The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2064-3

Joint ICTP/IAEA Advanced School on in-situ X-ray Fluorescence and Gamma Ray Spectrometry

26 - 30 October 2009

Calibration of the detectors/Source of contamination (assumption of vertical distribution)

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In Situ Gamma Ray Spectrometry

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Joint ICTP/IAEA Advanced School on in-situ X-ray Fluorescence and Gamma Ray Spectrometry

Trieste – Italy, 26-30 October 2009

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Schedule for today

- The position and role of the in situ gamma ray spectrometry
- Calibration and disturbing effect
- Spectrum evaluation
- QA

General tasks of the environmental monitoring unit during emergency situation

- **Airborne exploration**
  - Spatial distribution large scale overview
  - Week quality information
  - Acceptable quantity information
    - Gamma dose rate conversion to the surface (1m height)


Gamma-probe

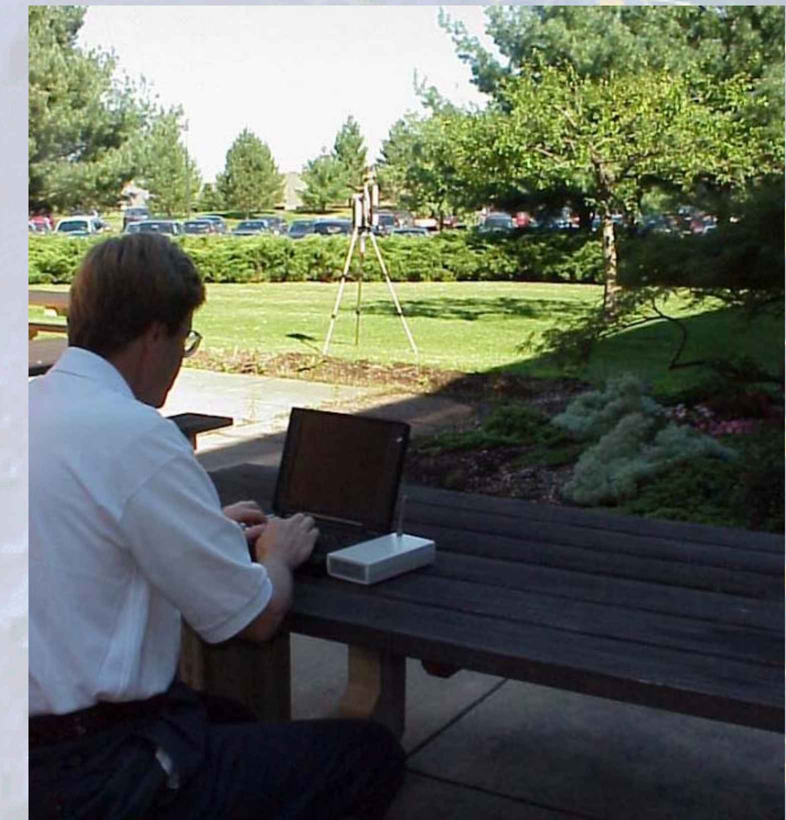
- **Surface monitoring by mobile units**
  - Detailed spatial distribution, exact location (1-5 m)
  - More precise quality and quantity information
    - Identification of radionuclide
    - Determination of the inventory (Bq/m^2, Bq/kg)
  - Sampling

- **Laboratory**
  - Exact quality and quantity determination
    - Gamma ray spectrometry
    - Chemical treatment of the samples and
      - Alpha spectrometry
      - Beta measurement (LSC, LSS)

- **Recommended facilities for mobile units**
  - **Route monitoring (for searching)**
    - GPS
    - High sensitivity gamma ray detector
      - Large volume plastic (10-40 L)
      - NaI(Tl) 4”x4”
    - Short time constant (max 5 s synchronized to the GPS point recording frequency)
  - **Gamma dose rate meter**
    - Sensitivity : 10 nSv/h-10 mSv/h
      - 3”x3” plastic 1 nSv/h-0.1 mSv/h
    - Non paralyzable
  - **Surface contamination monitor**

- **Recommended facilities for mobile units**
  - **In situ gamma ray spectrometer**
    - Detector : HPGe
    - Rel.eff. : 15-35% (1332.5 keV Co-60)
    - Compact, robust, solid state
    - **p-type** (over 100 keV or **n-type** from 10 keV)
    - Preamplifier
      - Should be fast (50000-100000 cps)
      - TRS
    - Analyzer
      - Digital (fast, fix conversion time)
      - Analog (still exist, good linearity but slow)
  - **New trend:** compact analyzer with build in detector and electro-cooling system

InSpector-2000 and RF modem



*digi*DART™
Portable HPGe MCA

Falcon 5000 Portable HPGe-Based Nuclear Identifier

PERFORMANCE

- ENERGY RANGE –
  - HPGe – 30 keV – 3.0 MeV.
  - GM TUBE – 30 keV to 1.4 MeV.
- FWHM FOR 20% BEGe DETECTOR –
  - <2.0 keV at 1332 keV.
  - <1.0 keV at 122 keV.
- ELECTRICAL COOLER –
  - TYPE – Pulse Tube Cooler.
  - TIME TO COOL DETECTOR – Three hours at 25 °C (77 °F).
  - WARRANTY – Five years; prorated.
- GPS
- MCA –
  - CHANNELS 256 – 8192 channels.
  - LIVE TIME CORRECTION – Live Time Correction (LTC) of spectral data.
  - Input Count Rate >500 kcps.
  - PRESETS – Live time (or real time) preset 1 to 10^6 seconds.
  - High Voltage Inhibit - High voltage is automatically inhibited until the detector has reached operating temperature.

