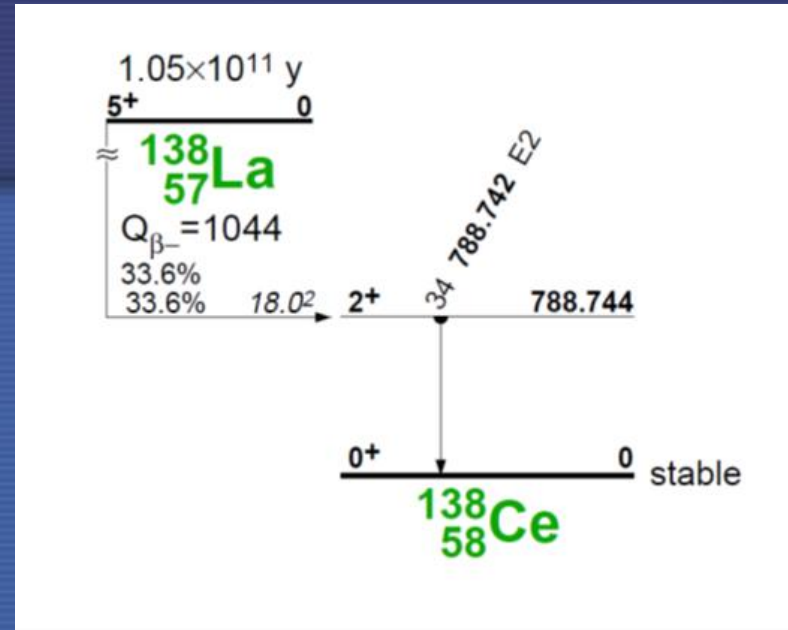
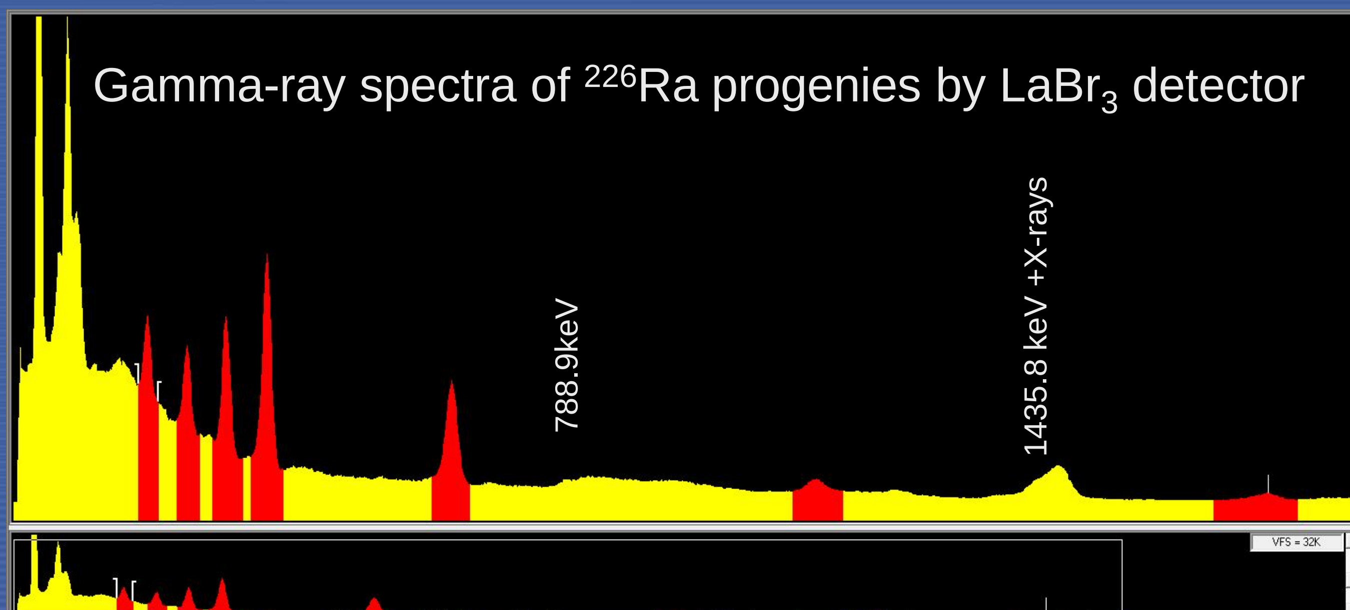

