JINR- Joint Institute for Nuclear Research, Dubna

Project: Radiation Protection and the Safety of Radiation Sources

INTEREST- INTERnational REmote Student Training at JINR
Wave 2

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INFLPR

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Radiation Protection and Dosimetry

Dosimetric Units

1 Gray (Gy) = 1 Joule/kg   1 rad = 100 erg/g = 0.01 Gy

$$1 \text{ Roentgen (R)} = (2.58 \times 10^{-4}\ Coul/kg) \text{ in air}$$

$$1\ Sv = 100\ rem$$

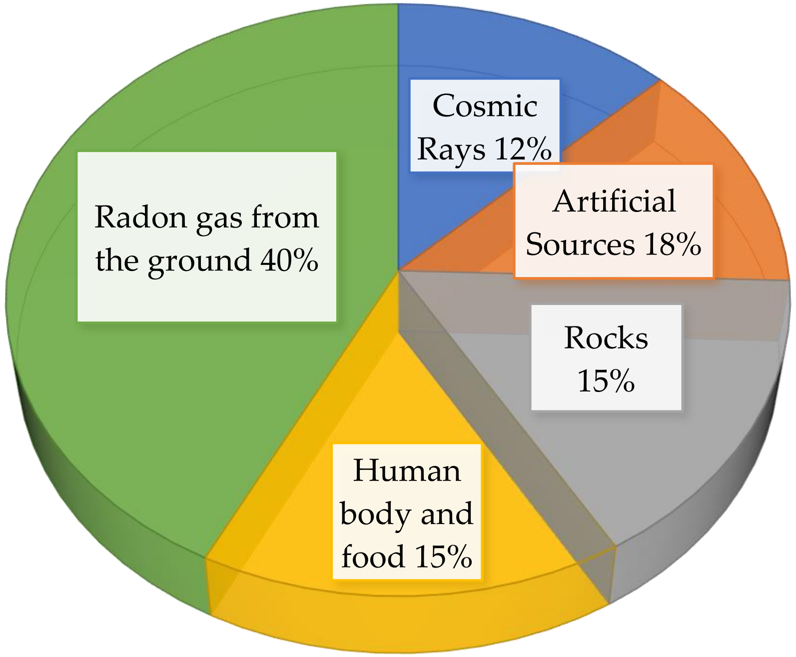


Figure 1. Sources of Radiation Exposure.

External Exposure

Internal Exposure to Radiation

- Inhalation
- Ingestion
- ^{131}I (β particles) thyroid
- ^{137}Cs (γ Rays) muscle and soft tissue
- ^{239}Pu (α particles) lungs, liver, bones

Figure 2. Types of Radiation Exposure.

Scintillation detectors

***Scintillation material* ->** produce scintillation of light when ionizing radiation passes through them

- *Inorganic scintillators*
- *Organic scintillators*
- *Gaseous scintillators*

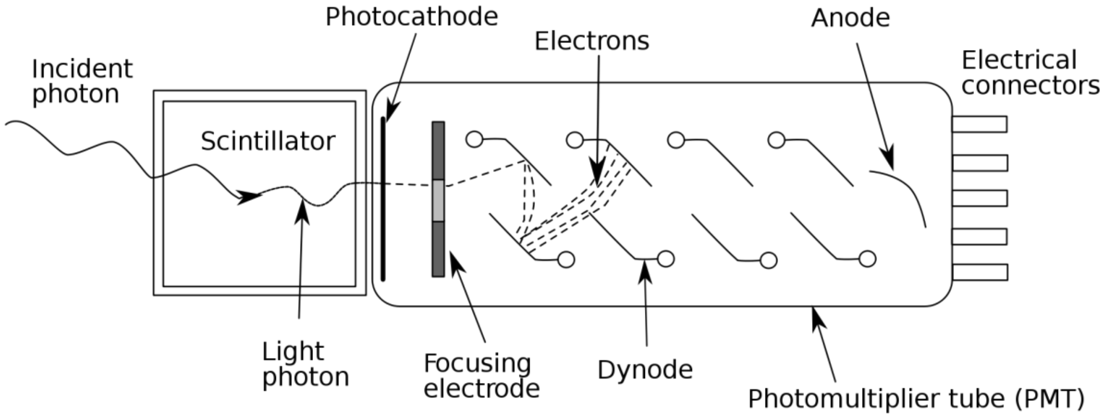
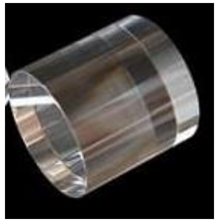


Figure 3. *A photomultiplier tube scheme.*

BGO – Bismuth Germanate ($Bi_4Ge_3O_{12}$)



- Wavelength range: *375- 650 nm*
- Crystals diameter*: 75- 300 mm* max lengths
- Applications: *PET, HEP, NP, space and medical physics*
- Highly effective gamma ray absorber

NaI (Tl) – Sodium Iodide (Tl)

- Wavelength range: *325- 550 nm*
- Crystals diameter*: 150- 400 mm max lengths*
- Applications: *TOF measurements, Positron lifetimes studies, PET, HEP and NP*

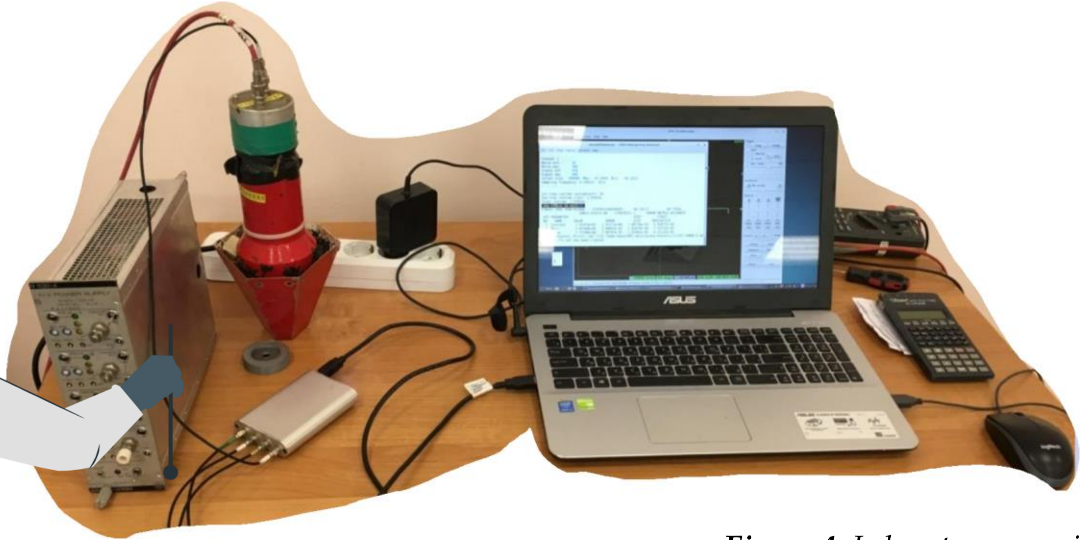
The basic properties of the scintillating crystals

Scintillator	Light output	Decay [ns]	λ_{max} [nm]	ϱ [g/ cm^2]	Hygroscopic
Na(Tl)	100	250	415	3.67	Yes
CsI	5	16	315	4.51	Slightly
BGO	20	300	480	7.13	No
BaF_2 (f/s)	3/ 16	0.7/630	220/310	4.88	Slightly
CaF_2	50	940	435	3.18	No
$CdWO_4$	40	14000	475	7.9	No
$LaBr_3$(Ce)	165	16	380	5.29	Yes
LYSO	75	41	420	7.1	No
YAG(Ce)	15	70	550	4.57	No