CONTROLLER

- HARDWARE – Tablet PC.
- OPERATING SYSTEM – Windows XP.
- DISPLAY – 1024 x 768 color display.
- COMMUNICATION WITH INSTRUMENT – Wireless Communication - 802.11g Wi-Fi.
  - Security by WEP or WPA 32 bit encryption. (Wireless lockout available for Wired communication only mode).
  - Wired Communication – RJ-45 (Ethernet cable).
- SPECTRUM UPDATE – Two seconds per 8k spectra.

SOFTWARE

Functions

- Dose.
- Locate.
- Spectrum.
- Identification Functions.
- Dose Alarm (Continuously monitored with configurable set point, audio alert and visual indication).
- Genie 2000 Basic Spectroscopy and Gamma Analysis packages included.
- Radionuclide Identification algorithms are user configurable. Nuclide Library, Identification Algorithm, measurement geometry and other adjustable parameters are predefined in Genie 2000 .ASF file (Analysis Sequence File).
- NUCLIDE LIBRARY – Configurable Library with Full Nuclide Editor (Default Library based on ANSI N42.34 specification).
- Secondary Analysis for SNM identifications to specify isotopic classification (RGPu, WGPu, HEU, DU…).
- ISOCS detector characterization available for numerical calibration and activity quantification of unique measurement geometries.

ORDERING INFORMATION

- F5000-20 – Falcon 5000 with 20% BEGe detector, S513 software and hard case.
- Includes:
  - 20% BEGe type HPGe detector.
  - One internal Li-Ion battery for four hours of detector operation (Falcon accepts up to two batteries).
  - S504 and S501 Basic Spectroscopy package and Gamma Analysis.
  - Falcon accessories such as cables, carrying case, shoulder strap, AC adapter and user manuals.
  - Hard carrying case.
  - (Requires controller below).
- F5000N-20 – Falcon 5000 with 20% BEGe detector, moderated neutron detector, S513 software and hard case.
  - 20% BEGe type HPGe detector.
  - Moderated neutron ^3He detector.
  - One internal Li-Ion battery for four hours of detector operation (Falcon accepts up to two batteries).
  - S504 and S501 Basic Spectroscopy package and Gamma Analysis.
  - Falcon accessories such as cables, carrying case, shoulder strap, AC adapter and user manuals.
  - Hard carrying case.
  - (Requires controller below).
- F5000COMP/RUG – Falcon 5000 Control Computer – Rugged xPlore iX104 equivalent.
- F5000COMP/UM – Falcon 5000 Control Computer – Mobile Sony® UX180P equivalent.

OPTIONAL ACCESSORIES

- F5000COL – Falcon 5000 screw-on tungsten collimator.
- ISXCF5K – ISOCS/LabSOCS Characterization for the Falcon 5000. Requires S573 ISOCS or S574 LabSOCS™ calibration software.
- F5000INTBAT – Falcon 5000 spare internal rechargeable Li-Ion battery.
- F5000BATCHARG – AC charger for one spare Li-Ion batteries outside Falcon 5000.

CE

ISO 9001 SYSTEM CERTIFIED

Calibration of the in situ gamma ray spectrometer

Basic principle

- IAEA TEC DOC 1092

where:

- A_s = surface contamination kBq/m^2 (inventory)
- N = peak area
- N_b= background
- t = spectrum collecting time, live time (s)
- P_γ= gamma photon emission probability (E, nuclide)

$$A_s(kBq/kg) = \frac{10 \cdot (N - N_b)}{C_f \cdot t \cdot P_\gamma}$$

- **C_f** = calibration factor (cm^2)

Detector calibration factor

$$C_f = \frac{R_f}{A_s} = \left(\frac{R_f}{R_0}\right)\left(\frac{R_0}{\Phi}\right)\left(\frac{\Phi}{A_s}\right)$$

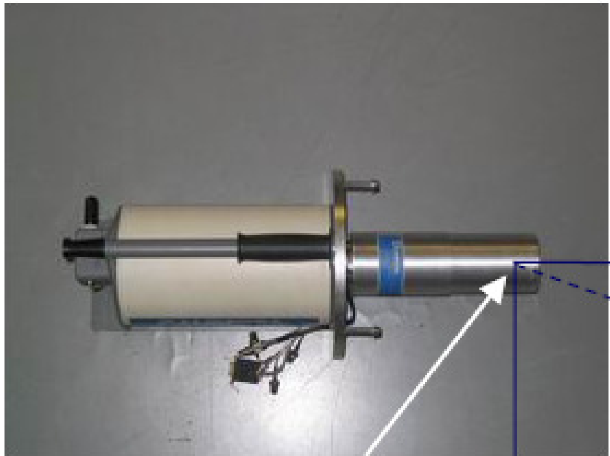
angular correction factor – correction factor required to account for the detector angular response

