Radioactive sources used in mining explorations and environmental risks

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Introduction

- Radioactive sources, mainly gamma sources and neutron sources, are widely used in mines for the exploration and extraction of natural resources such as oil, gas, uranium, etc.

- The gamma source is generally used associated to a gamma radiation detector, to detect the rays diffused by the rocks of the mine. The ratio of the number of gamma rays scattered to that emitted by the source gives informations on the formation's characteristics as composition, density, porosity….

- The neutron source is used coupled with thermal and /or epithermal neutrons detectors. The measured ratio of the intensity of the slow-neutrons to those of the source is also related to the physical characteristics of the formations of the explored mine.

- The radioactive sources used provide valuable information on the formations of the explored mine but on the other hands the risks of ionized radiations on environment and workers are not negligible.

- Replacing the radioactive sources commonly used by another investigative device, safer for workers and the environment, is a big challenge and the present study is a part.

Natural Gamma ray measurements

- Measurement of natural radioactivity: Most geological formations contain potassium K40, Th232 and U238 (natural radioactive elements).

Element	Life time (y)	Gamma ray characterestic (MeV)
K40	$1.3\ 10^9$	1.46
Th232	$1.4\ 10^9$	2.62
U238	$4.5\ 10^9$	2.43

- **Experimental Set-up used:** Scintillator coupled to a gamma ray spectrometer: measurements of gamma rays energies and intensities

Gamma-gamma rays measurements

- Detection of scattered gammas rays emitted by a radioactive source (source of Cs 137)
- Medium density's measurement : Intensity of the gamma rays scattered decrease with density's increase
- Deduce a quantitative estimation of the medium's porosity
- **Measurement Sensitivity :**
- **Interference with natural gamma rays**
- **source-gamma ray detecteur distance**
- **Gamma ray efficacity and resolution**
- **Experimental Set-up used:** source of Cs 137 coupled to two gamma rays detectors

Neutron-neutron meausurements

- Slowing down of the fast neutrons emitted by neutron's source (Am-Be source) : used to determine porosity, humidity index,underground's physical state (gaz or fluid).

Meaurement sensitivities:

- Neutron's source energies
- Source-detector distance
- Radiative neutrons capture by the presence of some elements like chlore
- Lack of nuclear data relating to neutron interaction cross sections
- **Experimental set-up used:** neutron source(Am-Be source) coupled to two neutron's detectors

