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Combined Fast-Neutron/γ-Ray Computed Tomography:

a single modality with which to discern both nuclear materials and contrived shielding configurations?

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Next Generation Nuclear

Overview

Introduction

Neutron Tomography

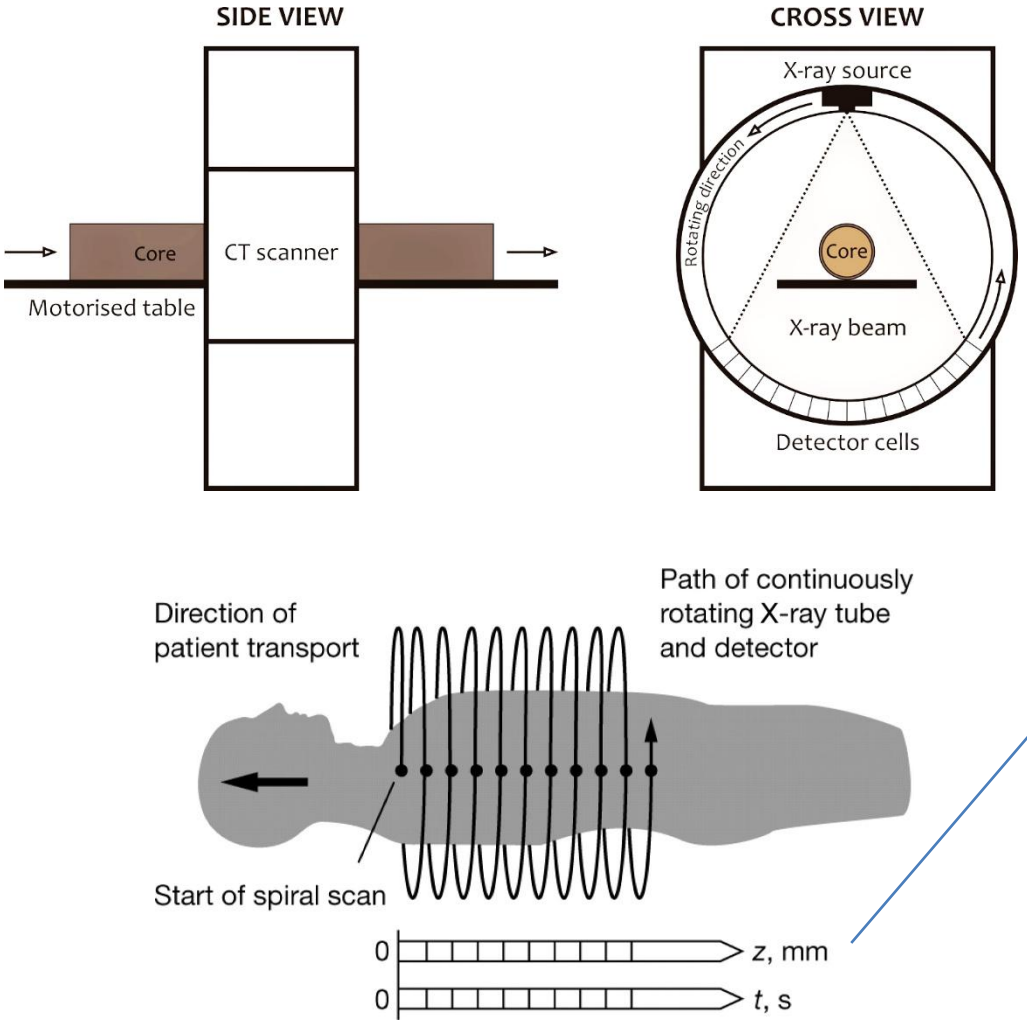
Motivations of this research

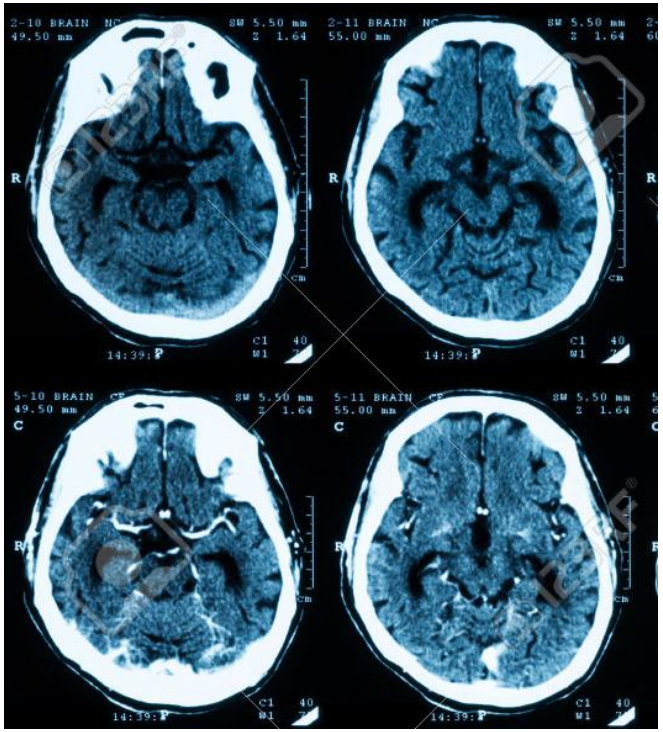
Methods and procedures

Simulation Results

Conclusions

Introduction: *CT scan machines*



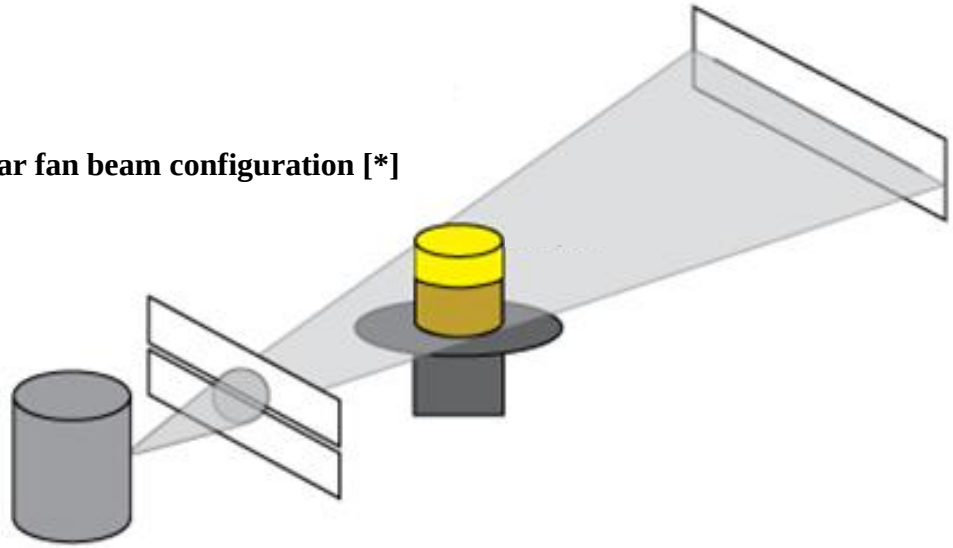


(*)

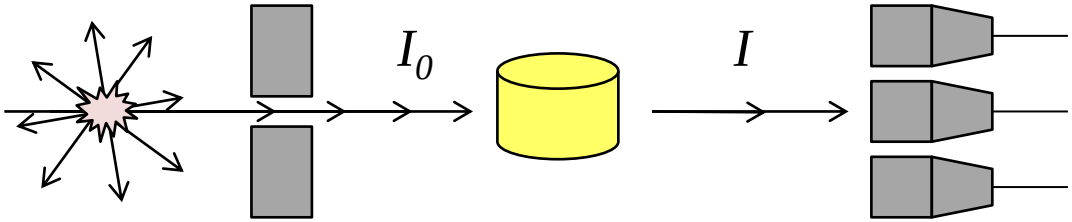
***** From CT scan of the brain comparison between with and without contrast media., online source ttps://www.123rf.com/photo_40329551_ct-scan-of-the-brain-comparison-between-with-and-without-contrast-media.html

