Monte-Carlo Applications for Nondestructive Nuclear Waste Analysis

M. Schumann[1], R. Engels[2], M. Frank[4], S. Furletov[2], J. Furletova[2], C. Genreith[1], A. Havenith[1,3], G. Kemmerling[2], J. Kettler[1,3], T. Krings[1], E. Mauerhofer[1], D. Neike[3], M. Rossbach[1], O. Schitthelm[5], R. Vasques[4], C. Carasco[6], E. Payan[6], B. Perot[6], J.-L. Ma[6]

[1]Institute of Energy and Climate Research - Nuclear Waste Management and Reactor Safety, Forschungszentrum Jülich GmbH
[2]Central Institute of Engineering, Electronics and Analytics ZEA-2 – Electronic Systems, Forschungszentrum Jülich GmbH
[3]Nuclear Engineering and Technology Transfer, RWTH Aachen
[4]MATHCCES, Department of Mathematics, RWTH Aachen
[5]Corporate Technology, Siemens AG
[6]Nuclear Measurement Laboratory, DEN, CEA, Cadarache

JÜLICH FORSCHUNGSZENTRUM

Introduction

Monte-Carlo Applications for Nondestructive Nuclear Waste Analysis

Radioactive waste packages have to pass a program of quality control in order to validate their conformance with national regulations prior to its transport, inter-mediate storage and final disposal. A main part of this quality control program is the analytical characterization of radio- and chemotoxic inventories in waste packages. For this purpose, non-destructive assays are applied preferably, because a representative sampling and a time consuming preparation of appropriate specimen for different analytical techniques is avoided. Thus, within several frameworks of cooperation the Forschungszentrum Jülich aims to develop and improve nondestructive assays for the routine characterization of radioactive waste packages at industrial scale. For research and development Monte Carlo techniques are used to simulate the transport of particle, especially photons and neutrons, through matter and to obtain the response of detection systems.

SGSreco

Segmented Gamma-Scanning

The radiological characterisation of low and intermediate level radioactive waste drums is performed by segmented γ-scanning (SGS). To reconstruct the activities of homogeneous and heterogeneous isotope contents in waste drums by SGS, an innovative method called SGSreco is developed. The Geant4 code is used to simulate the response of the collimated detection system for waste drums with different activity and matrix configurations. These simulations allow a far more detailed optimization, validation and benchmark of SGSreco, since the construction of test drums covering a broad range of activity and matrix properties is time consuming and cost intensive.

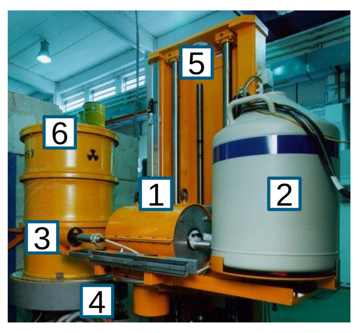


Fig. 1: γ-Scan-System Gernod 2 at the Forschungszentrum Jülich.
1 HPGe detector with collimator
2 Dewar with liquid nitrogen
3 Dose-Rate-Probe
4 Turntable
5 Lifting system
6 Radioactive waste drum

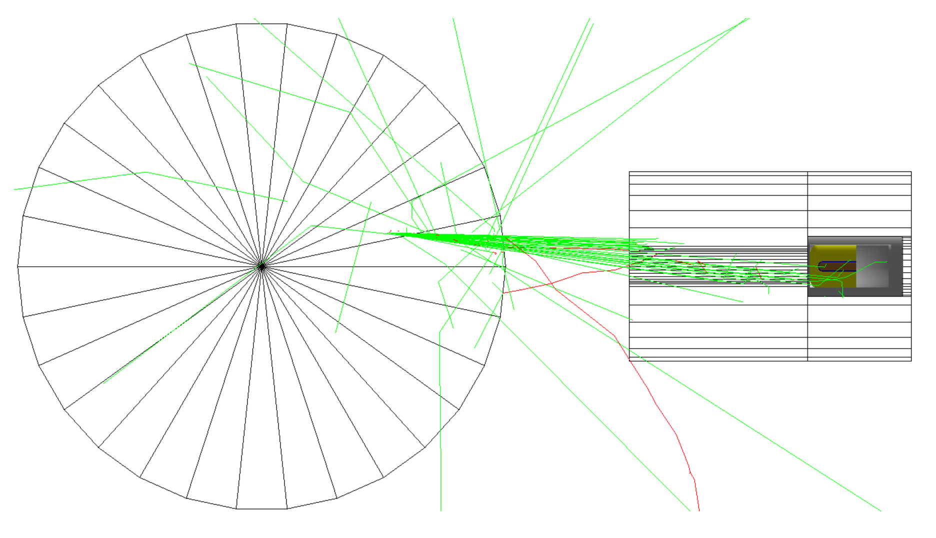


Fig. 2: Geant4 visualisation of a point source in a drum directed to the collimated detection system.

