JOINT INSTITUTE FOR NUCLEAR RESEARCH
Dzhelepov Laboratory of Nuclear Problems

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of Radiation Sources

Supervisor:
Dr Said AbouElazm

Student:
Ahmed Medhat Kamal Elkhadrawy,
Egypt,
Ain Shams University

Participation period:
Nov 02 – Dec 11, Wave 2

Dubna, 2020

Contents:-

1-Introduction

Scintillation detectors

a-BGO–BismuthGermanate($Bi_4Ge_3O_{12}$)

•Highly effective gamma ray absorber

•Diverse applications: PET, HEP, NP, space and medical physics

•Crystals:75mm max diameters;300 mm max lengths

•Wavelength range:375-650nm.

b- NaI(Tl)–SodiumIodide(Tl)

•A well established and the most extensively used scintillator

•Used for detection of gamma rays of low and intermediate energies

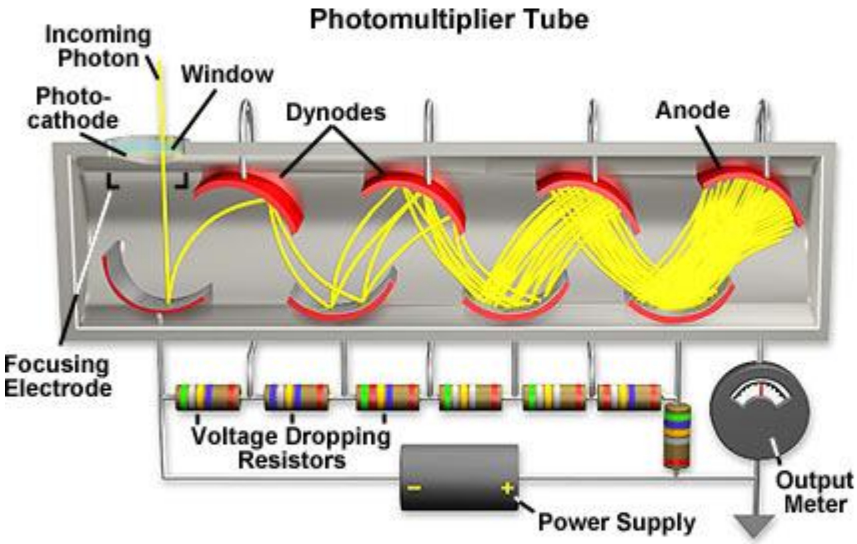
•Diverse applications :TOF measurements, Positron lifetimes studies. PET, HEP and NP

•Have an optical output well match to the maximum sensitivity of commonly available PMTs and it is independent of temperature.

•Crystals:150mm max diameters;400mm max lengths

•Wavelengthrange:325-550nm. [1]

c- Photomultiplier tube (PMT)



Photomultiplier tubes are extremely good at converting light into an electrical signal; electrical pulses can be obtained from a few hundred visible photons.

Photocathode Photomultiplier tubes are vacuum tubes in which the first major component is a photocathode. A light photon may interact in the photocathode to eject a low-energy electron into the vacuum.

This process can be thought to occur in three steps

1) Absorption of the photon and energy transfer to the electron in the photocathode material
2) The migration of the photoelectron to the surface of the photocathode
3) Escape of the electron from the photocathode surface

Domino ring sampler

The Domino Ring Sampler (DRS) chip, developed at P.S.I.1, is a high performance device in the category of high frequency (up to 6 GS/s) and large bandwidth (hundreds of MHz at -3 dB) samplers.

