

Investigation of the Partial Defect Tester (PDET) for the detection of fuel pins diversion in the frame of spent fuel safeguards verification

Gisella Marzari

SCK•CEN mentor

Riccardo Rossa

SCK•CEN co-mentor

Alessandro Borella

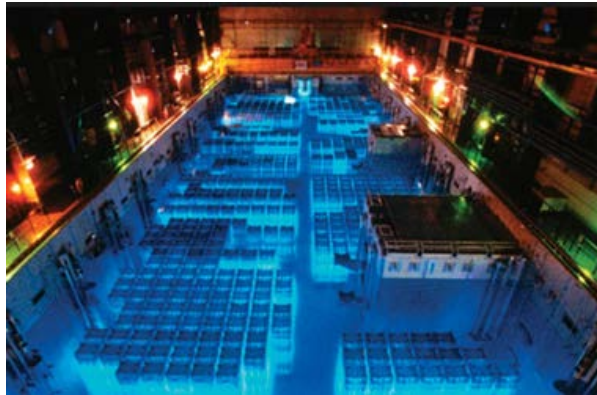
Promotor

Prof. Piero Ravetto

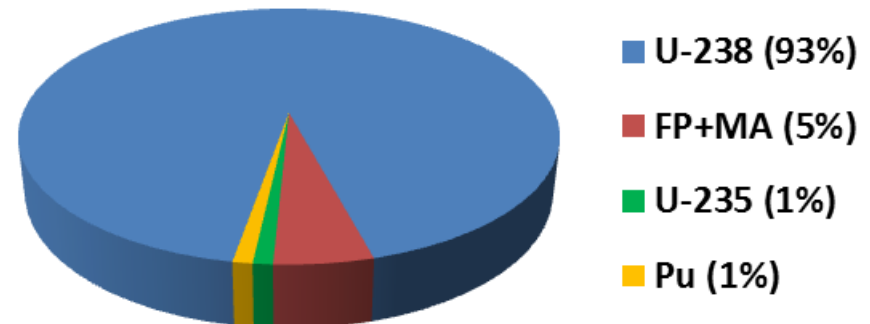
- Introduction
 - Spent nuclear fuel
 - PDET
- Reference conditions for PDET detector
 - Detector type
 - Spent fuel characteristics
- Influence of the spent fuel assemblies in the storage rack
- Analysis of partial defect capabilities
- Final conclusions

Introduction: the spent nuclear fuel

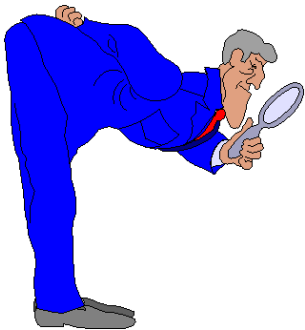
- **Spent nuclear fuel** is the fuel discharged from the reactor after irradiation and stored in pools



Composition of Spent Nuclear Fuel (*)

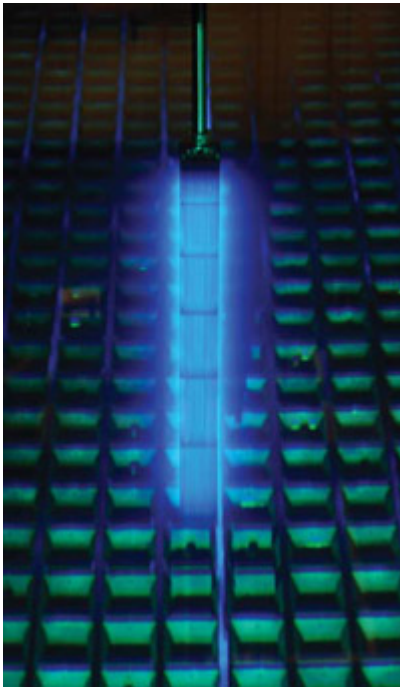


* IAEA Spent Fuel Reprocessing Options, 2008



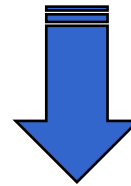
The fissile material content of spent nuclear fuel is such that **safeguards inspections** are required to avoid potential proliferation.

Introduction: the spent nuclear fuel



Spent fuel is one of the most difficult materials to verify

- Very high neutron and gamma emissions
- Significant decay heat after discharge
- No direct access to the material



Non Destructive Assays Techniques

Introduction: aim of the work

- The **Partial Defect Tester*** is a detector based on neutron and gamma measurements within the spent fuel assembly

