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Developing a radiation field-based monitoring system for the transport and storage cask inventory during extended interim storage

Mira Stephan et al.

Correspondence to: Mira Stephan (mira.stephan@hszg.de) and Michael Wagner (michael.wagner3@tu-dresden.de)

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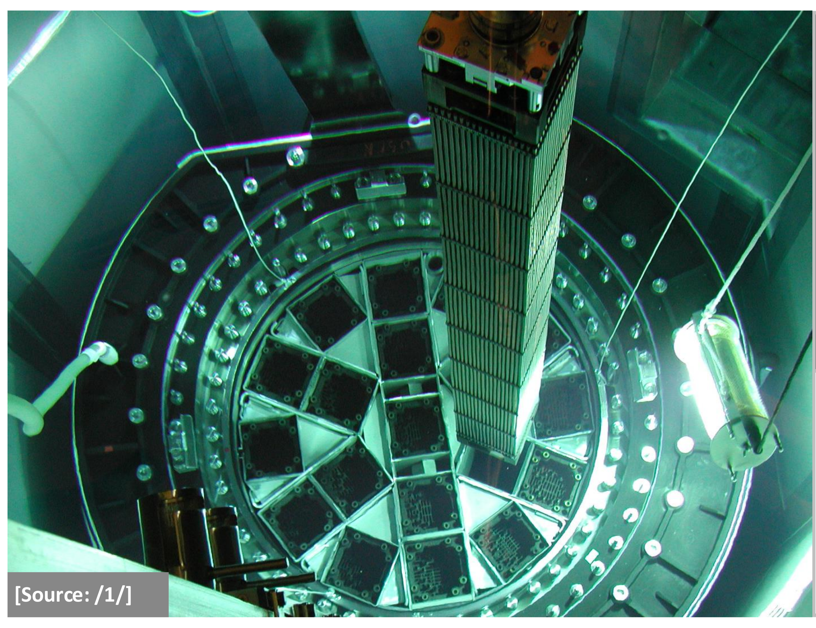
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Developing a radiation-field-based monitoring system for the transport and storage cask inventory during extended interim storage

Author: M. Stephan[1], S. Reinicke[1], A. Kratzsch[1], M. Wagner[2], S. Kobelt[2], U. Hampel[2,3]

[1]Institute for Process Technology, Process Automation and Measurement Technology, Hochschule Zittau/Görlitz – University of Applied Sciences, Zittau, 02763, Germany

[2]Chair of Imaging Techniques in Energy and Process Engineering, Institute of Power Engineering, Technische Universität Dresden, Dresden, 01062, Germany

[3]Institute of Fluid dynamics, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, 01328, Germany

Corresponding Author: mira.stephan@hszg.de, Michael.Wagner3@tu-dresden.de

Motivation and Task

Situation in Germany

Expiring licence:
Transport and storage cask licence limited to 40 years
→ begin to expire in the 2030s /2, S.90/

No operational long-term storage facility:
Long-term storage facility yet to be found
→ not available before 2050 /3, S.42/

Prolonged interim storage


[Source: /6/]

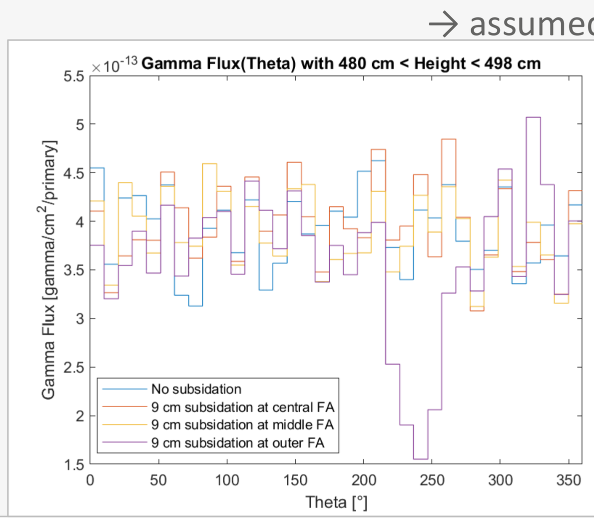
Investigation of non-invasive cask monitoring concepts