Gamma-neutron measurements

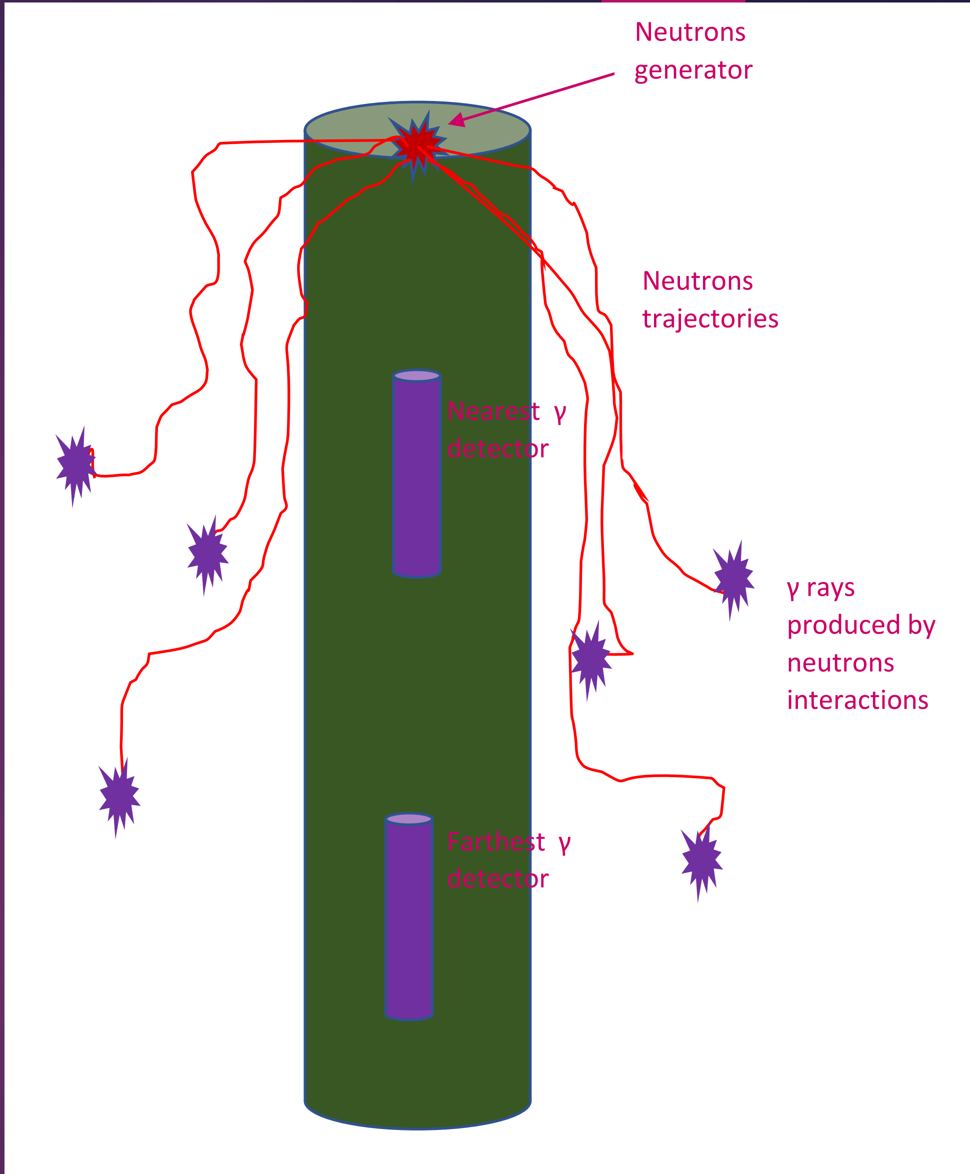
- Detection of gamma rays from inelastic scattering and radiative capture
- Used to identify the fluid nature present in the formation by determining

  H, C, O proportions
- Quantify Ca and Mg presence

- Measurements sensitivity:
- Neutrons source energies
- Geometric configuration of the used experimental Set-up
- Gamma detectors responses
- Algorithms used for gamma rays spectra analysis
- Nuclear data library (nuclear cross sections)
- **Experimental set-up used:** Pulsed neutron generator coupled to neutrons detectors

Density measurements

- **Experimental set-up:**
- Pulsed neutrons generator emits 6 10^7 n/s
- γ rays detectors: NaITl Scintillators coupled to γ rays spectrometer
- Detection of the γ rays produced by neutrons interaction with the medium surrounded the set-up.



Predicted correlation :

$\log N_{\gamma Farthest}$ α ρ_{FS} (density determined from $N_{\gamma Farthest}$)

$\log N_{\gamma Nearest}$α ρ_{NS} (density determined from $N_{\gamma Nearest}$)

- $N_{\gamma Farthest}$: number of γ rays recorded by the farthest detector
- $N_{\gamma Nearest}$: number of γ rays recorded by the nearest detector
- Δρ: density's correction is calculated using the correlation

