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Field measurements with portable detectors

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Outline

- Main types of radiation detectors
- Radiation monitoring using portable detectors
  - In Environmental assessments
  - In Radiation protection

Radiation detection: why is it needed?

Unfortunately, human beings cannot sense the presence of radiation.

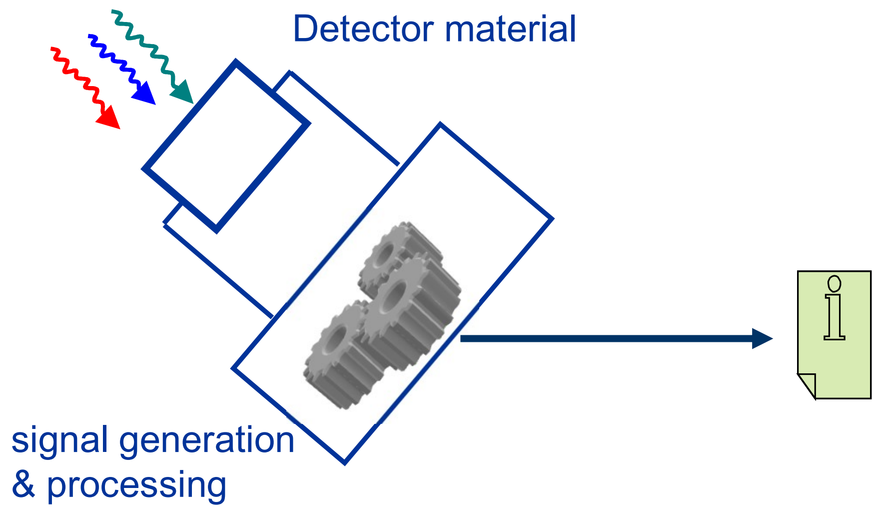
It is not visible,
it cannot be touched,
it does not smell, taste nor sounds

Some device is needed….

https://rebellion.nerdfitness.com/index.php?/topic/112485-gemma-takes-a-measured-approach/