1.05×10[11] y
5+
0
138 57 La
QEC=1737
66.4%
1435.795 E2
66
0.206 ps
2+
1435.811
66.4%
17.2[2]
stable
0+
0
138 56 Ba


1.05×10[11] y
5+
0
138 57 La
Qβ–=1044
33.6%
33.6%
18.0[2]
788.742 E2
34
2+
788.744
0+
0
stable
138 58 Ce


Gamma-ray spectra of 226Ra progenies by LaBr3 detector
788.9keV
1435.8 keV +X-rays
VFS = 32K

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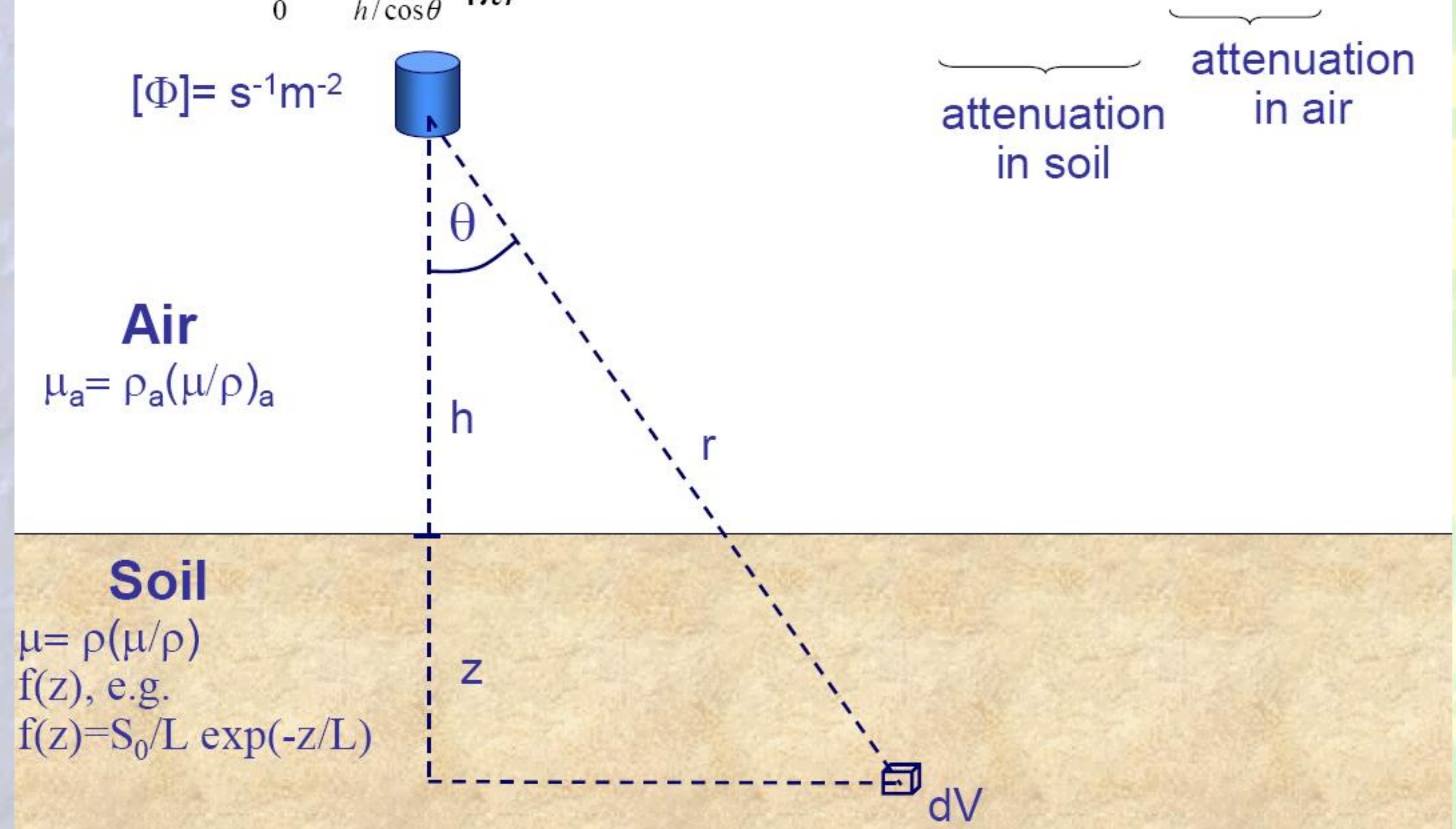
The Φ/A_s

