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# Simulation of photo-neutron induced activation gamma rays for copper characterization in scrap metal



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October 21, 2021



## Outline :

- I. **Introduction**
- II. **Numerical model**
- III. **Activation gamma rays simulation**
- IV. **Copper activation gamma rays assessment**
- V. **Conclusion and prospects**



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➤ **Context:**

*I. Introduction*

- Arcelor Mittal Research & Development program to explore **non destructives techniques** to characterize **copper** in scrap metal

*II. Numerical Model*

- CEA List **know-how** and experience in **Neutron Activation Analysis** using a **LINEar electron ACcelerator (LINAC)** coupled to a **photo-neutron conversion target**

*III. Activation gamma rays Simulation*



*IV. Copper activation gamma rays assessment*



*V. Conclusion & Prospects*

## ➤ The SAPHIR Facility:

### I. Introduction

- French acronym for “*System of Photon Activation and Irradiation*”

### II. Numerical Model

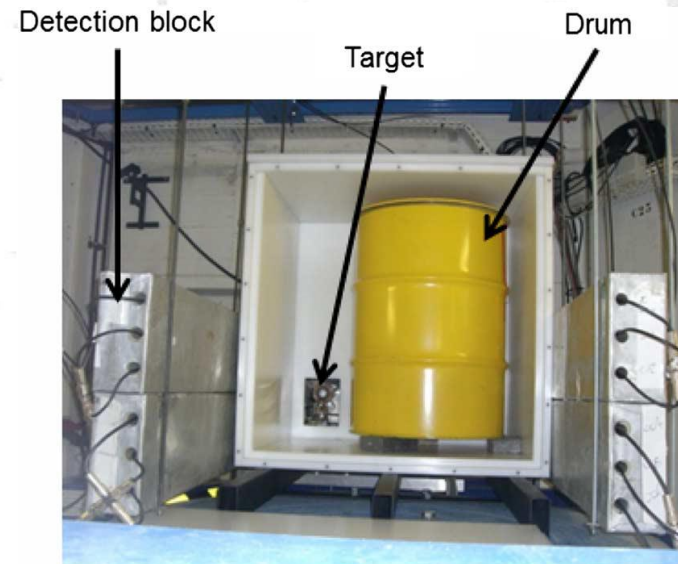
- Since 2012 : Installation of a 6 or 9 MeV **LINATRON M9** linac from Varex Imaging Corp.
- Use of a 16 kg **Deuterium Oxide photo-neutron conversion target** for neutron activation applications

### III. Activation gamma rays Simulation

- High Density Polyethylene (HDPE) neutron interrogation cell

### IV. Copper activation gamma rays assessment

### V. Conclusion & Prospects



## ➤ Background study:

- Experimental analysis to characterize copper in scrap metal :

- ❖ 220 L drum and 125 g to 1253 g copper samples in three positions
- ❖ Detection limits range from some dozens to hundreds of grams for the median and peripheral positions
- ❖ Copper sample in the central position is **undetectable**

➔ Need to simulate **photo-neutron induced copper gamma rays contribution** to support Linac based NAA investigations

## ➤ Objectives of the present study:

- To establish and validate a computational scheme to simulate Linac based neutron activation analysis performances for different copper distributions in scrap metal