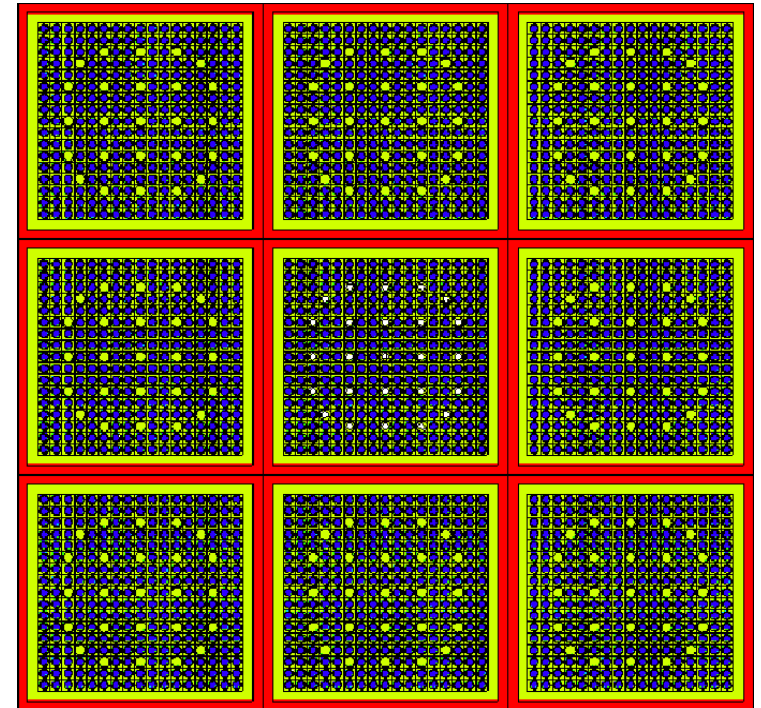


- The aim of the work is to investigate if the PDET can be used for partial defect verification
- Detection threshold of **50%** missing pins in the fuel element

* Developed by Lawrence Livermore National Laboratory (LLNL)

Introduction: the MCNP model

- PWR 17x17 fuel element
- 3x3 storage fuel rack immersed in water (no boron)
- Detector length set to 2 m and inserted in the central fuel element
- Reference spent fuel library* used for the fuel characteristics
 - Material composition
 - Source intensity



* Rossa R., et al., Development of a reference spent fuel library of 17x17 PWR fuel assemblies, ESARDA BULLETIN, No. 50, Dec 2013

- In this work, only neutron flux will be considered.
 - spontaneous fission of transuranic elements
 - induced fission in the residual fissile material
- The detector response N is the number of neutrons detected per neutrons emitted

$$N = \frac{\textit{detected neutrons}}{\textit{neutron source}} = \int_E \sigma_{DET}(E) \cdot \varphi(E) dE$$

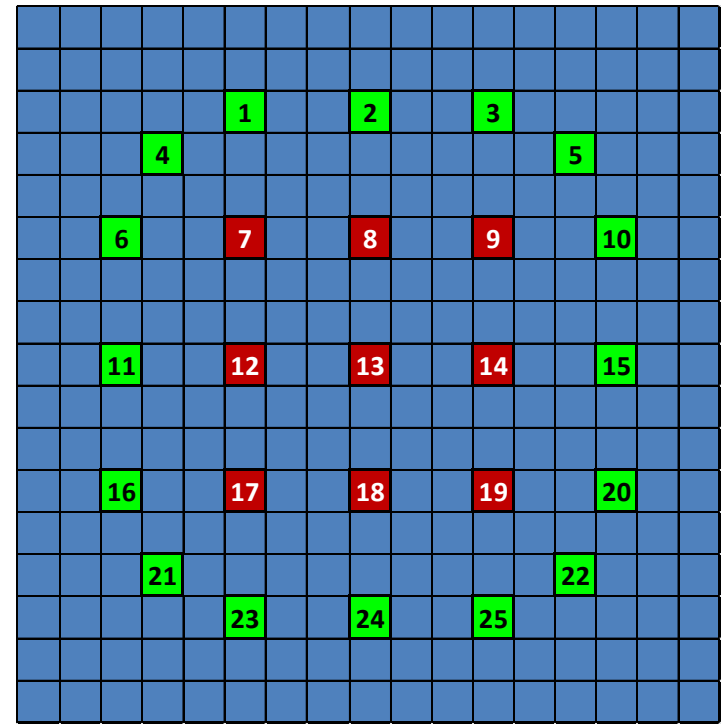
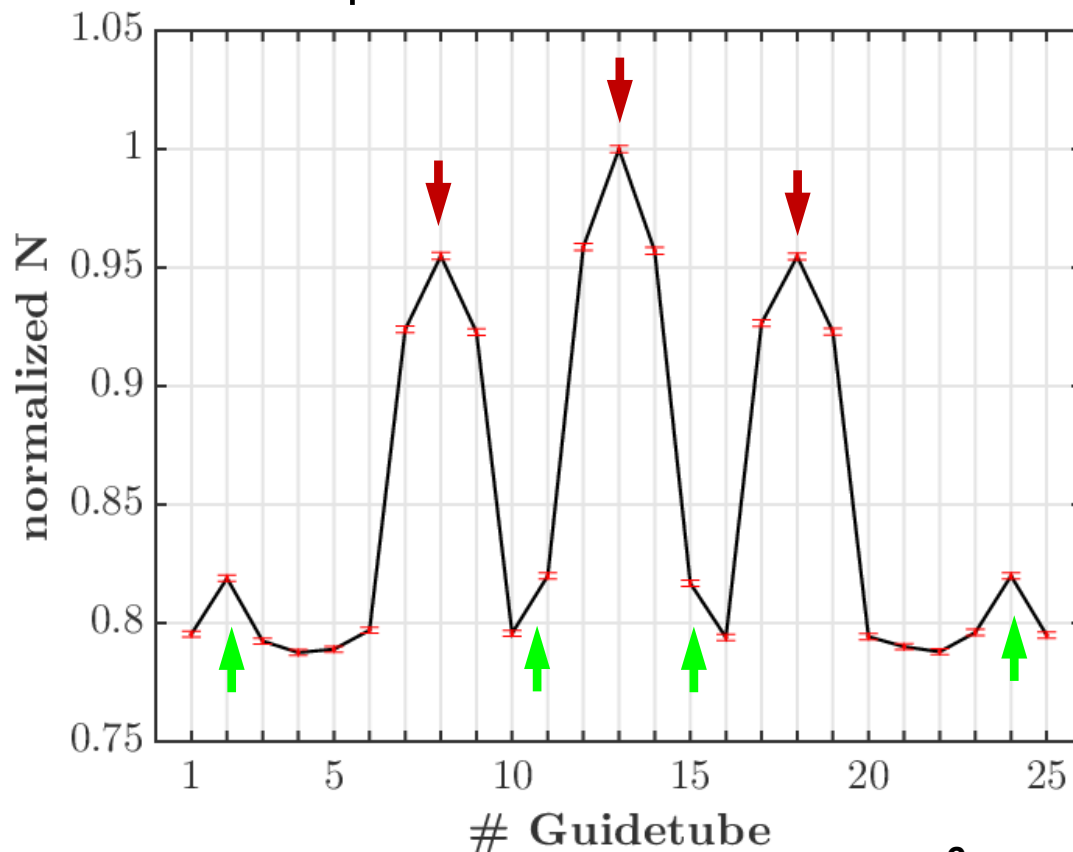
$\sigma_{DET}(E)$ **cross section of the active material in the detector***