Introduction: *CT general technique*

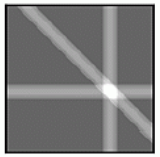
Planar fan beam configuration [*]



Radiation Source **Collimator** **Sample** **Detector array**



Scan in a huge number of different positions, rotating and translating the sample (**Projections**)



Measure μ for each projection

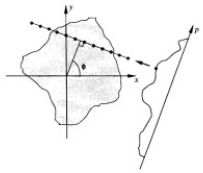


Image Reconstruction

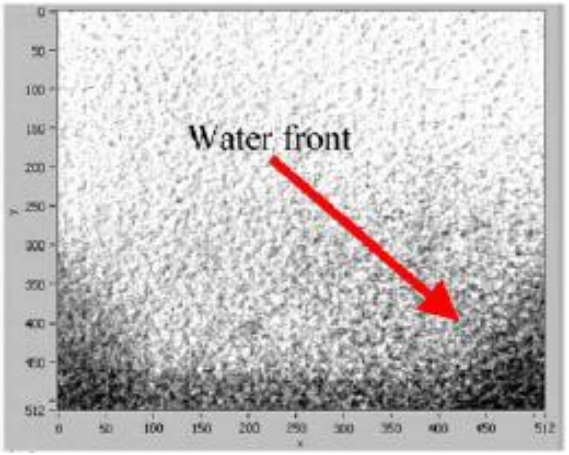
Beer-Lambert Law: $I = I_0 e^{-\mu x}$ → μ = Attenuation Coefficient

Different Materials → *Different Attenuation Coefficient* → *Different Image Contrast*

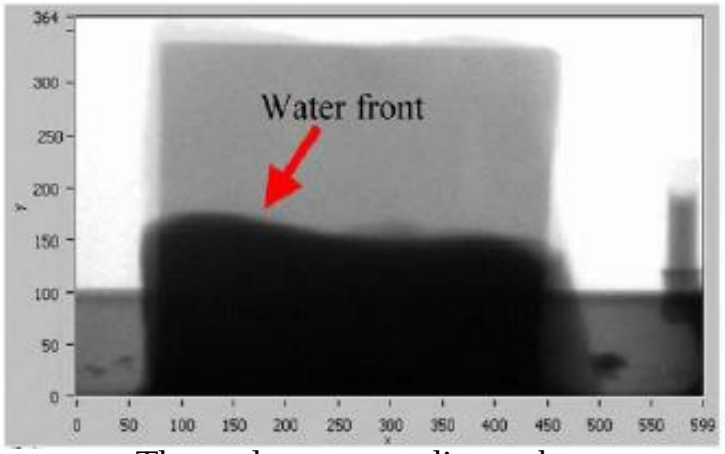
* Online source http://serc.carleton.edu/research_education/geochemsheets/techniques/CT.html

Neutron Tomography

Water level in a stone



X-ray



Thermal neutron radiography

Effective for:

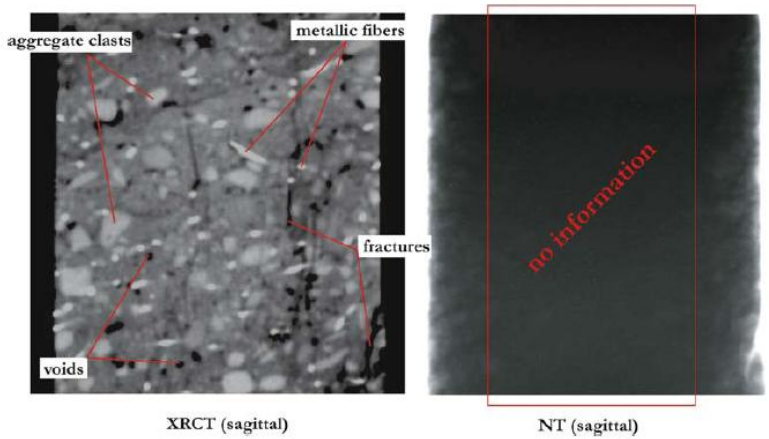
Low mass and low density features: porosity, hydration, fissures…

Applications:

- Archaeological samples
- Geological materials
- Civil engineering assessments
- Assay for nuclear energy
- Security and safeguards

Masschaele, B., Dierick, M., Cnudde, V., Van Hoorebeke, L., Delputte, S., Gildemeister, A., Gaehler, R. and Hillenbach, A., High-speed thermal neutron tomography for the visualization of water repellents, consolidants and water uptake in sand and lime stones, (2004) Rad. Phys. Chem. vol. 71, pp. 807-808.

Neutron Tomography



Thermal neutrons → (relatively) easily detectable; difficult to probe high density materials

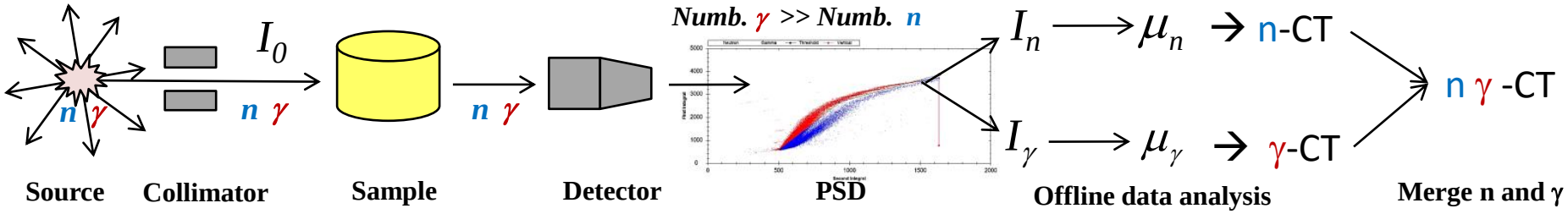
Fast neutrons → Difficult to be detected; strong penetration capabilities

Christe, P., Bernasconi, M., Vontobel, P., Turberg, P. and Parriaux, A., Three-dimensional petrographical investigations on borehole rock samples: a comparison between X-ray computed- and neutron tomography, (2007) Acta Geotechnica, vol. 2, pp. 269-279.

Neutron sources	Spectrum	Industrial scale applications	Final n-CT image resolution
Nuclear Reactors	Mainly Thermal	☹	☺
Accelerators and/or Spallation sources	Thermal and Fast	☹	☺
Neutron Generators	Fast	😐	☺ 😐
Radioactive sources (AmBe, ^{252}Cf)	Fast	☺	?