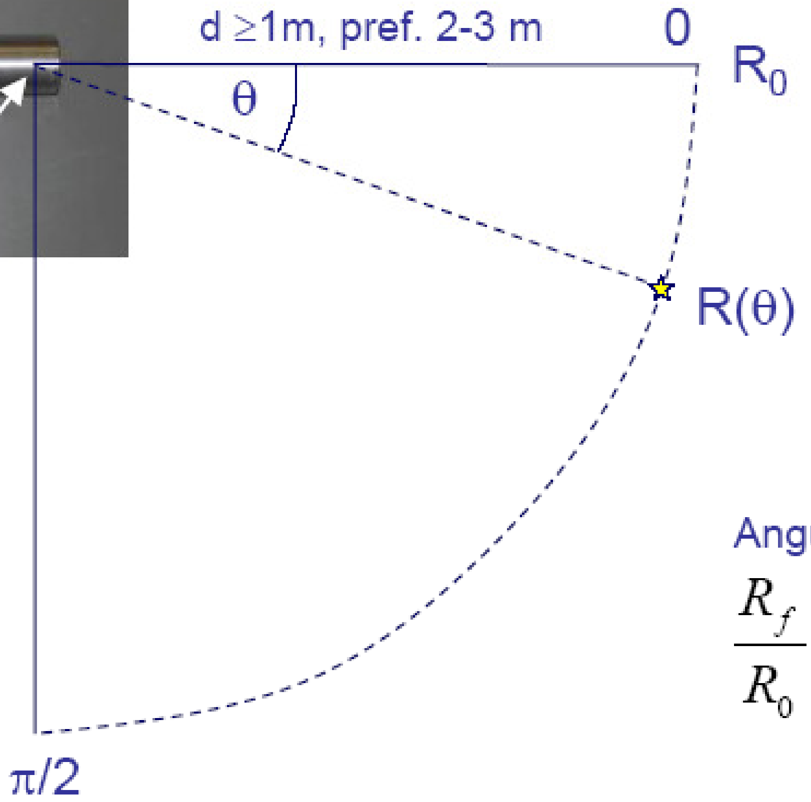
response factor - neat peak count rate due to a unit primary photon flux density of energy E incident on the detector (normal to the detector face)

geometrical factor – total photon flux density at the detector per unit concentration or deposition inventory of the radionuclide

R_f= net count rate

Calibration – detector characteristics





R(θ) – net count rate in a full-energy peak, at angle θ

Flux at the detector's effective center:

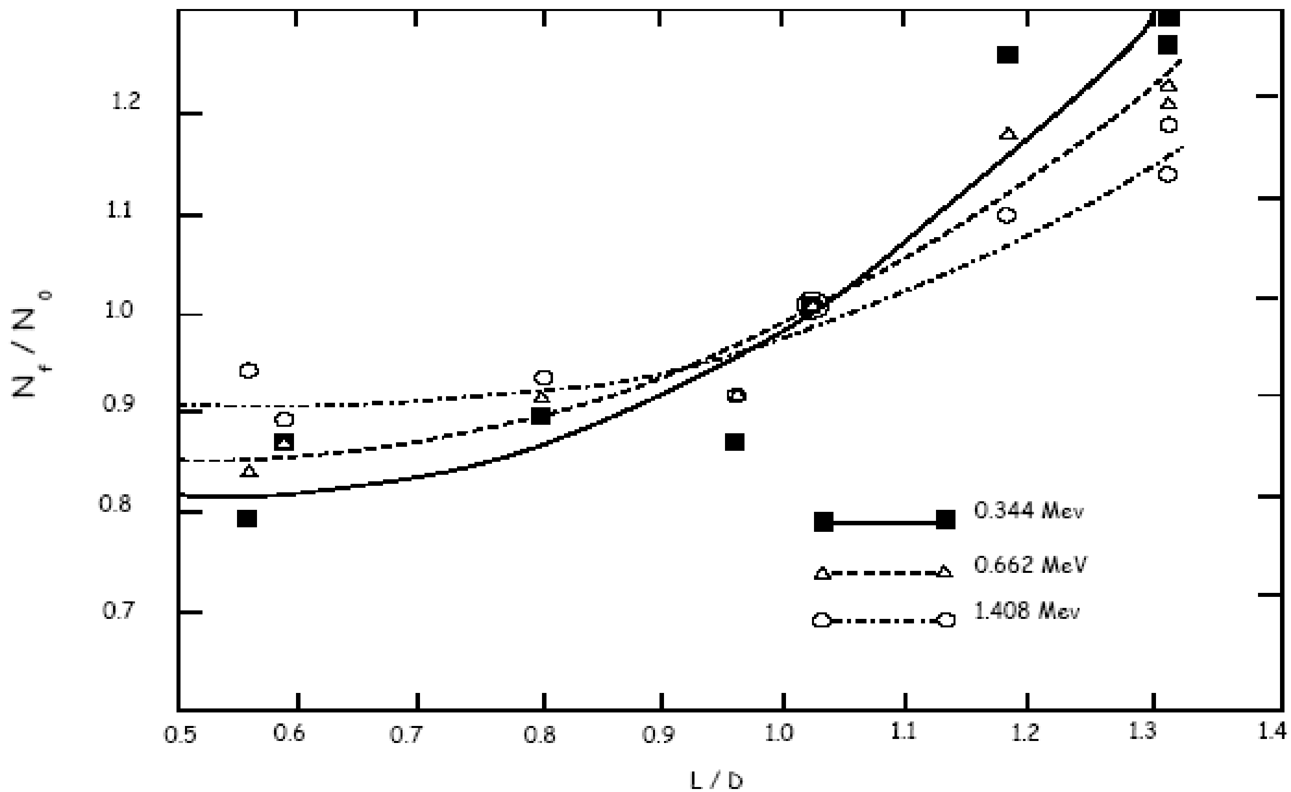
$$\Phi_0 = \frac{AI_\gamma}{4\pi r^2} e^{-\mu_a (r-x)}$$

Angular correction factor:

$$\frac{R_f}{R_0} = \int_0^{\pi/2} \frac{\Phi(\theta)}{\Phi} \frac{R(\theta)}{R_0} d\theta$$