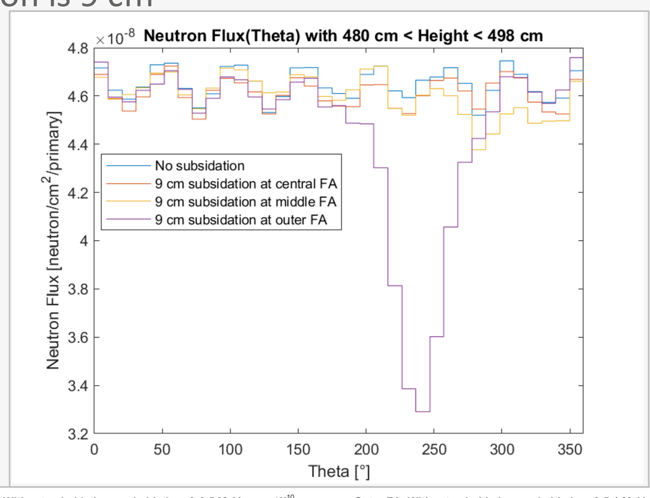
Radiation-field-based concepts promising /4, 5/:
→ Investigation of gamma- and neutron-fields for major inventory changes
→ Construction of a partially automated gamma and neutron detector
→ Investigation of cosmic muon scattering for major inventory changes
→ Implementation of a suitable procedure for the inverse problem in muon imaging
→ Construction of a suitable muon detector

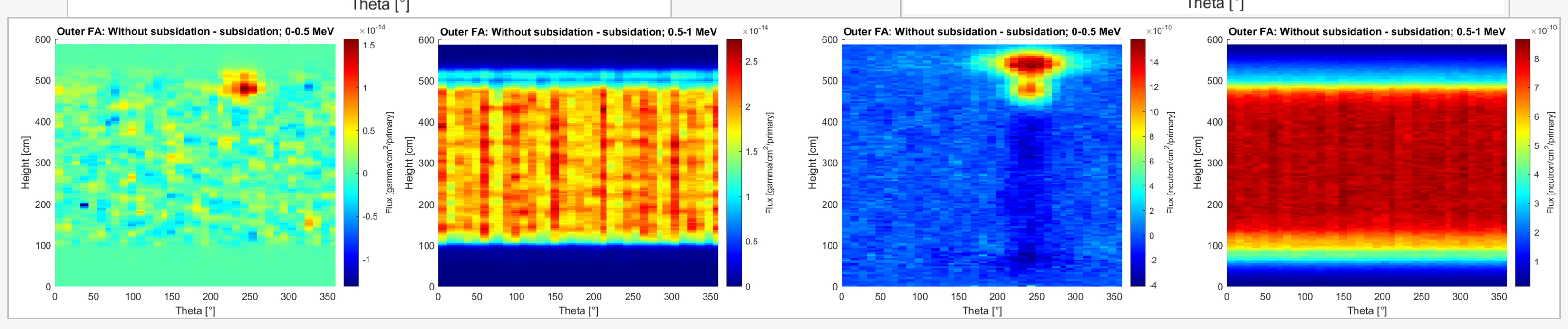
Support safety during prolonged interim storage and elongation of approval

Gamma- and Neutron-Fields: Simulation

- Radiation-field outside CASTOR® V/19-cask at the cylinder surface (simulated with MCNP6.2)
- Spent nuclear fuel: medium burn-up of 56.79 GWd/tHM and 5 years cooling time
- Fuel distribution changes: → axial redistribution at different fuel assembly positions
  → assumed vertical subsidation is 9 cm