Δρ function ρ_{FS} - ρ_{NS}

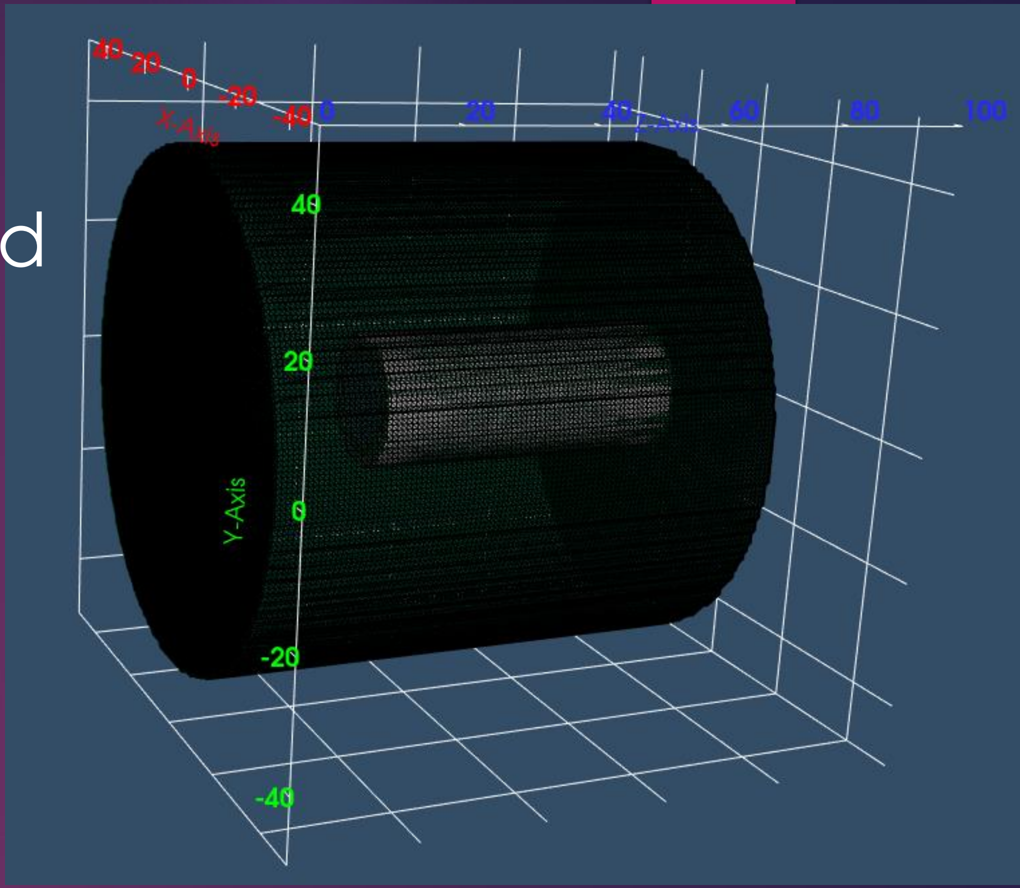
The bulk density is determined as: ρ = ρ_{FS} + Δρ

Monte Carlo simulation

❖Phits code version 3.29 is used to carried out Monte Carlo simulation

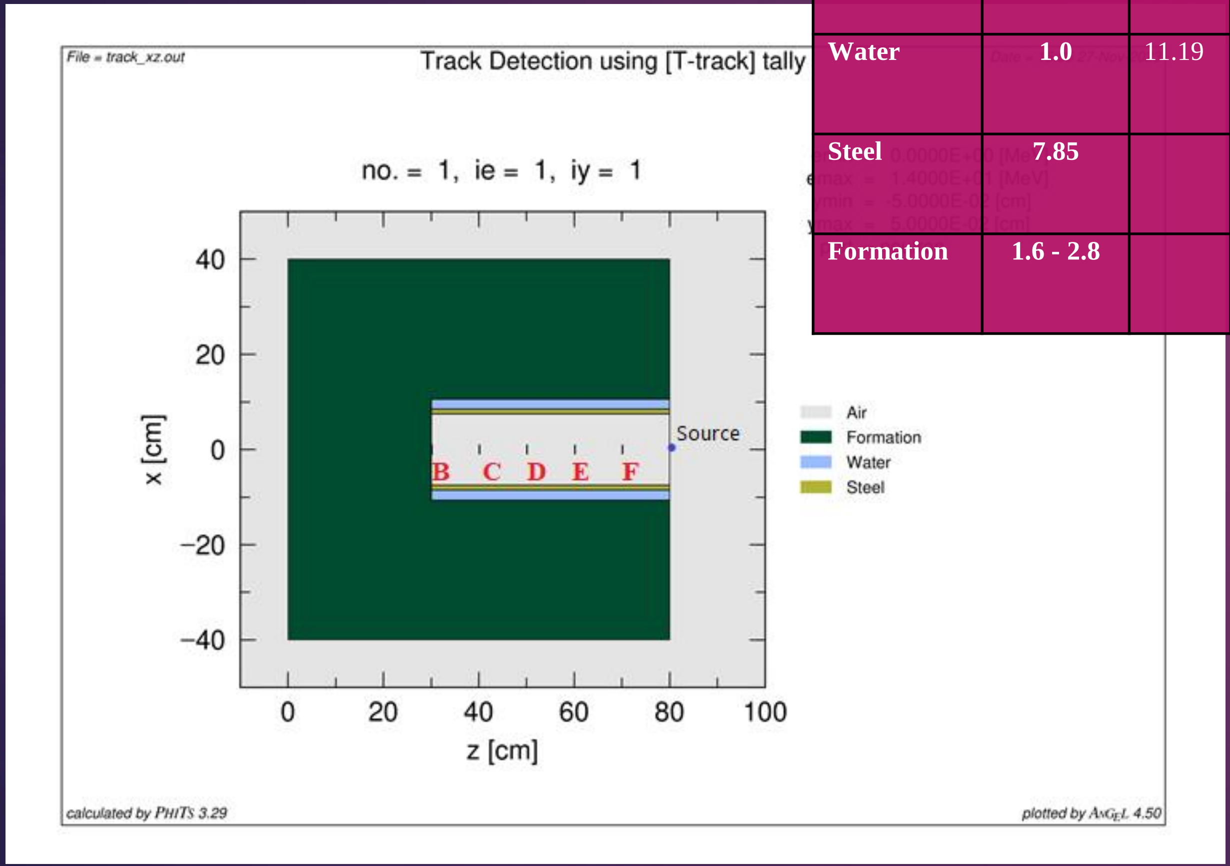
❖Experimental set-up :
steel cylinder (15 cm diameter , 50 cm height) contains
neutron generator , the two γ detectors positionned at
(x,y)=(0,0)