Na(Tl) ←

BGO ←

Experimental Set-up



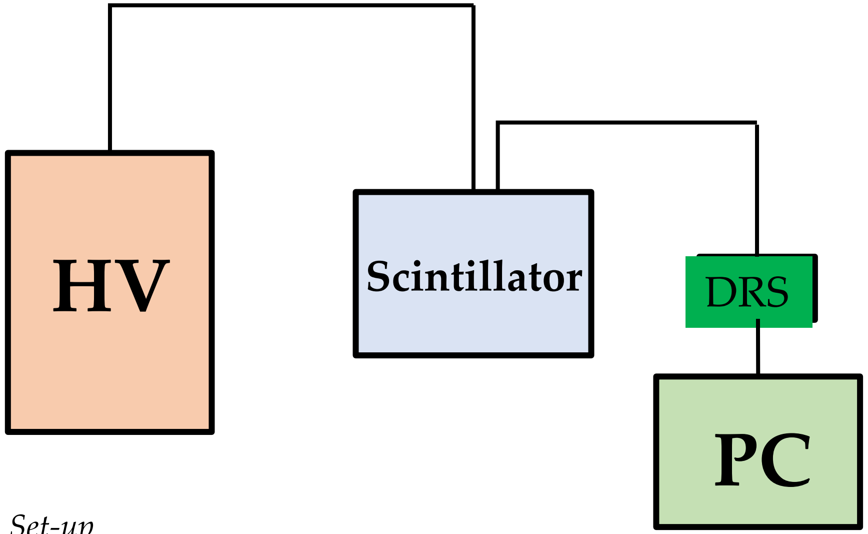


Figure 4. Laboratory experimental Set-up

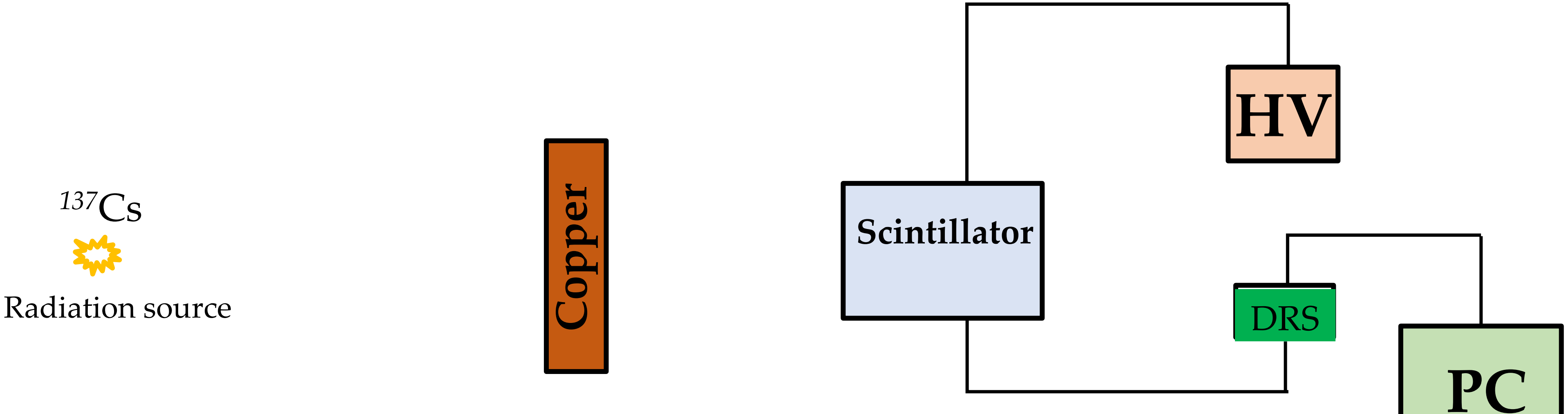


Figure 5. Experimental Set-up used to determine the attenuation coefficient

Task 1. The relation between the resolution and applied voltage for BGO and NaI(Tl) scintillation detectors

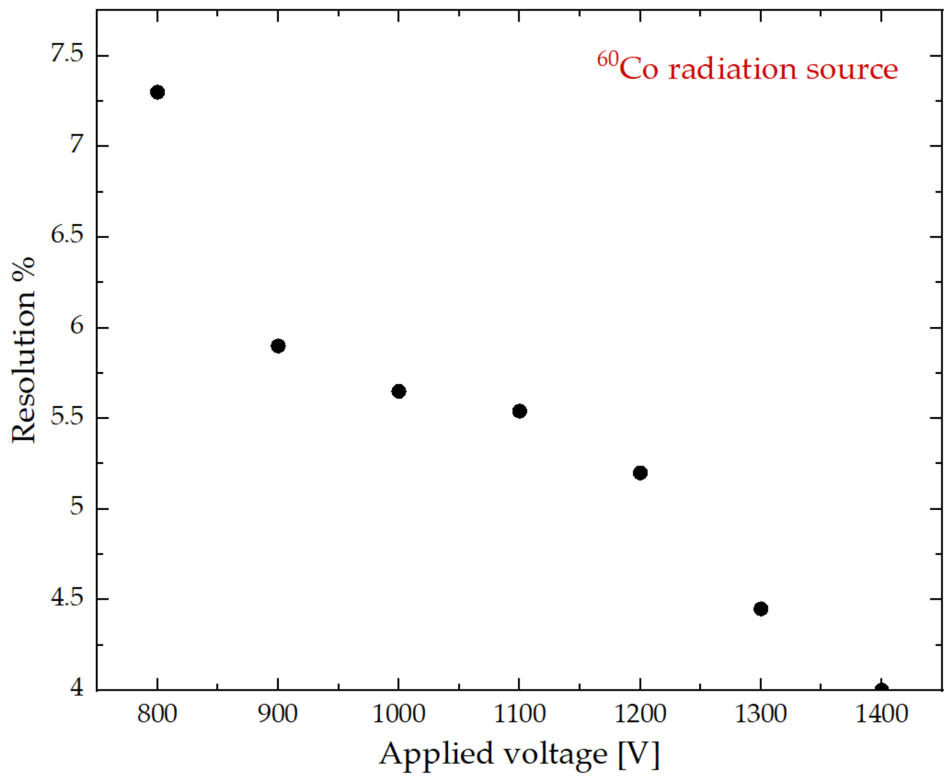


Figure 6. *The relation between the resolution and applied voltage for **NaI(Tl)** Scintillation detector.*

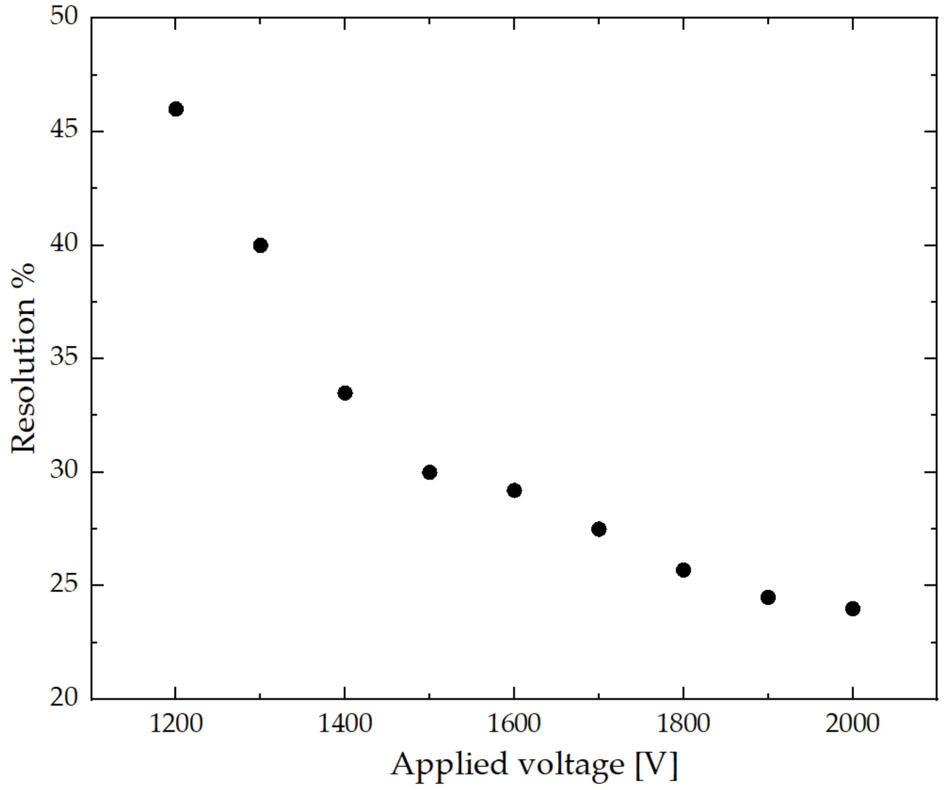


Figure 7. *The relation between the resolution and applied voltage for **BGO** Scintillation detector.*

Task 2. Identification of unknown sources

- The energy of each peak was determined using the ***linear energy calibration curve***
- Equation calibration curve for NaI(Tl)