$\varphi(E)$ **neutron fluence**

* M.B. Chadwick et al., "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data", Nuclear Data Sheets Volume 112, Issue 12. December 2011

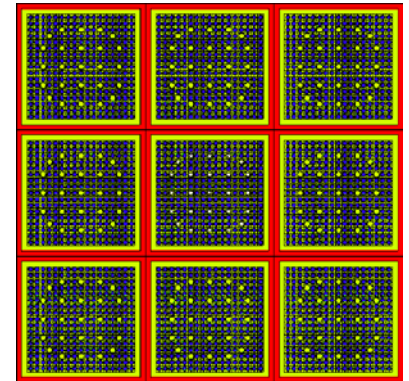
Introduction: the MCNP model

- The effect of the source intensity is canceled out by normalizing N to the maximum value among the 25 guide tube positions.



Reference conditions for PDET detector: detector type and fuel parameter

- Same composition for fuel in storage rack
- No sensitivity to detector type:
U-235 cross section used
- Each reference rack characterized by:
 - Initial enrichment
 - Burn up
 - Cooling time
- No sensitivity to **initial enrichment, cooling time**
- Small sensitivity to **burn up**



Influence of the spent fuel assemblies in the storage rack: effect of the central FA

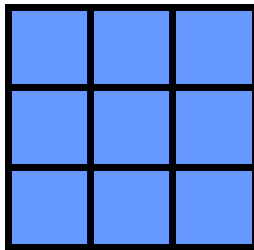
- BU variations in the central fuel assembly

CENTRAL
freshU-60 GWd/t

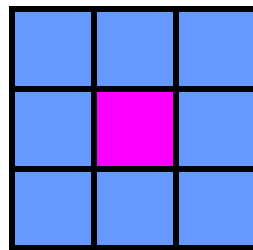
LATERAL
60 GWd/t

CORNER
60 GWd/t

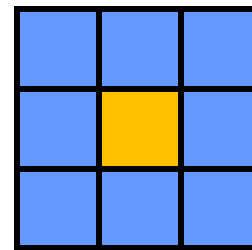
Comparison rack: HHHH



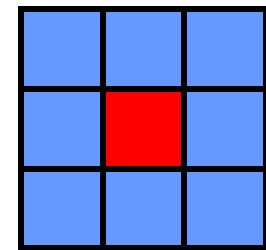
FHHH



LHHH



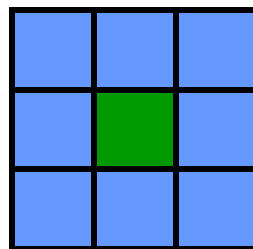
20HHH



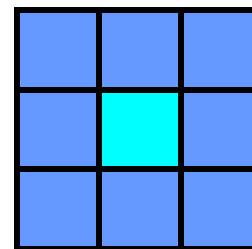
Burn up:



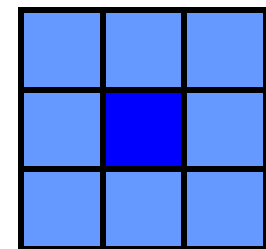
MHHH



40HHH

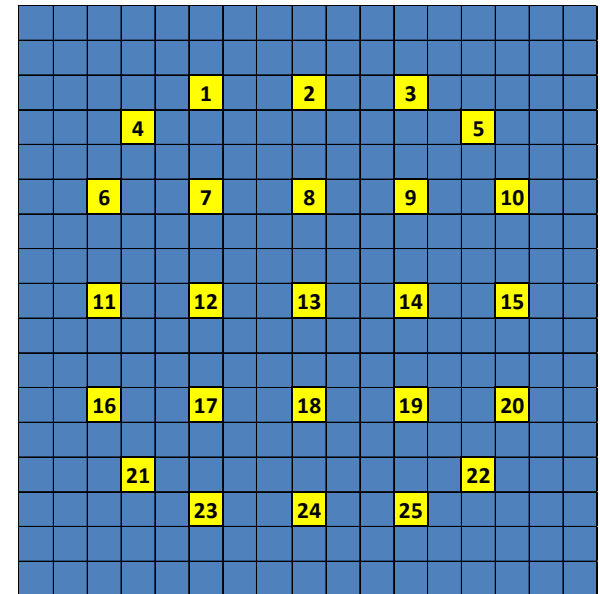
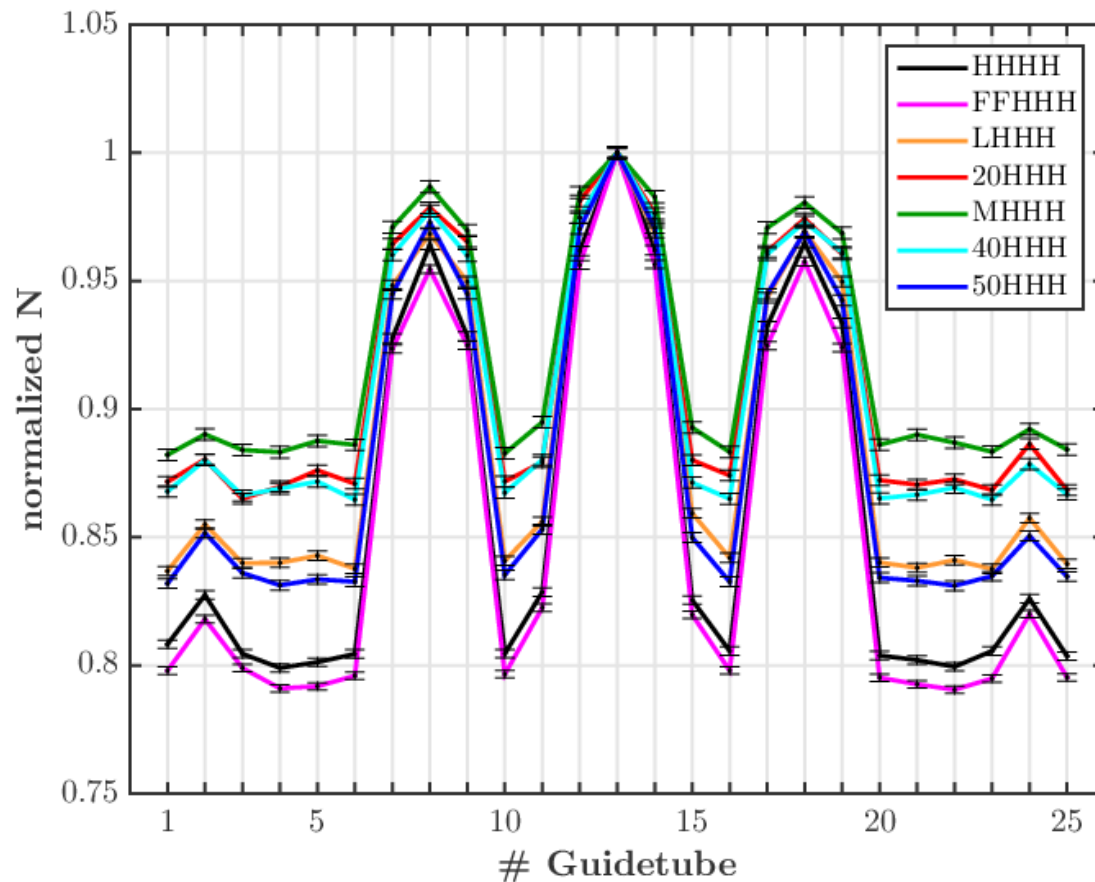


50HHH



Influence of the spent fuel assemblies in the storage rack: effect of the central FA