Theoretical model for photon flux calculation

$$\Phi = \int_{0}^{\pi/2} d\theta \int_{h/\cos\theta}^{\infty} \frac{S_0}{4\pi r^2} e^{-z/L} \cdot 2\pi r^2 \sin\theta \cdot e^{-\mu(r-h/\cos\theta)} \cdot e^{-\mu_a h/\cos\theta}\, dr$$



Calculation of unscattered photon flux for different radionuclide depth distributions

Exponential

$$\Phi = \frac{1}{2} S_0 \left\{ E_1(\mu_a h) - e^{\frac{\mu_a}{\mu}\frac{h}{L}} E_1\left[\left(1 + \frac{1}{\mu L}\right)\mu_a h\right] \right\}$$

Uniform

$$\Phi = \frac{1}{2} S_V \frac{\mu_a}{\mu} \left[\frac{1}{\mu_a h} e^{-\mu_a h} - E_1(\mu_a h) \right]$$

Plane

$$\Phi = \frac{1}{2} S_0 \, E_1(\mu_a h)$$

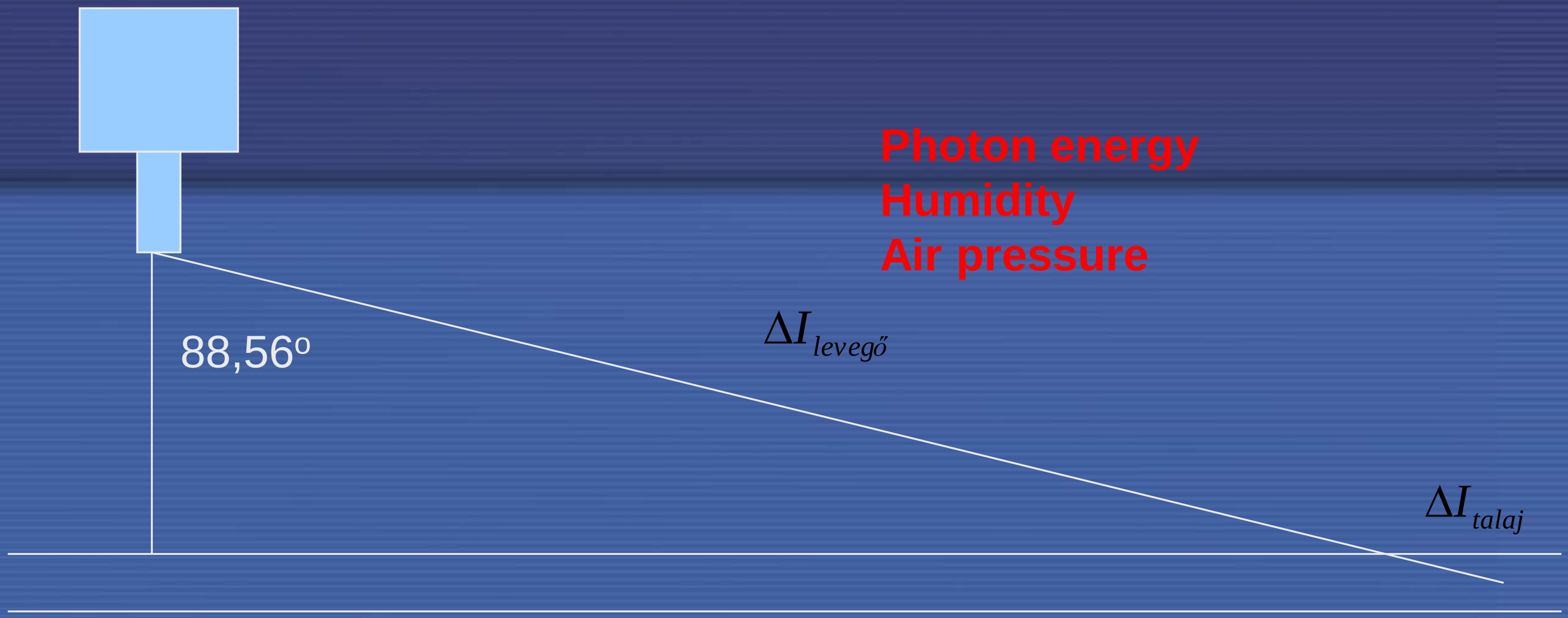
The function $E_1(x)$ is the 1st order exponential integral