Y= (0.0098 X) + 1.3316

- **Y**- PMT signal
- **X-** energy of the unknown source

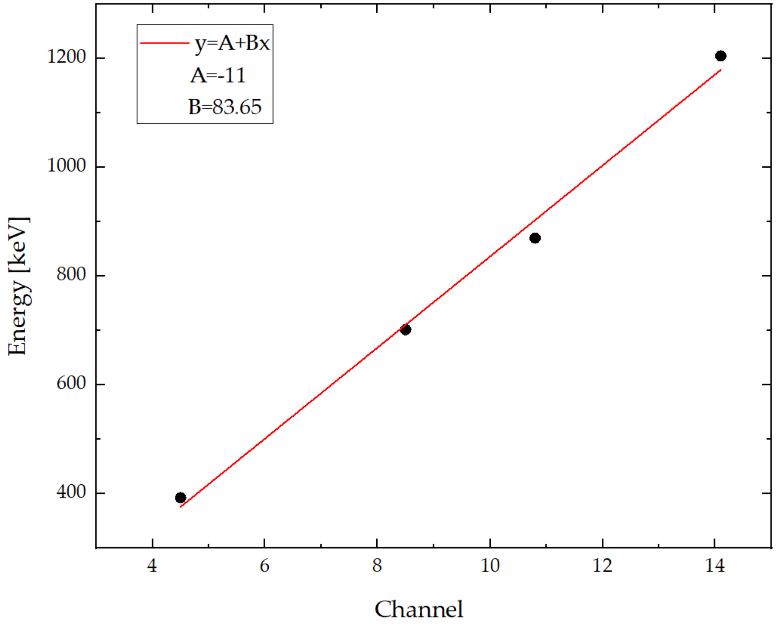


Figure 8. *Energy calibration function for* ^{241}*Am spectrum.*

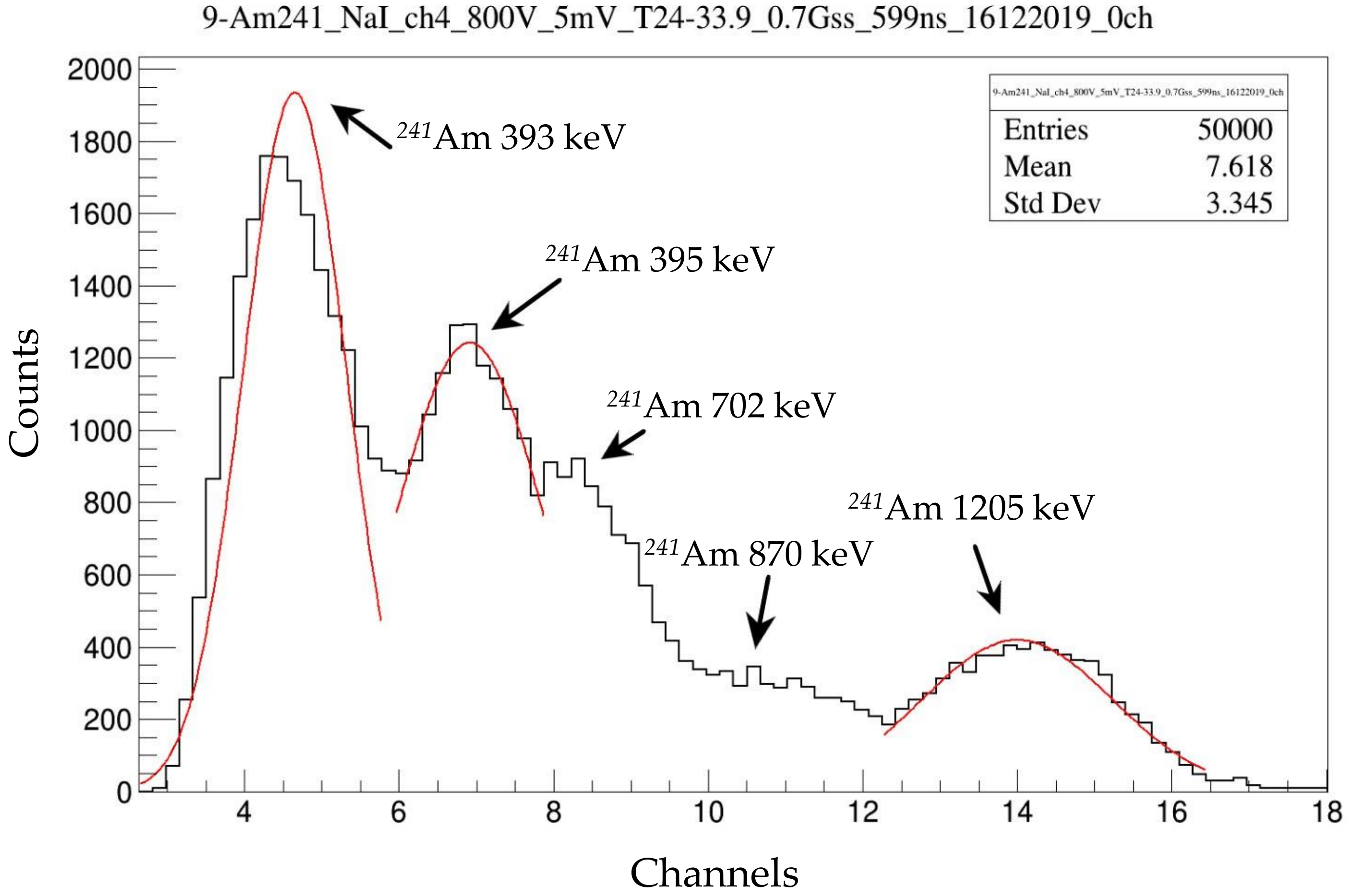


Figure 9. ^{241}*Am spectrum resulting from measurements with* ***NaI(Tl)*** *scintillation detector at* ***1400 V*** *and* ***5 mV*** *from DRS software.*

Task 2. Identification of unknown sources

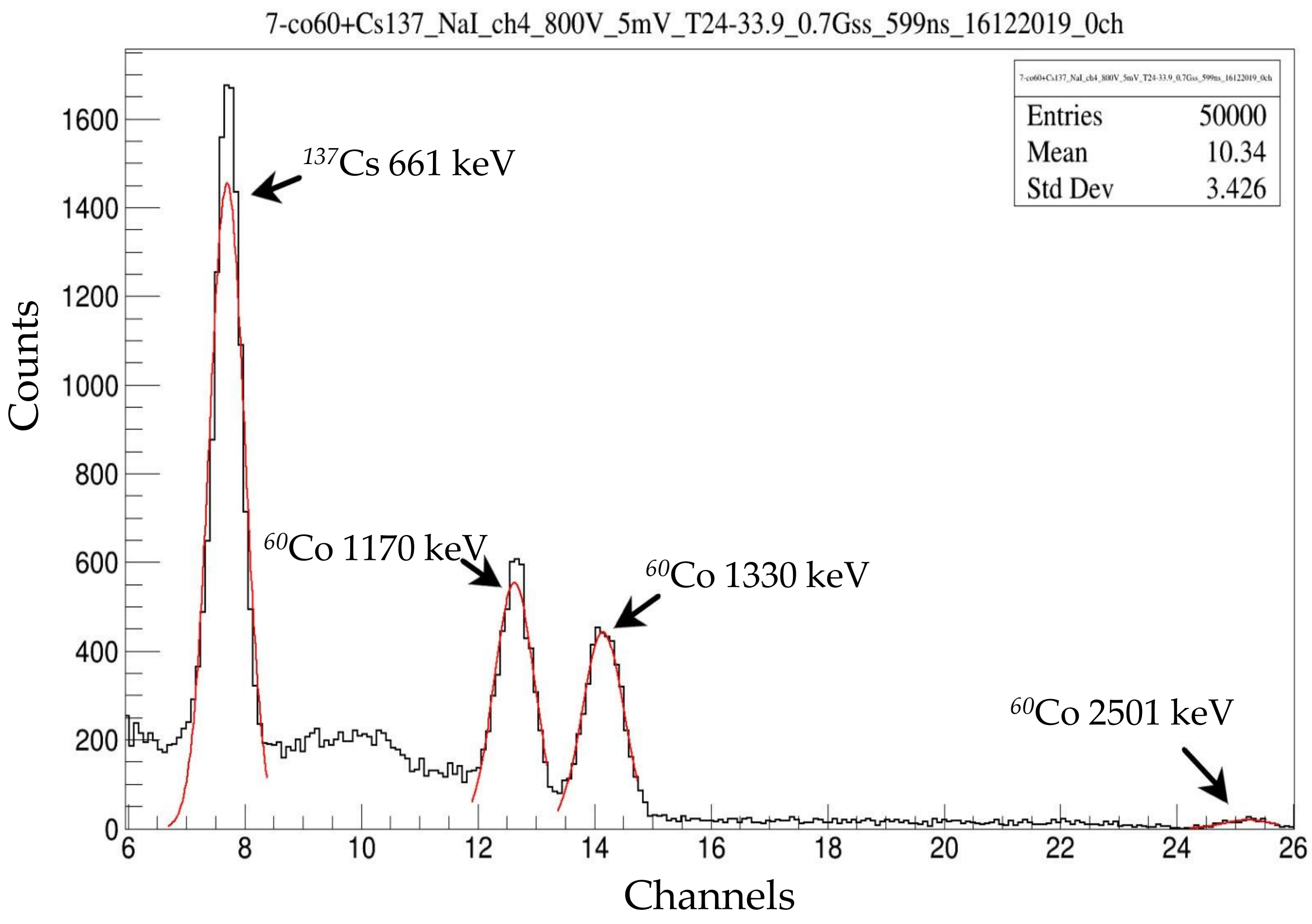


Figure 10. *^{60}Co and ^{137}Cs spectrum resulting from measurements with* ***NaI(Tl)*** *scintillation detector at* ***1400 V*** *and* ***5 mV*** *from DRS software.*