Angular correction factor

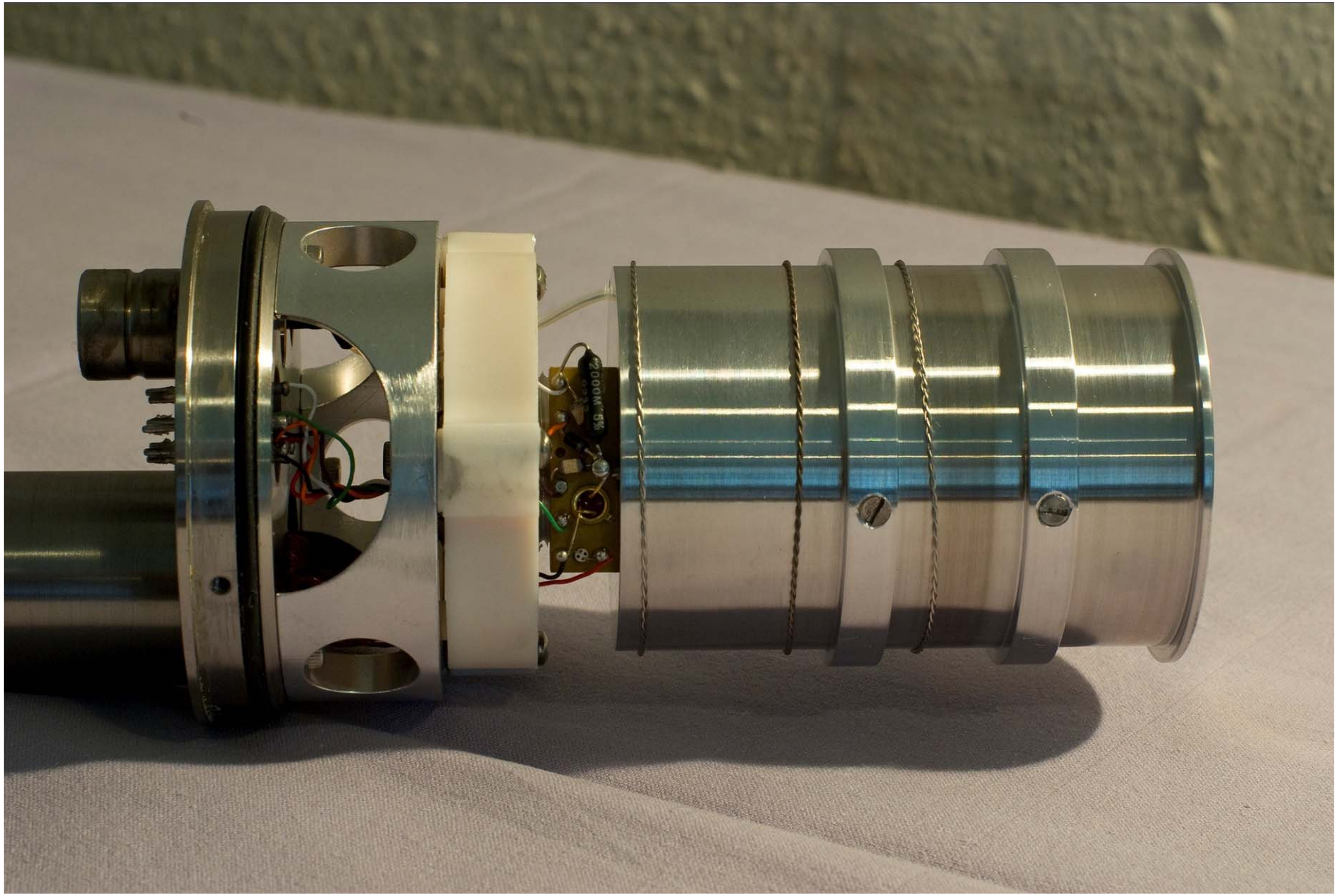
Angular correction factor R_f/R_0 as a function of Ge crystal length/diameter L/D ratio at three different energies for a downward facing detector for a uniform with depth source profile in the soil.



Clearly detector parameters:

- Detector efficiency, R_o/Φ
- Angular correction factor, R_f/R_o
- Function of the:
  - Energy, keV
  - Size of the detector
  - Type of the detector (p, n, or XTRa)
  - Internal structure of the detector