$$E_1(x) = \int_x^{\infty} \frac{e^{-t}}{t} dt$$

Series expansion

$$E_1(x) = -\gamma - \ln x - \sum_{n=1}^{\infty} \frac{(-1)^n x^n}{n \, n!}$$

$$\gamma = 0.57721\,56649\ldots$$



Photon energy
Humidity
Air pressure

40 m

Vertical distribution

Conditions

Soil characteristic and composition:

O:	57.5%
Al:	8.5%
Si:	26.2%
Fe:	5.6%
Ca, Mg, etc.:	2%

Density: 1.06-1.6 kg/dm^3

Dry content

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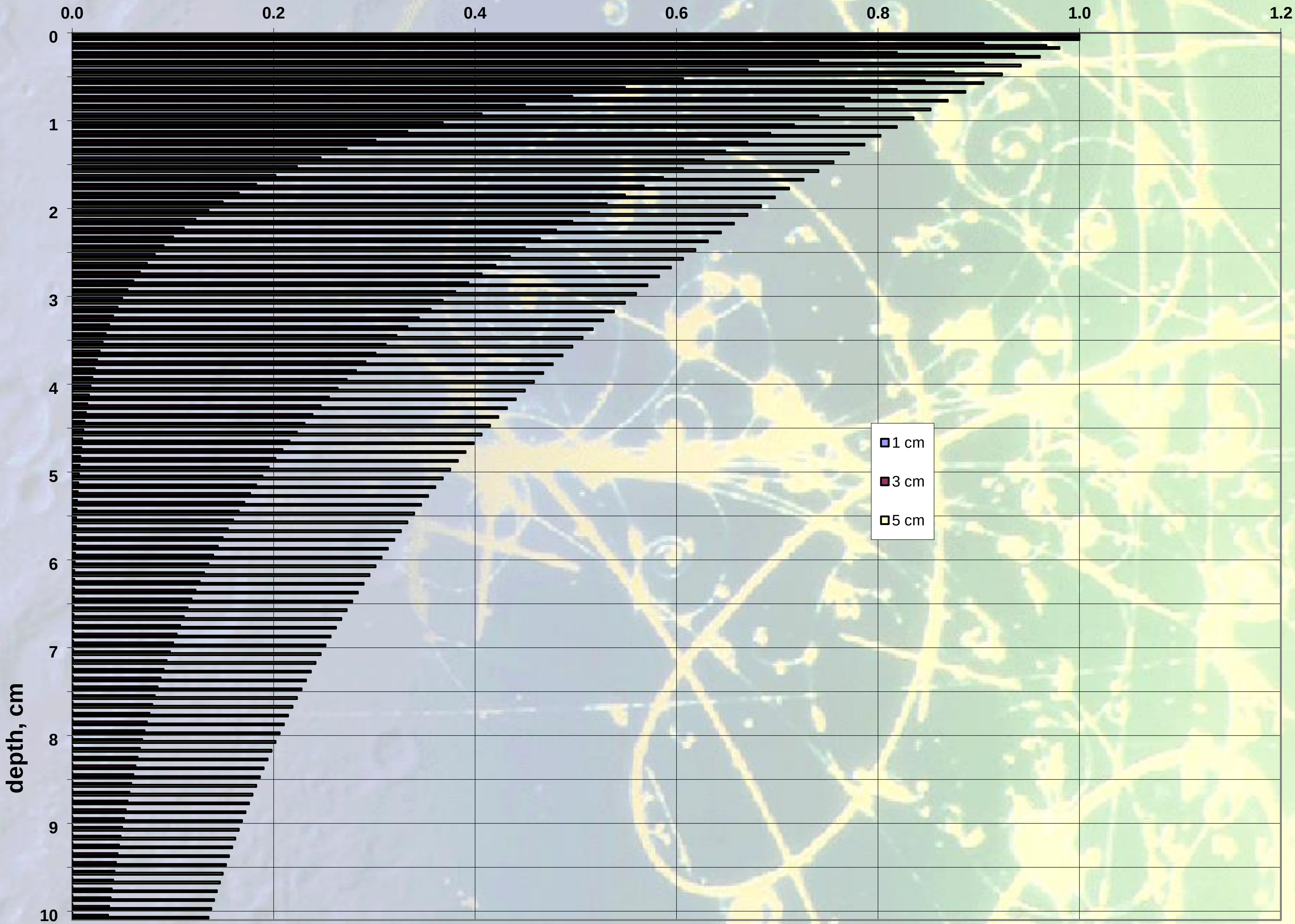
Vertical distribution in case of different relaxation length