Aims of this research

Identify the optimum combinations of materials (source, collimator, detectors,…) with which to test a combined γ-ray/fast-neutron tomography system

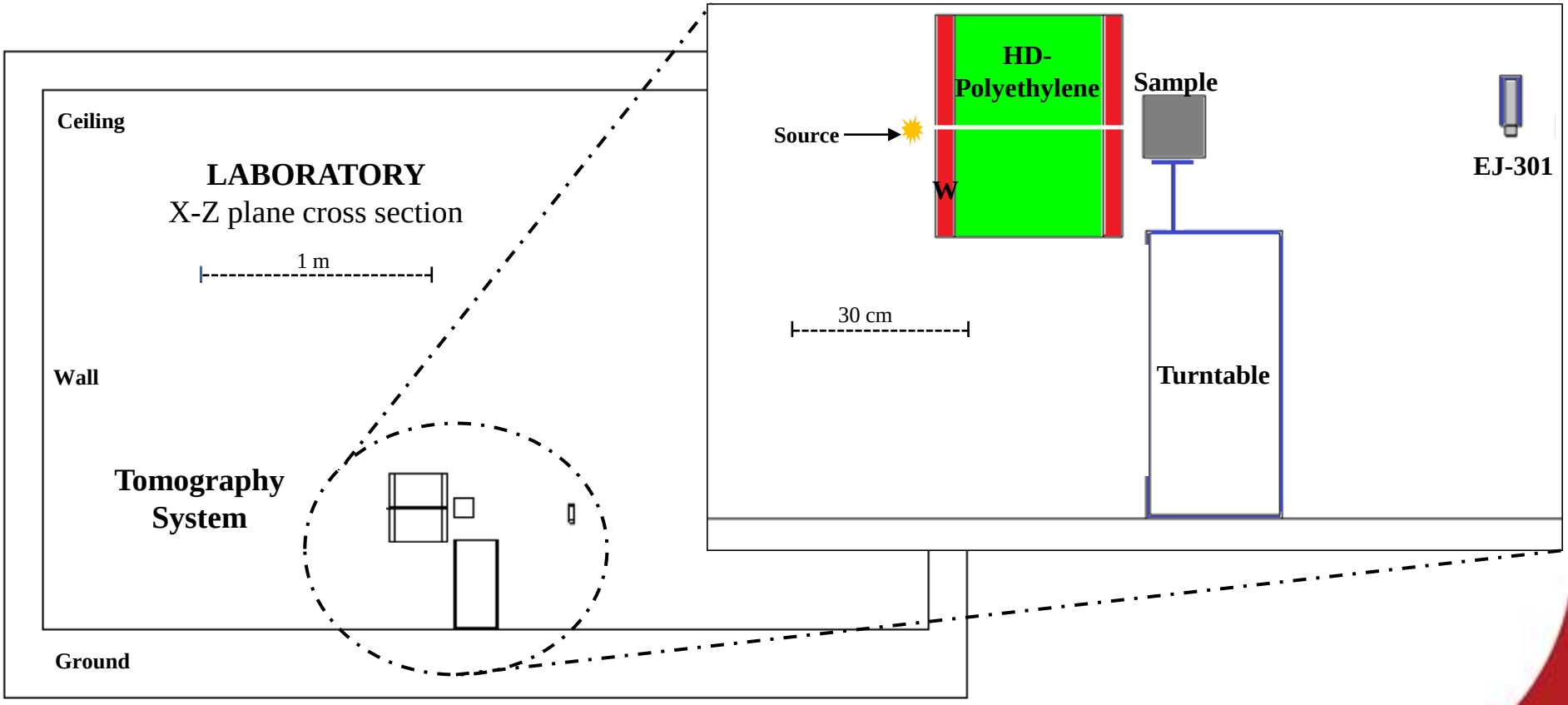


Novelty:	Candidates
Use of a **UNIQUE source** for both n and γ	AmBe – ^{252}Cf
Use of the **SAME detection system for both n and γ**	**Organic Scintillation Detectors** With proper electronics and read out system they allow **real time pulse shape discrimination** (PSD):
Use of **fast neutrons**	they penetrate deeper into substances than thermal neutrons.

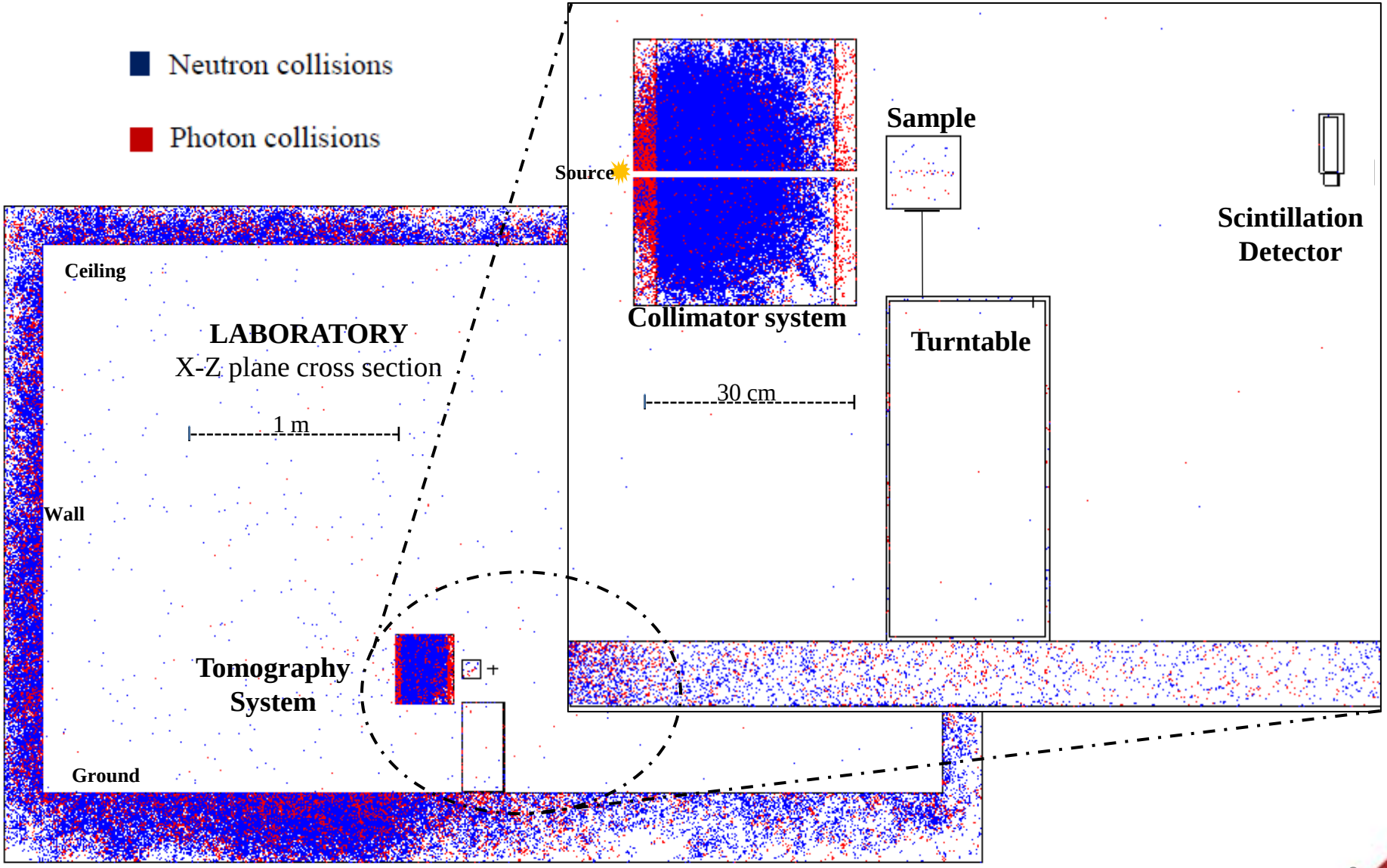
Suitability for industrial applications and *in-situ*, non-destructive assessments.