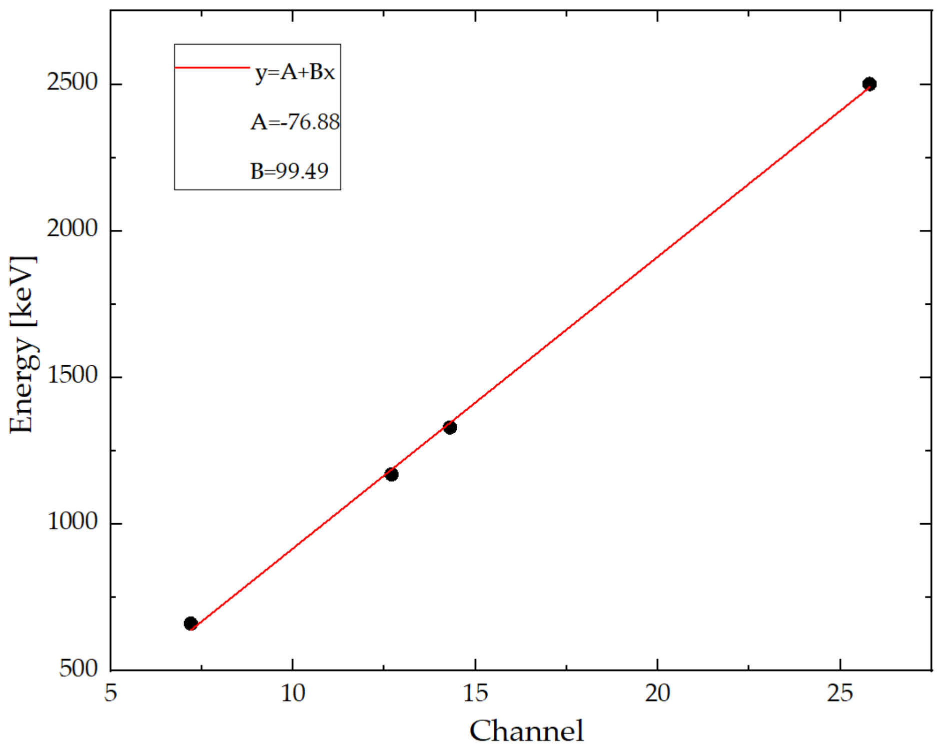


Figure 11. *Energy calibration function for ^{60}Co and ^{137}Cs spectrum resulting from measurements with NaI(Tl) scintillation detector at* ***1400 V*** *and* ***5 mV*** *from DRS software.*

Task 2. **Identification of unknown sources**

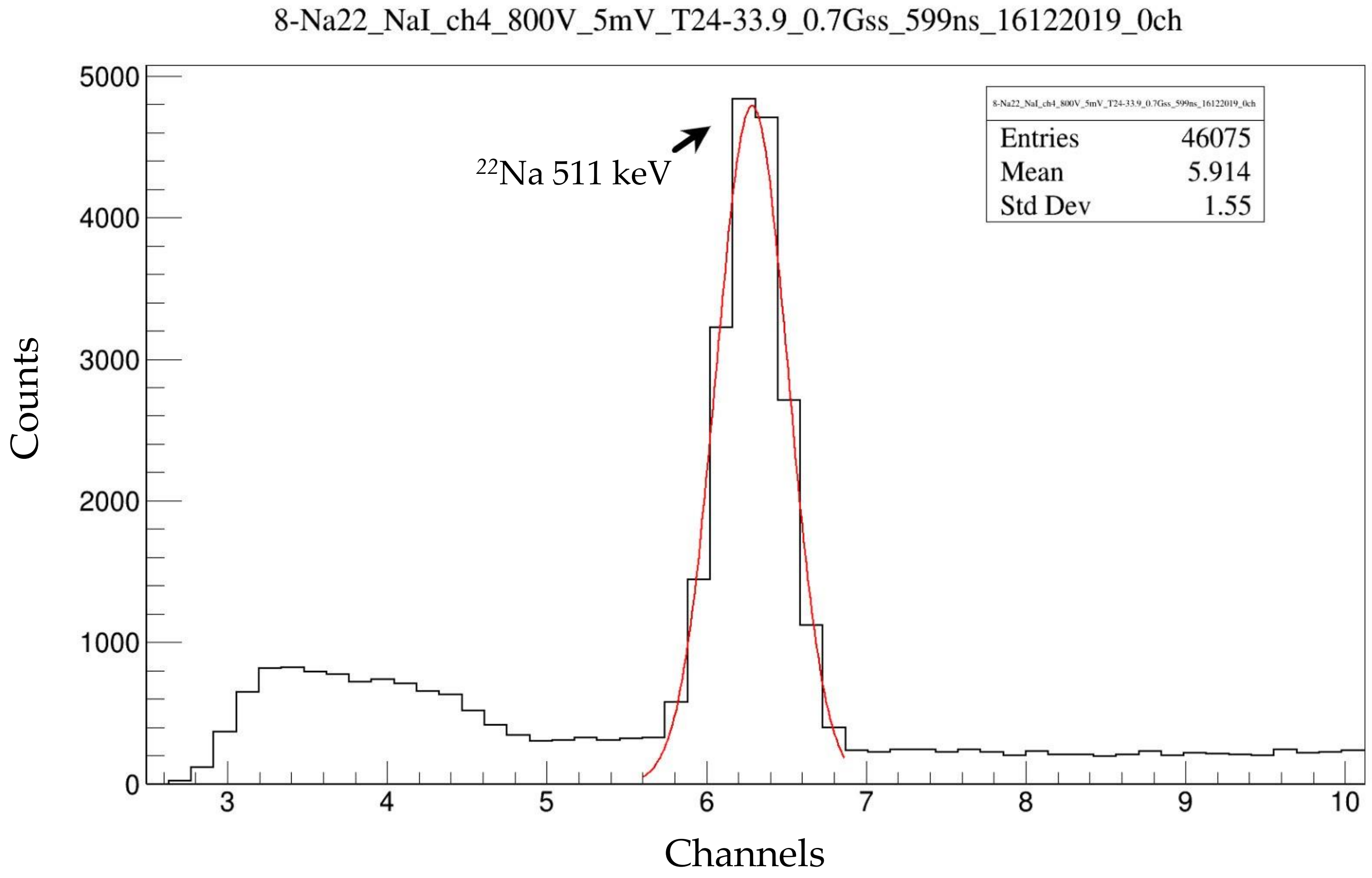


Figure 12. ^{22}Na *spectrum resulting from measurements with* **NaI(Tl)** *scintillation detector at* ***1400 V*** *and* ***5 mV*** *from DRS software.*