- BU variations in the central fuel assembly

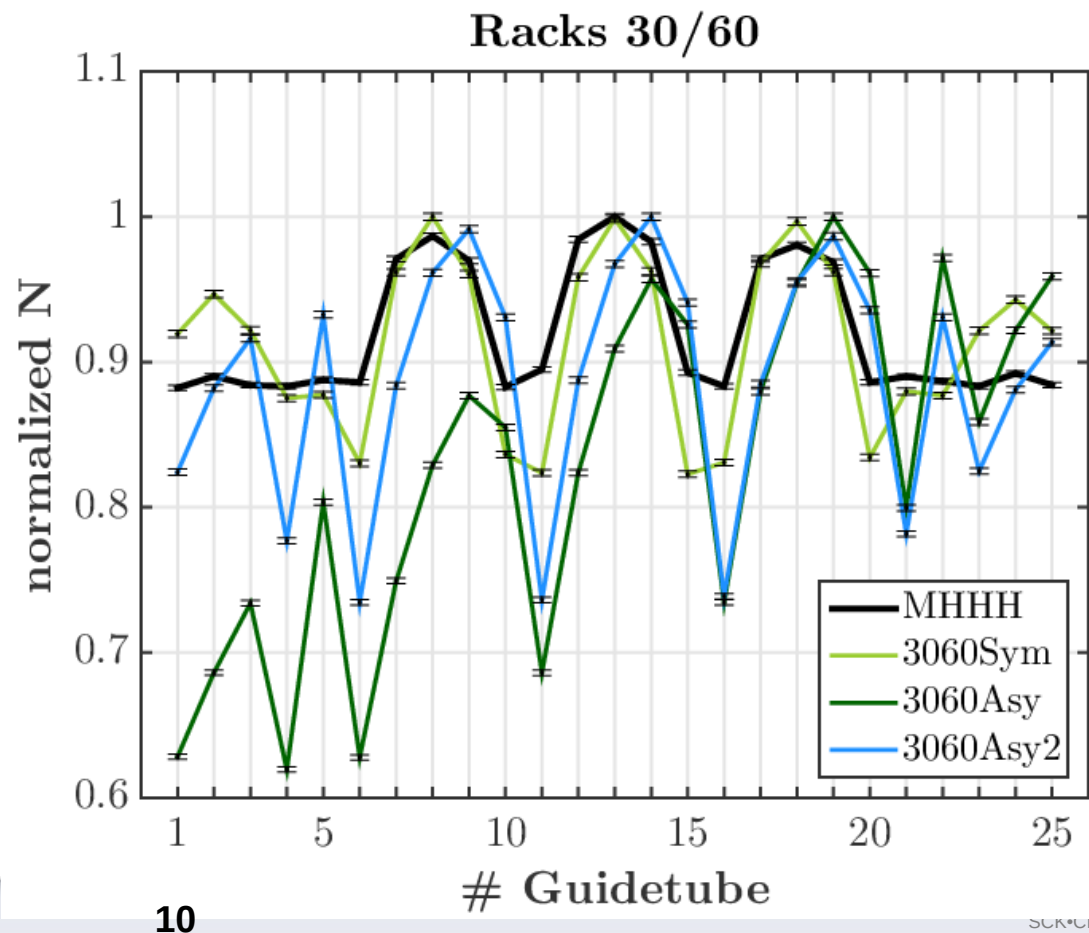
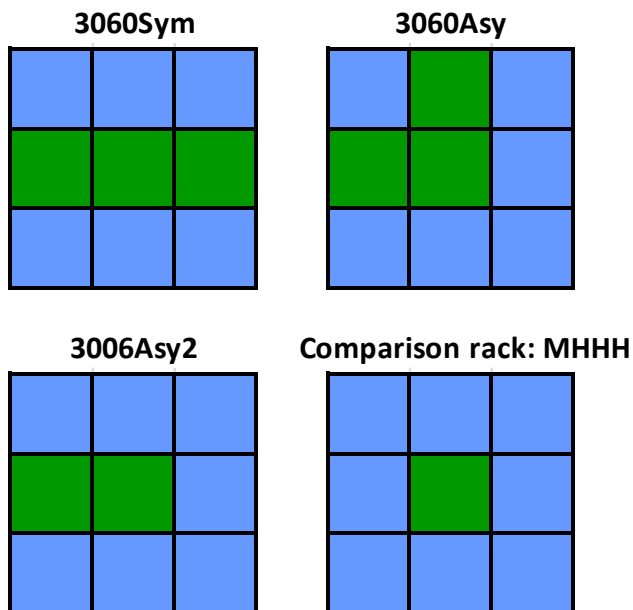


- To evaluate the impact of the lateral and corner assemblies: racks **30/60** and **10/50**

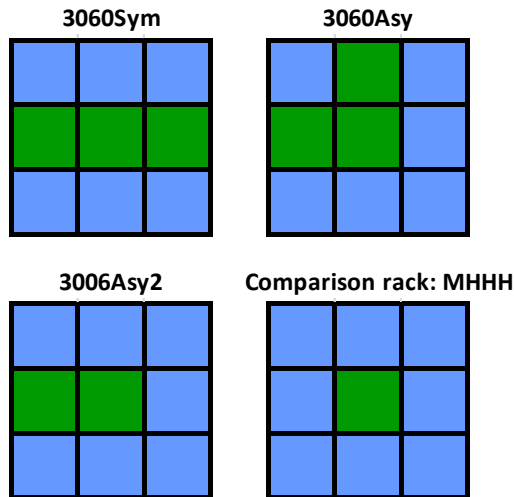
Influence of the spent fuel assemblies in the storage rack: effect of the lateral FA

