Status and Challenges for Detectors in Nuclear Physics

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IAEA
International Atomic Energy Agency

Some Important Facilities and Experiments:

- Nuclear spectrometry (incl. radioactive beams, AGATA, GERDA, NUSTAR, FAIR, Spiral2)
- Hadron physics (Jefferson lab, PANDA at FAIR)
- Heavy ion physics (RHIC, ALICE)
- Ion beam accelerators
- Spallation sources and research reactors
- Nuclear applications (dosimetry, environmental monitoring, cultural heritage)
- Etc ….

Presentation

- 1 - Overview of the different types of detectors used in nuclear physics
- 2 - Few applications at the IAEA
- 3 - Future directions
- 4 - Conclusions

Overview

- Various types of radiation detectors are used depending on the energy and the type of particle to be counted and the purpose of the measurement.

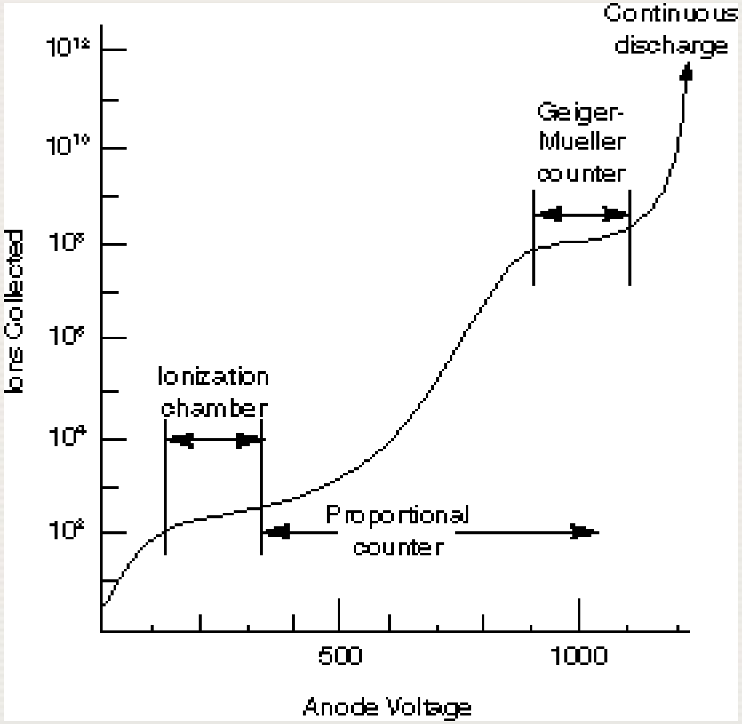
- The 3 mains types of radiation detectors are the gas-filled detectors, the scintillators-based and the semiconductor detectors

Gas-filled Detectors

Description

- Ionization chamber: The output signal is proportional to the particle energy dissipated in the detector. The measurement of particle energy is possible.
- Only strongly ionizing particles (α, protons, fission fragments, or heavy ions) are detected.
- Application: Beam monitoring