Task 2. Identification of unknown sources

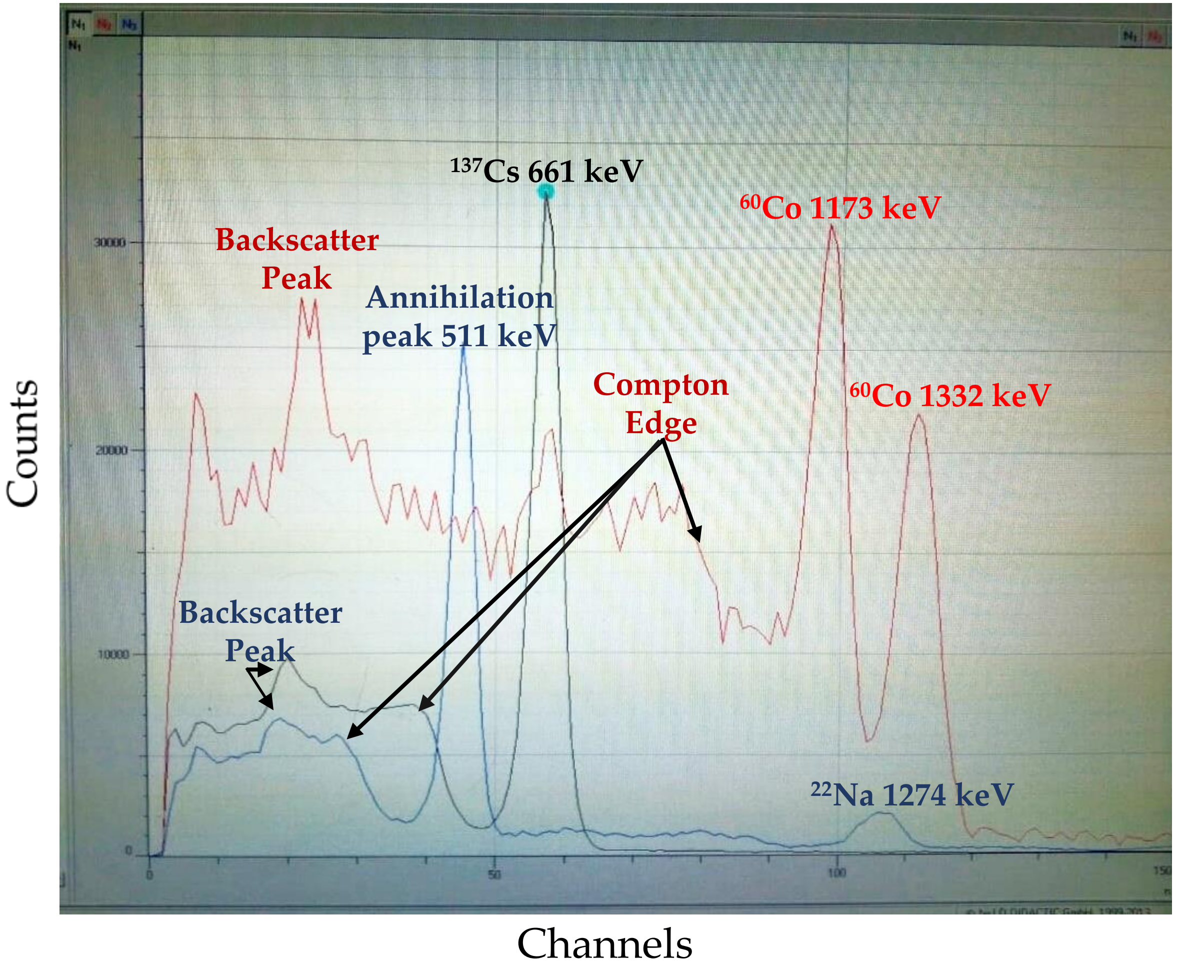


Figure 13. Spectra resulting from measurements with ^{137}Cs monoenergetic source.

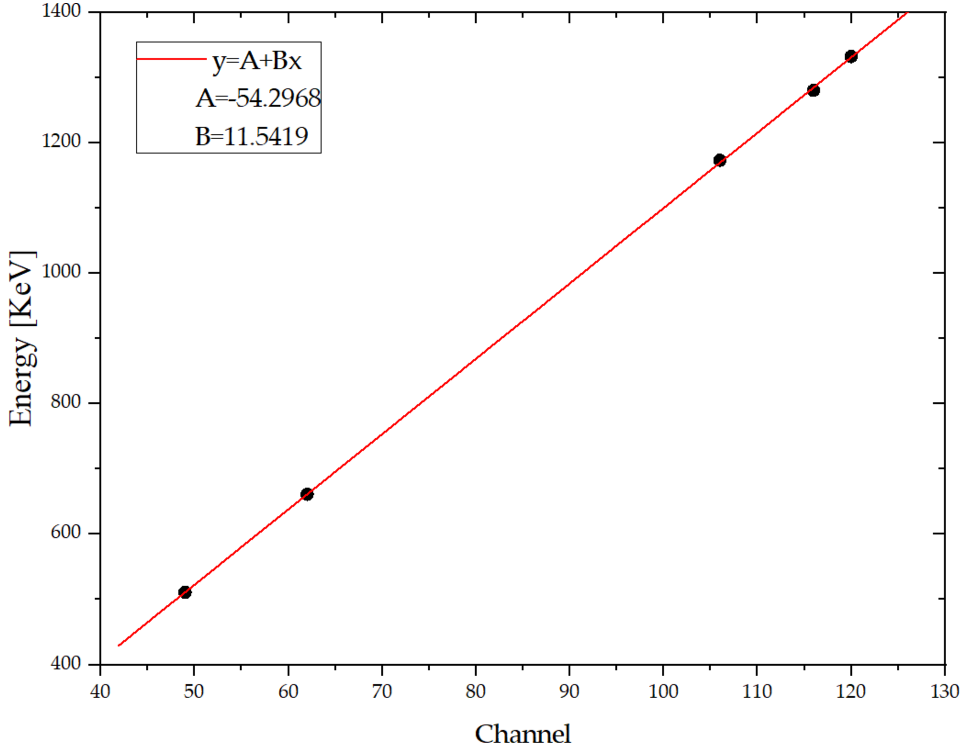


Figure 14. Energy calibration function for ^{137}Cs spectrum.

Task 3. Attenuation of γ radiation as a function of thickness and atomic number Z

Linear attenuation coefficient (μ): $I = I_0 \cdot e^{-\mu x}$

Mass attenuation coefficient (μ_{mass}): $\mu = \mu/\rho_{material}$

Experiment equipment:

- Detector: BGO scintillation detector
- Voltage: 2000 V
- Source: ^{137}Cs, E_{Cs}= 661 keV
- Attenuation material: Cu, Al

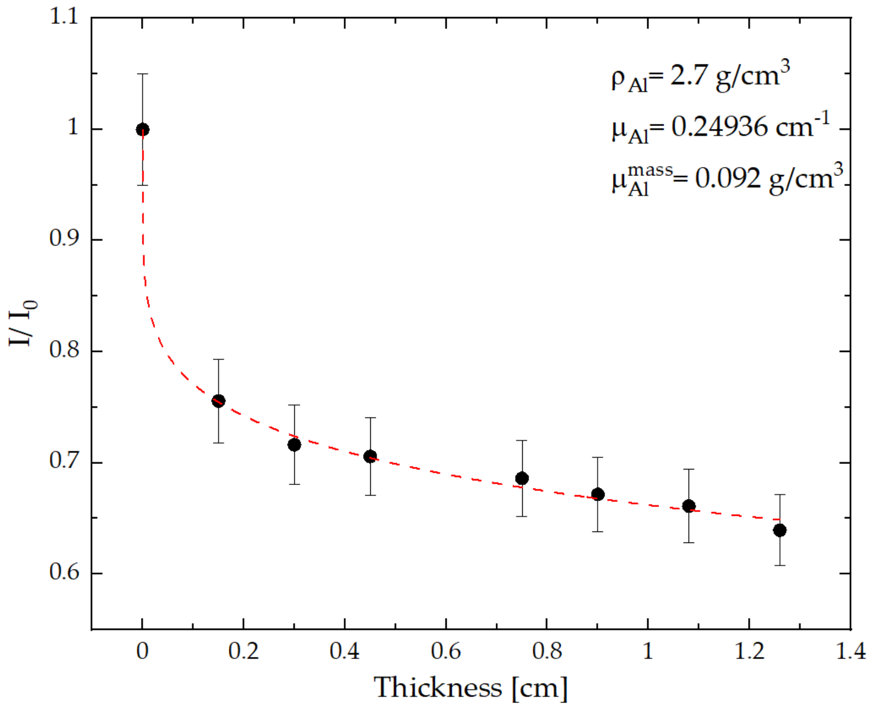


Figure 15. Determination of attenuation coefficient for ***Al*** *using* **BGO** scintillation detector *and the radiation source* ^{137}Cs (661 keV)

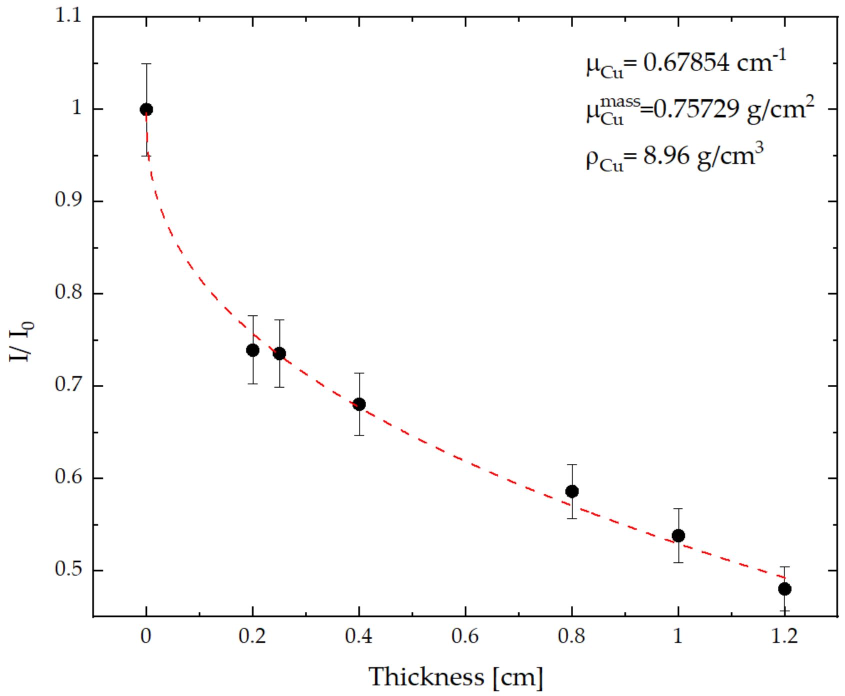


Figure 16. Determination of attenuation coefficient for ***Cu*** *using* **BGO** scintillation detector *and the radiation source* ^{137}Cs (661 keV)