- BU variations in lateral assemblies
 - Symmetric and asymmetric patterns

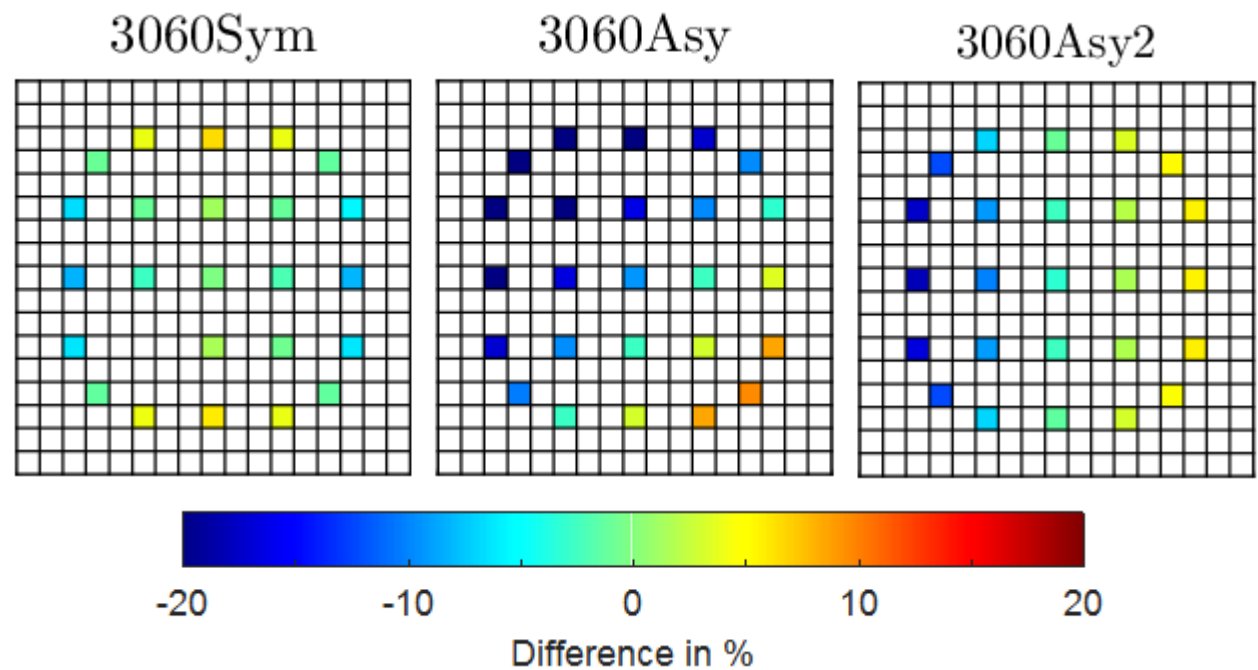
- Racks **30/60**



Influence of the spent fuel assemblies in the storage rack: effect of the lateral FA



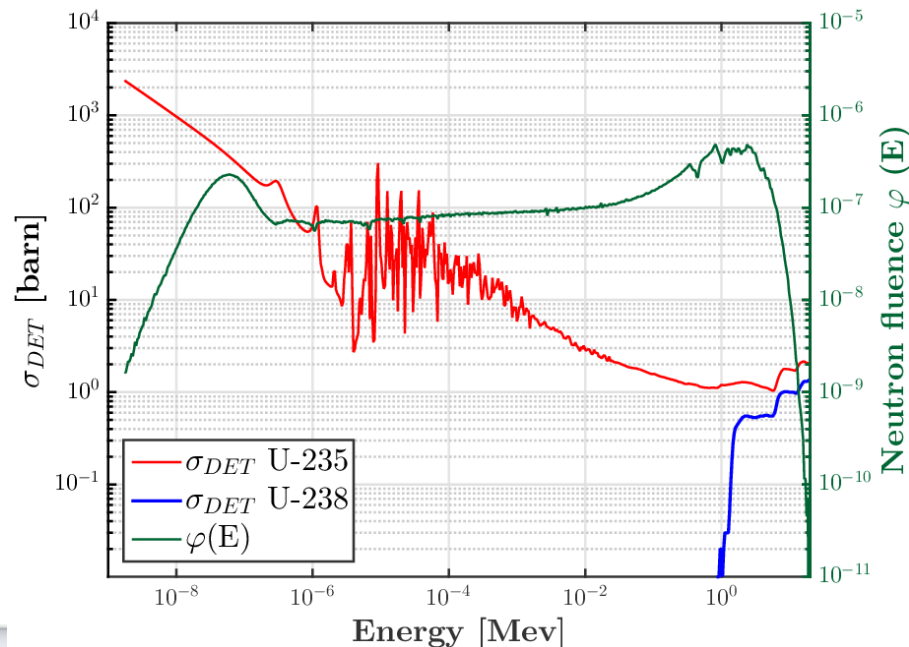
- BU variations in lateral assemblies
 - Racks **30/60**



All the uncertainties are less than 0,4%.