n-type HPGe detector

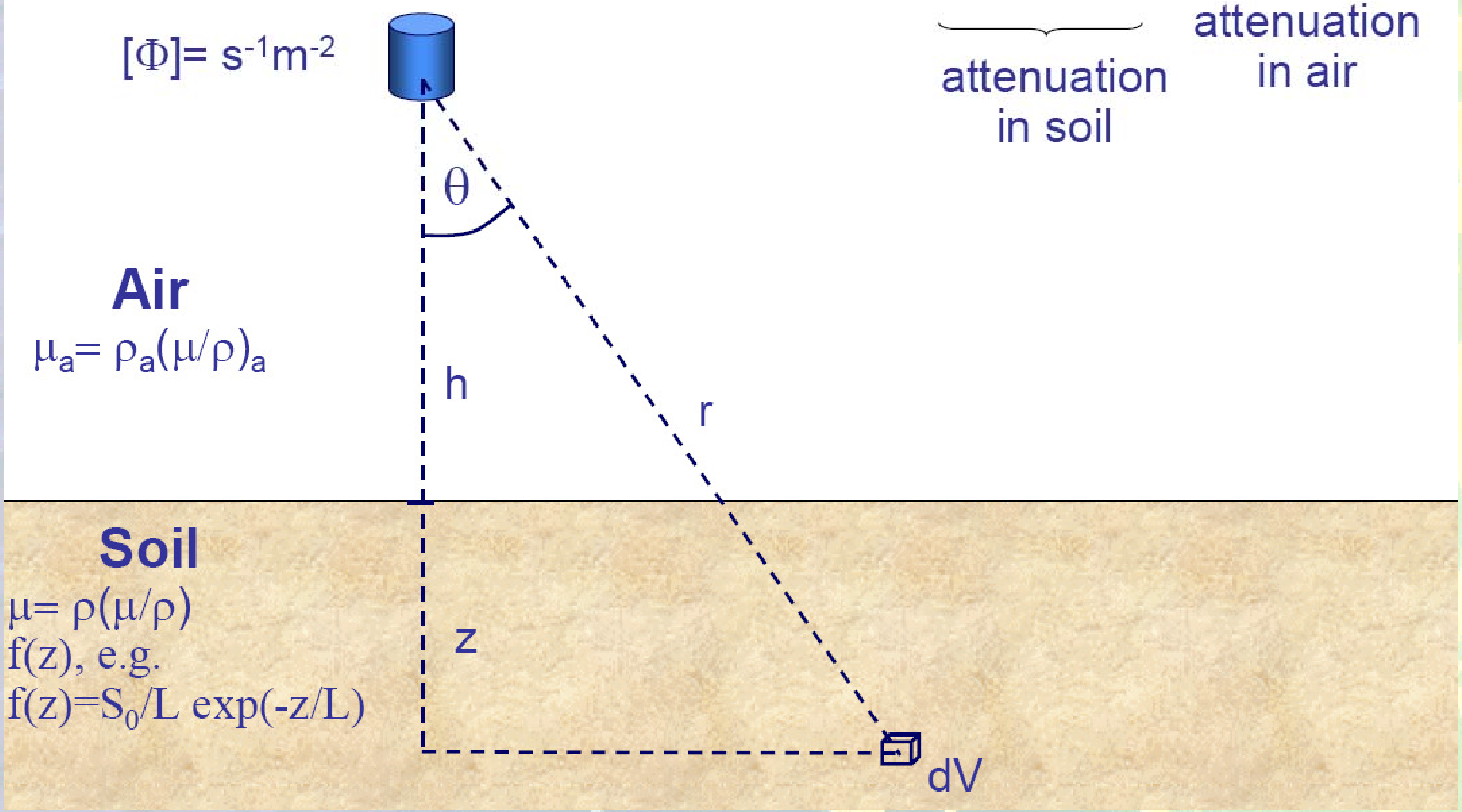


n-type HPGe detector

The Φ/A_s

Theoretical model for photon flux calculation

$$\Phi = \int_0^{\pi/2} d\theta \int_{h/\cos\theta}^{\infty} \frac{S_0}{4\pi r^2} e^{-z/L} \cdot 2\pi r^2 \sin\theta \cdot \underbrace{e^{-\mu(r-h/\cos\theta)}}_{\text{attenuation in soil}} \cdot \underbrace{e^{-\mu_a h/\cos\theta}}_{\text{attenuation in air}} \, dr$$



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

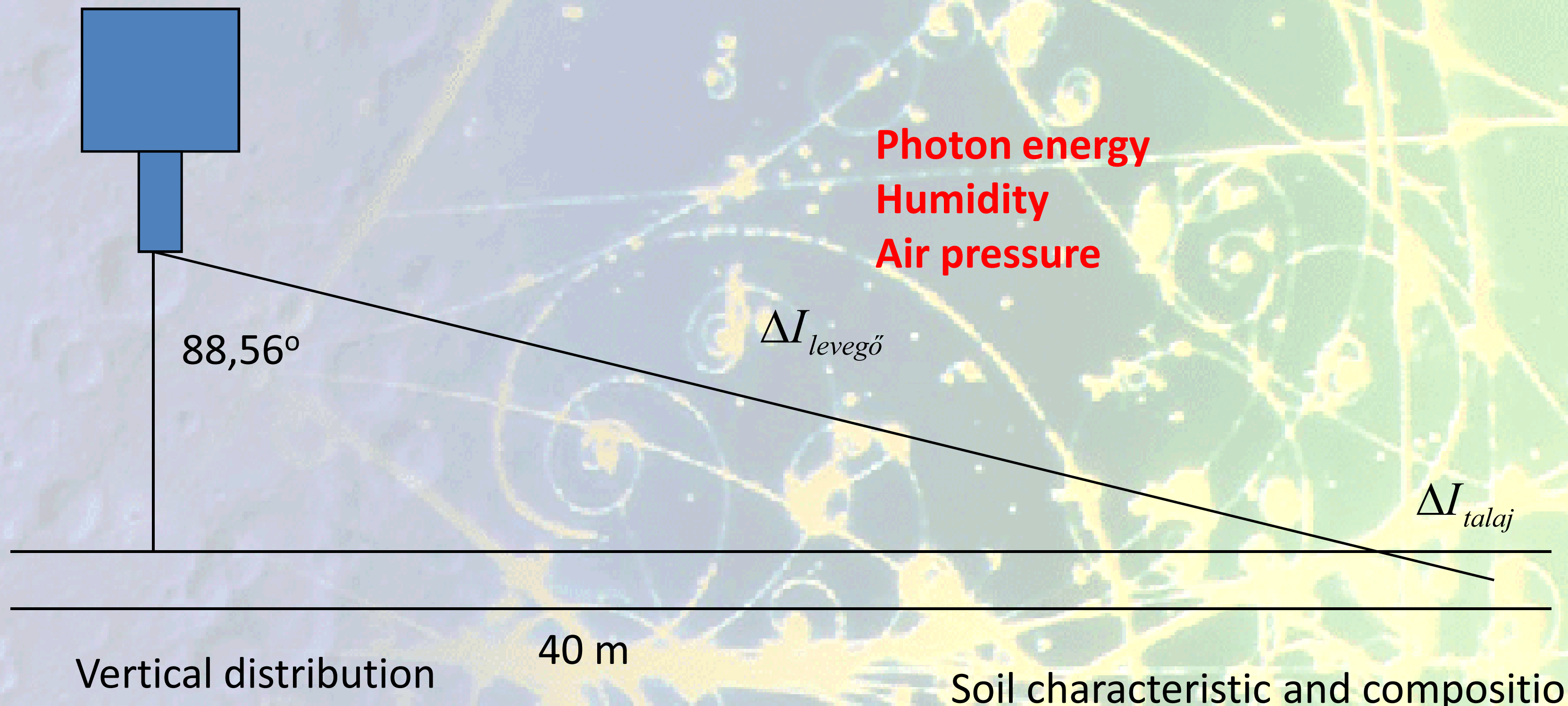
$$E_1(x) = \int_x^\infty \frac{e^{-t}}{t} dt$$