The meaning of the relaxation length, L

Vertical distribution		L, cm			
		1 cm	2 cm	3 cm	5 cm
Depth	1 cm	**0.632**	**0.393**	**0.283**	**0.181**
	2 cm	0.233	**0.239**	**0.204**	**0.149**
	3 cm	0.085	0.145	**0.145**	**0.121**
	4 cm	0.032	0.088	0.104	**0.1**
	5 cm	0.011	0.053	0.075	**0.081**
	10 cm	0.007	0.082	0.153	0.233
	15 cm			0.036	0.085
	20 cm				0.032
	25 cm				0.011

The effect of the detector position and soil density ^{137}Cs, l=3cm

Soil density: 1.05 kg/dm^3			
	95 cm	100 cm	105 cm
Efficiency	1.34E-04	1.33E-04	1.32E-04
a, Bq/m^2	1771	1777	1786
Soil density: 1.6 kg/dm^3			
a, Bq/m^2		2317	

Effect of the relaxation length
a, Bq/m^2

L, cm	1,05 kg/dm^3	1,6 kg/dm^3
1	1005	552
2	1276	1571
3	1777	2317
5	2302	3128

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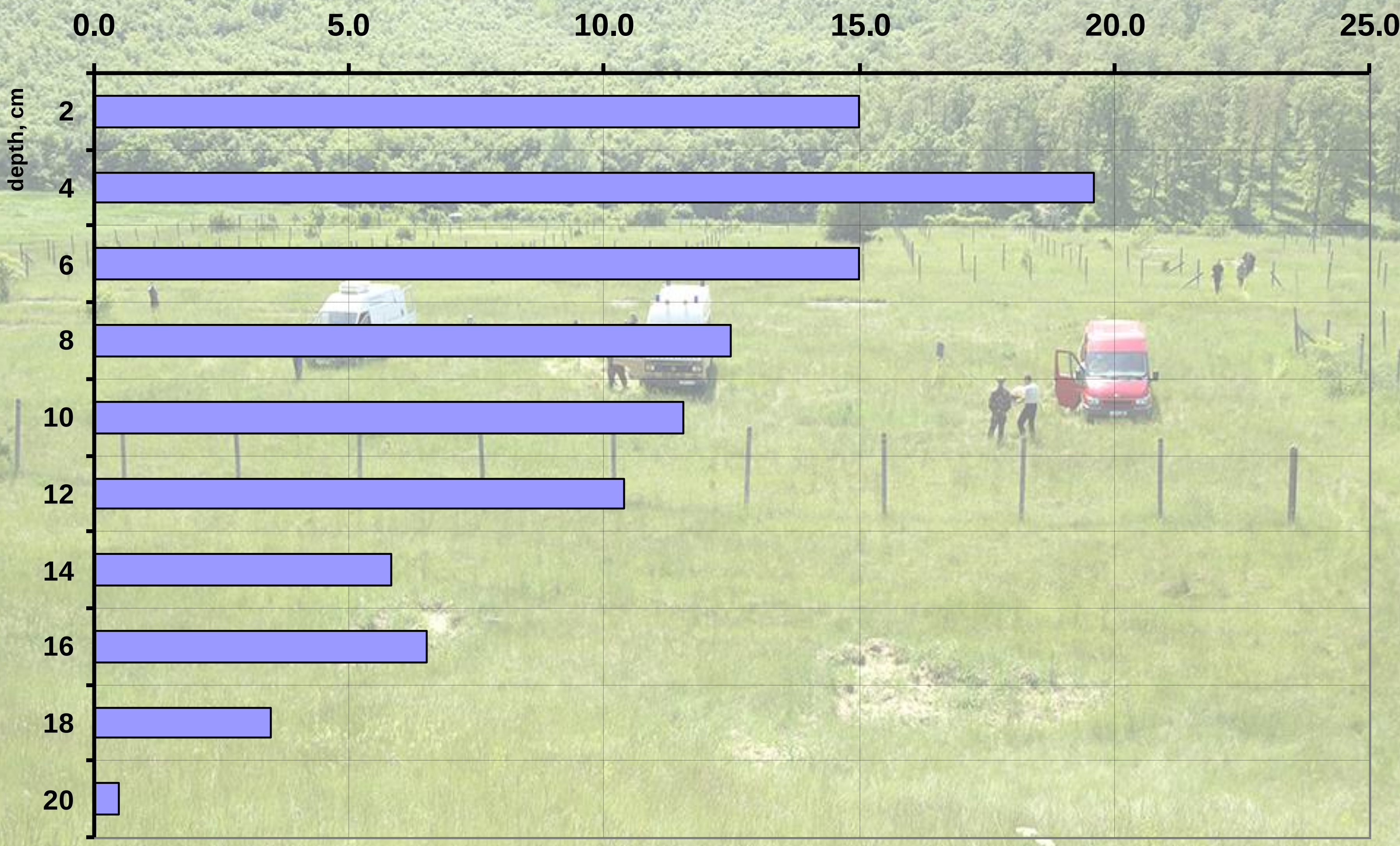
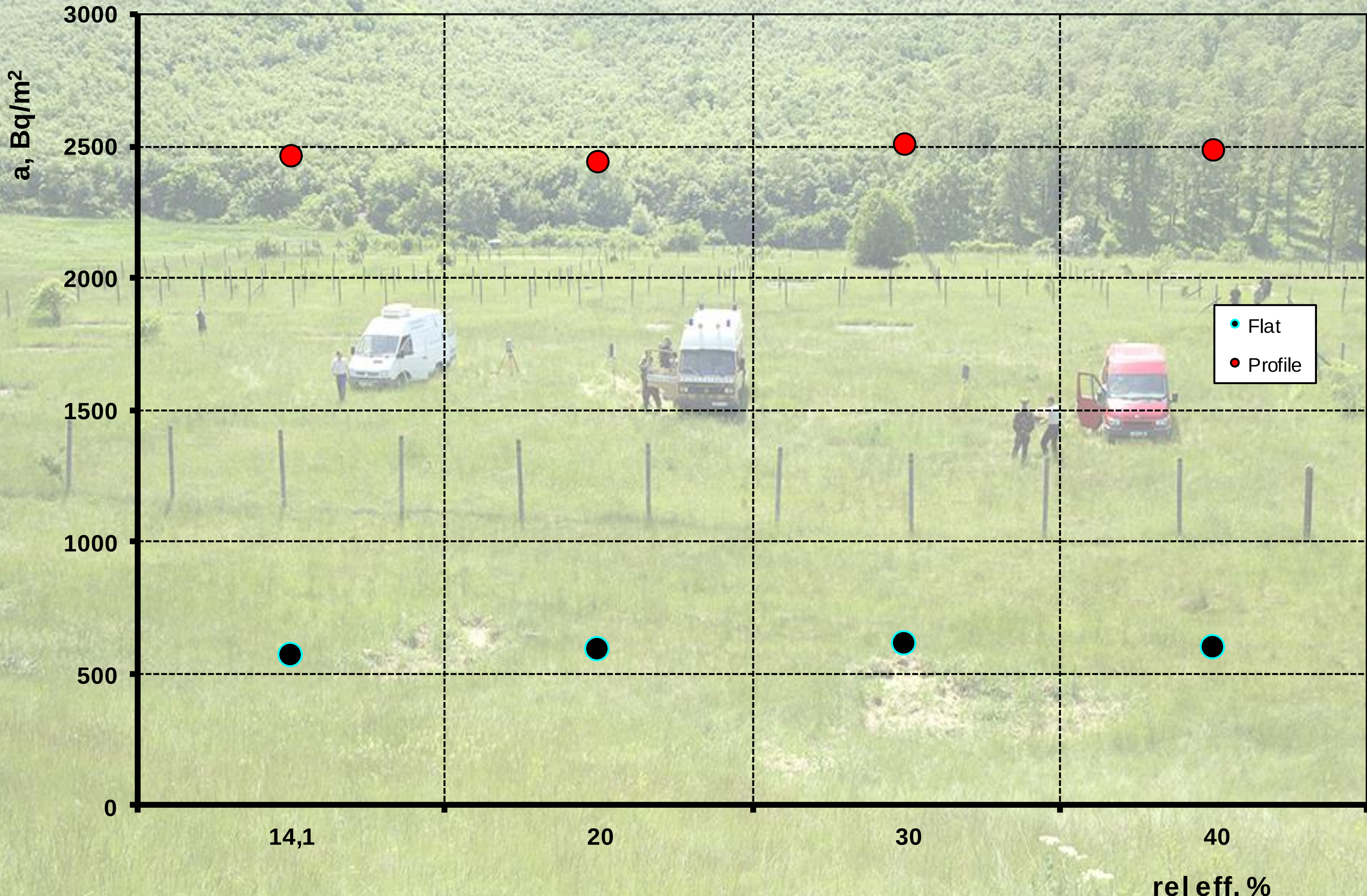
Vertical distribution of Cs-137 (%), at the site of in-situ measurement