The black cylinder (the formation to charactherize): 80cm diameter , 80cm height



Compounds of different materials used for Monte Carlo simulation

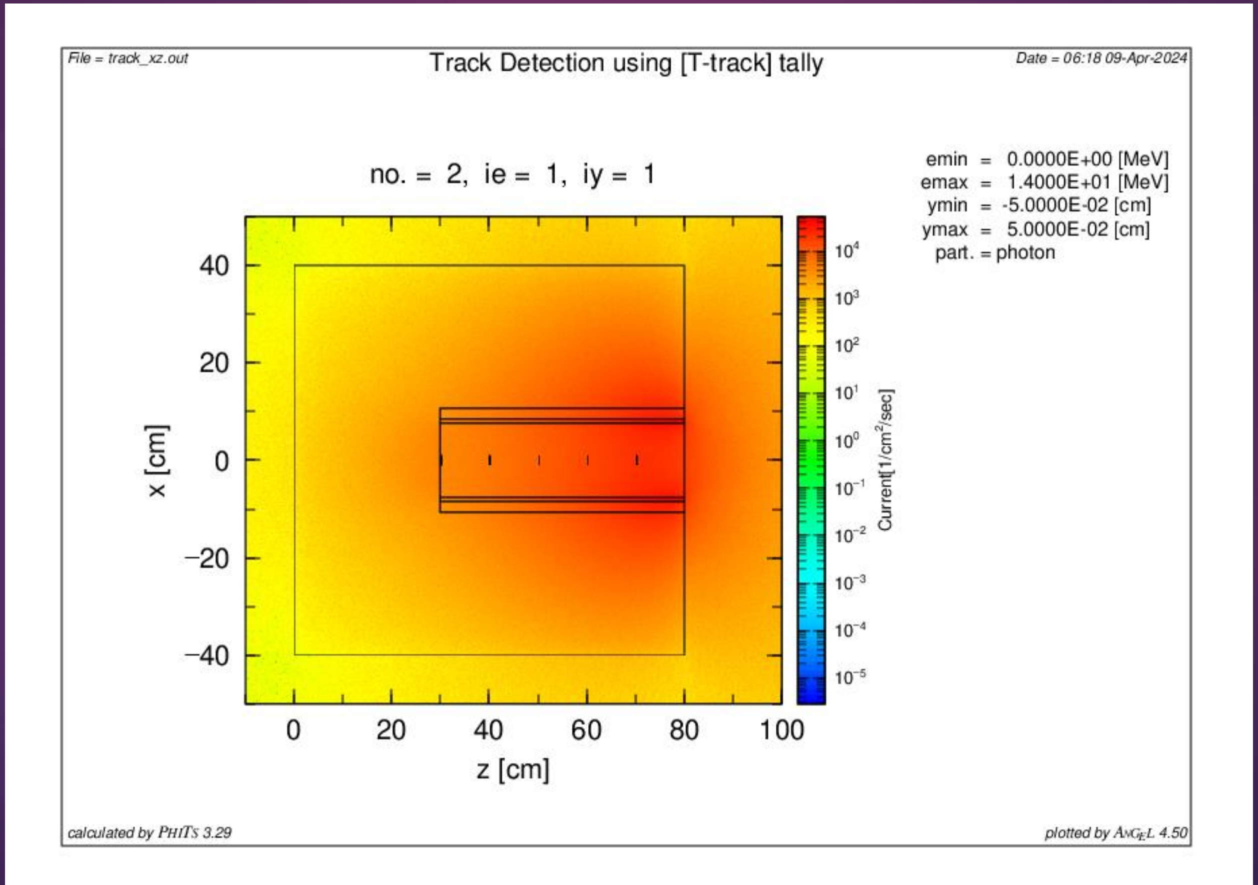
	Density [g/cm3]	Compositions (%)														
		H	O	Si	Al	Fe	Ca	Na	K	Mg	C	S	P	Mn	N	Ar
Air	0.00121		23.2												75.5	1.3
Water	1.0	11.19	88.81													
Steel	7.85			0.4		98.66					0.25	0.05	0.04	0.6		
Formation	1.6 - 2.8		51.27	43.84	0.79	1.12	0.64	0.89	1.2	0.4						