Series expansion

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

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

Disturbing effects



Photon energy
Humidity
Air pressure

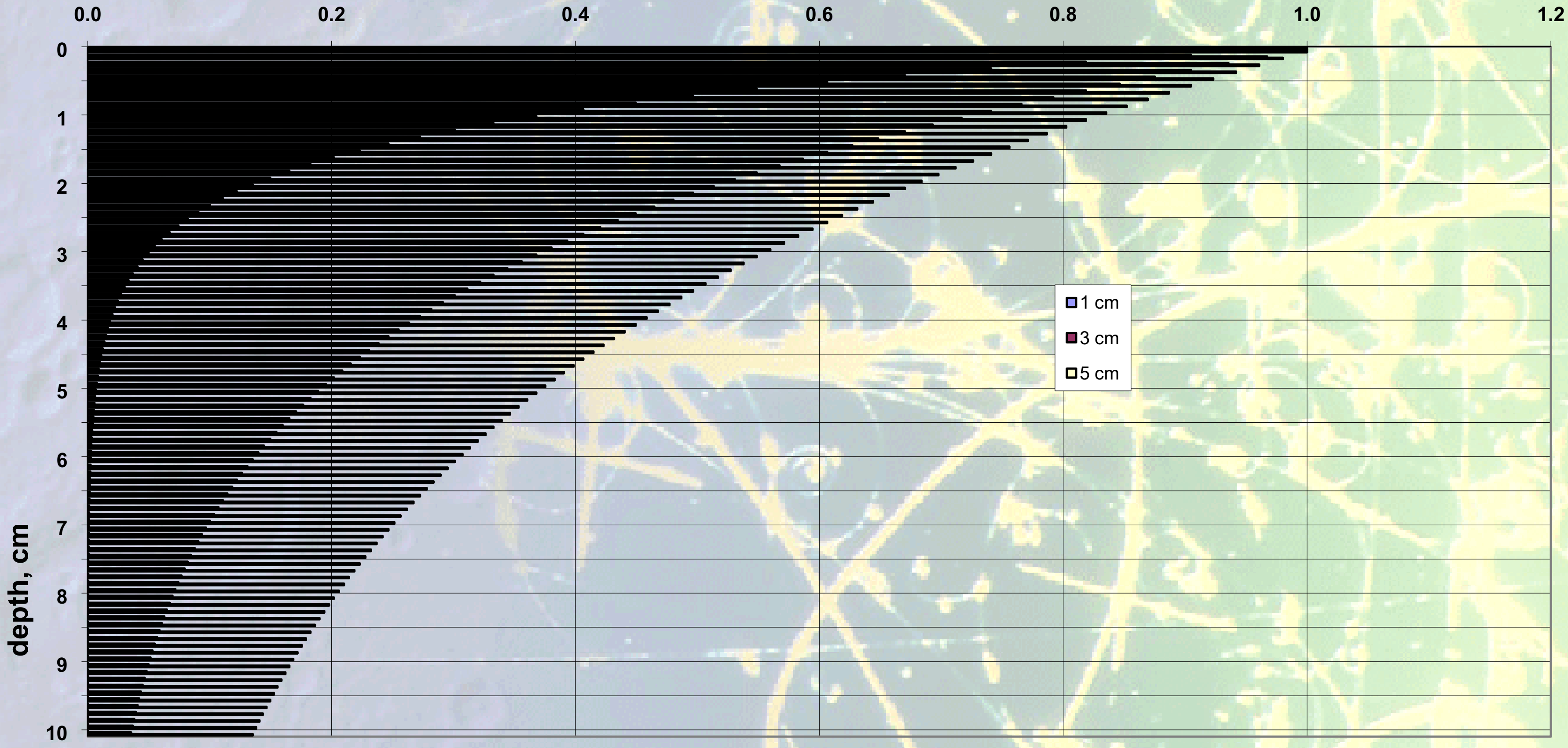
Soil characteristic and composition:

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

Density: 1.06-1.6 kg/dm^3

Dry content

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

Effect of the relaxation length

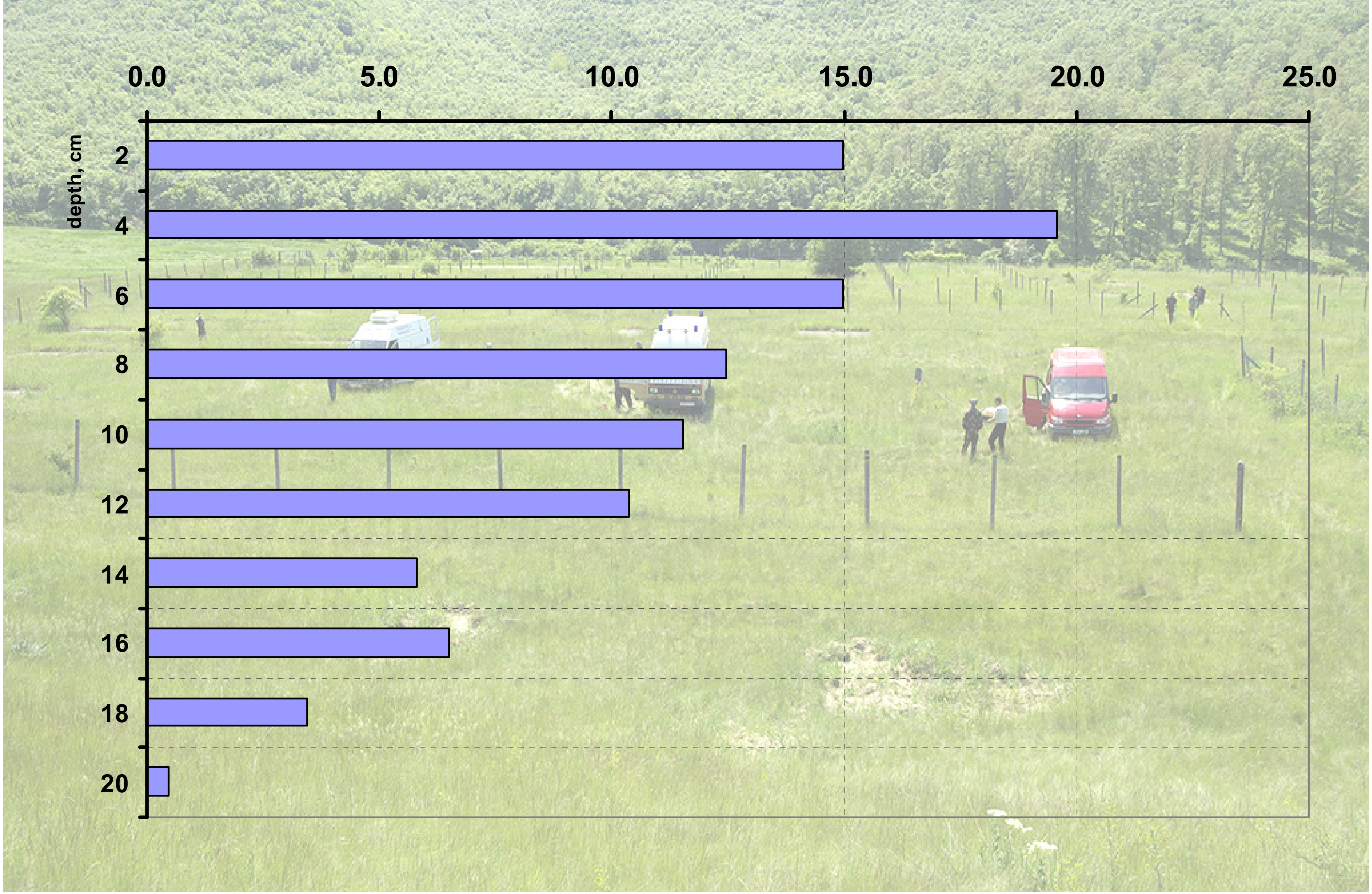
a, Bq/m²

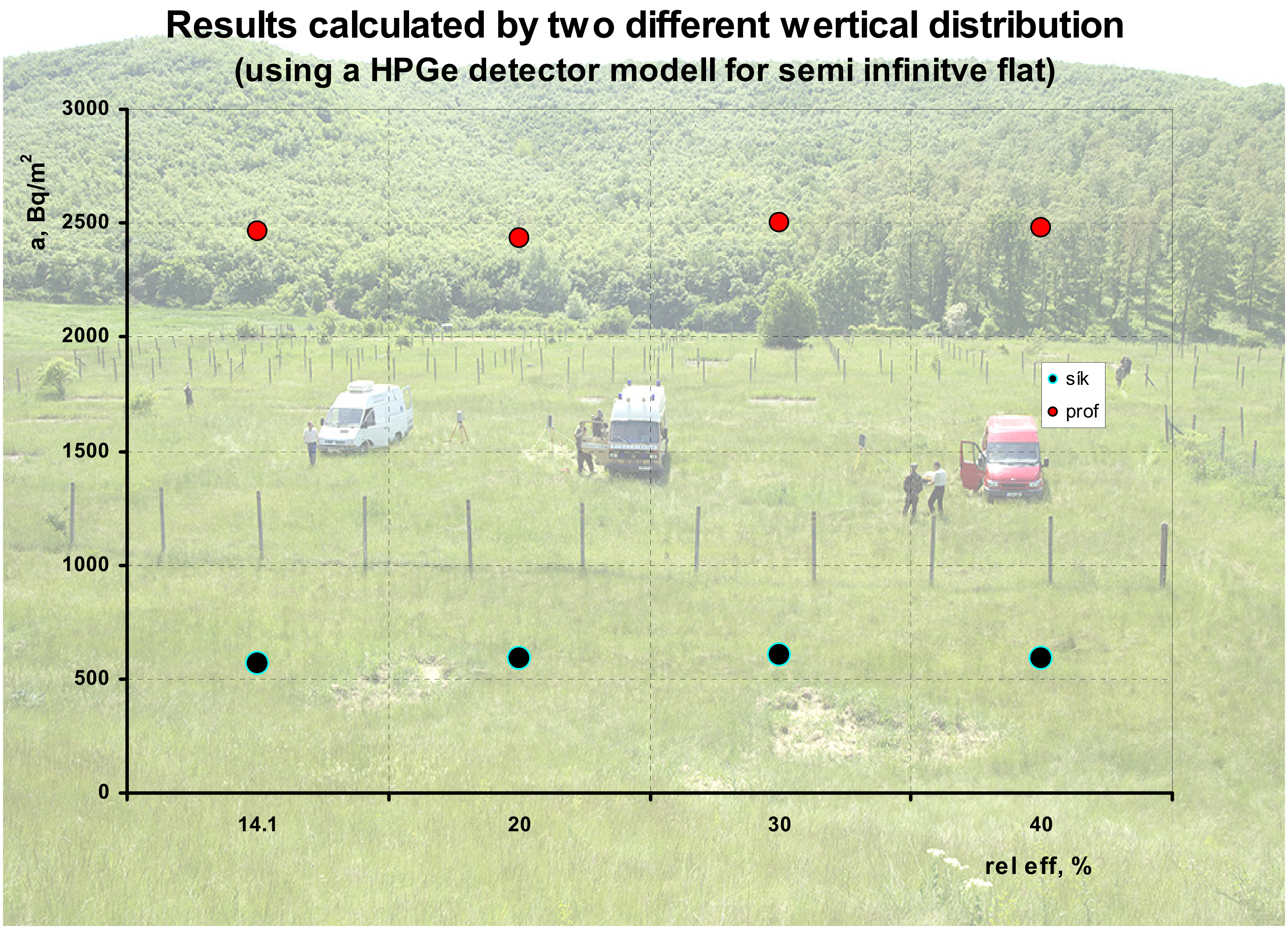
L, cm	1,05 kg/dm³	1,6 kg/dm³
1	1005	552
2	1276	1571
3	1777	2317
5	2302	3128