Results calculated by two different wertical distribution

(using a HPGe detector modell for semi infinitve flat and real vertical distribution)

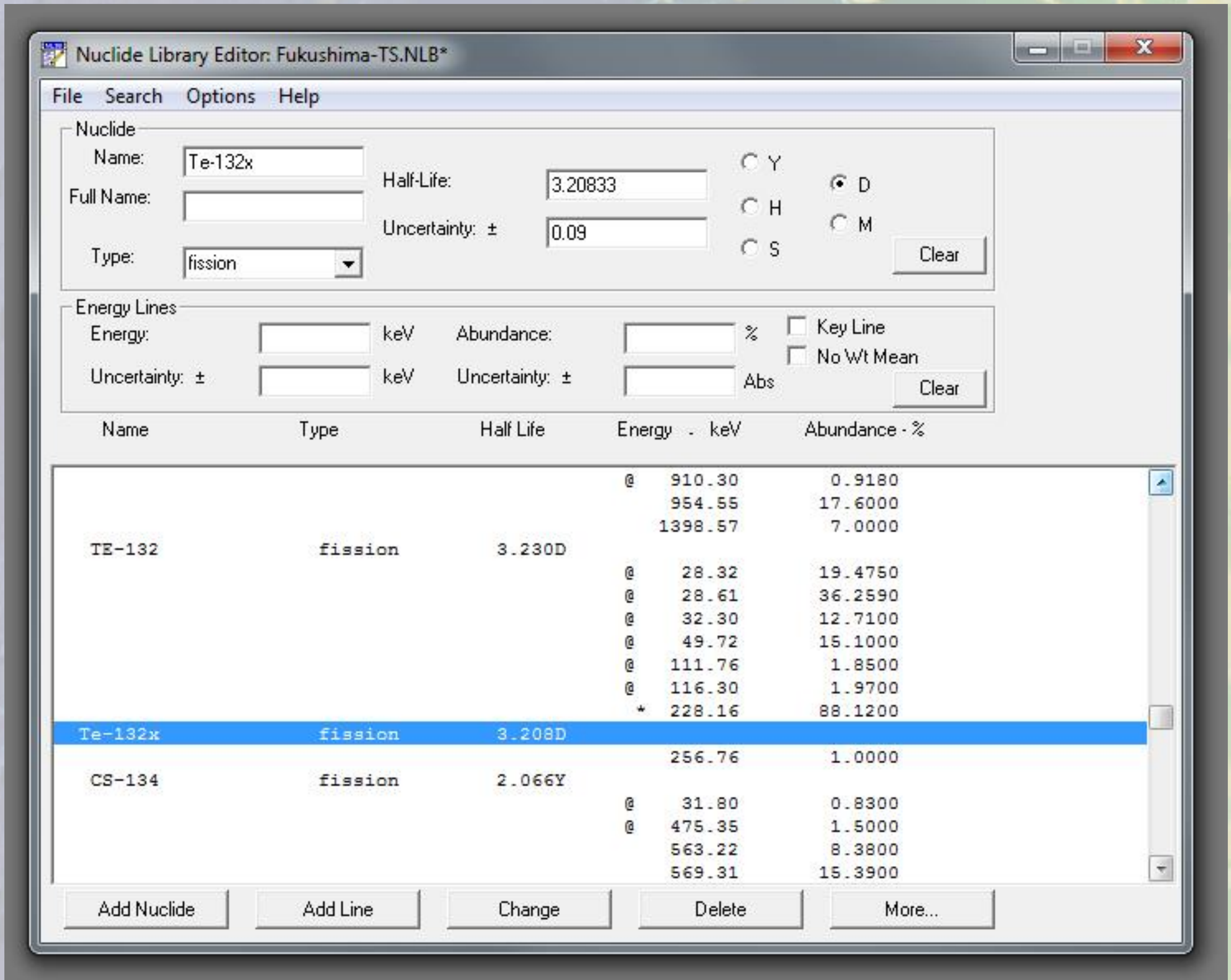


Possibilities

- Manual calibration and calculations
  - Time consuming
  - Required several high activity calibration sources
  - Difficult to use it if the conditions are changed
- Software solutions
  - ISOCS or equivalent software necessary
  - a characterized detector is required (expensive)
  - Flexible
  - Fast

Measurement and spectra evaluation

- Energy calibration
- Background measurement (if necessary, detector bkg)
- Isotope identification (working library)
- Activity calculation
  - using the appropriate efficiency curve for the given vertical distribution (man made pollutant, Cs-137, Cs-134)
  - using the efficiency curve for the homogeneous distribution (NORM: U, Th, K)


Nuclide Library Editor: Fukushima-TS.NLB*
File Search Options Help
Nuclide
Name: Te-132x
Full Name:
Type: fission