The 3 main regions

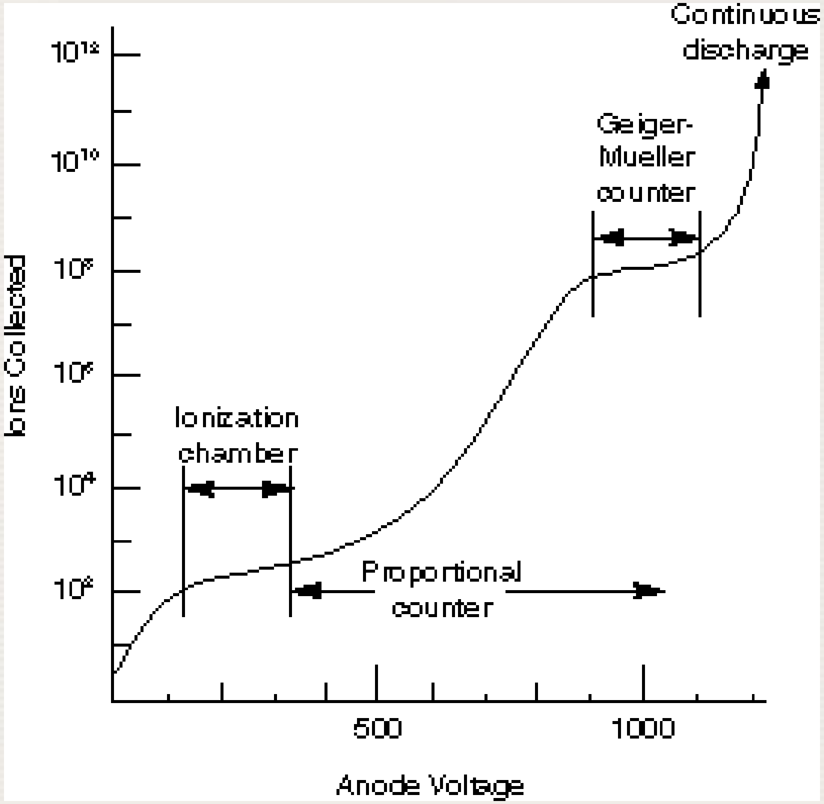


Gas-filled Detectors

Description

- Charge multiplication takes place and the output signal is proportional to the particle energy deposited in the detector.
- Measurement of any charged particle is possible.
- Applications: Counters, LPSD and 2D detectors

Proportional Counters

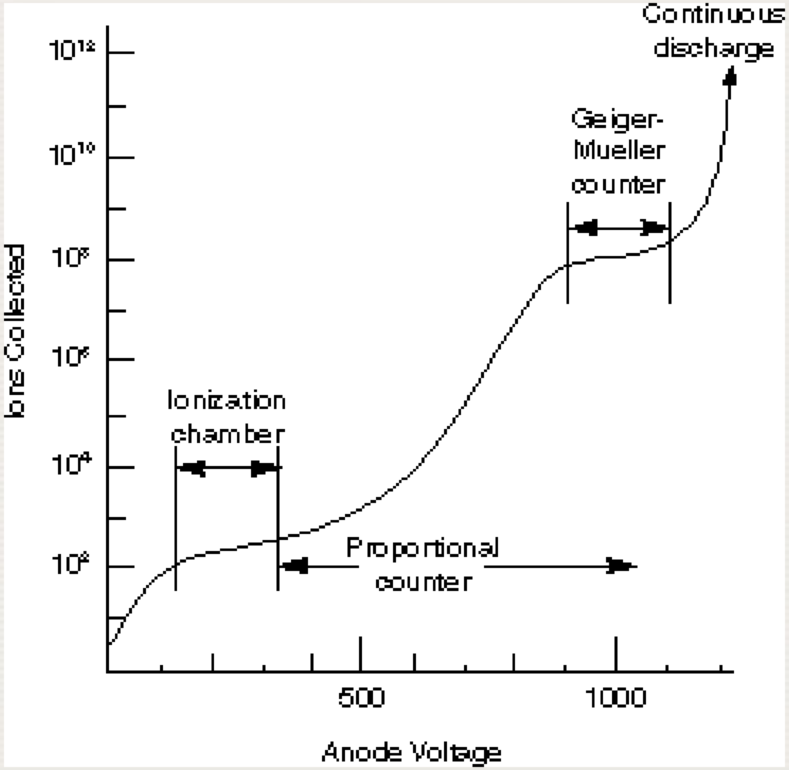


Gas-filled Detectors

Description

- Operation in avalanche mode. The signal is strong and no amplifier is required and their signal is independent of the particle type and its energy.
- GM provides information only about the number of particles.
- Application: Geiger counter

Geiger Counter



Status & Challenges

- The technologies of these detectors are mature and commercially available.

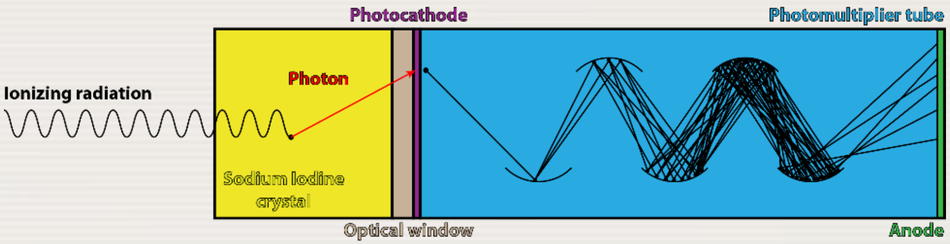
- The challenges are for high rate applications where the polymerization effect is still an issue.