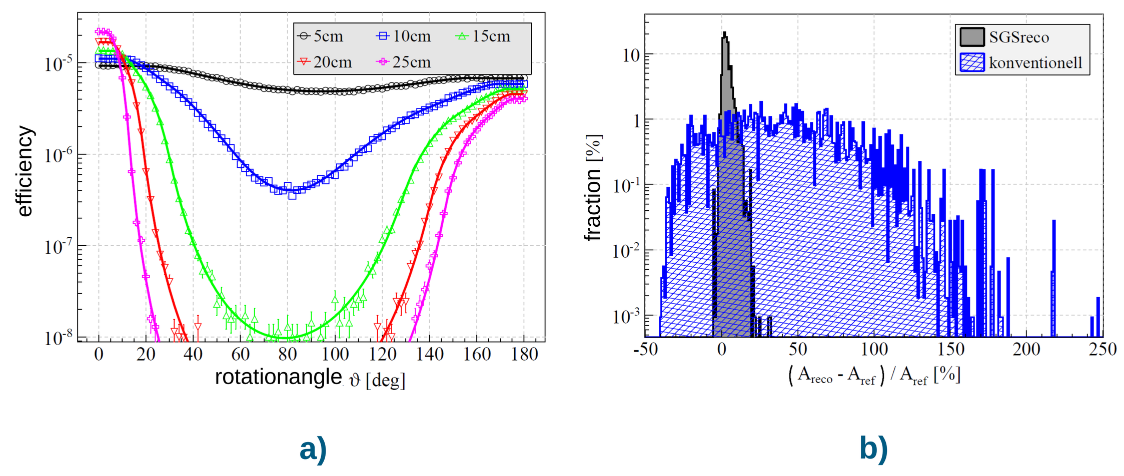


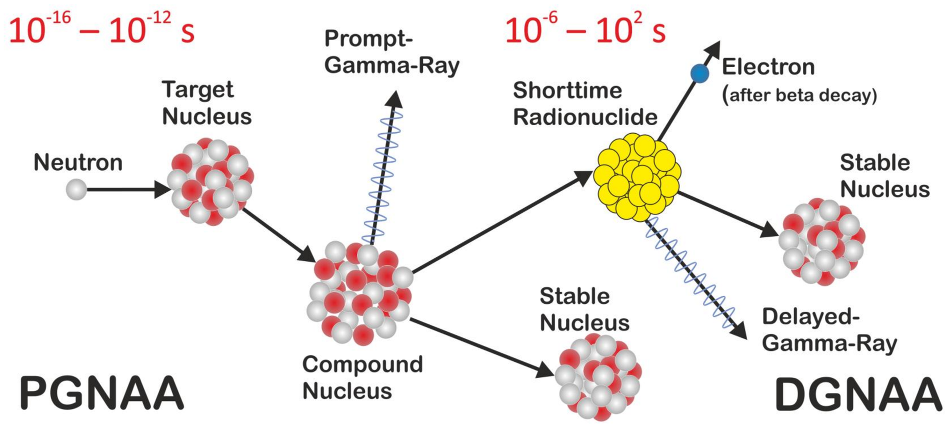
Fig. 3: a) Comparison of simulated (points) and by SGSreco calculated (line) efficiency for an ^{152}Eu point source.
b) Deviation of the reconstructed to the real entire activity of a drum with the SGSreco algorithm compared to the conventional method for two to five point sources.

MEDINA

In cooperation with: RWTH AACHEN UNIVERSITY ▪ cea

Prompt-Gamma-Neutron-Activation-Analysis

The MEDINA test facility (Multi Element Detection based on Instrumental Neutron Activation) was developed to characterize the elemental composition of radioactive waste drums. MEDINA is based on prompt and delayed gamma neutron activation analysis (P&DGNAA) using a 14 MeV neutron generator. MCNP simulations are carried out to study the response of the MEDINA facility in terms of γ-spectra, time dependence of the neutron energy spectrum and neutron flux distribution.