Half-Life: 3.20833
Uncertainty: ± 0.09
Y
H
S
D
M
Clear
Energy Lines
Energy: keV
Uncertainty: ± keV
Abundance: %
Uncertainty: ± Abs
Key Line
No Wt Mean
Clear
Name Type Half Life Energy - keV Abundance - %
@ 910.30 0.9180
954.55 17.6000
1398.57 7.0000
TE-132 fission 3.230D
@ 28.32 19.4750
@ 28.61 36.2590
@ 32.30 12.7100
@ 49.72 15.1000
@ 111.76 1.8500
@ 116.30 1.9700
* 228.16 88.1200
Te-132x fission 3.208D
256.76 1.0000
CS-134 fission 2.066Y
@ 31.80 0.8300
@ 475.35 1.5000
563.22 8.3800
569.31 15.3900
Add Nuclide
Add Line
Change
Delete
More...

Genie2k and ISOCS

- To be installed „INSPECTOR" version
  - The hardlock is not required
  - The spectra collection works only with portable CANBERRA analysers
- GeometryComposer
  - It is a standard accesorry of the software package
  - It can works with the Genie2k on interactive way when the ISOCS utility is installed
- The detector characterisation dataset should be installed also
- There is a „demo" detector database ☺
- Libraries
- Interactive peak fit