Scintillator Detectors

- Scintillators materials produce spark or scintillation of light when ionizing radiation passes through them. The operation is in 2 steps:

1) Absorption of the incident radiation energy and production of the photons.
2) Amplification of the light by a PMT or an APD

- They can be divided in 3 groups: inorganic Scintillators, organic Scintillators and gaseous Scintillators.



Inorganic Scintillators

Applications

- NaI(Tl), CsI are the most commonly used for ɤ-rays. (sizes up to 0.75m Dia, 0.25m thick). Used for all nuclide identification applications
- CaF_2 (Eu) efficient for β particles and X-rays with low ɤ sensitivity.
- LiF/ZnS for neutron imaging with wavelength shifting-fiber detector

Properties of some inorganic scintillators

Mterial	λ(nm)	ε(%)	dec(μs)
NaI(Tl)	410	100	0.23
CaF_2(Eu)	435	50	0.94
CsI(Na)	420	80	0.63
CsI(Tl)	565	45	1.00
$Bi_4Ge_3O_{12}$	480	8	0.3
$CdWO_4$	530	20	0.9
^{6}LiI(Eu)	470	30	0.94

Organic Scintillators

Applications for crystal, liquid, plastic and gaseous scintillators

- Crystal have faster response time compared to inorganic ➡ faster timing resolution.
- Liquid scintillators are used in large volume to increase the efficiency and reduce ɤ/n ratio.
- Mixture of noble gases: low ɤ, short decay, Light output per MeV doesn't depend on the charge or the mass of the particle. Suitable for heavy charged particles (α, fission fragments, ….

Properties of some organic scintillators

Material	λ(nm)	ε(%)	dec(ns)
Anthracene	445	100	30
NE-102	385	65	2
NE-110	350-450	60	3
NE213	350-450	60	2
Pilot B	350-450	68	2
Pilot Y	350-450	64	3

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Organic Scintillators

- Plastic scintillators
  - Plastic scintillators have similar properties to those of liquid scintillators.
  - They don’t need a container and can be machined in any size or shape and inert to water, air and many chemical.
  - Applications include large area detector array for neutron measurements and ɤ-ray large area space telescope

Scintillators: Status & challenges

- Future works will be focused on the light output conversion and gamma discrimination while maintaining a fast decay time.
- Transparent scintillators are attractive
- The phoswich detector (which measures low level of radiation in presence of considerable background) needs to be improved for neutron spectroscopy, CT and SPECT. Coincidence measurement in α/β/ɤ spectrometry

Semiconductors

- Operate like ionization chambers
- Si and Ge are the most used but CZT, HgI_2 and CdTe are promising.
- Ge(HPGe, GeLi), Si have a very good energy resolution (for spectroscopy applications) but requires continuous cooling and are therefore bulky and expensive.
- CZT and HgI_2 can operate at room temperature for Mossbauer spectroscopy with a limited energy resolution.

Semiconductors: Challenges

- Damages are seen with particle fluence in the order of 10^{12} (P/m^2) for heavy ions and 10^{14} (α or n /m^2) for both Si and Ge.
- Future directions will focus on improving the radiation damage on semiconductors.
- Diamond or SiC are viable candidates

Some IAEA Projects

- Active personal dosimeter
- Continuous air particle monitors
- **Area monitoring and Environmental monitoring**
- Foot and surface contamination monitoring
- Whole body counter
- Portal monitor and passive detection
- Coincidence and anticoincidence detection systems
- Nuclear medicine
- **X-ray spectrometry**
- Detection of Nuclear materials/non-proliferation issues
- **Unmanned aerial vehicles for radiation detection**
- **Portable Gamma spectroscopy**

The Proposal for the UHVC Project

To develop a multipurpose Ultra High Vacuum Chamber (UHVC) for applying simultaneously various complementary and advanced variants of X-Ray Spectrometry (XRS) techniques, including:

- Total Reflection X-ray Fluorescence Analysis (**TXRF**)
- Grazing Incidence XRF analysis (**GIXRF**)
- Near Edge X-ray Absorption Fine Structure (**NEXAFS**)
- X-ray Reflectometry (**XRR**)

under different excitation modes:

- laboratory x-ray source
- synchrotron radiation
- charged particle beams

UHVC Instrumentation: Motorized 7-axis sample manipulator

The sample manipulator includes:

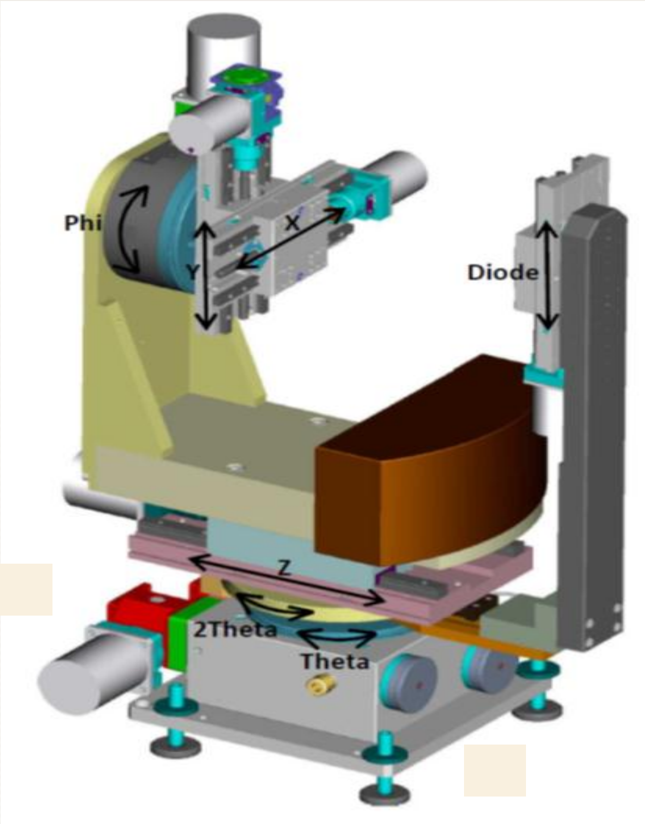
Four (4) linear stages (‘X’, ‘Y’, ‘Z’, ‘Diode’)

Three (3) goniometers (‘Theta/2Theta’, ’Phi’)

Aiming at moving the sample to be investigated in various directions/ orientations with respect to the exciting X-ray beam or/and with respect to the detectors.

X-ray Detectors:

Ultra Thin Window (UTW) Silicon Drift Detector (SDD, 30 mm^2, FWHM <133 eV @ Mn-Ka, 75 eV @ C-Ka) and photodiodes (Si)



The ‘Theta’ axis would provide an accuracy better than 0.15 mrad in the range of -5-110 degrees

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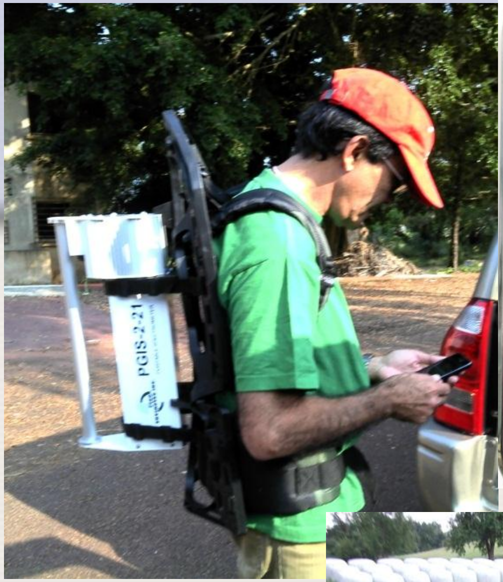
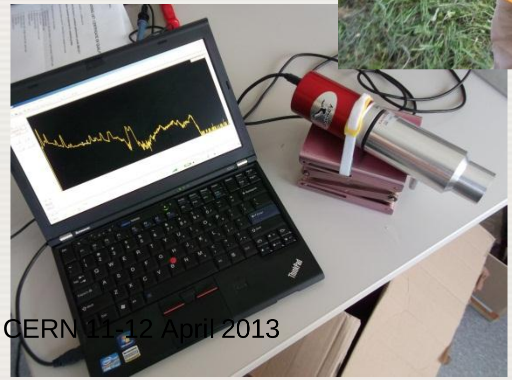
“Backpack” Systems