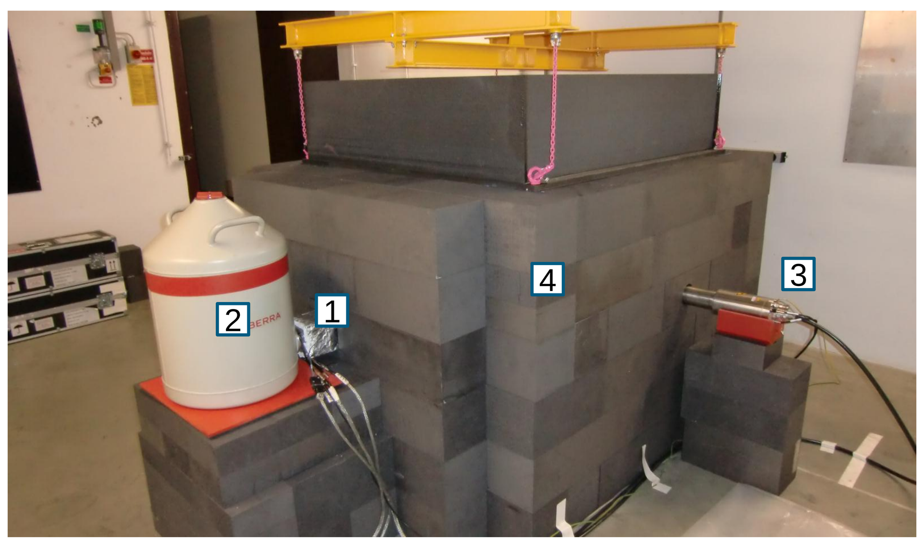


Fig. 4: The MEDINA test facility
1 HPGe detector with neutron shielding
2 Dewar with liquid nitrogen
3 Neutron generator
4 Graphite chamber