Monte Carlo simulations (MCNPX)

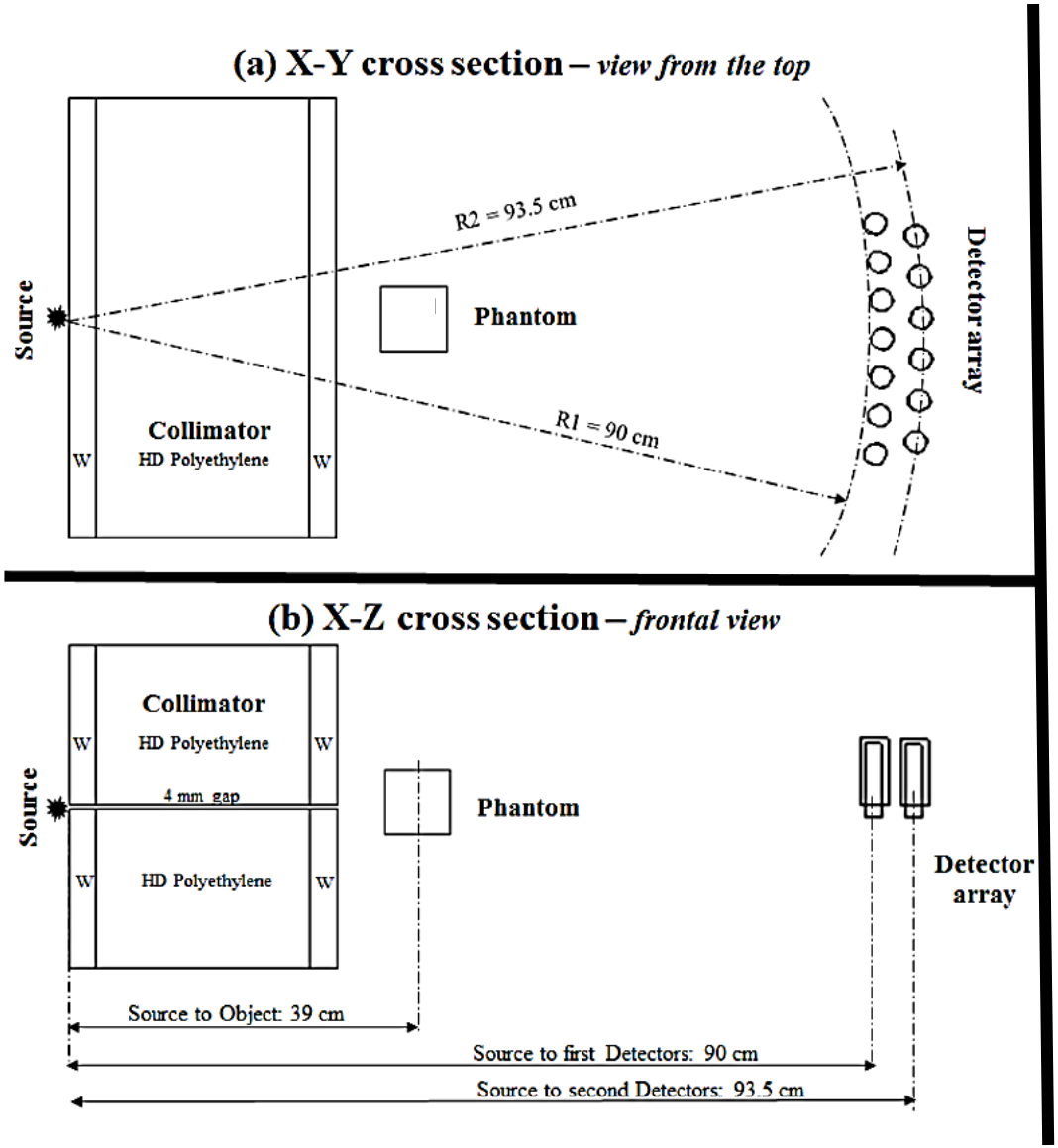
- **Source**: **AmBe** – neutrons between 1 and 10 MeV; Gammas 4.4 MeV
- **Collimator**: 3cm **Tungsten** (or Lead) blocks and high density **Polyethylene**
- **Detectors**: Organic Liquid Scintillators **EJ-301** (the smaller the better)



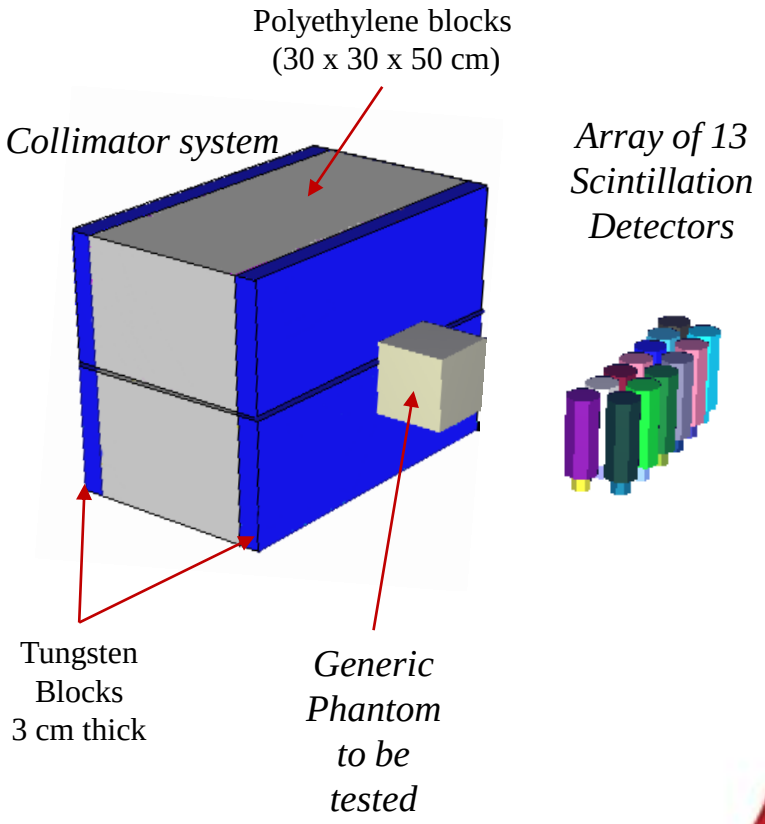
Monte Carlo simulations (MCNPX)



System design – (MCNPX)