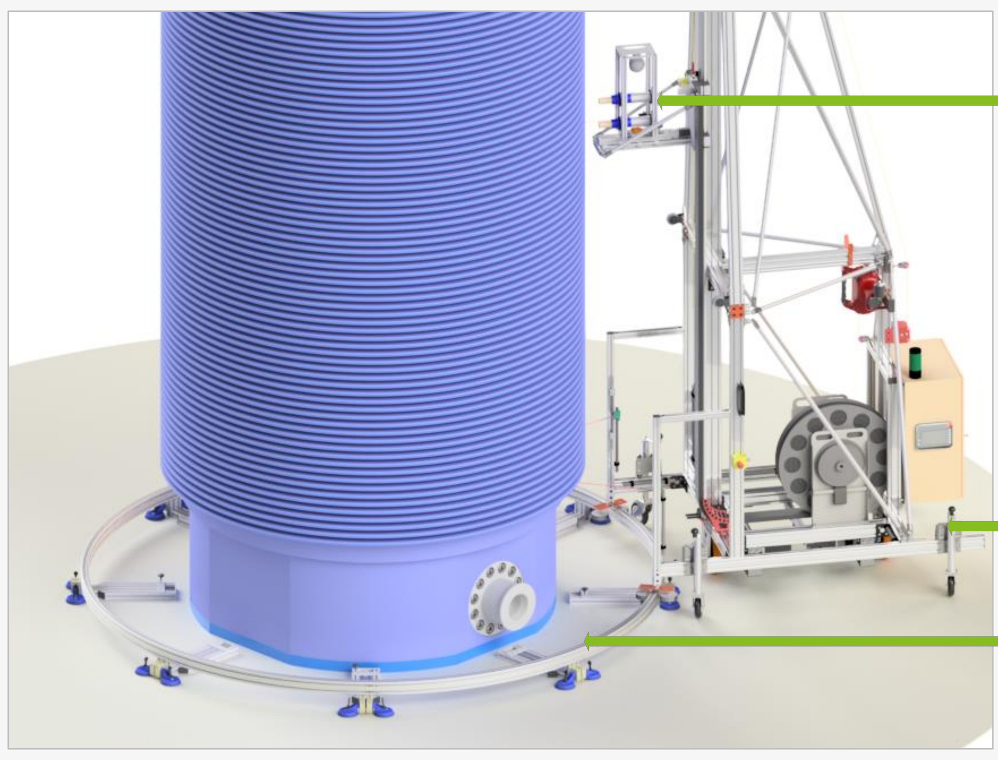




- Gamma-field shows only changes at outer fuel assembly
- Subsiduation more recognizable at lower energies

- Neutron-field shows changes at outer and inner fuel assembly
- Subsiduation more recognizable at lower energies

Gamma- and Neutron-Fields: Measurment System



CLYC sensors:
Enable the joint and separate detection of gamma and neutron radiation

Movable carrier structure:
Provides partially automated positioning of the sensors on the CASTOR®-wall

Rail system:
Ensures a well-defined distance between the measuring system and the CASTOR®