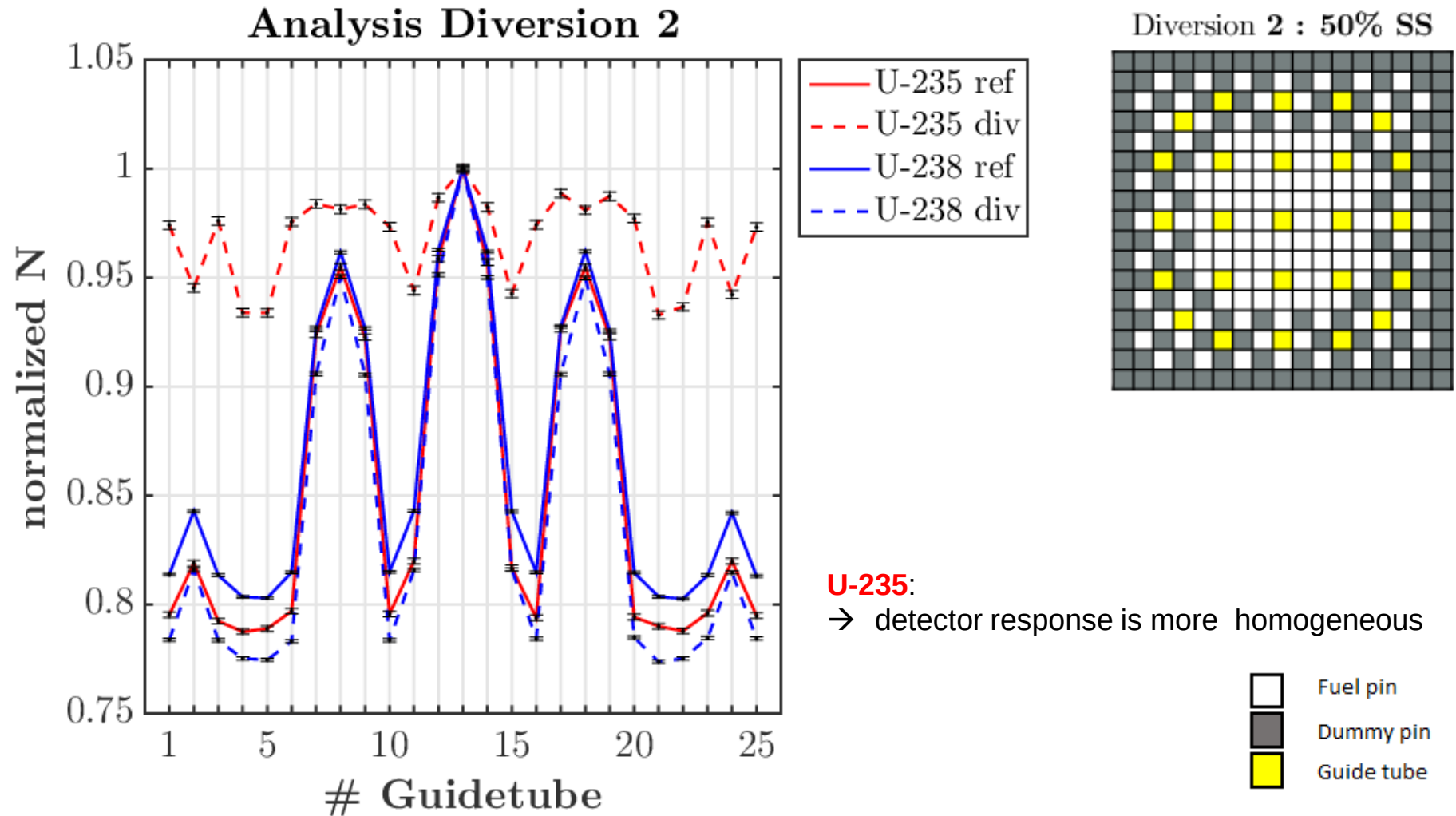
Analysis of partial defect capabilities

- Reference rack considered: IE=3.5% BU=30 GWd/t and CT=5 y.
- Fuel pins replaced with dummies made in **SS** in the **central** fuel element
- Decreasing fraction (from 50% to 15%) of dummies is considered to test the PDET.



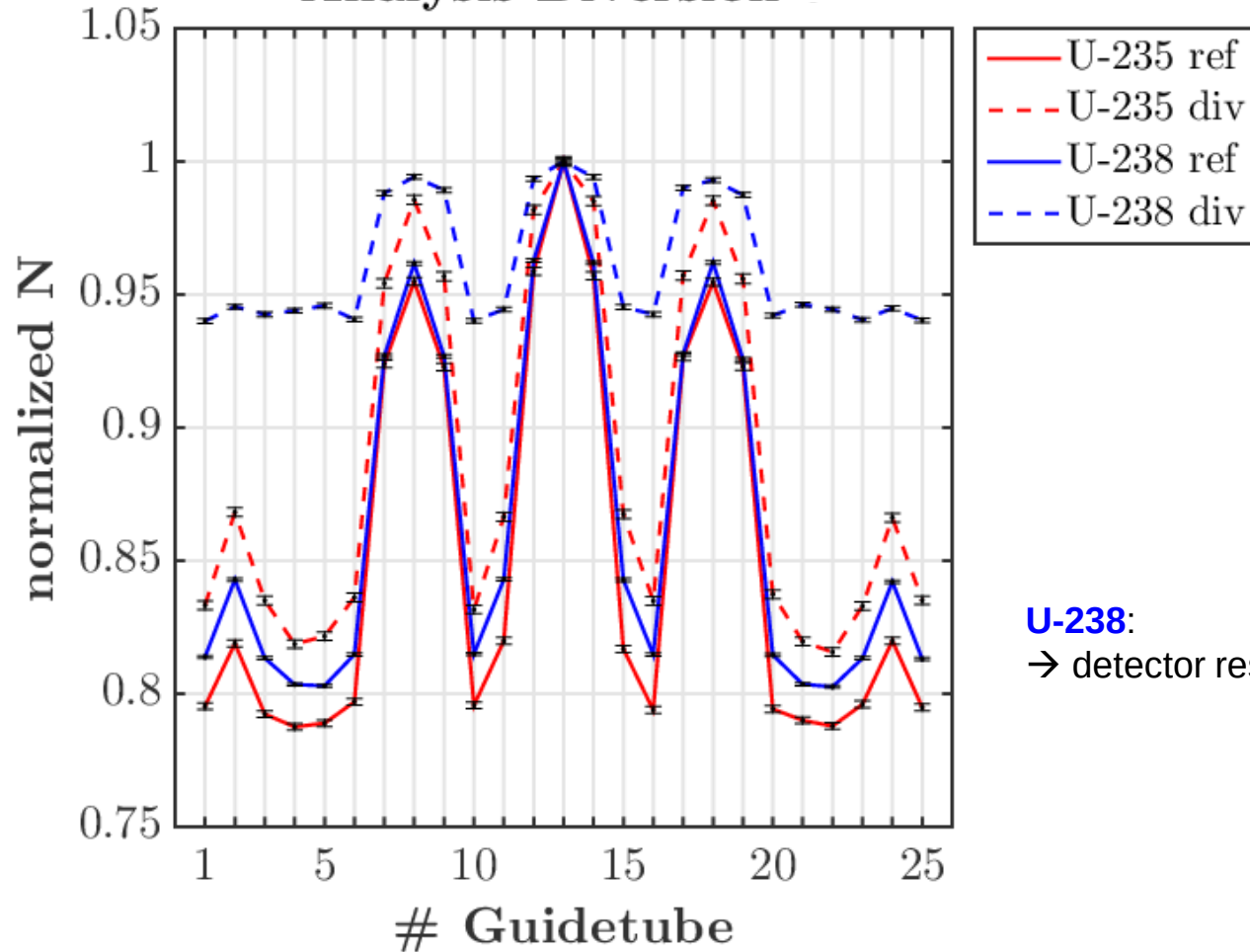
- Thanks to the different fission cross section of U-235 and U-238, we can differentiate the detection of thermal from fast neutrons.