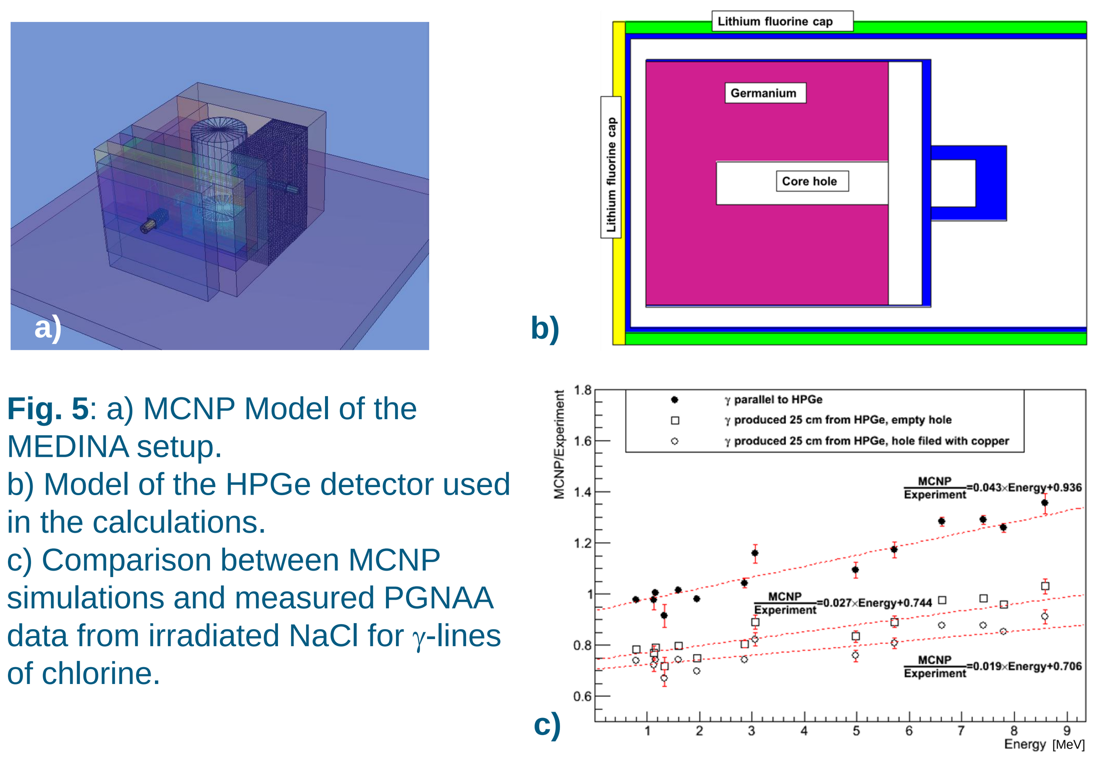


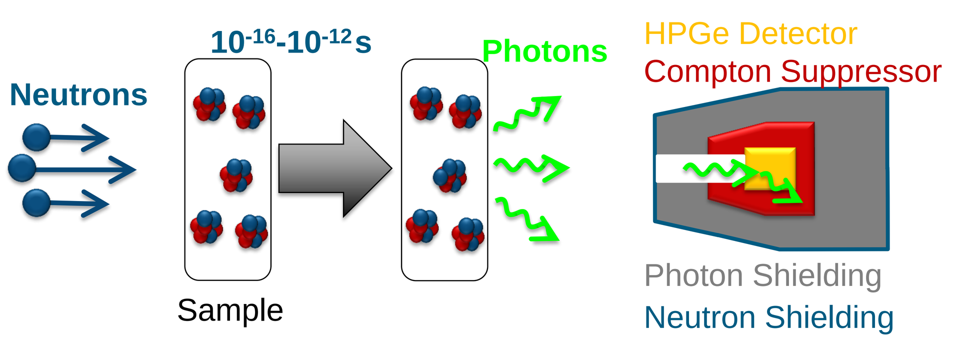
Fig. 5: a) MCNP Model of the MEDINA setup.
b) Model of the HPGe detector used in the calculations.
c) Comparison between MCNP simulations and measured PGNAA data from irradiated NaCl for γ-lines of chlorine.

TANDEM

In cooperation with: TUM ▪ EK ▪ BERKELEY LAB

Prompt-Gamma-Activation-Analysis

A promising approach for the characterization of actinide contents in small specimen like swipe samples is based on prompt gamma activation analysis (PGAA). Thus, the quantitative determination of actinides relies on the precise knowledge of partial neutron capture cross sections. The goal of the TANDEM (Trans-uranium Actinides' Nuclear Data – Evaluation and Measurement) Collaboration is the precise measurement and evaluation of these cross sections at the PGAA facilities in Budapest and Munich. Geant4 is used to optimally design the detection system with Compton suppression and to evaluate the self-attenuation of photons within the sample.



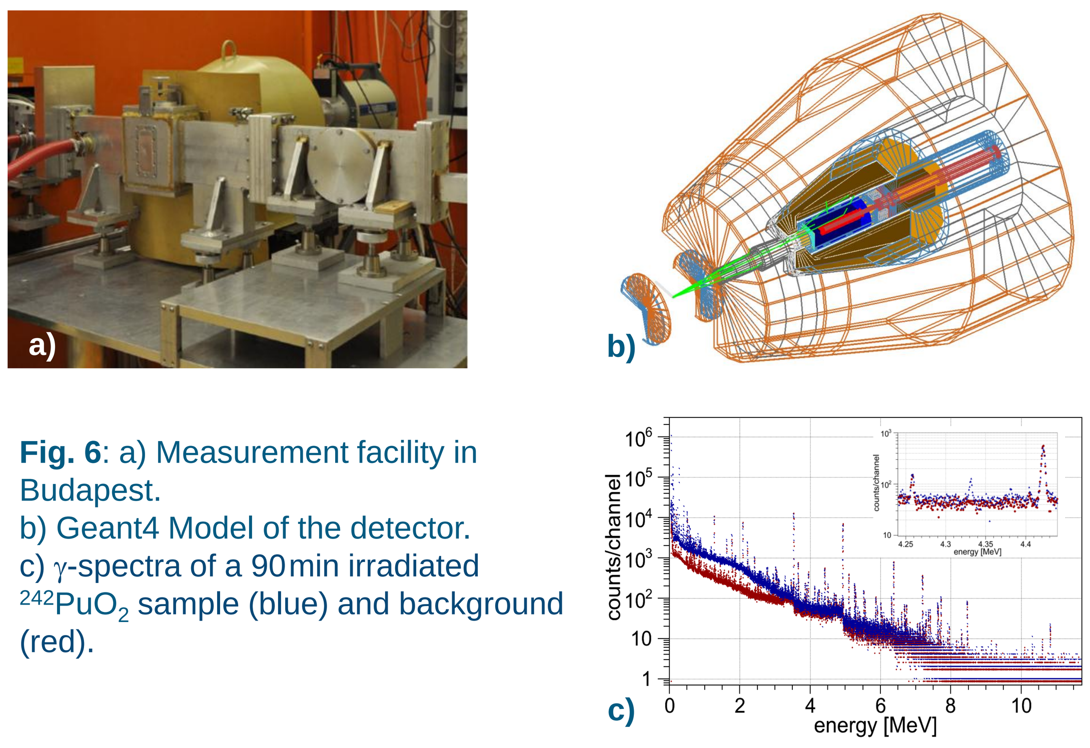


Fig. 6: a) Measurement facility in Budapest.
b) Geant4 Model of the detector.
c) γ-spectra of a 90 min irradiated $^{242}PuO_2$ sample (blue) and background (red).