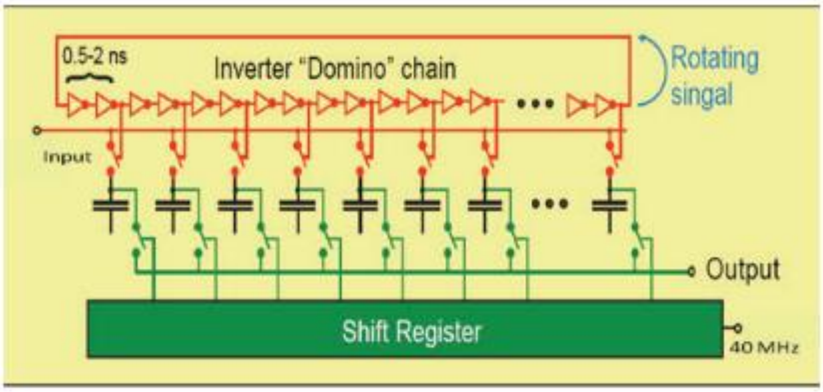


Figure 1 Simplified scheme of DRS chip

Principle of operation

The sampling frequency in the GHz range is generated with a series of inverters by a sampling signal freely propagating through these inverters in a circular fashion (”domino” principle). The analog input signal is stored in a switched capacitor array of 1024 cells. A trigger signal stops the running ”domino wave”, freezing the charge in the sampling capacitors. The individual cell contents are then readout by a shift register and digitized by a user selected ADC external to the chip.[2]

Radiation dose and units

During the early days of radiological experience, there was no precise unit of radiation dose that was suitable either for radiation protection or for radiation therapy. For purposes of radiation protection, a common “dosimeter” used was a piece of dental film with a paper clip attached. A daily exposure great enough just to pro- duce a detectable shadow, called a “paper-clip” unit, was considered a maximum permissible dose. For greater doses and for therapy purposes, the dose unit was frequently the “skin erythema unit.”Because of the great energy dependence of these dose units as well as other inherent shortcomings, neither of these two units could be biologically meaningful or useful either in the quantitative study of the biological effects of radiation or for radiation safety purposes. Furthermore, since the fraction of the energy in a radiation field that is absorbed by the body is energy dependent, it is necessary to distinguish between radiation exposure and radiation absorbed dose.

Absorbed dose

Radiation damage depends on the absorption of energy from the radiation and is approximately proportional to the mean concentration of absorbed energy in irradiated tissue. For this reason, the basic unit of radiation dose is expressed in terms of absorbed energy per unit mass of tissue, that is,

Radiation absorbed dose= $\frac{\Delta E}{\Delta m}$ **Eq (1)**

The unit for radiation absorbed dose in the SI system is called the gray (Gy) and is defined as follows: One gray is an absorbed radiation dose of one joule per kilogram.

The gray is universally applicable to all types of ionizing radiation dosimetry— irradiation due to external fields of gamma rays, neutrons, or charged particles as well as that due to internally deposited radionuclides.

Exposure unit

One exposure unit is defined as that quantity of X- or gamma radiation that produces, in air, ions carrying one coulomb of charge (of either sign) per kilogram of air. It does not have a special name, and is being called an "X unit" in this textbook for convenience.

1X unit= $\frac{1C}{1\ Kg\ air}$ **Eq (2)**

The exposure unit is based on ionization of air because of the relative ease with which radiation-induced ionization can be measured. At quantum energies less than several kilo electron volts and more than several mega electron volts, it becomes difficult to fulfill the requirements for measuring the exposure unit. Accordingly, the use of the exposure unit is limited to X- or gamma rays whose quantum en- ergies do not exceed 3 MeV. For higher energy photons, exposure is expressed in units of watt-seconds per square meter and exposure rate is expressed in units of watts per square meter. The operational definition of the exposure unit may be converted into the more fundamental units of energy absorption per unit mass of average energy dissipated in the production of a single ion pair in air is 34 eV. air by using the fact that the charge on a single ion is 1.6 × 10−19 C and that the average energy dissipated in the production of a single ion pair in air is 34 eV. [3]

Therefore,

1 X unit = 1 $\frac{1C}{1\ Kg}$ air × $\frac{1\text{ ion}}{1.6\times10^{-19}\text{ C}}$ × 34 $\frac{eV}{ion}$ × 1.6 × 10^{-19} J /eV × $\frac{1\text{ Gy}}{\text{J/kg}}$ = 34 Gy (in air). **Eq (3)**

2- Project goals

1- Radioactivity. Different types of radiation sources. Detection of radiation.

2- Spectrum of alpha, beta and gamma sources.