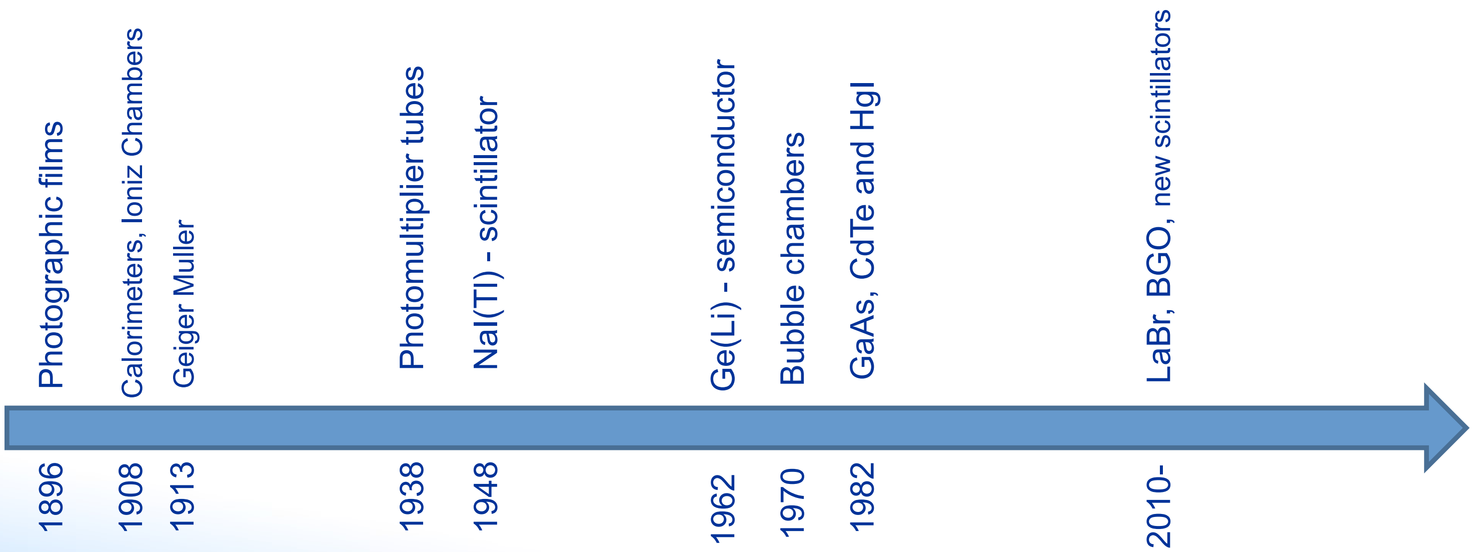
Detectors

- Ionizing radiation can be measured through the physical and chemical effects of its interaction with matter.
- Detectors contain a sensitive material, consisting of a compound that experiences changes when exposed to radiation.
- Another component or device is needed to convert these changes into measurable signals.



Detectors, by the way of functioning

- Passive
  - produces a radiation-induced signal, which is stored/accumulated in the device. The device is then processed and the output is analysed.
- Active
  - An active detector produces a radiation-induced signal that can be displayed as a direct reading of the detected activity or dose rate in real time



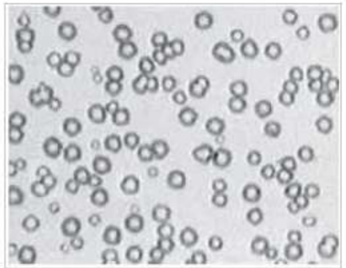
https://journals.lww.com/health-physics/Fulltext/2005/06000/A_HISTORY_OF_RADIATION_DETECTION_INSTRUMENTATION.8.aspx

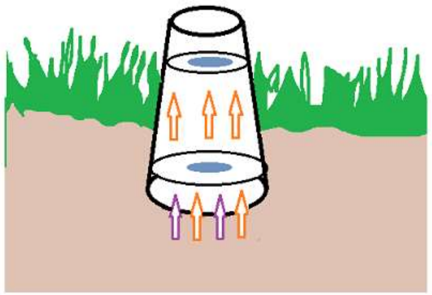
Passive detectors (cumulative effect)

Detector denomination	Sensor material	Energy proportionality	Effect used for detection
Track etch	Film	None	Alpha particles create damage (tracks)
Film dosimeters	Film	None	Chemical interaction with photo-emulsion
Luminescence dosimeters	Special crystals / mineral	None	Electrons in the crystal's atoms are driven to higher energy states by incident radiation. Later luminescence is excited by either thermal (TLD) or optical stimulation (OSLD)

Passive detectors (cumulative effect)

- Used when a response to radiation integrated over time is useful.
  - Field measurements to assess environmental baseline levels
  - Personal dosimetry (integrated dose)





Radon reach both films, whereas thorn reach only the lower film

Active detection features: Efficiency

- A measure of the probability that an incident photon or particle will be producing a response in the detector.
  - It is usually quoted as the ratio of recorded events (counts) to the original activity