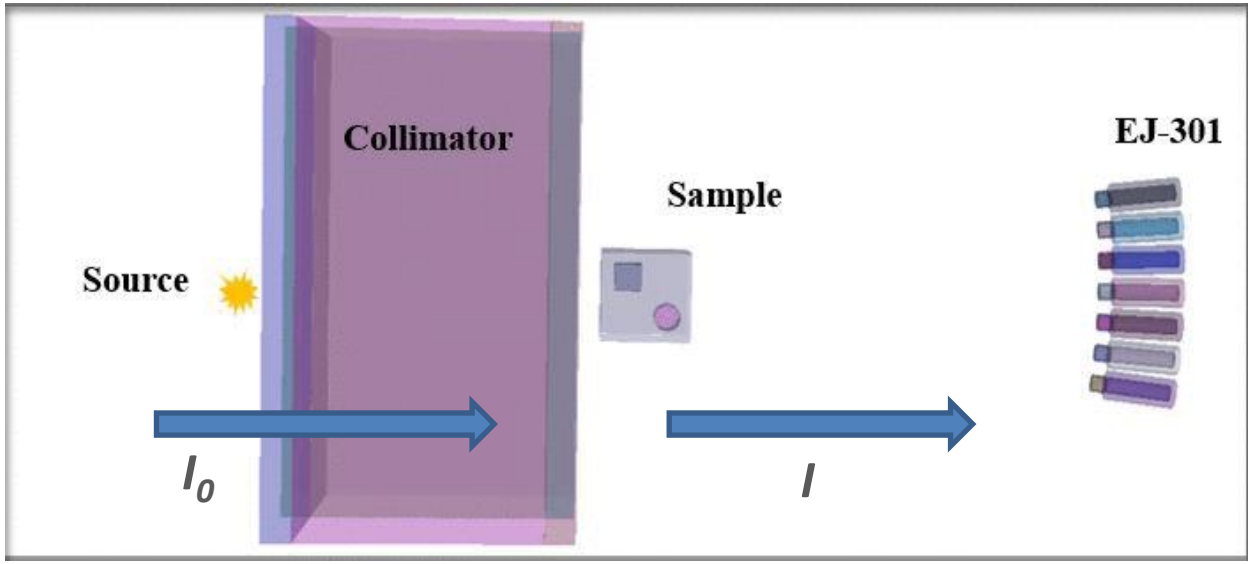


3D View

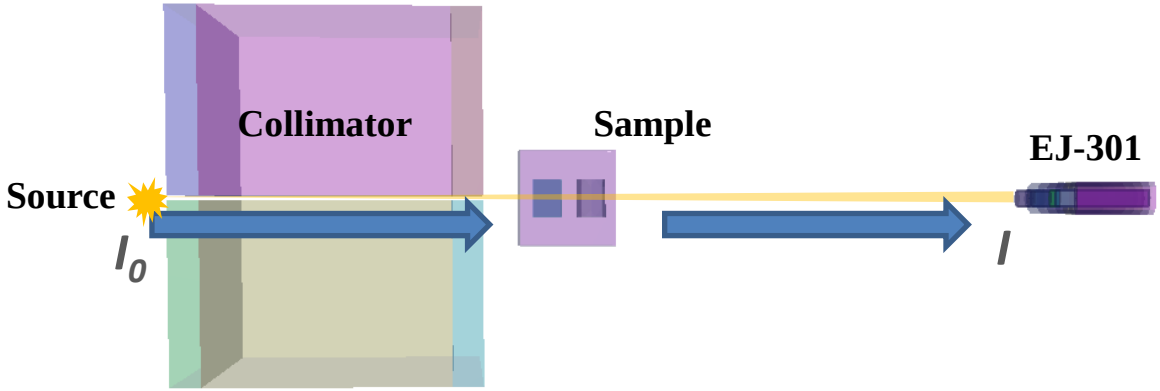


Methods and procedures

X-Y cross section



X-Z cross section



Beer-Lambert Law: $I = I_0 e^{-\mu x}$

$X_1 - Y_1 - Z_1 - \mu_1$
$X_2 - Y_2 - Z_2 - \mu_2$
$X_3 - Y_3 - Z_3 - \mu_3$
.....
$X_N - Y_N - Z_N - \mu_N$

Nyquist-Shannon theorem

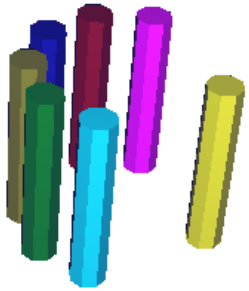
N = minimum number of projections needed:

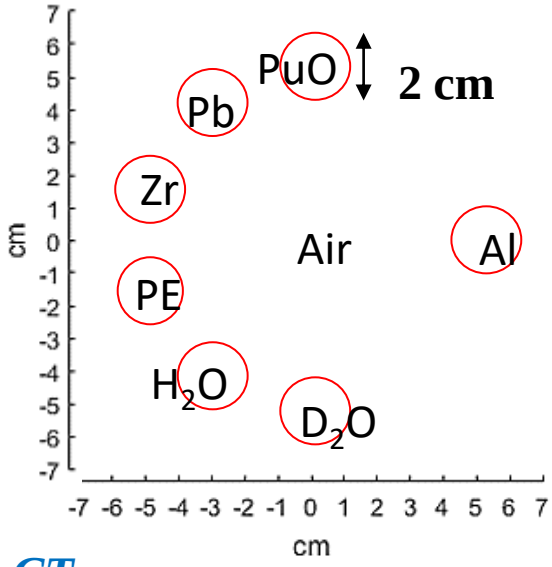
$$N = \pi I_{pix}$$

I_{pix} = Object dimensions in pixels

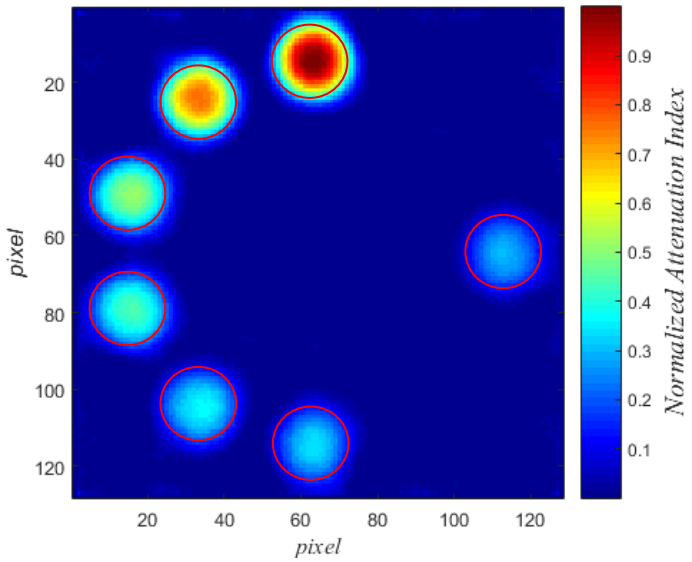
Simulation results

Samples

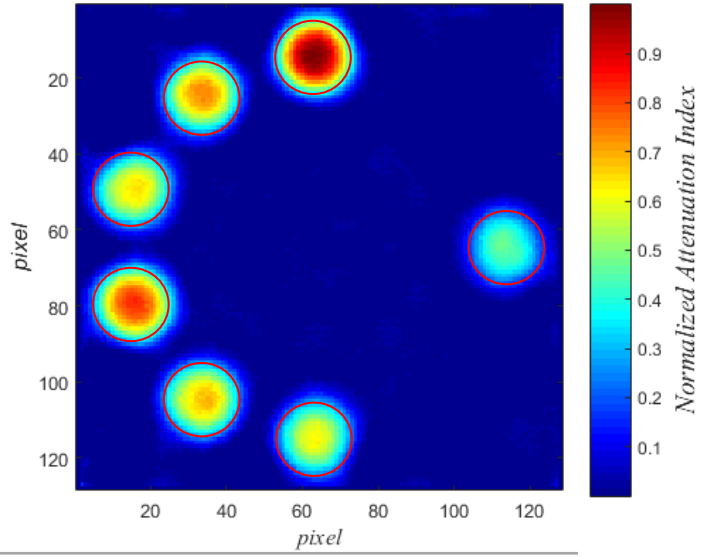




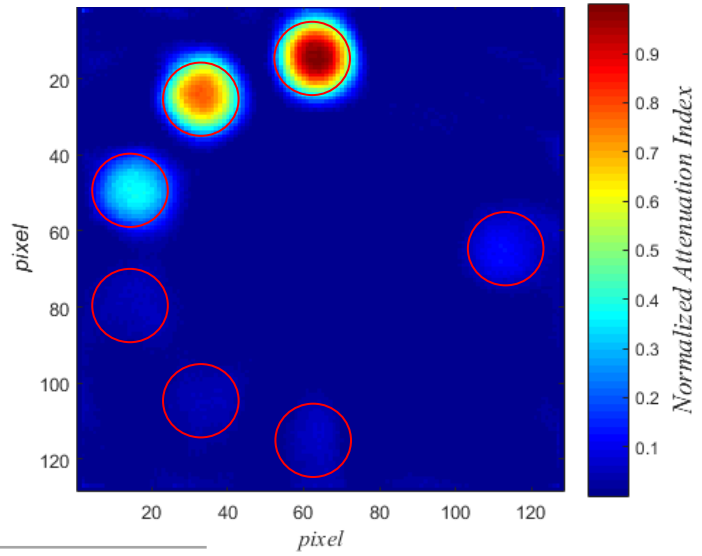
n/γ - CT



n - CT

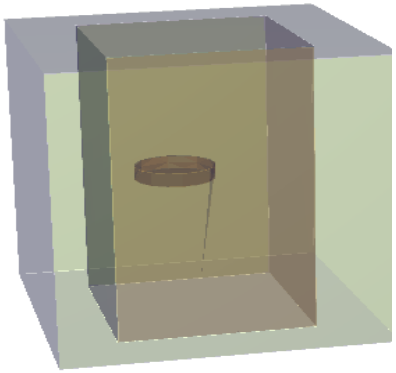


γ - CT

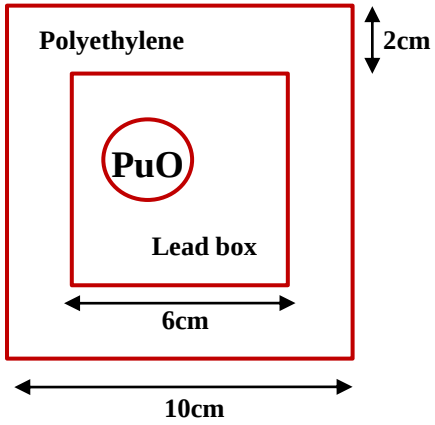


Simulation results – *Plutonium oxide*

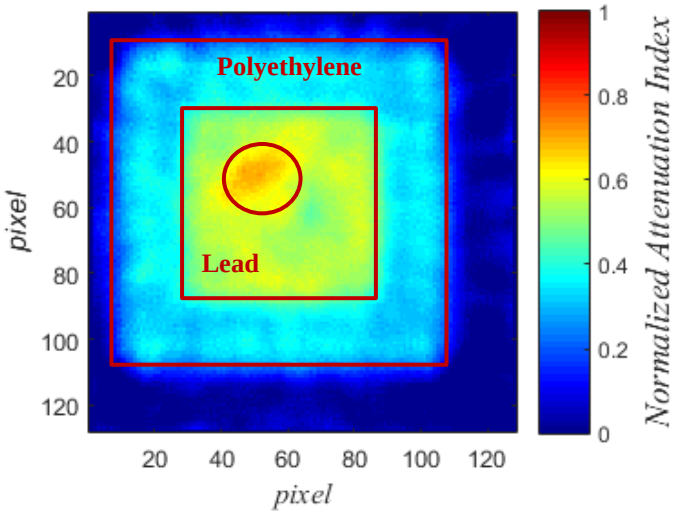
Sample - 3D View



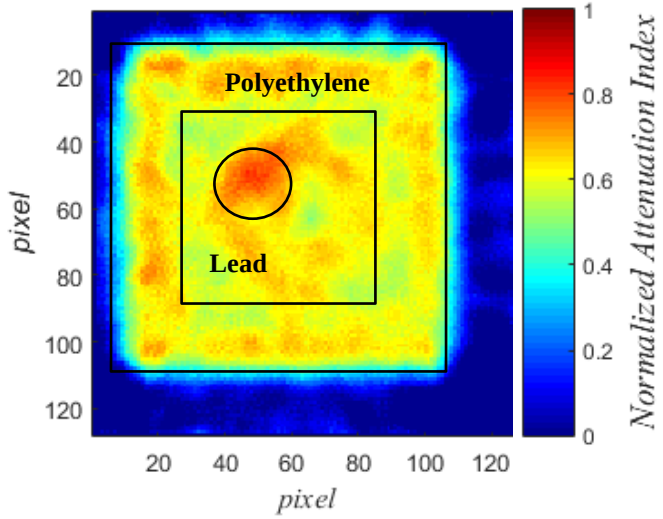
Sample – xy section



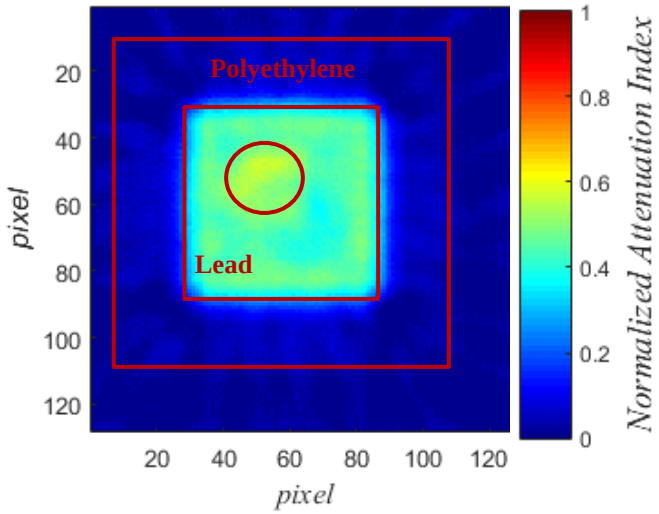
n/γ - CT



n - CT

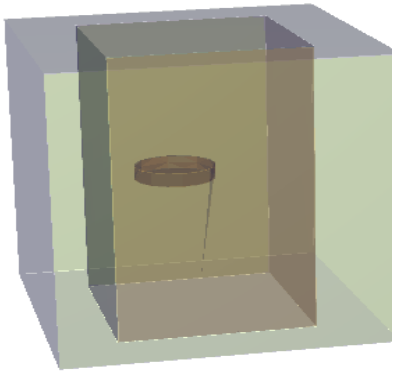


γ - CT

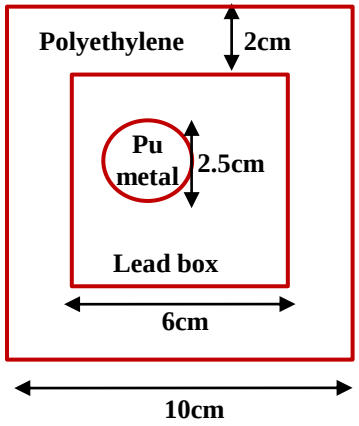


Simulation results – *Plutonium metal*

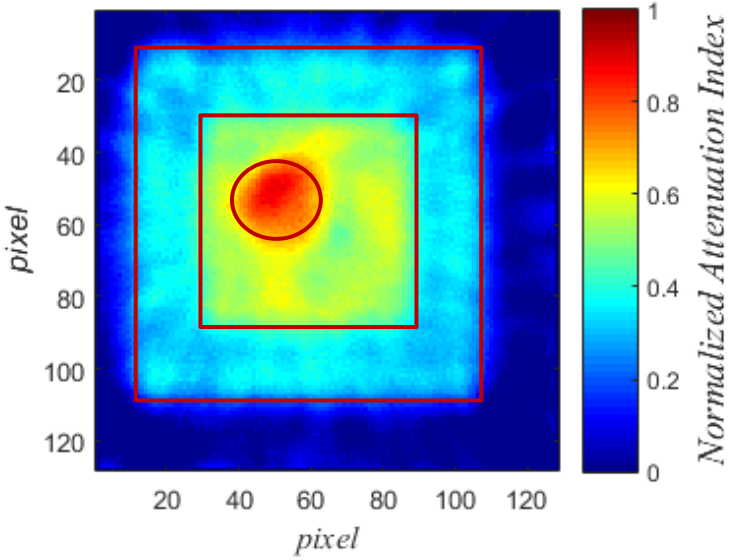
Sample - 3D View



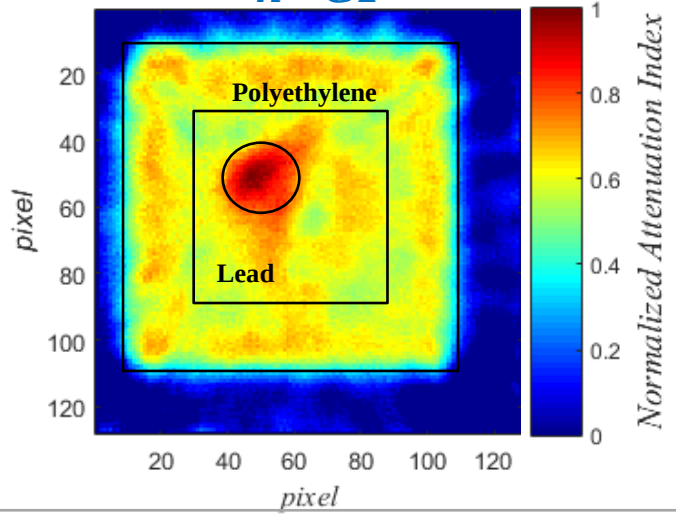