Experimental set-up is intoduced in aborehole surounded with mud (water)

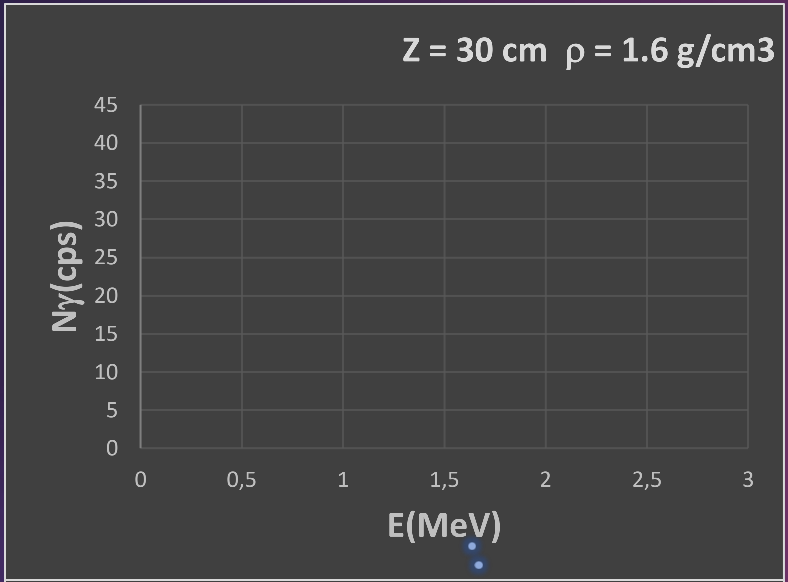
For each density's formation, the number of γ rays are recorded at different positions: B, C, D, E and F

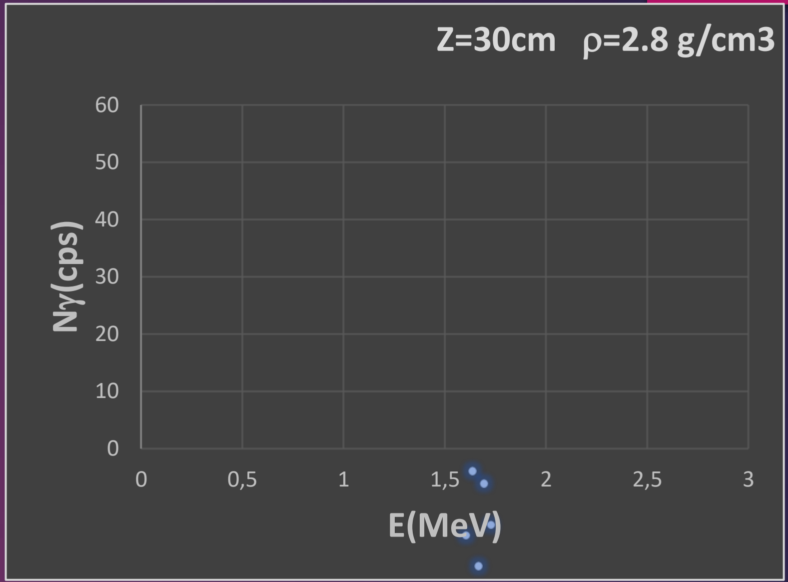
Exemple of photon flux distribution, given by Monte Carlosimulation, of the γ rays resulting from neutrons interactions with the medium of 1. 6 g/cm3 density.
Results of track of $2.5\ 10^8$ neutrons source.