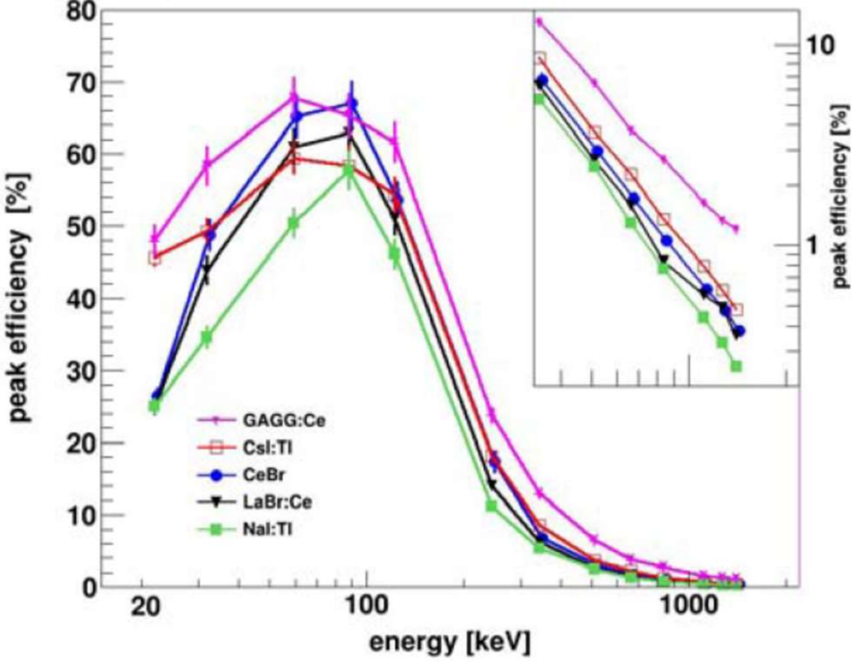
- Absolute efficiency ε_{abs} is composed by the detector intrinsic efficiency ε (number of recorded events to the number of photons or particles impinging in the detector) and the effective solid angle of detection G (fraction of photons or particles that reach the detector to the total number of radiation emitted by the source).

$$\varepsilon_{abs}(E) = G \times \varepsilon(E)$$

Active detection features: Efficiency

- Intrinsic efficiency can vary with the energy of the incident radiation,
  - Low energetic photons/particles can be attenuated in the detector entrance window.
  - At large energies the probability of travelling through the detector volume without producing an interaction increases and the efficiency drops.

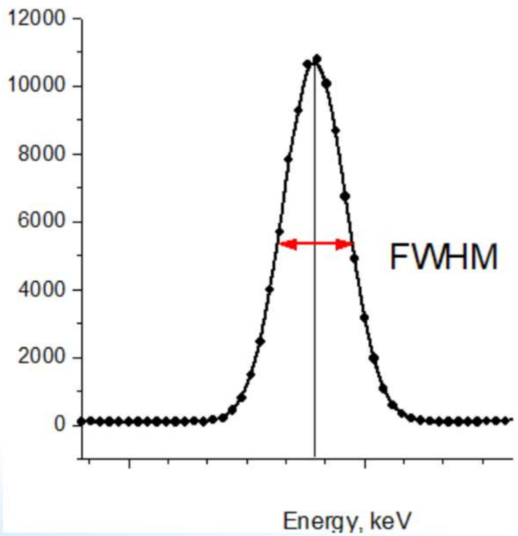
Relative efficiency:
Efficiency as compared to that of a NaI(TI) scintillation detector with 3” x 3” crystal volume



NUKLEONIKA 2017;62(3):223-228

Active detection features: Energy resolution

- A measure of detector's ability to distinguish between two gamma rays or alpha particles having different energies.
  - Specified using some reference energies: In gamma spectrometry the conventional energies (in kilo electron volts, keV) are 122 (^{57}Co), 662 (^{137}Cs) and 1176 (^{60}Co).



