# Projects in Nuclear Safeguards at Chalmers

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# Outline

- A method for neutron multiplicity counting with fission chambers in current mode
- A methodology for partial defect testing of spent nuclear fuel

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# Nuclear Safeguards at Chalmers (I)

- A method for neutron multiplicity counting with fission chambers in current mode

  - Collaboration between Chalmers and BME – Budapest University of Technology

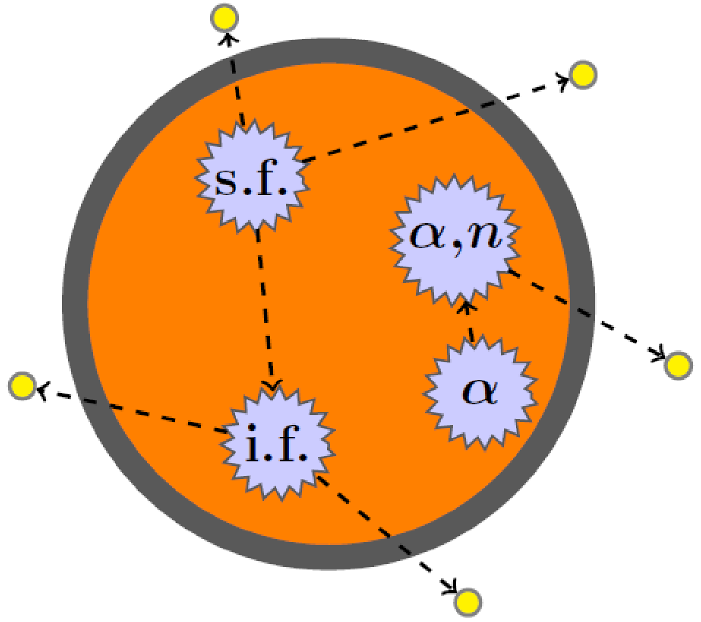
  - PhD student: Lajos Nagy

    - Supervisor at BME: Máté Szieberth
    - Supervisors at Chalmers: Imre Pázsit, Anders Nordlund, Paolo Vinai

    - Started in 2016 – PhD exam in September 2020

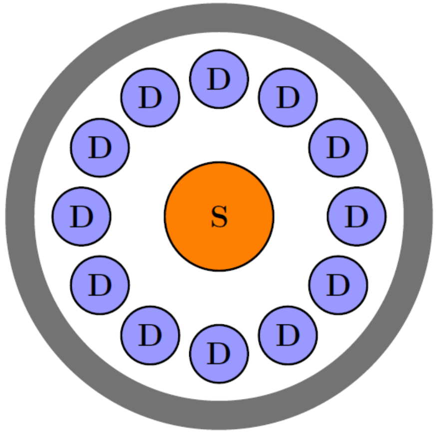
# Neutron multiplicity counting – Background

- Non-destructive assay method for estimating unknown parameters of samples with spontaneously fissioning materials
  - Emission of neutrons in a heavy-nuclide sample



# Neutron multiplicity counting – Background

- Basics of the technique




→ Counting statistics of detectors operating in pulse mode → Singles, Doubles, Triples

↓

Sample mass
Self-multiplication
(α,n) reactions

# Neutron multiplicity counting – Project

- Pulse counting mode
  - Sensitivity to the detector dead time

- Alternative version of multiplicity counting inherently free of dead time issues
  - Use of fission chambers in current mode and a corresponding model