3- Attenuation of gamma radiation as a function of thickness and atomic number Z

4- Ranges of alpha and beta particles

5- Shielding properties of different materials and examples of shielding calculations

6- Calibration of a gamma scintillation spectrometer in terms of energy and activity

7- Calibration of an alpha spectrometry system in terms of energy and activity

8- Radiation dose and units.

9- Portable monitors for alpha, beta, gamma radiation. Determination of the background level of radiation .Methods of surveys.

3- Scope of work

The training was focusing on learning more about scintillation detectors (NaI and BGO) and comparing their efficiency in detection of radiation. The training focused also on learning how to calculate the resolution of scintillation detectors and comparing the resolution at different applied voltage. One of the assignments of the training was determining the energy calibration curve from ^{60}Co and ^{137}Cs data to calculate the energy of unknown sources.

The last assignment was determination of attenuation coefficient of gamma ray by using the following equation

$$I = I_0 e^{-\mu x} \qquad \textbf{Eq (4)}$$

By plotting the relation between I/I_0 (Y-axis) and thickness (x) on x-axis , the attenuation coefficient (μ) can be determined for different materials (Cu - Al).

4- Methods

a- Resolution calculation

For calculation of the resolution of NaI and BGO detector at different applied voltage. Root software was used for opening the data files, fitting the curves and calculating full width half maximum (2*sigma) and the mean.

Resolution was calculated by dividing mean/2*sigma (Figure 2)

b- Calibration curve

Calibration curve is that curve used for energy calculation of unknown source , therefore to plot the calibration curve, sources of known energy must be used . The plot was done by drawing relation between PMT signal from NaI and BGO detectors and Energy (**Figure 5**).

The aim of this task was determination of Am-241 source unknown energy from the calibration curve (**Figure 5**)

c- Attenuation coefficient determination

For determination of attenuation coefficient of different materials , the relation between I/I0 and thickness (x) was plotted (**Figure 7**) and the attenuation coefficient was calculated from the curve fitting equation.