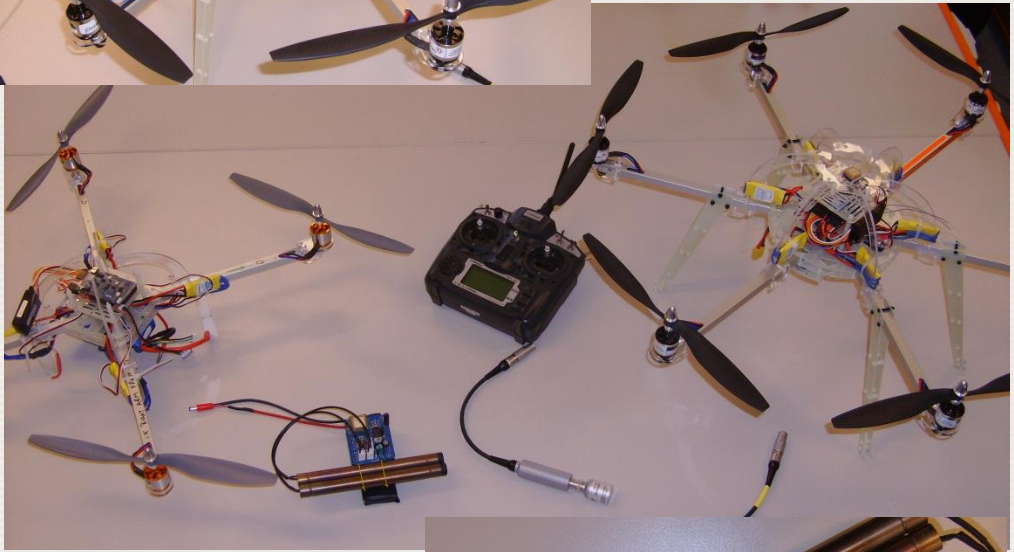
- NaI(Tl) 0.347l; Android controlled
  - PGIS-2-21
  - PicoEnvirotec
  - Remediation:
    - Gabon, Azerbaijan
- BGO 1x1.5”;
  - Gamma Surveyor II
  - GF Instruments
  - Gabon, Austria
- LaBr (1x1.5”) + OSPREY
  - Canberra
  - Austria (Soil Erosion)

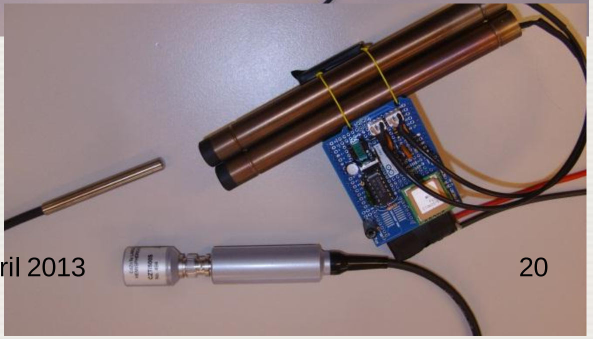




Aerial Radioactivity Monitoring

- Quad-/Hexa-copter drones
- Electric motors
- LiPo batteries
- Semi-autonomous
  - GPS
  - Autopilot
- Radiation monitoring
  - Doserate (GM)
  - Spectroscopic (e.g. CZT)
- Open source
  - Example is Arduino controlled





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Future tasks

- Establish a list of experiments in nuclear physics and determine in detail the detector requirements.

- Many other detectors not mentioned here are being used in nuclear physics. They include the MCP, the Anger camera, the SSND, the APD, the SiPM, the Cherenkov detectors, the calorimeters, etc

Conclusions

- Future efforts will focus on improving the timing/spatial resolution for some experiments while the efficiency and the energy resolution be important for the others.

- Thanks to all the NASL team.