# Neutron multiplicity counting – Project

- A theory has been developed for fission chambers in current mode

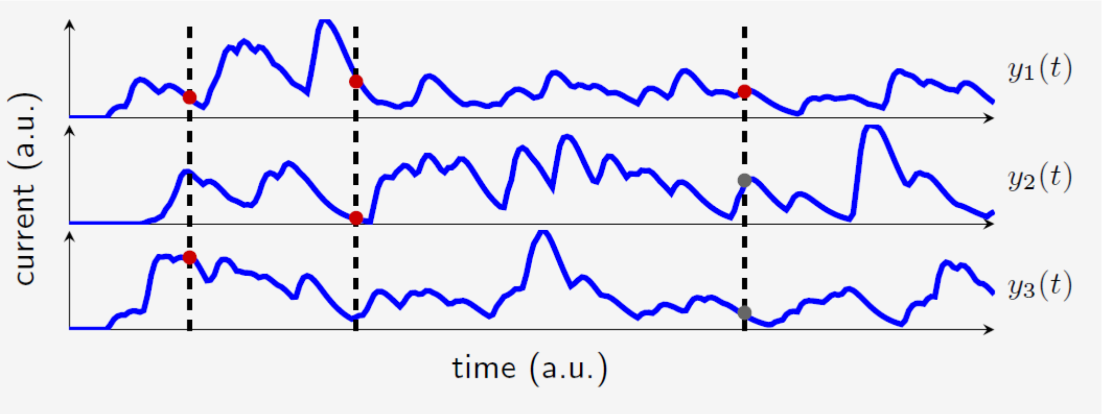
Time-resolved signals of the detectors → Exctraction of statistical moments of the signals

↓

Relationship with singles, doubles and triples rates

↓

Sample mass
Self-multiplication
($\alpha$,$n$) reactions



# Neutron multiplicity counting – Project

- Relationships between the moments of the signal from 1 detector and singles ***S***, doubles ***D*** and triples ***T*** rates
  - 3-point statistics and including the treatment of the time delay

Mean of the detector current → $\kappa_1 = S\langle a\rangle I_1$

Auto-covariance function → $\mathrm{Cov}_2 = \frac{1}{2}\left[S\langle a^2\rangle + 2D\langle a\rangle^2\right] I_1^2$

Auto-bicovariance function → $\mathrm{Cov}_3 = \frac{1}{6}\left[S\langle a^3\rangle + 2D\langle a\rangle\langle a\rangle^2\xi + 6T\langle a\rangle^3\right] I_1^3$

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# Neutron multiplicity counting – Project

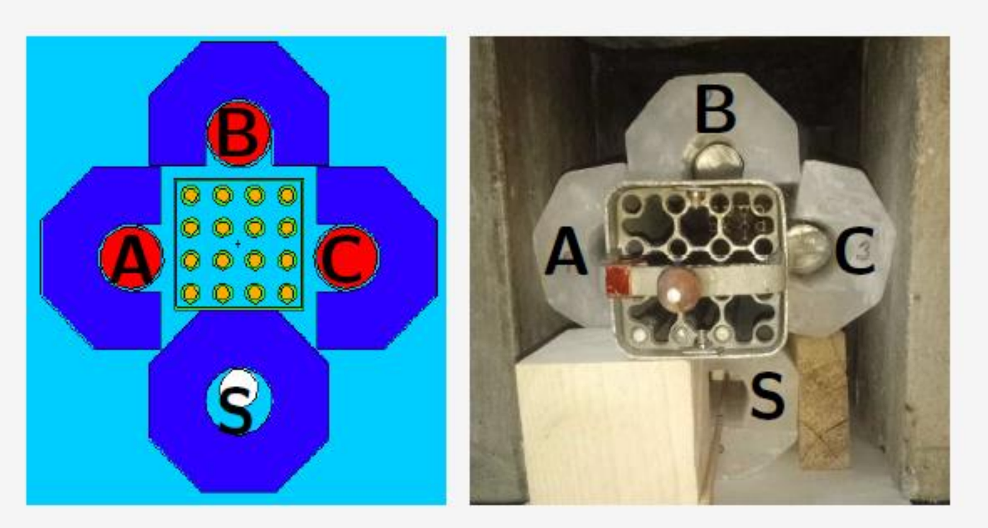
- Relationships between the moments of the signals from two or three detectors and doubles ***D*** and triples ***T*** rates
  - 3-point statistics and including the treatment of the time delay

Cross-covariance function with 2 detectors → $\mathrm{Cov}_{1,1} = 2D\langle a\rangle^2 I_1^2$

Cross-bicovariance function with 3 detectors → $\mathrm{Cov}_{1,1,1} = 6T\langle a\rangle^3 I_1^3$