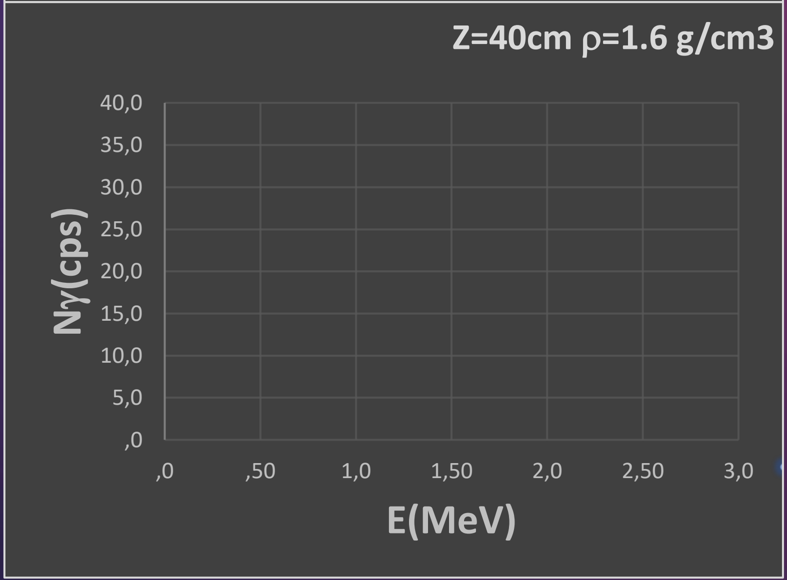


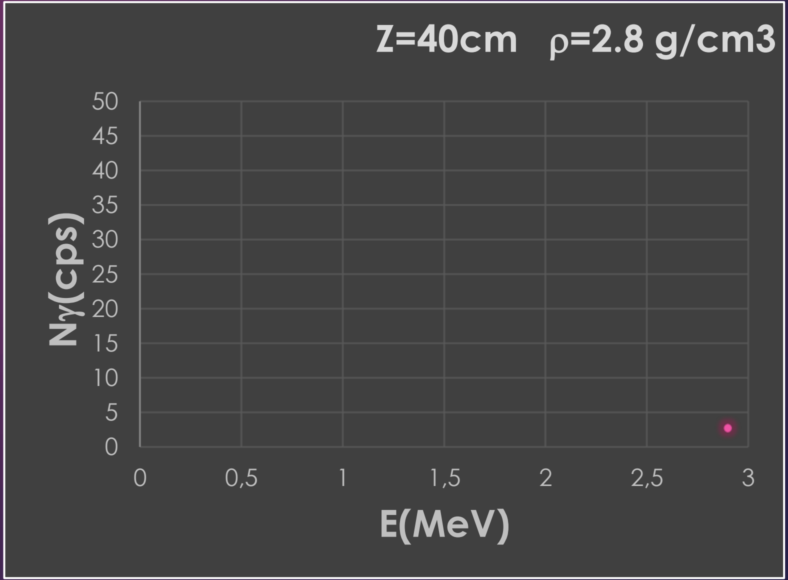
Results

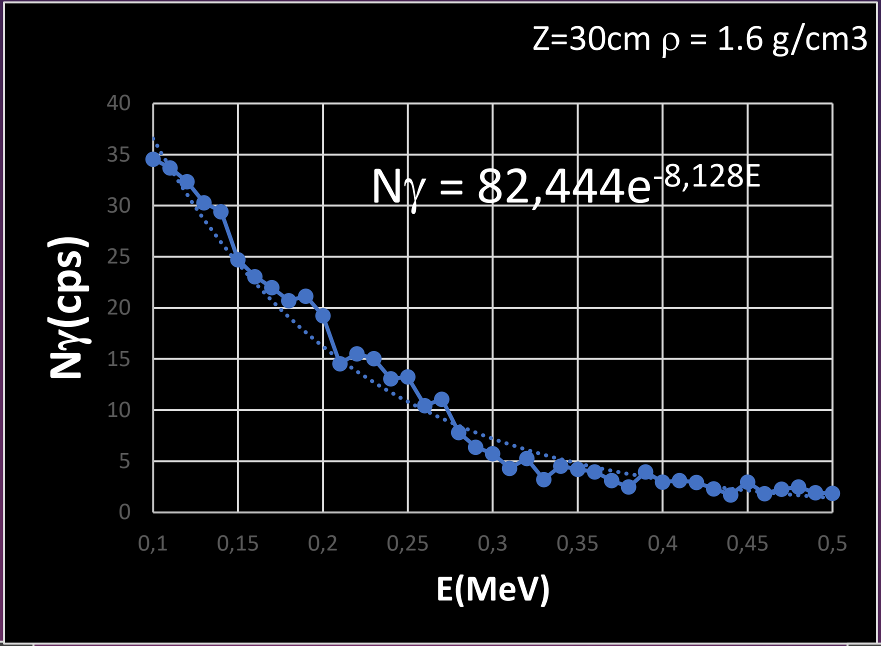
Examples of γ rays spectra obtained for differentes densities at differentes positions from the neutron generator