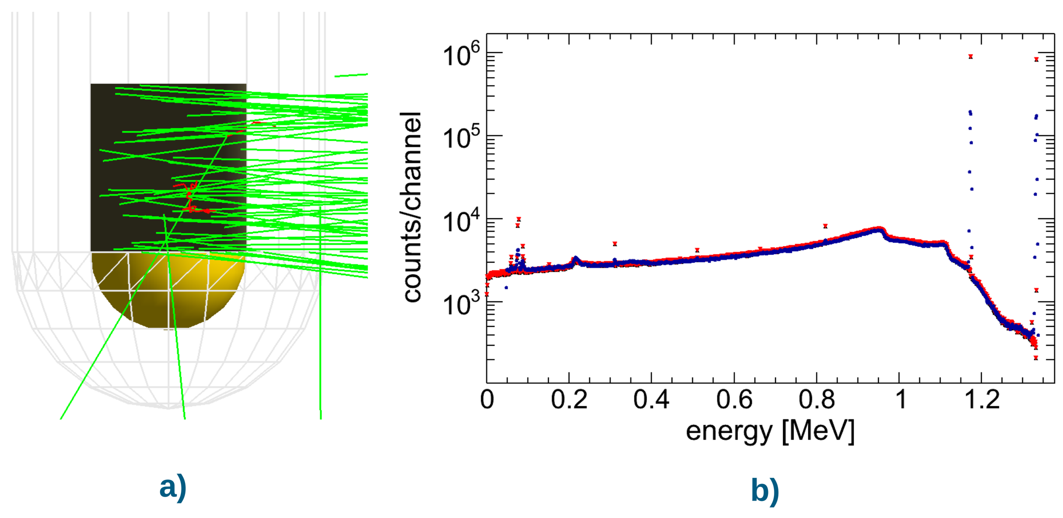


Fig. 7:
a) Geant4 simulation for the correction of γ-self-attenuation within the sample.
b) Geant4 simulation of a ^{60}Co source in (red) compared with a measured spectrum (blue).

NISRA

In cooperation with: RWTH AACHEN UNIVERSITY ▪ SIEMENS

Neutron-Radiography

In a cooperation between RWTH Aachen University, Forschungszentrum Jülich and Siemens AG the feasibility of a compact Neutron Imaging System for Radioactive waste Analysis (NISRA) is studied. The system is based on a 14 MeV neutron source and an advanced detector system (a-Si flat panel) linked to an exclusive converter/collimator for fast neutrons. The detector response is simulated with Geant4 to optimize components of the system.

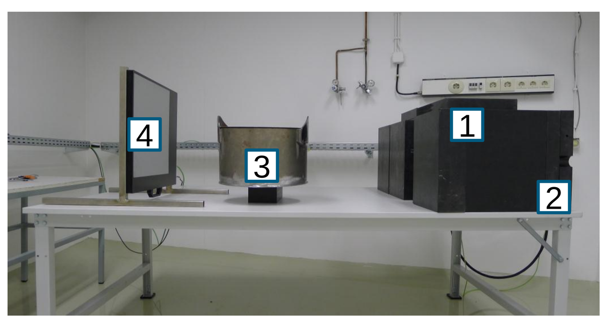


Fig. 8: Experimental Setup.
1 Neutron generator within the shielding
2 Shielding and collimator
3 Sample
4 Detector