A. Sari et al., *Appli. Radiat. Isot.* (2020)

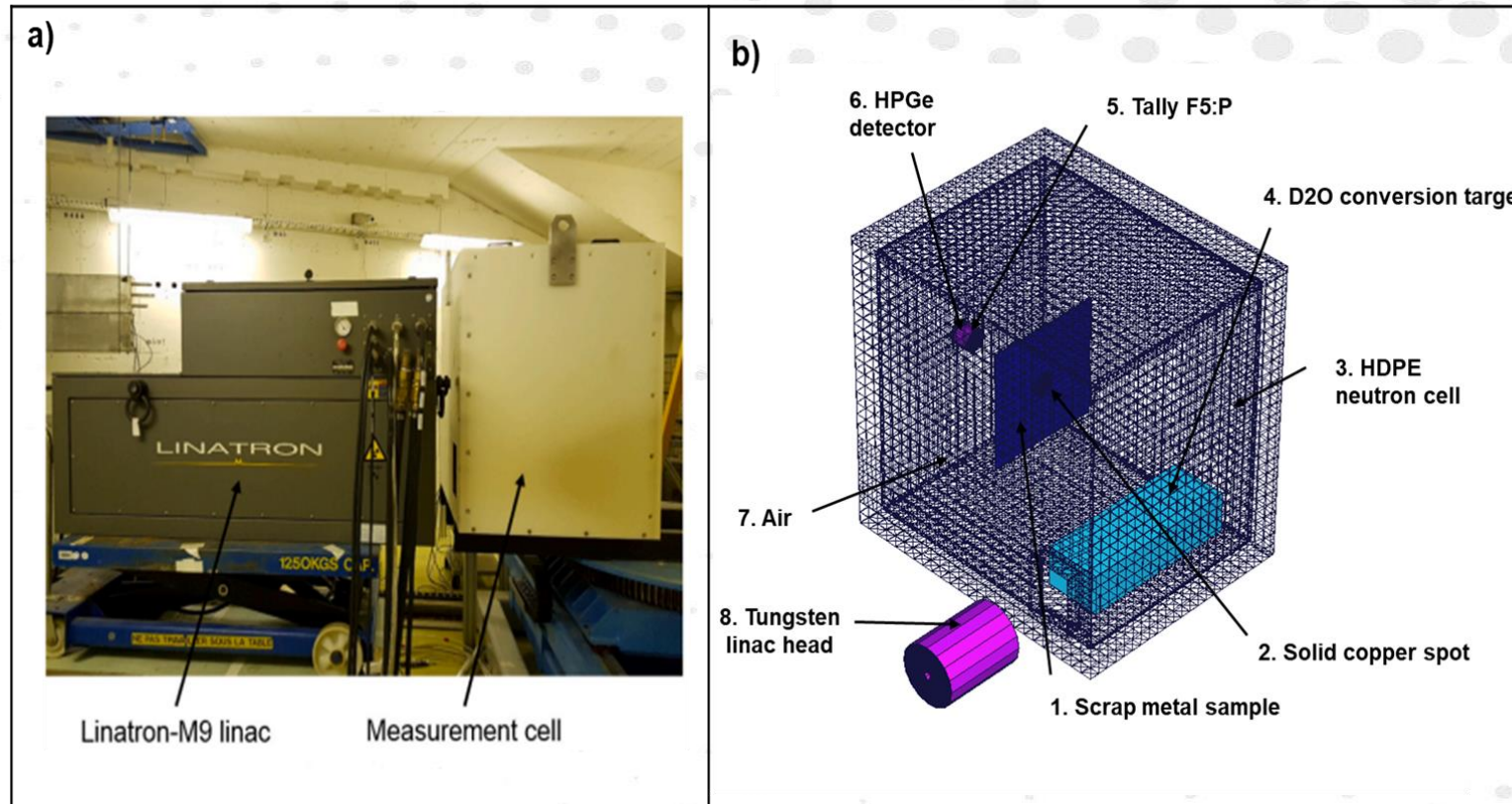


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➤ Numerical description of the cell components:

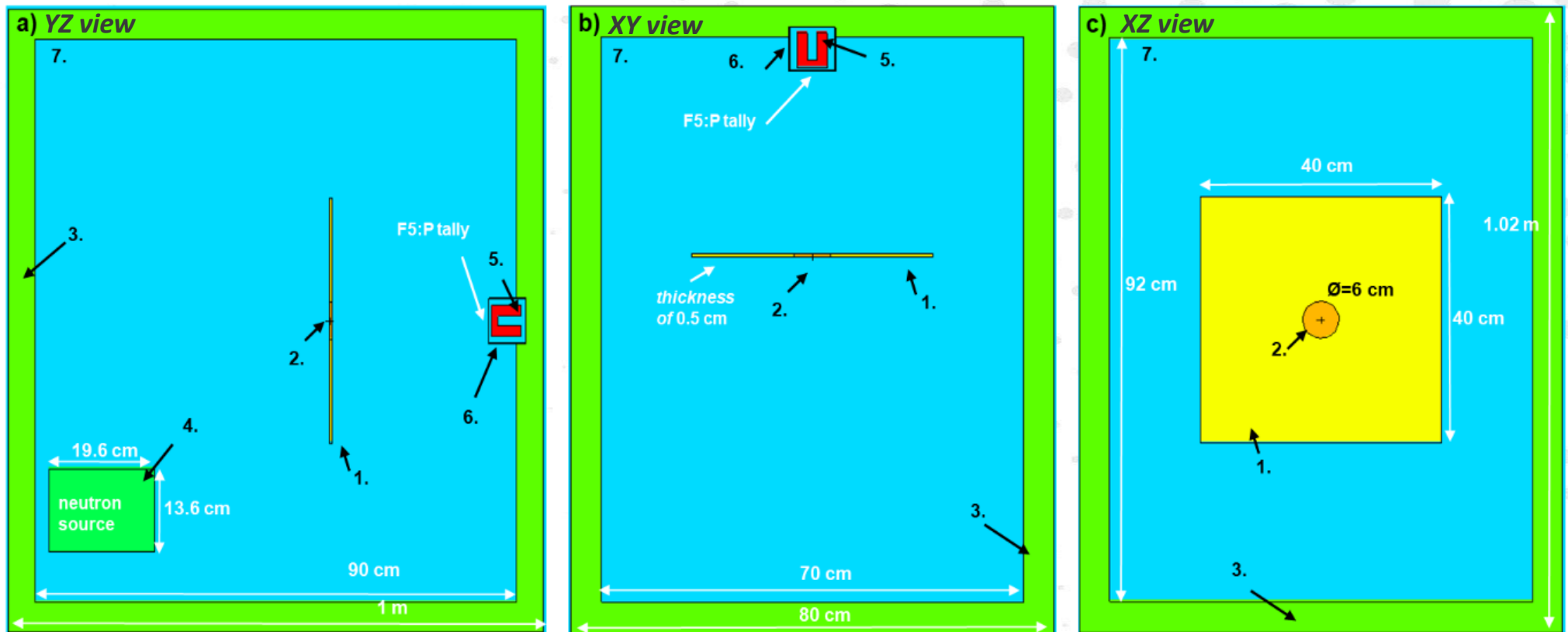


- Main items description with MCNP6 for the study of linac-based delayed gamma neutron activation analysis



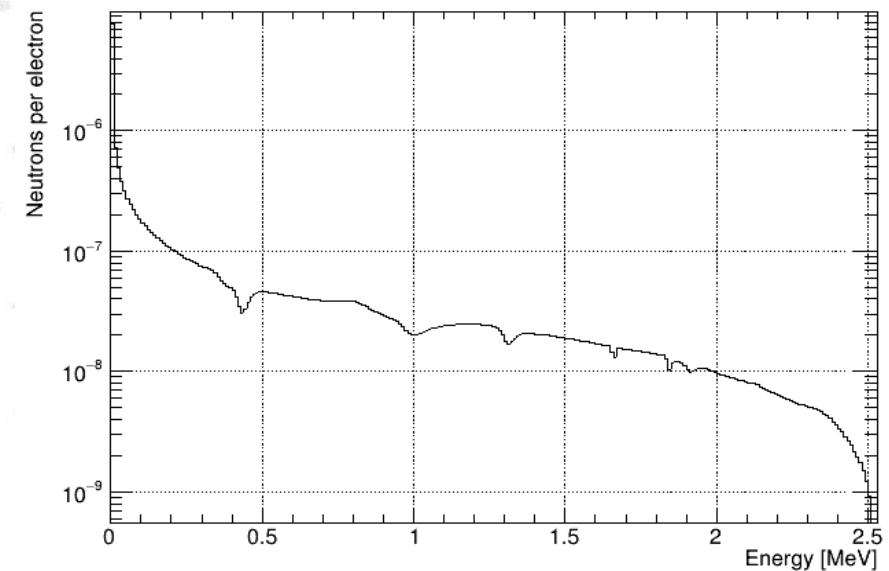
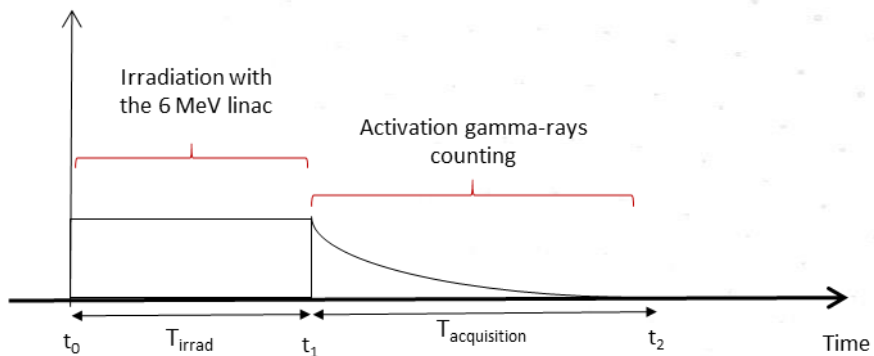
### ➤ Copper mass configuration:

- Solid disc-shaped **copper mass** of **126.6 g** in the middle of a planar scrap metal matrix
- Calculation of activation gamma rays with a **F5:P variance reduction point tally** in front of a **HPGe crystal**



## ➤ Neutron source description:

- Temporal description for a **2-h irradiation pulse** followed by a **2-h measurement**
- NPS of  **$10^{10}$  source neutrons isotopically emitted** by the 16 kg Deuterium Oxide ( **$D_2O$** ) target
- Distribution for an initial **6 MeV linac energy** corresponding to a  **$2.03 \times 10^9 \text{ n.s}^{-1}$  neutron emission**





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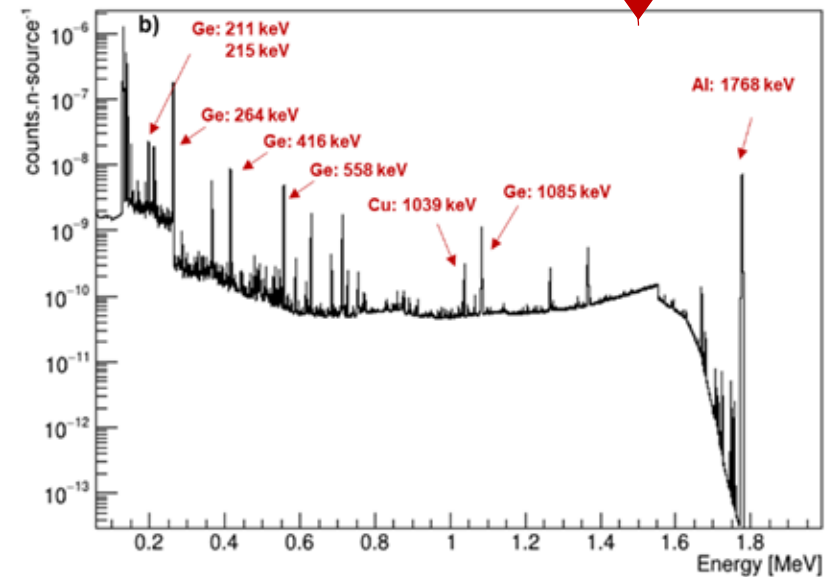
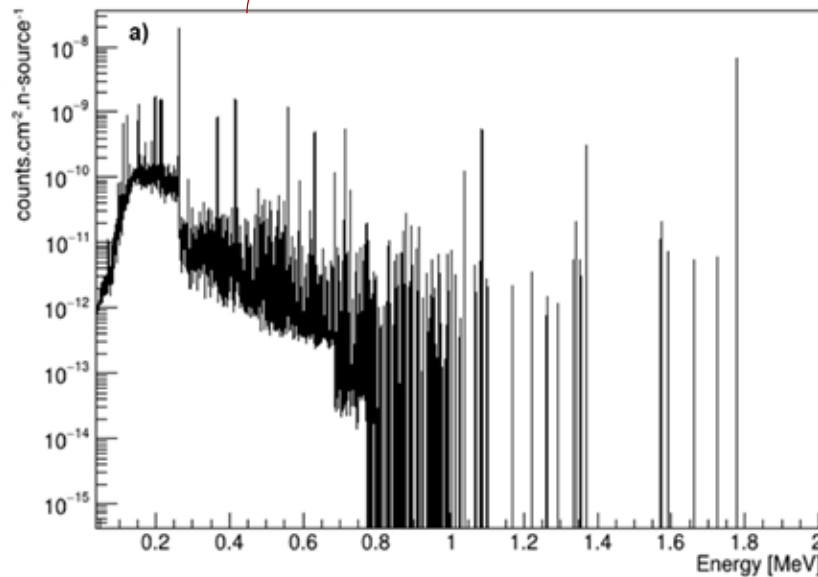
### ➤ Numerical approach:

- Use of **ACT** (ACTivation control card) with NONFISSION = P and DG = Lines options for **activation gamma rays creation and transport** in single step calculations with **CEA List's cluster (several hundred cores)**
- Smearing the F5: P output tally with a **33% relative efficiency HPGe** with MODAR Software (MCNP Output Data Analysis with Root)

$$S(E) = \int_{E'} F5:P(E') \times RF_{HPGe33\%}(E', E) dE'$$

*F5:P(E')*

*Smearing output spectrum with the Response Function of a 33% HPGe*



➤ Main measured delayed gamma rays:

Activated Element	Cu	Al	Ge	W		
Associated reaction	$^{65}\text{Cu}(n,\gamma)^{66}\text{Cu}$	$^{27}\text{Al}(n,\gamma)^{28}\text{Al}$	$^{76}\text{Ge}(n,\gamma)^{77}\text{Ge}$	$^{182}\text{W}(n,\gamma)^{183\text{m}}\text{W}$	$^{184}\text{W}(n,\gamma)^{185\text{m}}\text{W}$	$^{186}\text{W}(n,\gamma)^{187}\text{W}$
Half-Life	5.120 min	2.241 min	11.30 hours	5.20 sec	1.670 min	23.72 hours
Activation Delayed Gamma rays (keV)	1039.2	1778.9	1085 714.4 631.8 558 416.3 264.4 211 215.5	160.5 107.9 102.5	187.9 173.7 164.3 131.6	685.7 618.3 479.5

- Presence of the **1039 keV copper delayed gamma-ray** above the active background Compton Continuum