Sample – xy section



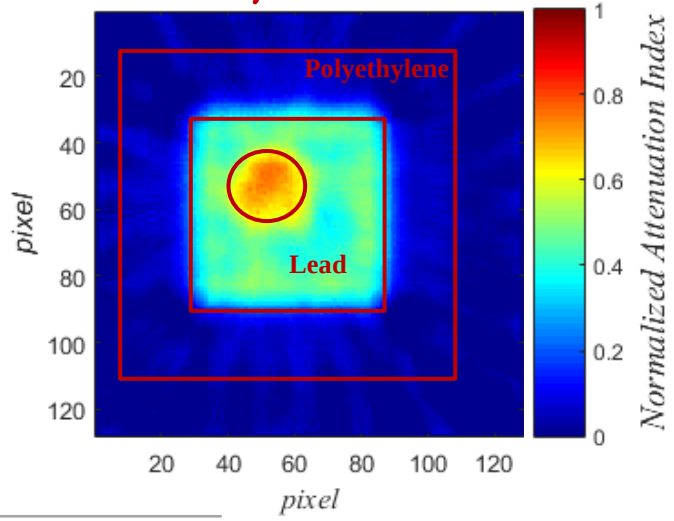
n/γ - CT



n - CT

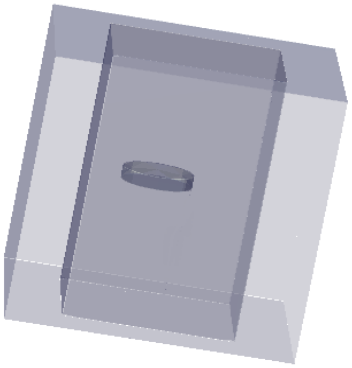


γ - CT

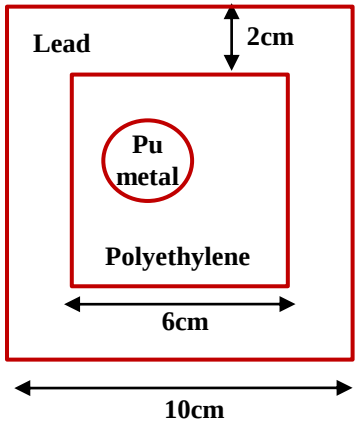


Simulation results – *Plutonium metal*

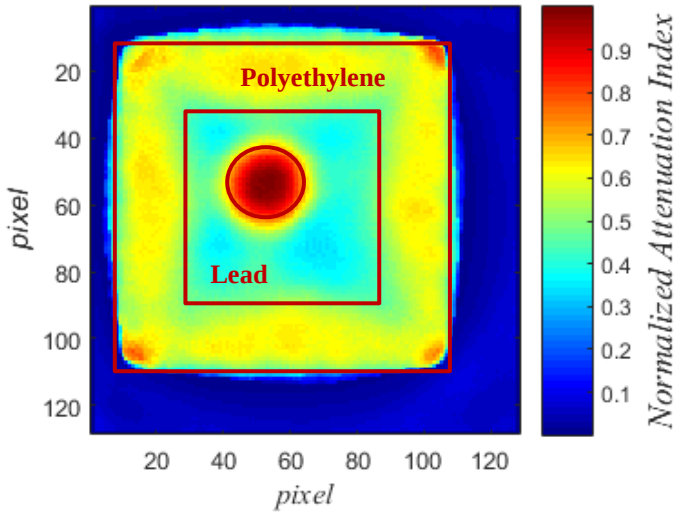
Sample - 3D View



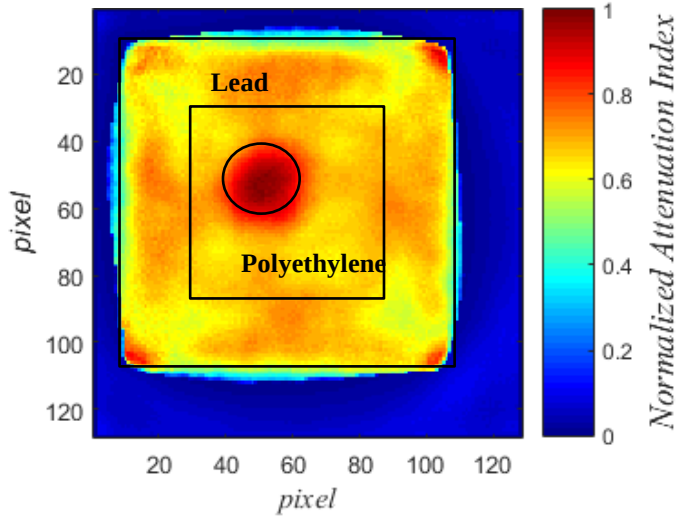
Sample – xy section



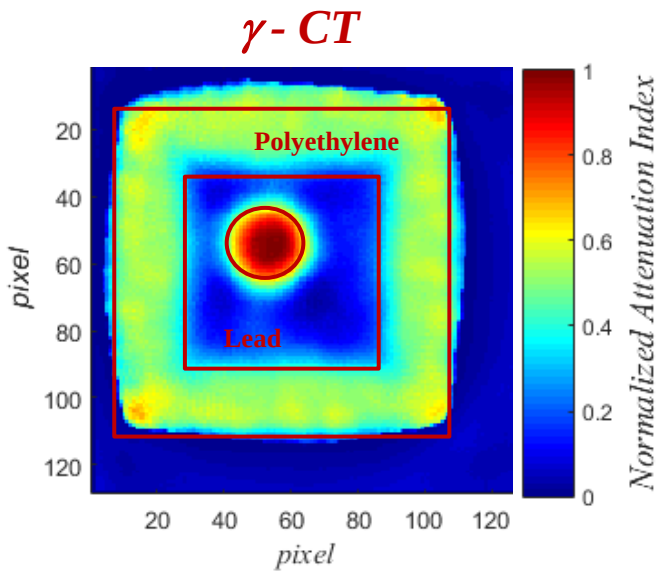
n/γ - CT



n - CT

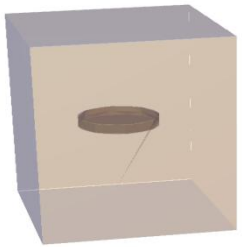


γ - CT

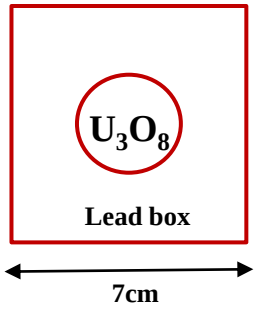


Simulation results – *Uranium trioxide*

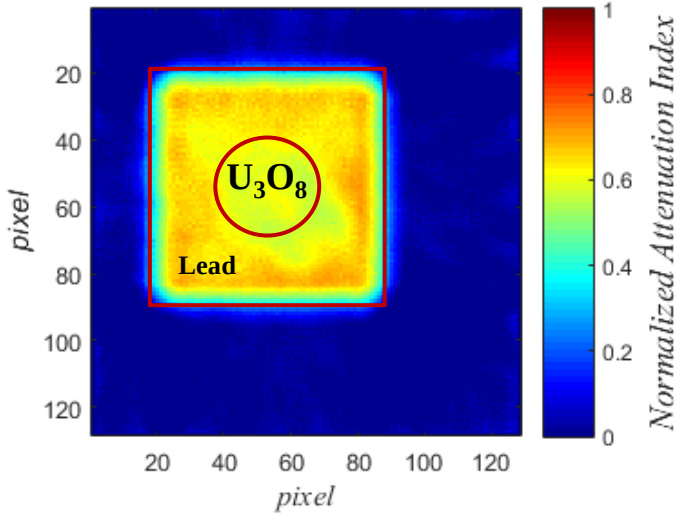
Sample - 3D View



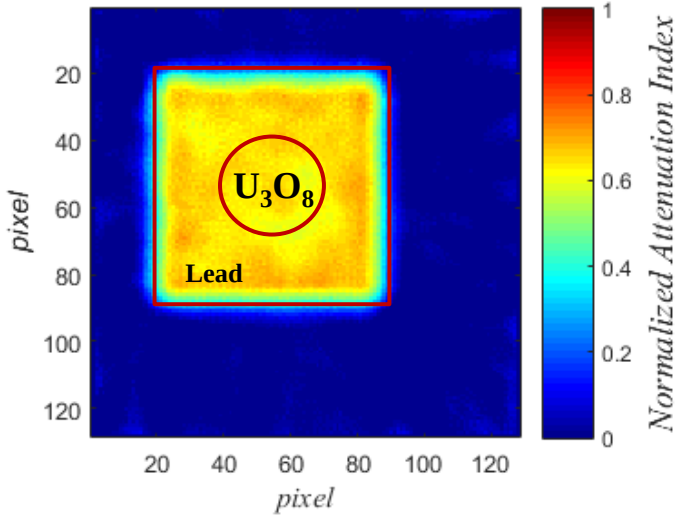
Sample – xy section



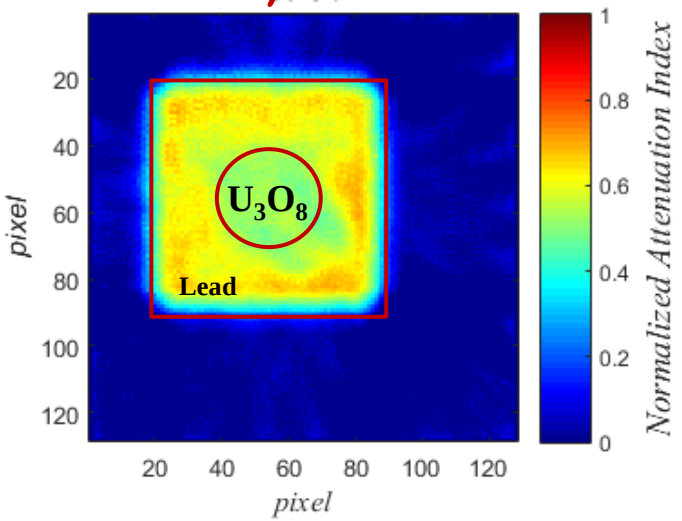
n/γ - CT



n - CT

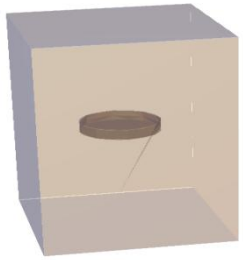


γ - CT

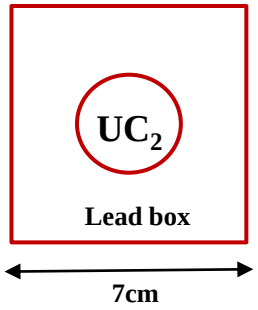