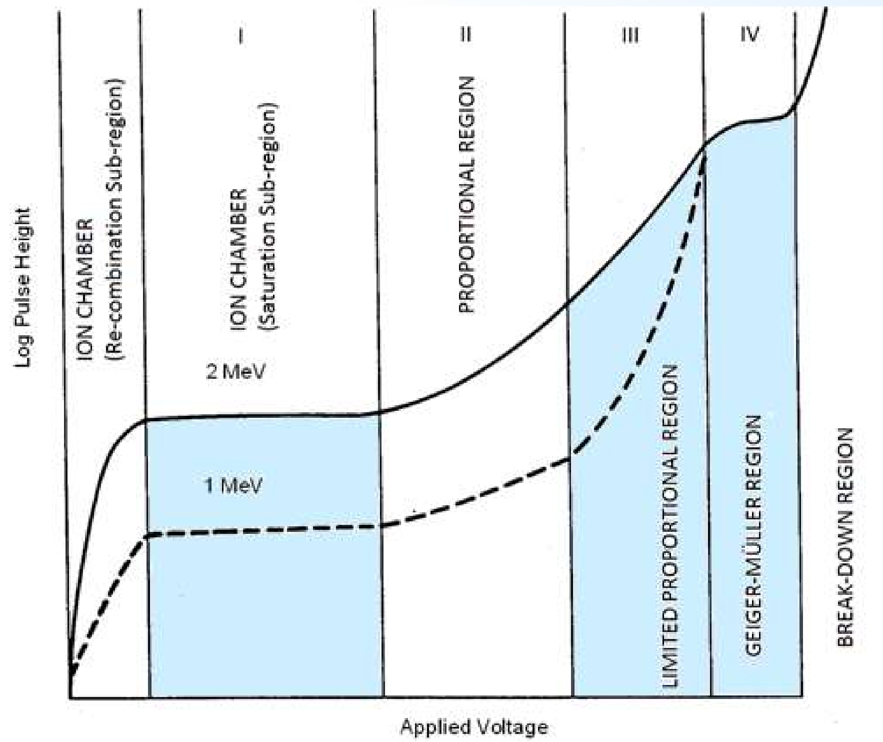
  - Calculated as Full Width at Half of the Maximum counts

Choice of radiation detector:

- What is/are the radionuclide(s) of concern?
- Do they emit alpha, beta or gamma/X ray radiation?
- Which is the expected activity concentration?
- Are the radionuclides distributed throughout depth or is the contamination deposited on the surface?
- Is the contamination expected to be distributed over large surface areas or in focalized 'hot' spots?

Sensor material – Gaseous counters

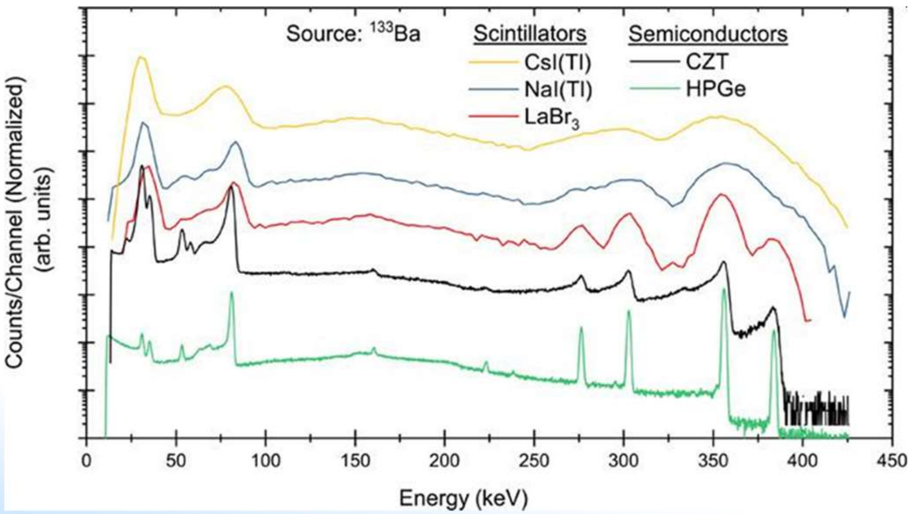
Detector	Energy resolution	Effect used for detection
Ionization chamber (recomb)	Poor	Voltage is low, only primary Ionization of the gas and collection of charge
Ionization chamber (ionization region)	None	the number of ion pairs produced is proportional to the number of ion pairs > knowledge about the energy needed to form a pair of ions > dose rate
Proportional counters	Limited ~ 15 %	High voltage is higher, but limited as to have an intensity of the sparks (amount of charge collected) proportional to the incident energy
Geiger Müller counters	None	Progressive growth of ionization in a strong electric field between the anode and the cathode Charge multiplication in avalanches



Radiation detectors (spectrometry)

- If the energy resolution is sufficient, the detector can be use to identify radionuclides