# Neutron multiplicity counting – Project

- Experimental set-up at BME for testing the developed theory
  - Fresh fuel assembly with 10% enriched uranium (variable number of rods)
  - $^{241}$Am-Be neutron source
  - 3 Fission chambers + data acquisition system



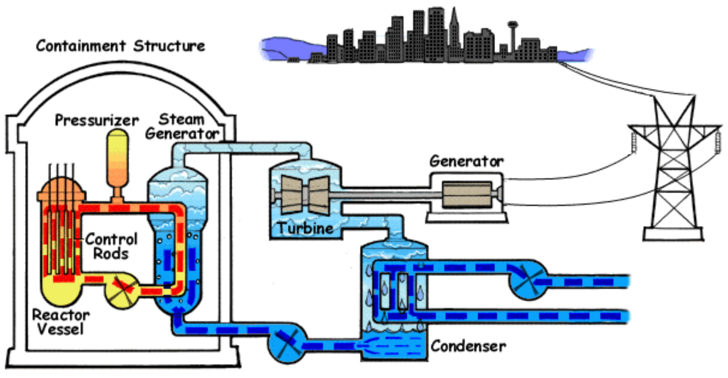
# Neutron multiplicity counting – Future work

- Tests of the methodology against experimental data
- Investigation of effects related to geometry, neutron spectrum and slowing down
- Use of detectors with higher efficiency
- Extension to reactivity measurements in subcritical systems

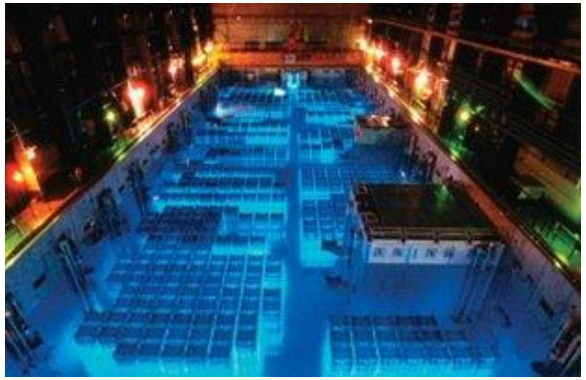
# Safeguards at Chalmers (II)

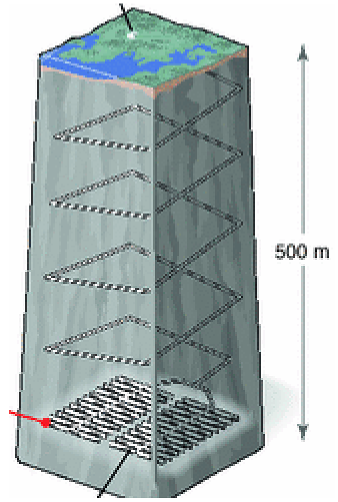
- A methodology to partial defect testing of spent nuclear fuel
  - Collaboration between Chalmers and SCK•CEN
  - PhD student: Moad Al-dbissi
    - Supervisors at Chalmers: Paolo Vinai and Imre Pázsit
    - Supervisors at SCK•CEN: Alessandro Borella and Riccardo Rossa
    - Starting date: December 2019/ January 2020

# Partial defect testing of SNF – Background



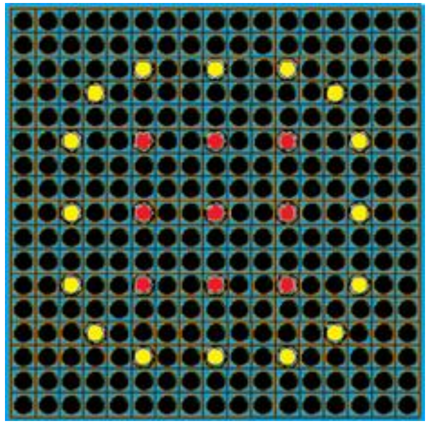

Need for methods to inspect many spent nuclear fuel assemblies and be sure no nuclear material is diverted