5- Figures

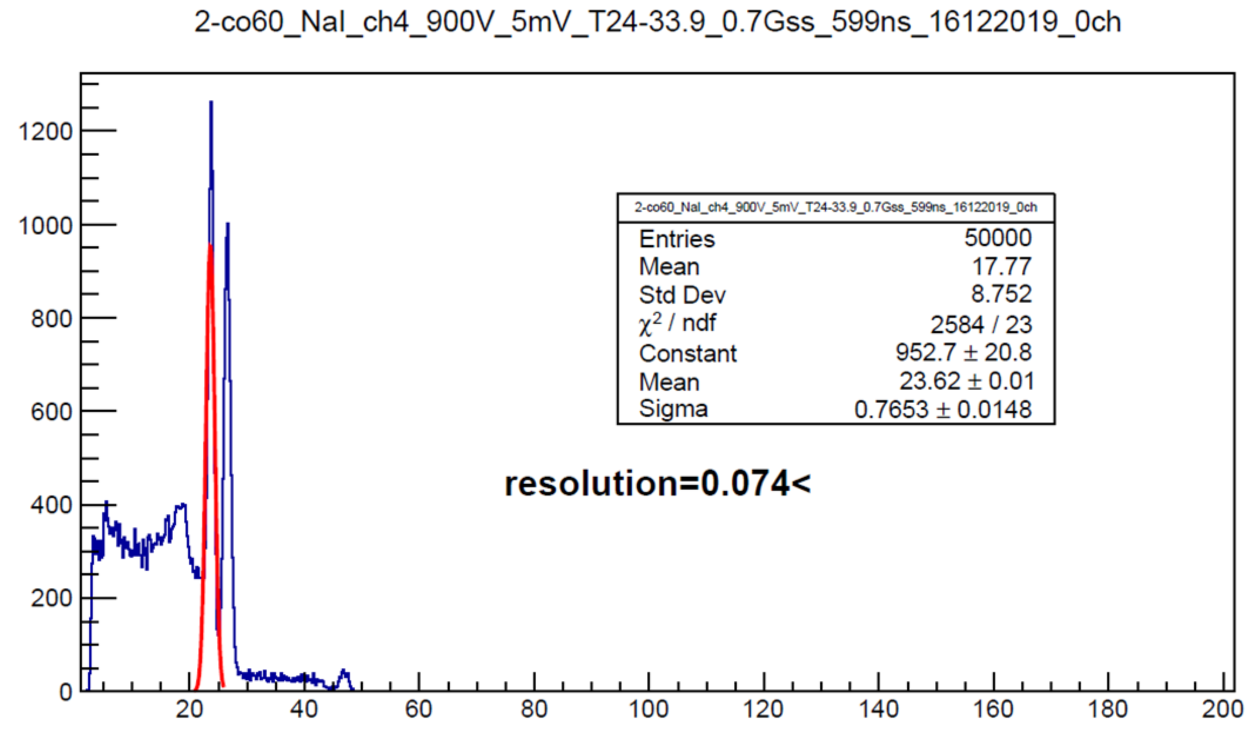


Figure 2 resolution calculation by root software for NaI detector

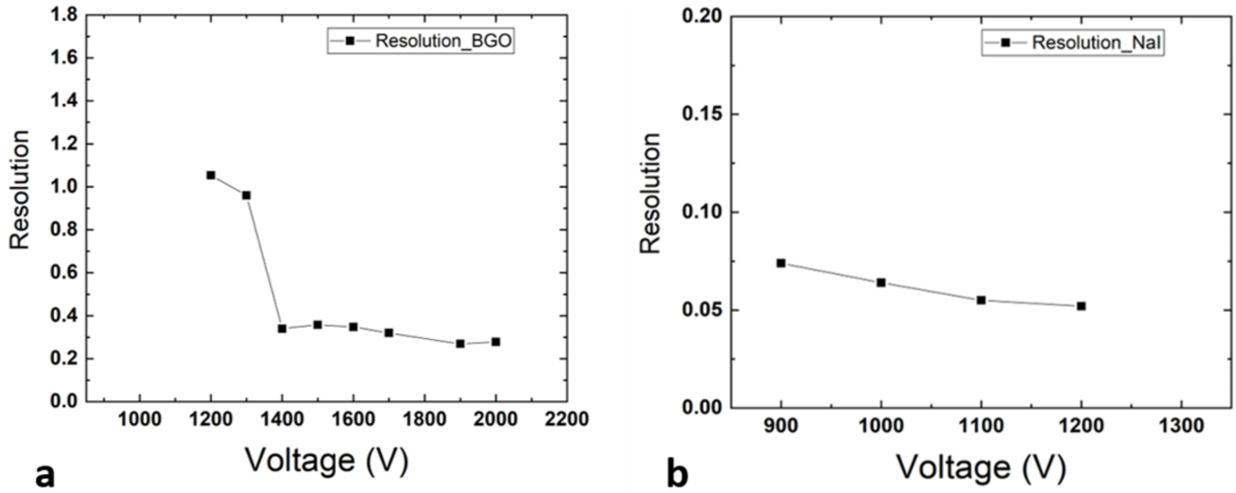
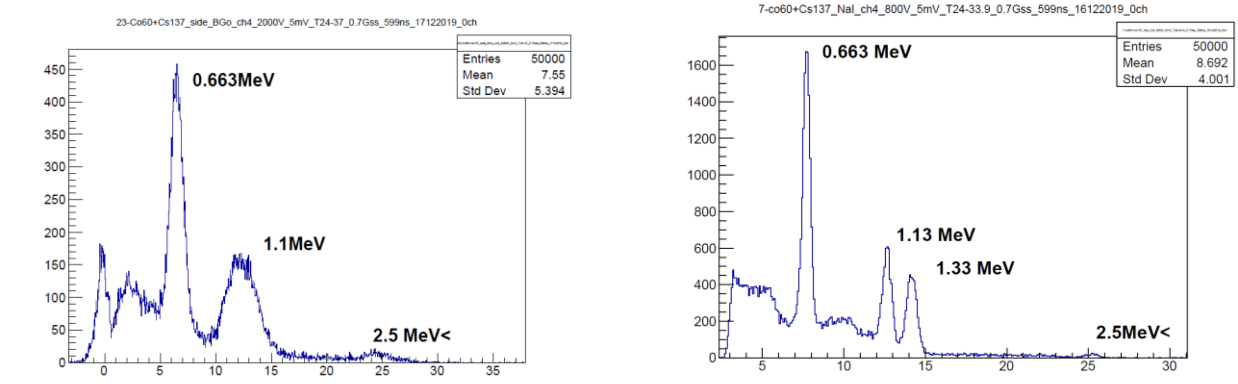