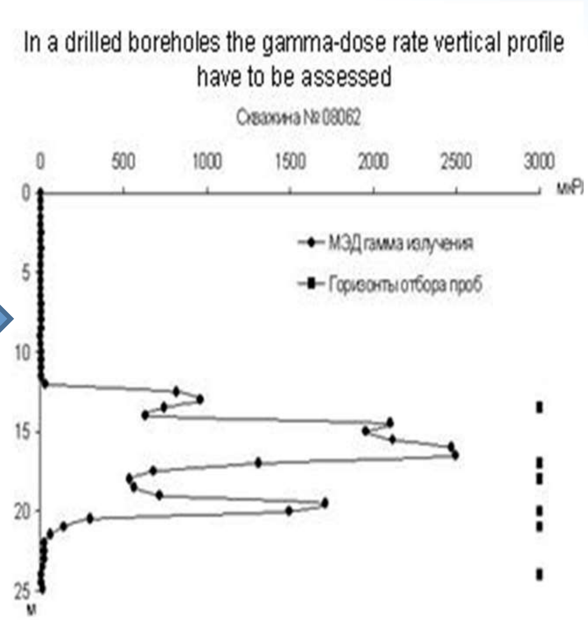
Detector denomination	Sensor material	Energy resolution	Effect used for detection
Scintillator	Crystals or organic materials	Moderate	Photons produce the emission of light in the scintillator, which is then sensed by an additional device
Semiconductor	Semiconductor with different conductivity arrangements	High	Pulses of charge are collected after the ionization of the semiconductor material



Main detectors used for field monitoring

Compartment	Measured	Detector
Aerosol / gas	Radon (alpha activity)	Surface barrier detectors 
Airborne Particulates	Alpha activity from filtered deposit	
Tailing repositories	Gamma activity Dose rate Concentration (Th, eU, K) distribution by depth	Borehole probes  

Methodology for assessing depth distribution of activity



Bore hole measurements
~ 10 cm depth interval

Main detectors used for field monitoring

Compartment	Measured	Detector		
Soil, sediments	Dose rate	 GM	Ionization chambers 	 Scintillators

Main detectors used for field monitoring

Compartment	Measured	Detector		
Surface measurements	Gamma activity	Scintillators		HPGe 
	Concentration (Th, eU, K)	Scintillators		

Main detectors for activity monitoring

Type	Sensor	Features	
Semiconductor	Si pin diode (β, x-rays) Si surface barrier (α)	- Small size - Smaller relative efficiency	
	CdZn(Te) (x, γ)		
	HPGe (γ) Pixelated detectors (orientation)	- High efficiency - High energy resolution	

Methodologies for surface measurements

Ground level				Aerial		
	Stationary	Backpacks / HH	Car-borne (*)	Different platforms		
						
Common detectors	HPGe Scintillator	Scintillators, GM, Ionization Chambers	HPGe, Large volume Scintill.	Arrangement of large crystal /plastic Scintillators		GM, Light weight Sc, CZT
Detector volume (cm^3)	~ 40 – 50 (HPGe)	~ 60 - 150 (Scintillator)	~ 4000 – 8000 (Scintillator assembly)	~ 8000 - 16000 (Scintillator assembly)		~ 50 - 100 (Scintillator)
Detector front area (cm^2)	~ 30	~ 15 ~ 30	~ 90 ~ 150	~ 90 ~ 150		~ 15
Distance to surface H (m)	1	1	~ 0.15	200 - 500	50 - 150	10

(*) *Mike Davies et al 2007 J. Radiol. Prot. 27 A51,* https://doi.org/10.1088/0952-4746/27/3A/S07

Summary

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- Detectors are selected based on the type of radiation, energy and emission direction

- In field measurements, portable or stationary instruments are used
  - Environmental monitoring/assessment, which requires a large number of samples to be measured, can be optimized by using two step approach: in-situ to reveal the spatial distribution and activity/dose rate levels and; laboratory analysis for cases where high accuracy is needed in the measurement results

- Instruments need to undergo periodic calibration

Useful references:

- https://kos.iaea.org/iaea-safety-glossary
- Diagnostic Radiology Physics: A Handbook for Teachers and Students, IAEA, ISBN 978-920-131010-1
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Thank you!