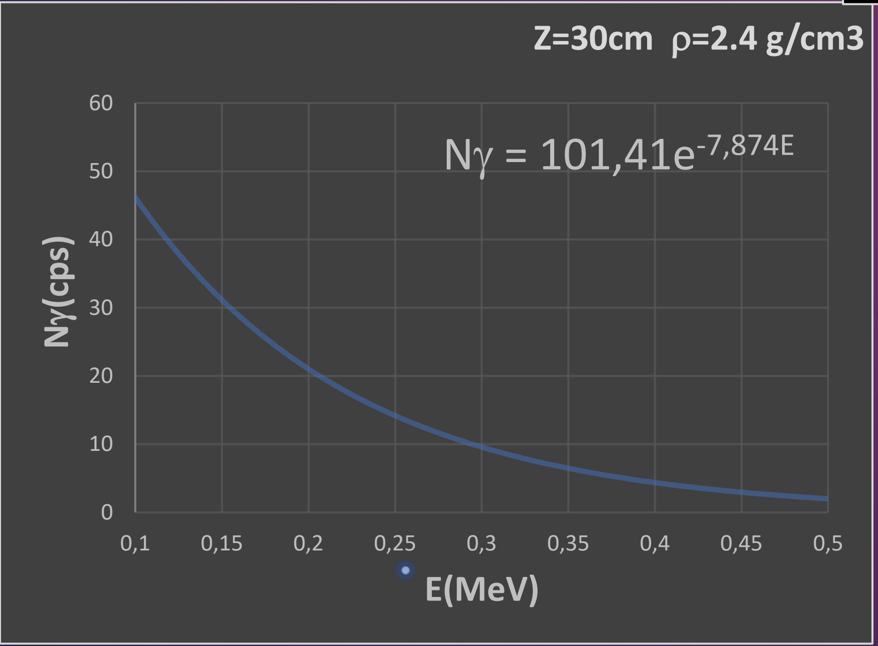




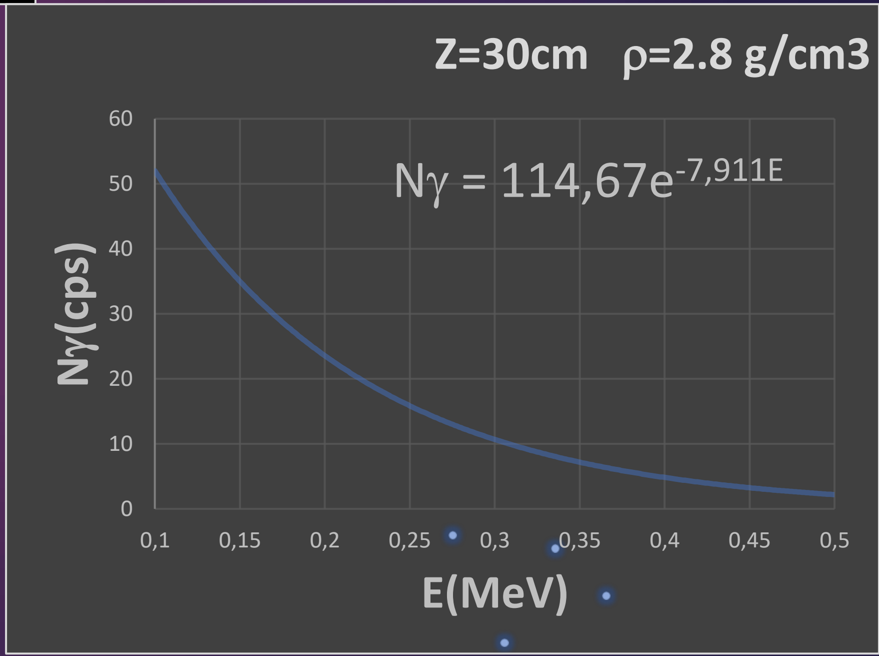






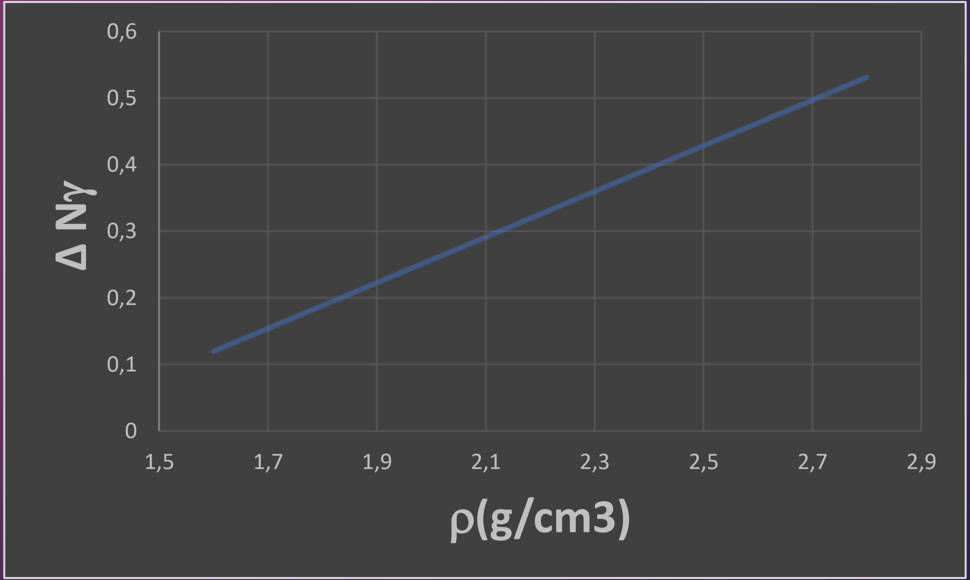


Energy spectra of the recorded γ in the energy bin[0.1 MeV, 0.5 MeV] at a distance of Z=30 cm from the neutron generator and for differentes densities



- $N_\gamma(E) = A\, e^{-\alpha E}$ for 0.1 MeV≤ E ≤ 0.5 MeV
- $N_\gamma(E)$: the number of γ rays recorded in the bin [E, E+dE]
- $\int_{E_0}^{E_0+\Delta E} N_\gamma(E)dE = \Delta\, N_\gamma$
- $\Delta\, N_\gamma$ has been calculated for $E_0 = 0.1\, MeV$ and ΔE = 0.1 MeV

ρ (g/cm3)	$\Delta\, N\gamma$
1,6	0,1144
2,4	0,41
2,8	0,52



Conclusion

- Pulsed neutron generator is more safe for workers and environment than radioactive sources

- The aim of this work is to study the possibility to replace the radioactive source (γ rays source), very used in minig exploration, by a pulsed neutron generator .

- The experimental Set-up proposed for this purpose is composed of a pulsed neutron generator coupled to two γ rays detectors.

- Phyts code version 3.26 is used to carried out Monte Carlo simulation

- The preleminary results shows that the number of γ rays recorded in a specified bin is linearly correlated to the formation's density

- The curve of calibration of the number of γ rays recorded function of the formation's density is used to determine unknown density of a given medium

- This work is still in progress to ameliorate the precision and to establish a complete calibration curve