Figure 3 Resolution vs applied voltage for (a) BGO detector, (b) NaI detector



(a) (b)

Figure 4 Energy vs PMT signal for CO+Cs sources for (a)BGO detector , (b) NaI detector

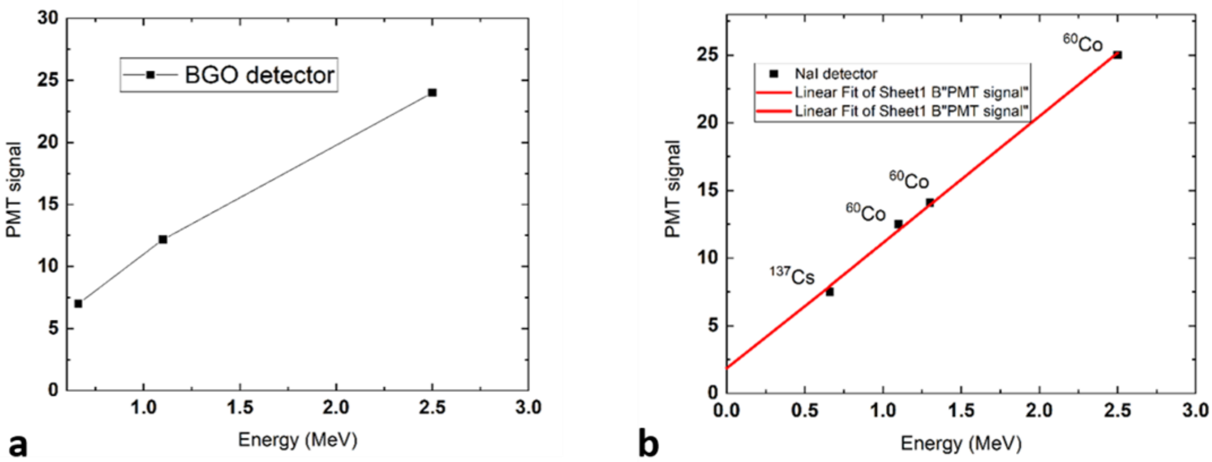


Figure 5 Calibration curve of (a) BGO detector, (b) NaI detector

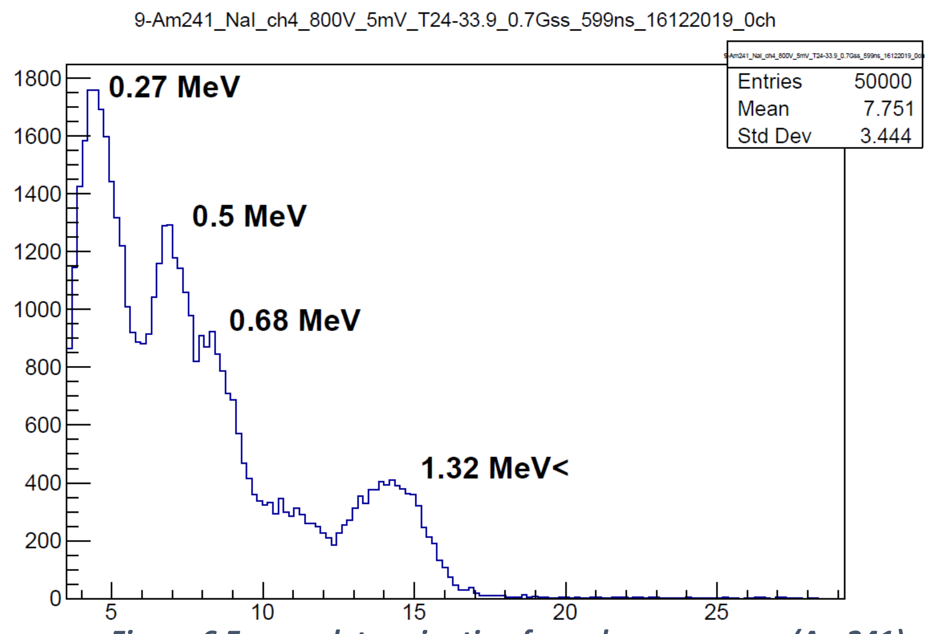


Figure 6 Energy determination for unknown source (Am241) using NaI detector

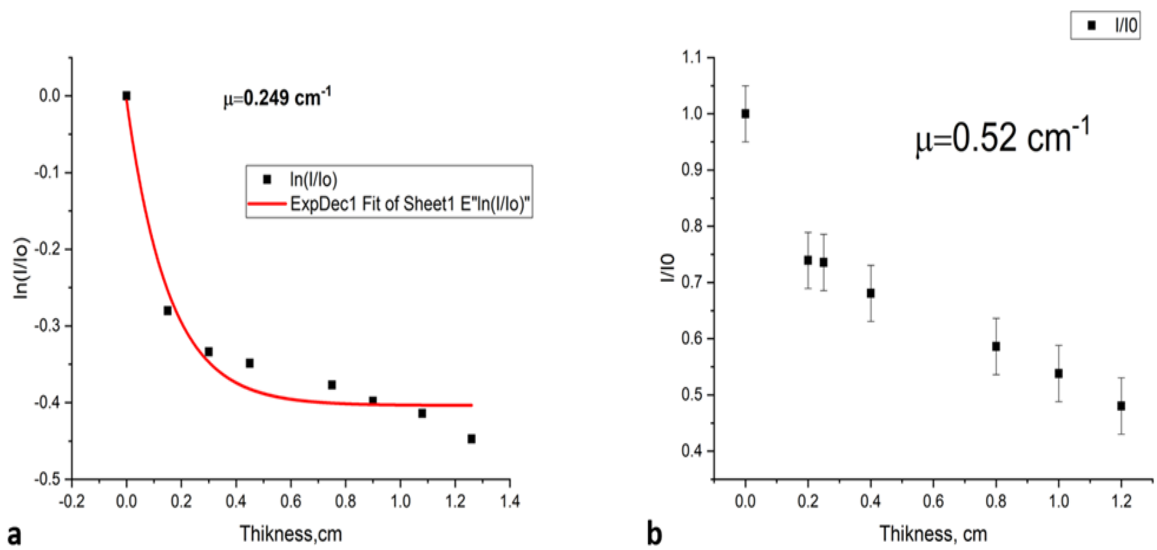


Figure 7 Attenuation coefficient determination of (a)Al and (b)Cu

6- Results and discussion

From **Figure 3**, it can be concluded that the resolution decreases by increasing voltage which means that the resolution enhances by increasing voltage in both types of detectors.

From **Figure 5**, the energy of Am-241 was determined for every peak as shown in **Figure 6** by using the calibration curve of NaI detector .

By drawing the relation between ln (I/I_0) and thickness (x) as shown in **Figure 7** , attenuation coefficient was determined for Al (**Figure 7** (a)) and Cu (**Figure 7** (b)).

7- Conclusion

The training focused on scintillation detectors and calculation of resolution for different detectors (NaI and BGO), and therefore comparing between them in their resolution. The energy of unknown source was determined by using calibration curve and finally the attenuation coefficient of Cu and Al were calculated using the relation between I/I_0 and thickness.

8- References

(1) Byun, S. H. Photon Spectrometry with Scintillators. *Radioisot. Radiat. Methodol.* 1–20.

(2) Calorimetry, D. Domino Ring Sampler (DRS) Performances In. **2010**, No. Iv, 1711–1717.

(3) Hitchcock, T.; Bullock, W. H.; Ignacio, J. S. *Chapter 15: Non-Ionizing Radiation*; 2009. https://doi.org/10.3320/978-1-931504-69-0.177.

9-Acknowlodgement

I would like to thank Dr.Said Abouelazm for allowing me to participate in this wonderful JINR school and I hope to attend the next summer school in Russia to observe everything I learned this year in experimental way. Many thanks for JINR committee and services for contacting with us and giving us all the recommended instructions about the school and thanks to Julia Rybachuk who was the first one to recommend this school to me.