Simulation results – *Uranium Carbide*

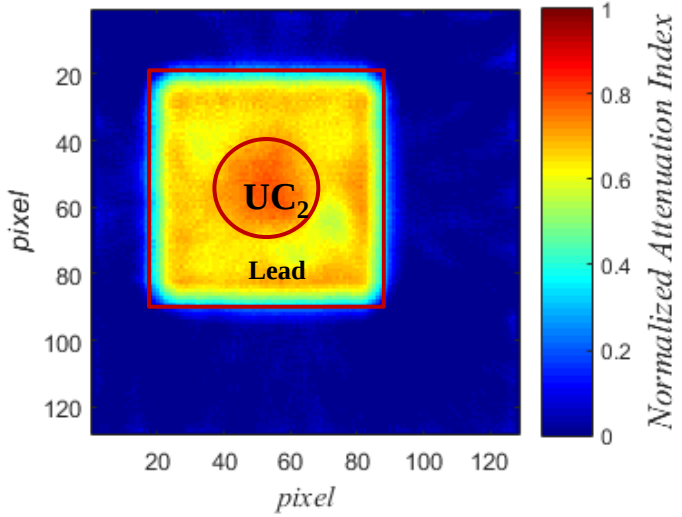
Sample - 3D View



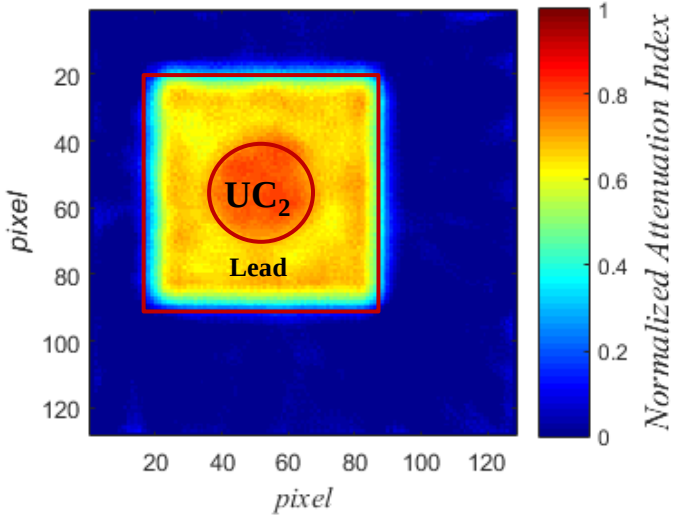
Sample – xy section



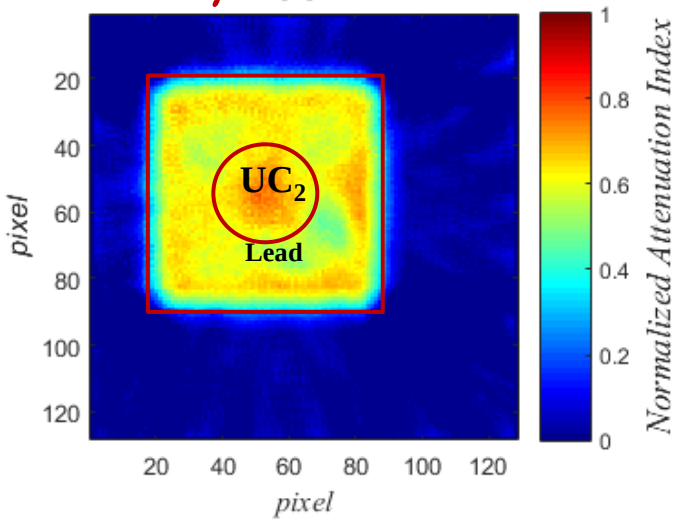
n/γ - CT



n - CT



γ - CT



Conclusions and Future Work

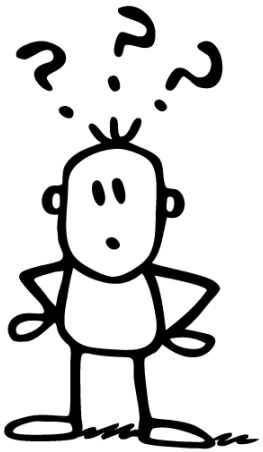
- **Reproduce** experimentally the simulated **system**
- Look at the experimental response with **different organic scintillation detectors**
- Test with **Cf-252** and **AmBe** source
- **Scattering** between detectors calculations
- Improvements in **image reconstruction** algorithms dealing with limited data
- **Errors** and **spatial resolution**

Thanks!

Lancaster University

EPSRC
Engineering and Physical Sciences Research Council

Any questions?



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