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	

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)
a, Bq/m2
3000
2500
2000
1500
1000
500
0
14.1
20
30
40
rel eff, %
sík
prof

The result of the manual calibration

Nuklid	E, keV	Nf/So					
		cps/(Bq/cm2)			Bq/kg	Bq/m^2	nGy/h
Be-7	477.4	0.197			0.0	0	0.0
Mn-54	834.8	1.295			0.0	0	0.0
Co-58	810.8	1.317			0.0	0	0.0
Co-60	1173.24	1.046			0.0	0	0.0
	1332.5	0.978			0.0	0	0.0
Zr-95	724.2	0.616			0.0	0	0.0
	756.7	0.761			0.0	0	0.0
Nb-95	765.8	1.367			0.0	0	0.0
Ru-103	496.9	1.686			0.0	0	0.0
Ag-110m	657.7	1.394			0.0	0	0.0
	884.7	0.910			0.0	0	0.0
Sb-125	176.3	1.836			0.0	0	0.0
	600.8	0.296			0.0	0	0.0
I-131	364.5	1.876			0.0	0	0.0
Cs-134	604.6	1.570			0.0	0	0.0
	795.8	1.142			0.0	0	0.0
Cs-137	661.6	1.300		269	14.4	690	0.7

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)
- 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 (U, Th, K)

References

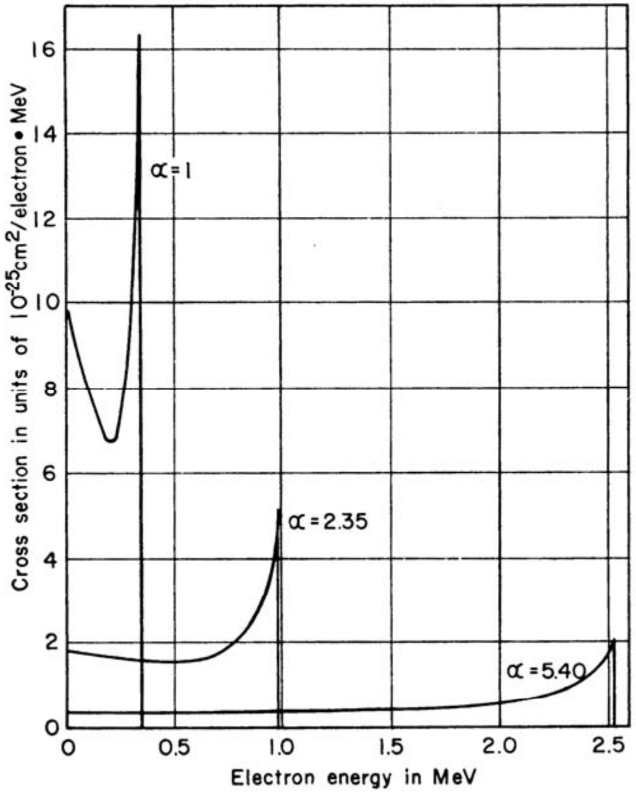
- ICRU REPORT 53 Gamma –Ray Spectrometry in the Environment, Beteheshada(1994)
- EML-557 In situ Gamma –Ray Spectrometry A tutorial for environmental radiation scientist, K.M Miller nad P. Shebell, US DOE 1993
- Generic procedures for monitoring in a nuclear or radiological emergency IAEA-TECDOC-1092, June 1999
- A theoretical comparison of methods of quantification of radioactive contamination in soil using in situ gamma spectrometry; J. MacDonald et. al; J. of Radiol. Prot. 1997 Vol. 17 No.1 3-15
- Uncertainties of in situ gamma spectrometry for environmental monitoring, W. Sowa et. al, Radiation Protection Dosimetry Vol. 27 No. 2 pp. 93-101 (1989)


Thank you for your attention!

Compton-effektus

or in terms of only the primary energy $h\nu$ and the electron energy T it can be written

$$\frac{\mathrm{d}_e\sigma}{\mathrm{d}T} = \frac{\pi r_0^2}{\alpha^2 mc^2}\left\{2 + \left(\frac{T}{h\nu - T}\right)^2\left[\frac{1}{\alpha^2} + \frac{h\nu - T}{h\nu} - \frac{2}{\alpha}\left(\frac{h\nu - T}{T}\right)\right]\right\}.$$



Compton effect. Differential cross section for giving a free electron a recoil energy in the interval between T and $T+\mathrm{d}T$. Eq. (41)

Wednesday

- Exercise
  - In situ gsp homogenous distribution
    - Determine the activity of the man made isotopes
    - Determine the activity of the natural series and K-40
  - In situ gsp supposed exponential distribution
    - Determine the activity of the man made isotopes
    - Determine the activity of the natural series and K-40
  - In situ gsp at flat distribution (concrete surface)
  - In situ gsp for low energy gamma emitters like Pb-210
  - Gamma dose rate "mapping"
  - Measurement of the contaminated object by in situ gsp
    - Isotope identification
    - Activity determination
  - Gamma dose rate measurement at the given location