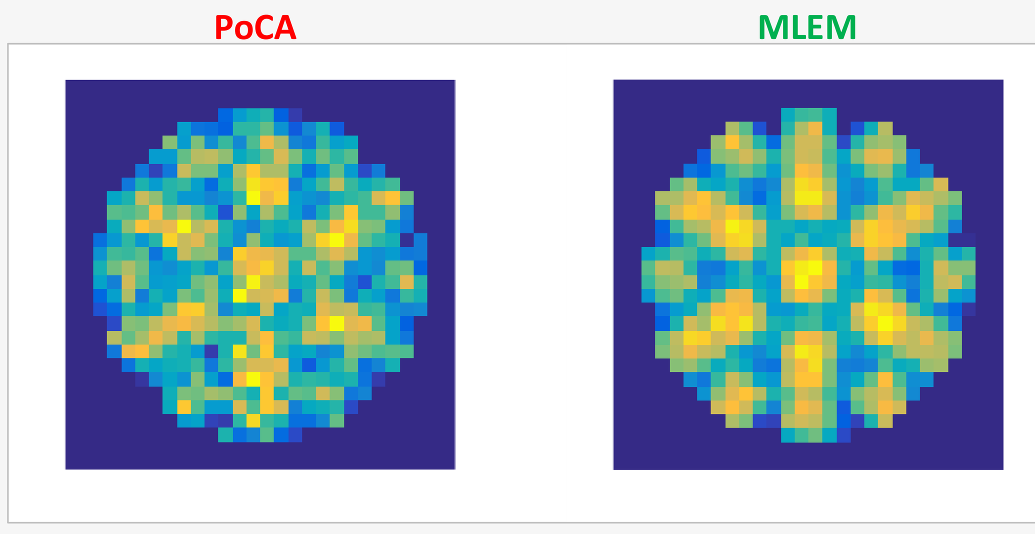
Cosmic Muons: Volume Reconstruction

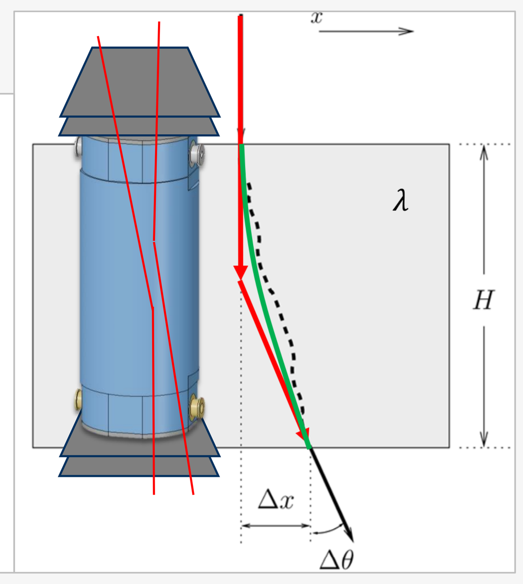
Maximum likelihood estimation:
- Discretization of the object
- Assume path through the object (PoCA or more likely path)
- Calculate the muon path length for every muon and voxel "system matrix"
- Solve the linear equation system with measured data **f(L,D)λ = D**

Full container simulation:
- Simulation of cosmic muons with G4beamline
- Measurement time ≈ 12 h (3.3*10^6 events)
- MLEM-reconstruction with region clustering "regularization", voxel size ≈ 6 x 6 x 4.5 cm^3

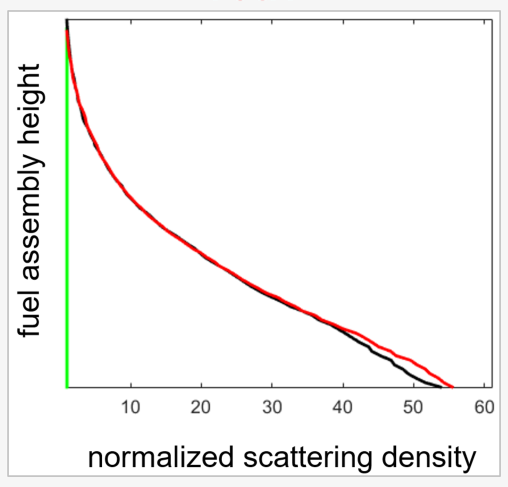
↑ Higher image quality
↑ Knowledge about the object included
↓ Higher computational effort
↓ The usual numerical problems

What is a cosmic muon?
- Mean momentum ≈ 3 GeV/c
  → highly penetrating particle
- Flux ≈ 1 cm^{-2} min^{-1}
- Mass ≈ 207 m_e
- Interaction with matter
  → energy loss and multiple coulomb scattering

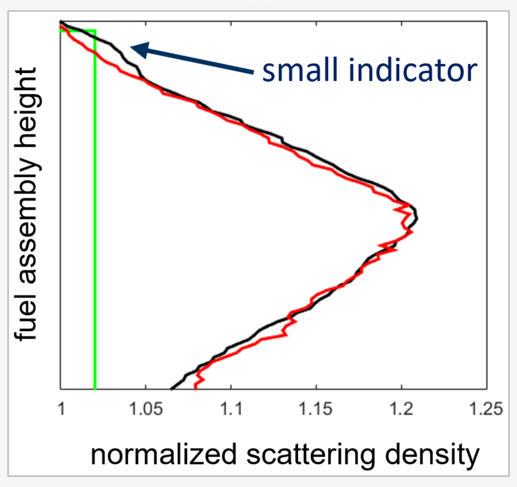




Simulation with fuel relocation:
- 9 cm vertical subsiduation → Vertical scattering density profile of central fuel assembly (normalized)



Reference case
9 cm of fuel relocation
Theoretic profile for relocation



- Algebraic volume reconstruction identifies fuel relocation
- Further development necessary for direct localization without reference
- → Construction of a muon detector and measurement at large scale geometries (Drift chambers preferred at the moment)

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Institut für Prozesstechnik, Prozessautomatisierung und Messtechnik
Prof. Dr.-Ing. Alexander Kratzsch
+ 49(0)3583 612 4282
a.kratzsch@hszg.de

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