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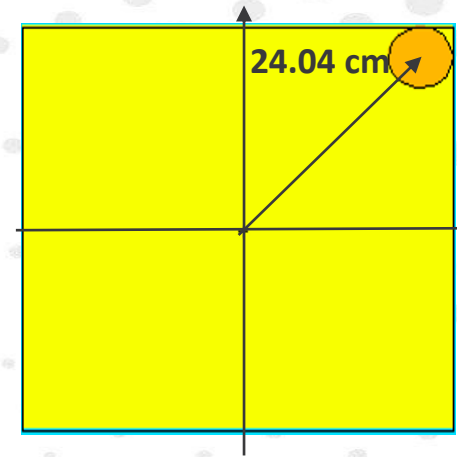
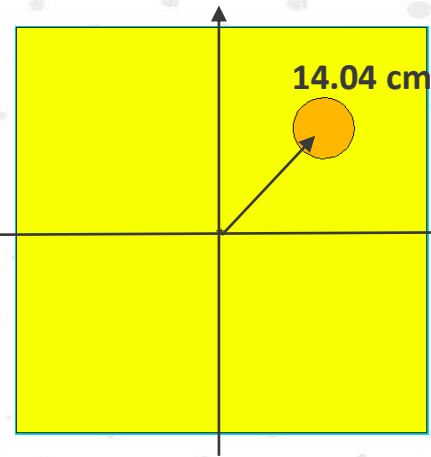
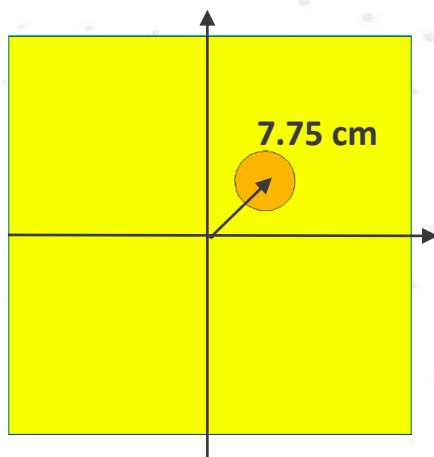
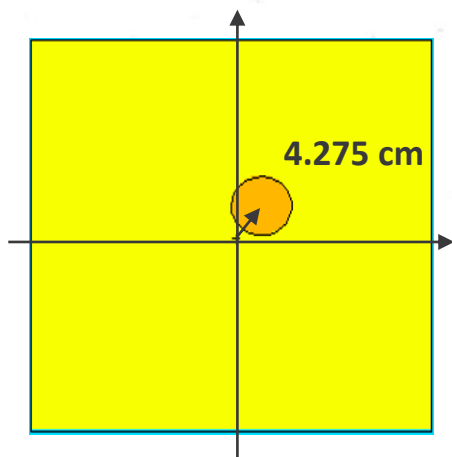
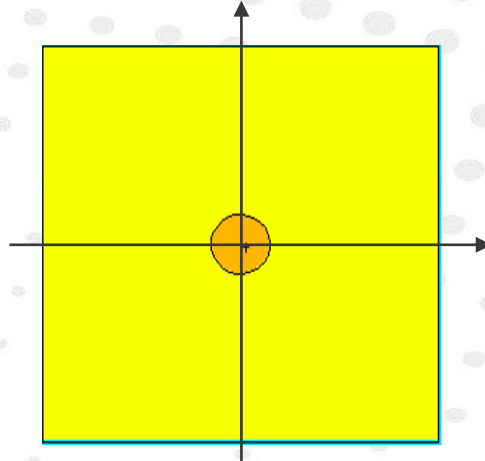
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➤ **Copper mass distance influence:**

Reference centered position



- **4 computations for the 126.6 g copper spot at increasing distances from the center of the scrap metal surface**

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## ➤ 1039 keV delayed gamma ray behavior:

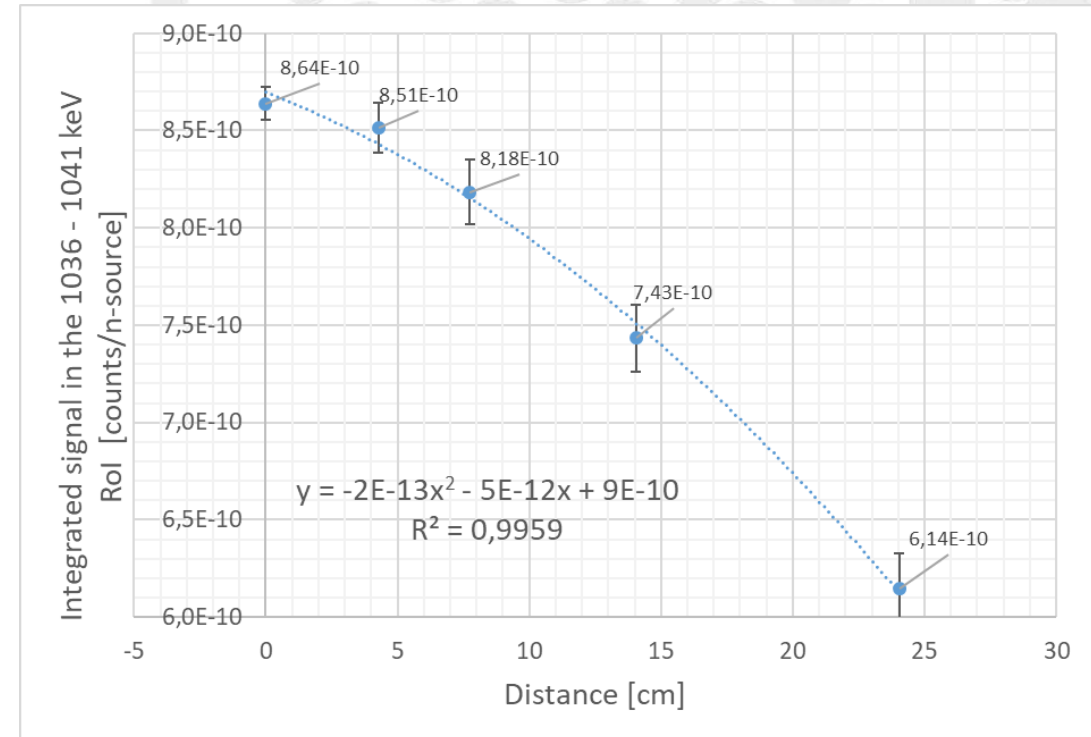
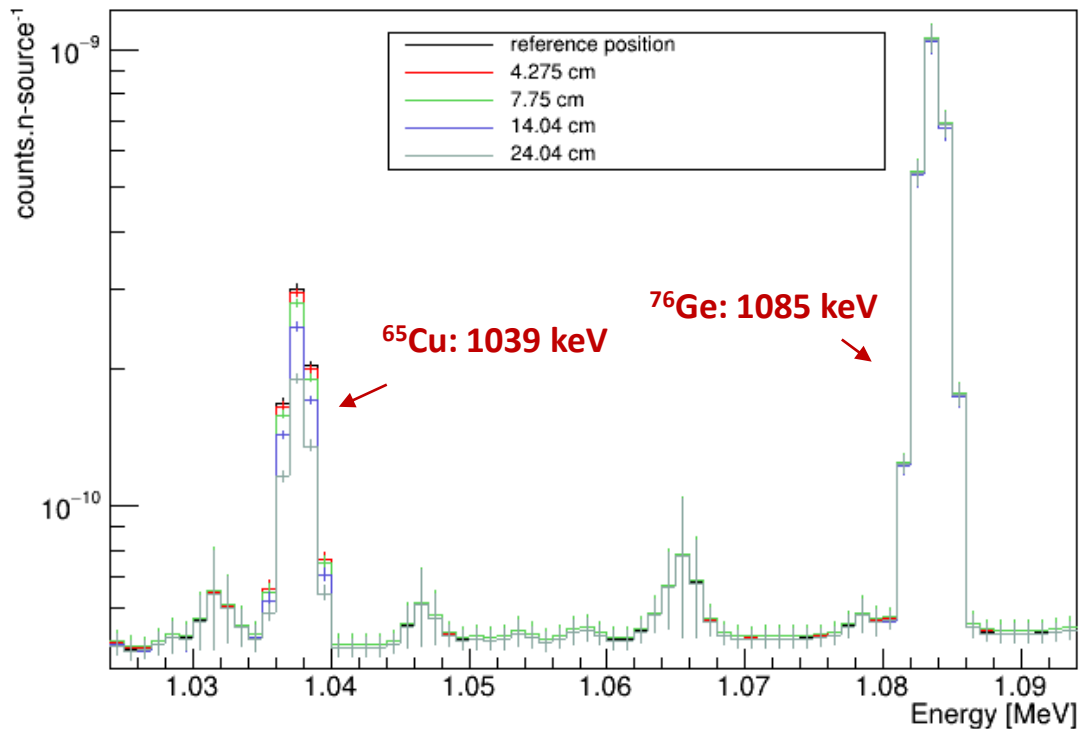
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- Integrated signal of interest in the 1039 keV *RoI* decreases following a  $1/\text{distance}^2$  physical law as expected
- Qualitative validation of the numerical approach 





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➤ **Conclusion:**

- **Validation** of the use of **MCNP6 ACT card** coupled to **MODAR Software**

- **Active background simulation** and **1039 keV detectability** over the Compton continuum **with a 33% HPGe detector**
- Proof of concept and **qualitative validation** to simulate the copper 1039 keV linac **photo-neutron induced delayed gamma ray**

➤ **Prospects:**

- **Quantitative validation** of the numerical approach with an additional comparison to experimental results
- Application of this calculation scheme for **L-DGNAA method performances estimation**
- Extrapolation of this computational scheme to **more realistic scrap metal geometries and copper distributions**

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*Thank you for your attention*

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