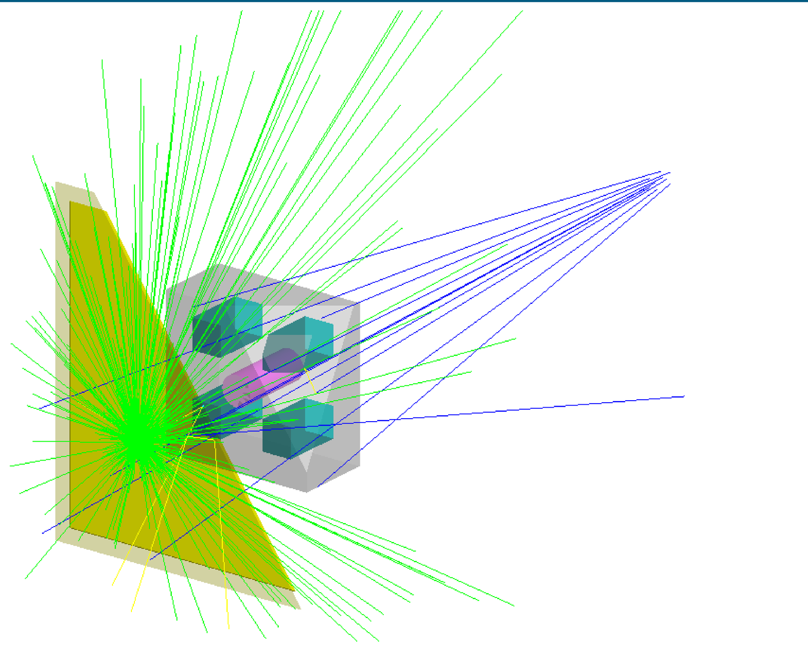


Fig. 9: Detailed Geant4 simulation of the NISRA system including samples with different materials, the converter and the detector with electronics.

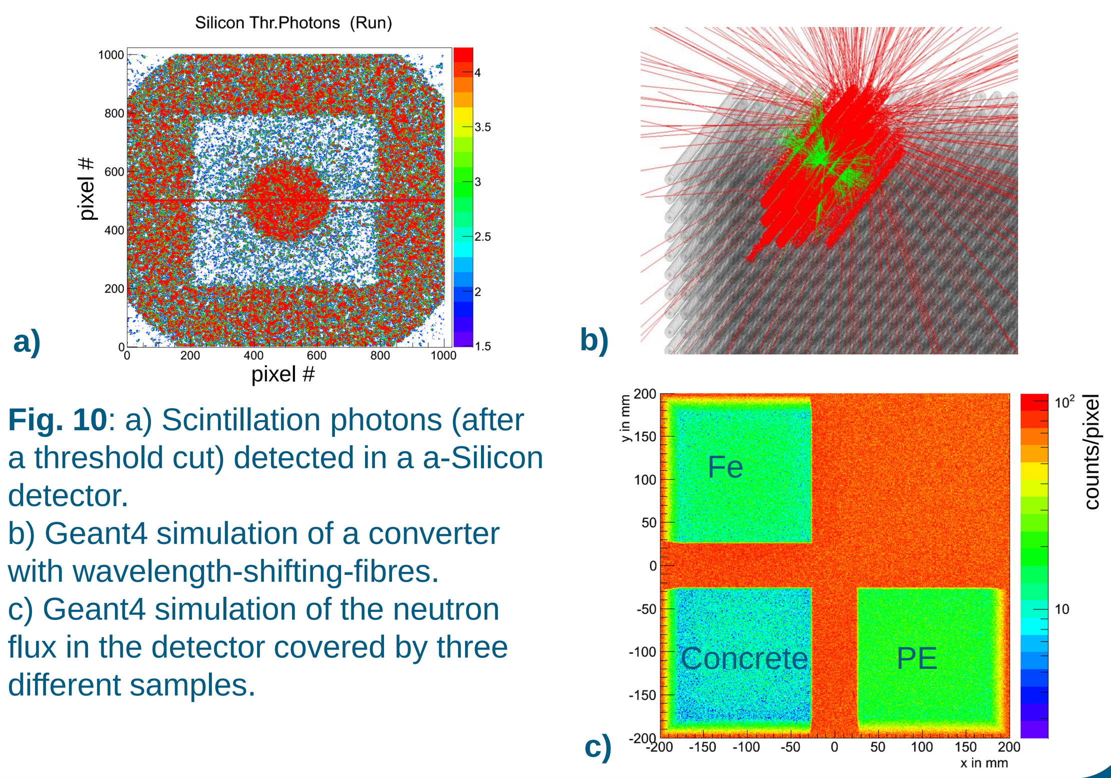


Fig. 10: a) Scintillation photons (after a threshold cut) detected in a a-Silicon detector.
b) Geant4 simulation of a converter with wavelength-shifting-fibres.
c) Geant4 simulation of the neutron flux in the detector covered by three different samples.

Mitglied der Helmholtz-Gemeinschaft

Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2013 (SNA + MC 2013) - La Cité des Sciences et de l'Industrie, Paris, France, October 27-31, 2013