The Energy Spectrum of Alpha Particles

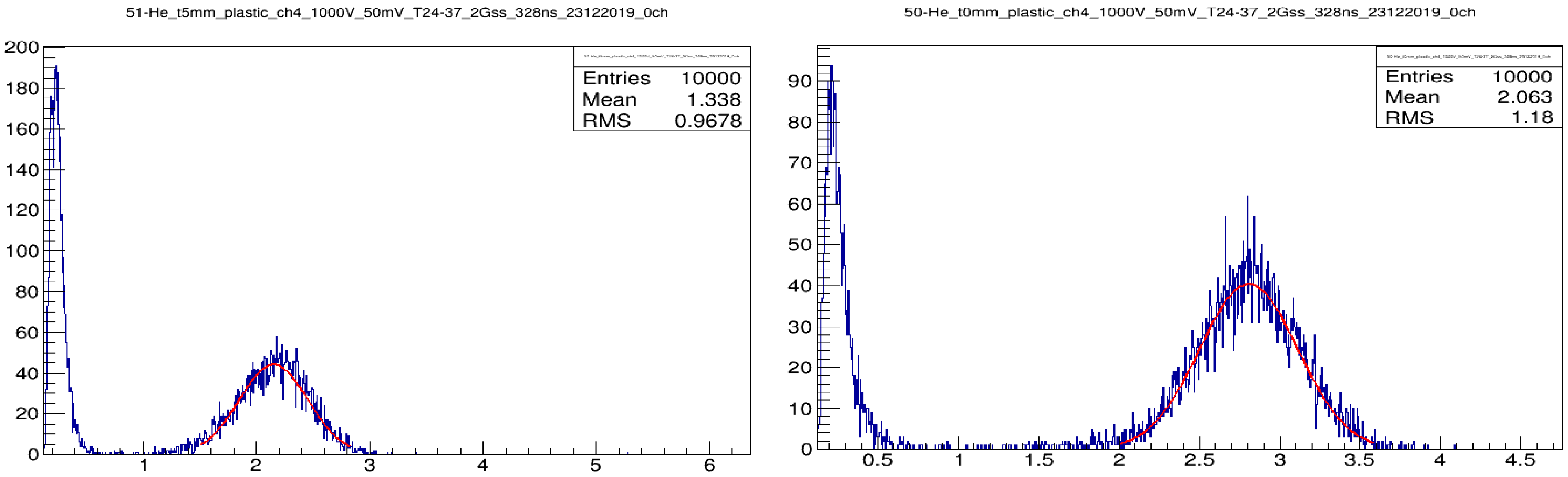


Figure 17. *The energy spectrum of alpha particles resulting from detector at* ***1000V*** *and* ***50mV****.*

Task 4. **Range of α-particles in air using SRIM code** (Monte Carlo)