# Partial defect testing of SNF – Background

Spent nuclear fuel assembly



Measurements of neutrons, gamma or Cherenkov radiation

Signal processing

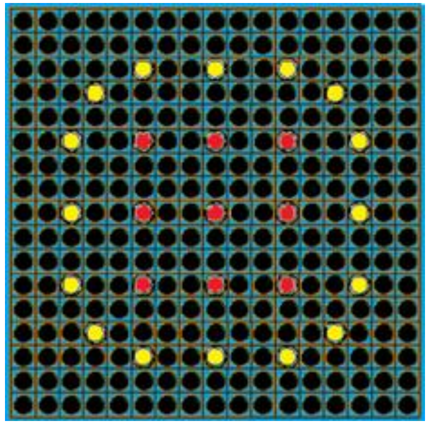
Any missing nuclear material?

# Partial defect testing of SNF – Background

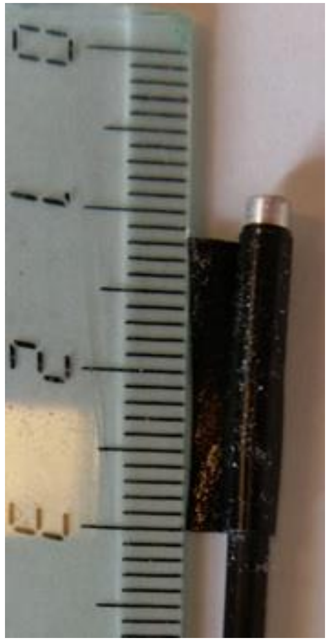
- According to the needs, the investigation of SNF are performed using
  - Cherenkov viewing devices
    - Fast and flexible
  - Gamma tomography and fork detectors
    - More accurate
    - The spent nuclear fuel assemblies need to be moved

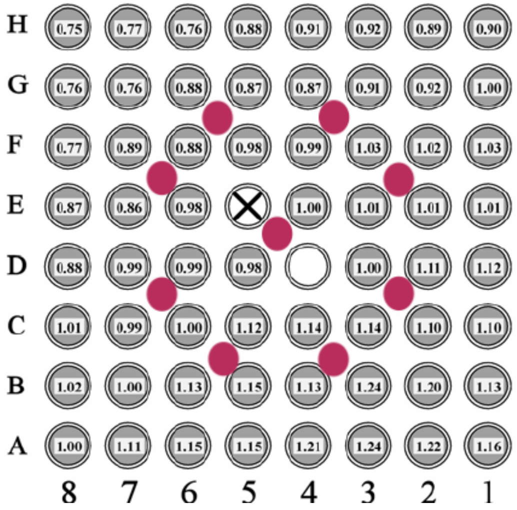
# Partial defect testing of SNF – Project

Spent nuclear fuel assembly



Measurements of neutrons with fiber optic detectors

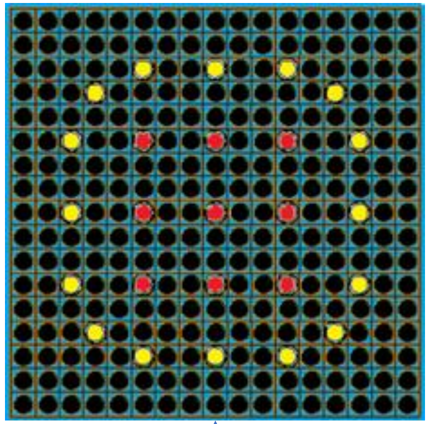





- Small size → usable in narrow spaces without moving the spent nuclear fuel assemblies
- Accurate measurements based on the neutron scalar flux and its gradient

# Partial defect testing of SNF – Project

Spent nuclear fuel assembly



Measurements of neutrons with fiber optic detectors

Machine Learning Algorithm

Training based on neutron flux simulations for the different configurations

Comparison between what it is measured and what it is expected

Automatic identification of possible missing fuel pins

# Conclusions

- 2 PhD projects in nuclear safeguards at Chalmers
  - Neutron multiplicity counting with fission chambers in current mode
  - Partial defect testing of spent nuclear fuel

- Collaboration with
  - BME (Hungary)
  - SCK • CEN (Belgium)

# Thank you

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