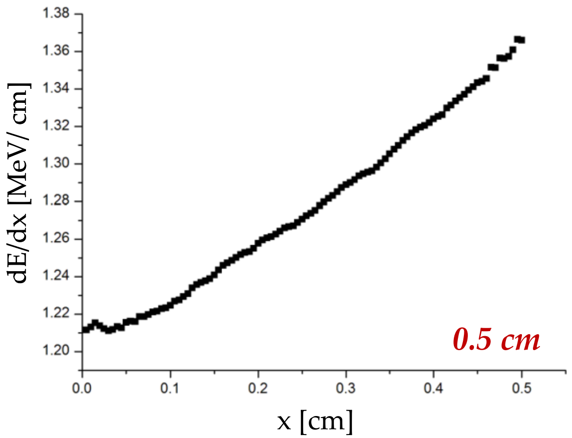


Figure 18. Stopping power of alpha particles in air at 0.5 cm, E= 5 MeV

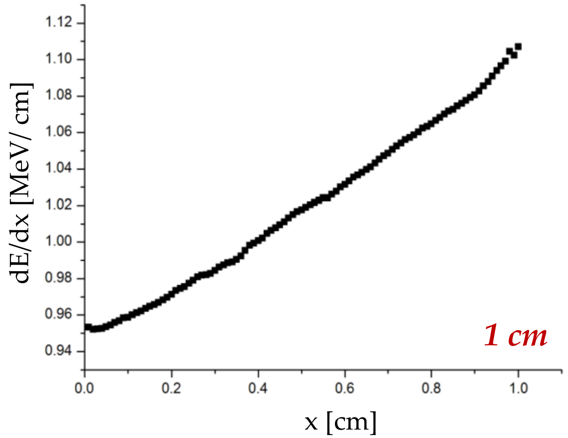


Figure 19. Stopping power of alpha particles in air at 1 cm, E= 5 MeV

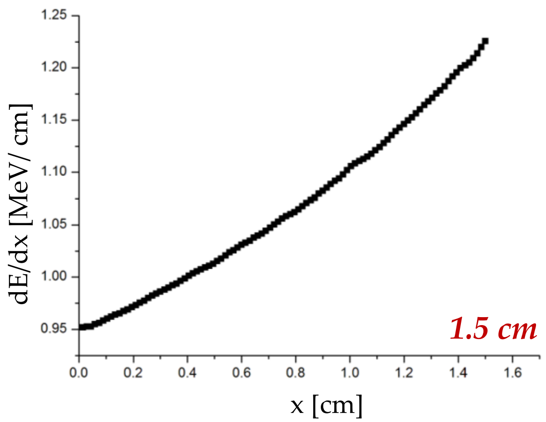


Figure 20. Stopping power of alpha particles in air at 1.5 cm, E= 5 MeV

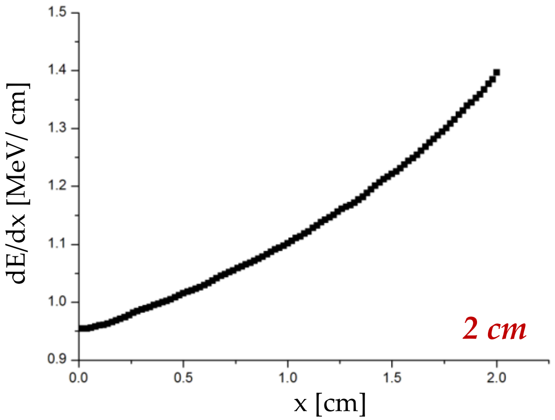


Figure 21. Stopping power of alpha particles in air at 2 cm, E= 5 MeV

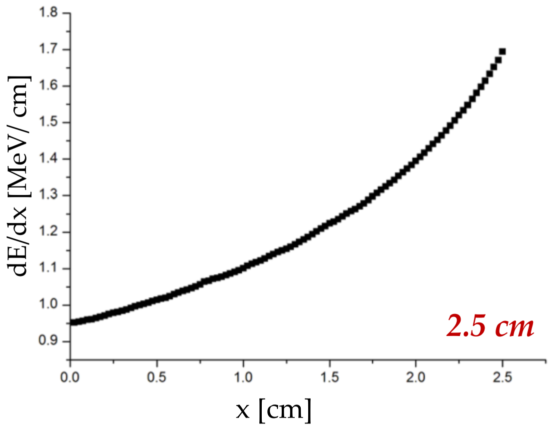


Figure 22. Stopping power of alpha particles in air at 2.5 cm, E= 5 MeV

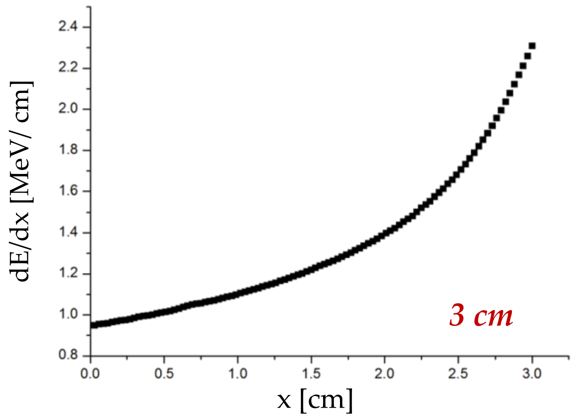


Figure 23. Stopping power of alpha particles in air at 3 cm, E= 5 MeV

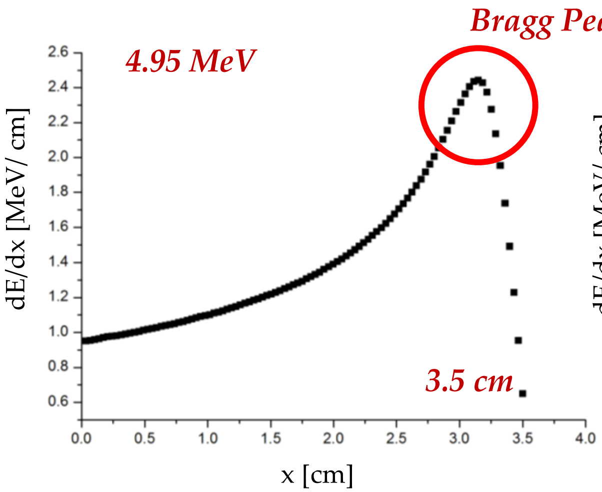


Figure 24. Stopping power of alpha particles in air at 3.5 cm, E= 5 MeV

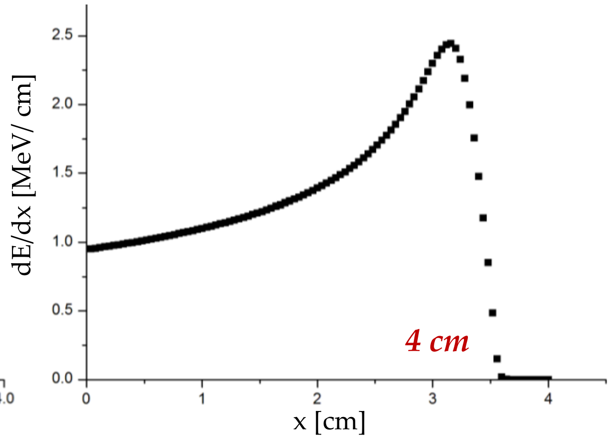


Figure 24. Stopping power of alpha particles in air at 4 cm, E= 5 MeV

Pixel Detectors

Characteristics of the pixel detector:

- ***Advanced detector*** similar to a digital camera;
- The main two parts: **1. Sensor- Si** and **2. Electronic chip**;
- Size of the sensor: *1.5 x 1.5 cm;*
- Pixels: *256* x *256 pixels (65.536 pixel);*
- Pixel size: *55 μm* x *55 μm;*
- High resolution detector;
- Used for the *registration different types of radiation* such as x- rays, gamma radiation, electrons, neutrons and charged particles.

Figure 25. *Laboratory Pixel detector*

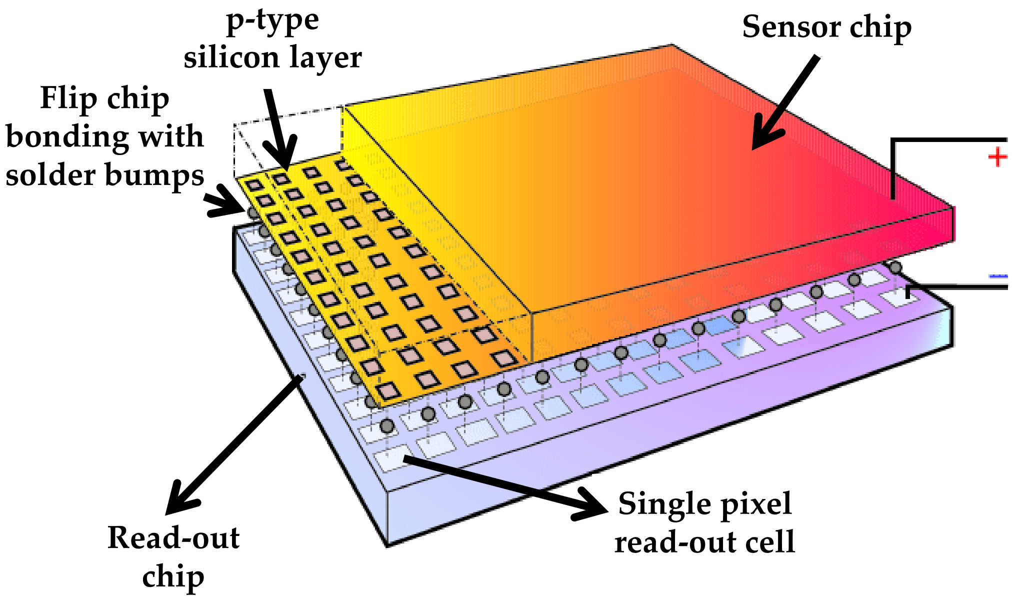


Figure 26. *Example of a Hybrid pixel detector with its components.*

Tlustos, L. & Heijne, Erik. (2005). Performance and limitations of high granularity single photon processing X-ray imaging detectors.

Task 5. Determination of α-particles rage in air using Pixel Detectors

- The Range of **Alpha** particles with (Am-241) energy about 3.5 MeV in air using pixel detector

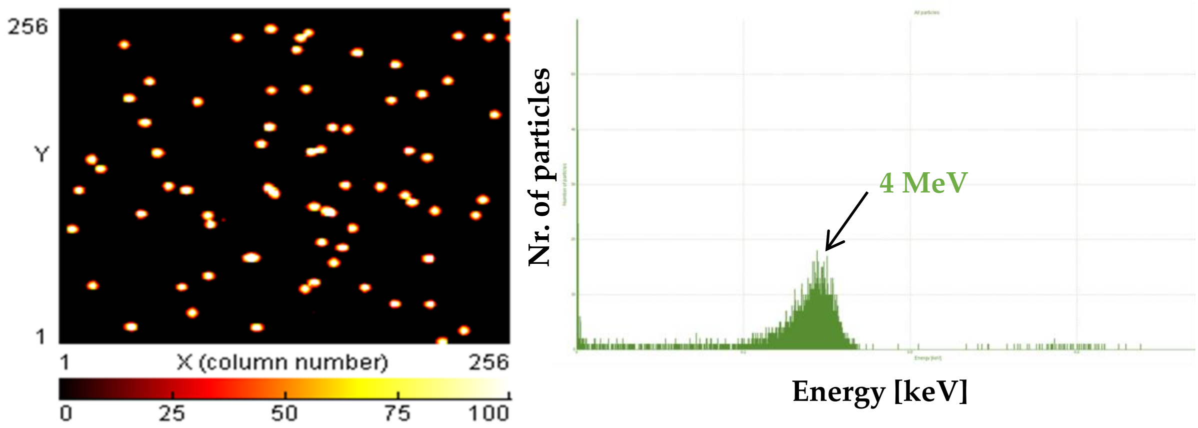


Figure 27. *The range of alpha particles in air at x= 0 cm distance from the source Am-241.*

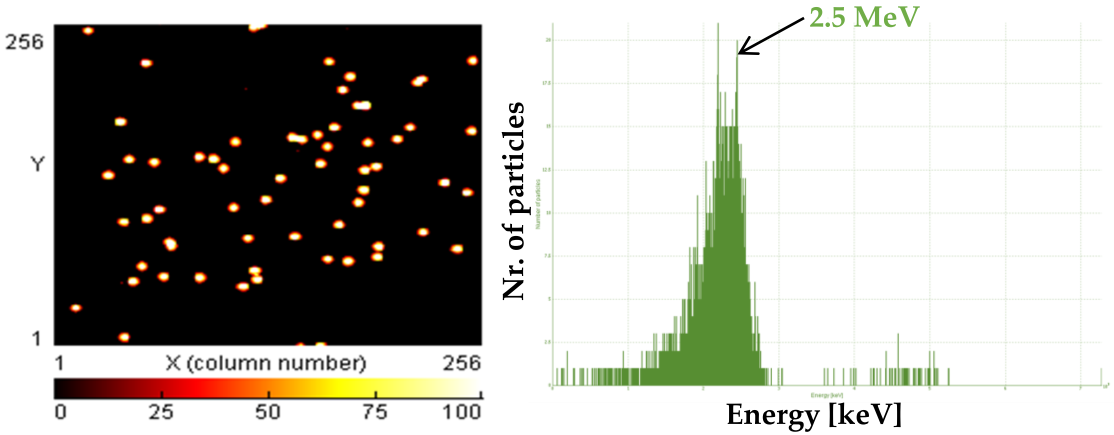


Figure 28. *The range of alpha particles in air at x= 1cm distance from the source Am-241.*

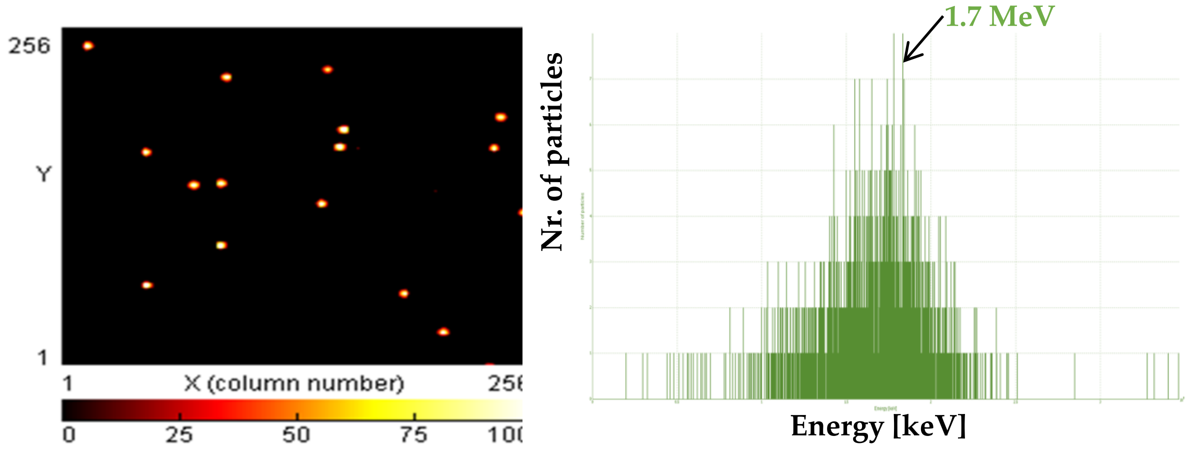


Figure 29. *The range of alpha particles in air at x= 2 cm distance from the source Am-241.*

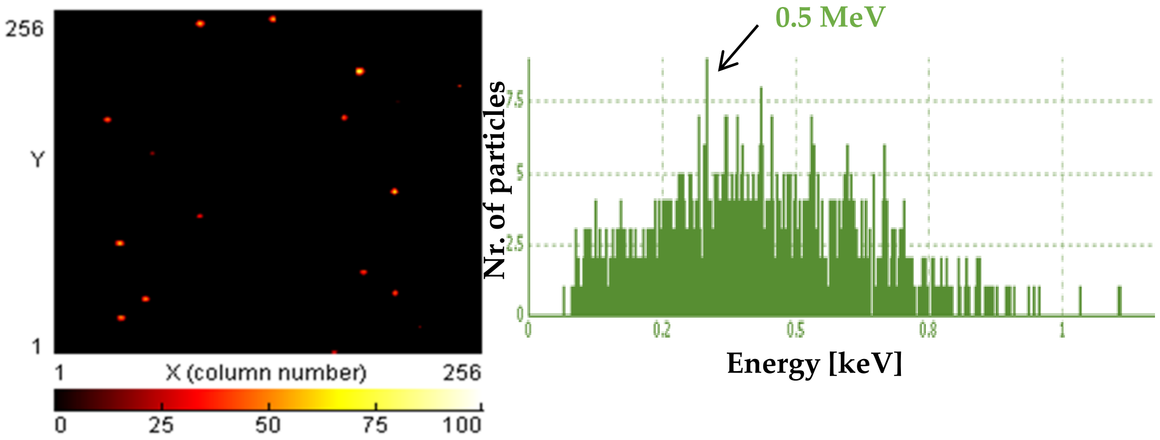


Figure 30. *The range of alpha particles in air at x= 2.5 cm distance from the source Am-241.*

Task 5. Determination of α-particles range in air using Pixel Detectors

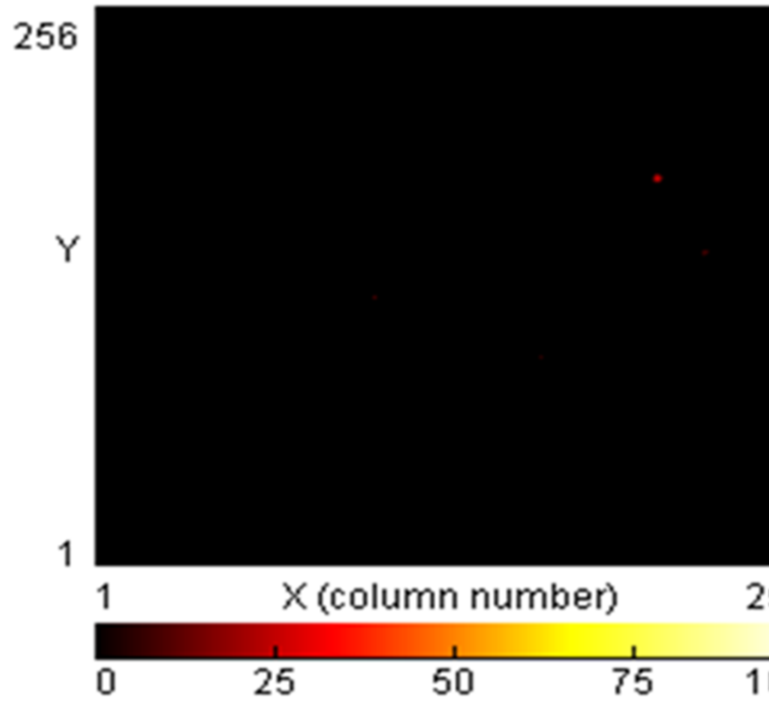


***Figure 31.** The **maximum** range of alpha particles in air at x= 3cm distance from the source Am-241.*

At 3 cm distance from the source there are no alpha particles detected!

Task 5. Determination of α-particles range in air using Plastic Detectors

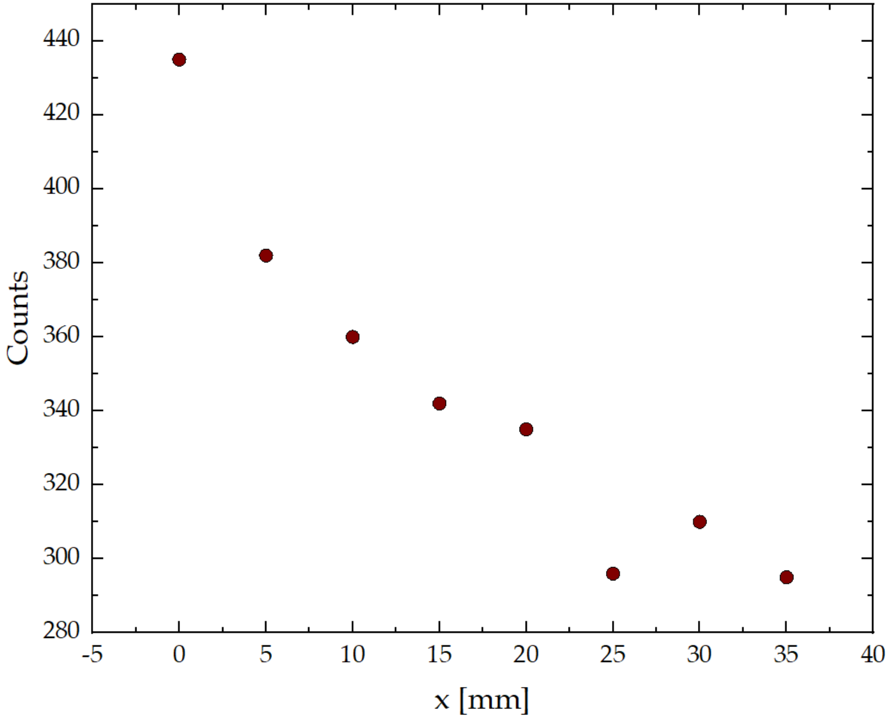


Figure 32. *The range of alpha particles resulting from measurements with* ***plastic detectors*** *at* ***2000 V*** *and* ^{239}*Pu* ***(5.1 MeV)***

Figure 33. *Example of plastic scintillator detectors.*

https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212

Conclusions

- The resolution and efficiency in the detection of radiation of two Inorganic Scintillation Detectors: BGO – Bismuth Germanate and NaI (Tl) was successfully determined
- The range of α-particles in air was determined using: Monte Carlo simulations via SRIM code, Plastic detectors, Scintillators and Pixel detectors
- The Attenuation coefficient (linear and mass) of γ radiation as a function of thickness and atomic number Z was determined (Cu, Al)
- Identification of unknown sources using the energy calibration function.

References

- William R. Leo, *Techniques for Nuclear and Particle Physics Experiments* (1994), Springer;
- Glenn F. Knoll, *Radiation Detection and Measurement,* (2010), Wiley, 4th Edition;
- Martin Shaw, *Nuclear and Particle Physics,* (2020), Wiley, 4th Edition;
- Attix, F.H., *Introduction to Radiological Physics and Radiation Dosimetry*, Wiley, New York (1986);
- Cember, H., *Introduction to Health Physics*, 3rd Edition, (2000) McGraw-Hill, New York.

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