Analysis of partial defect capabilities: 50% of dummies

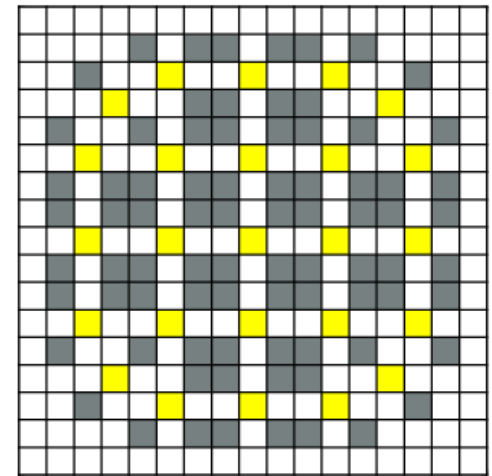


Analysis of partial defect capabilities: 30% of dummies

Analysis Diversion 4

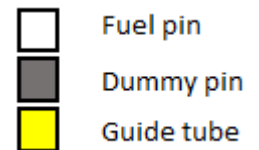


Diversion 4 : 30% SS



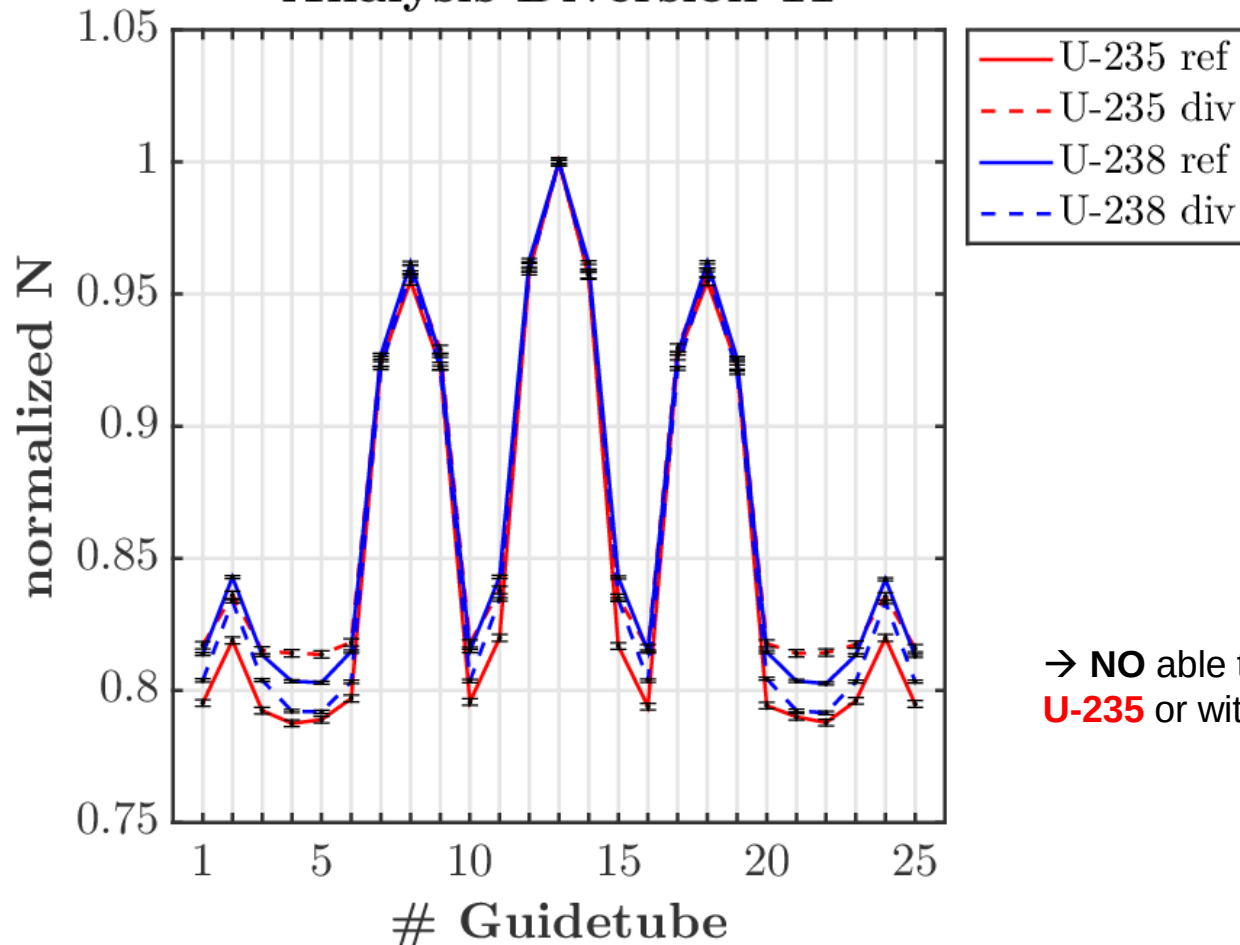
U-238:

→ detector response is more homogeneous

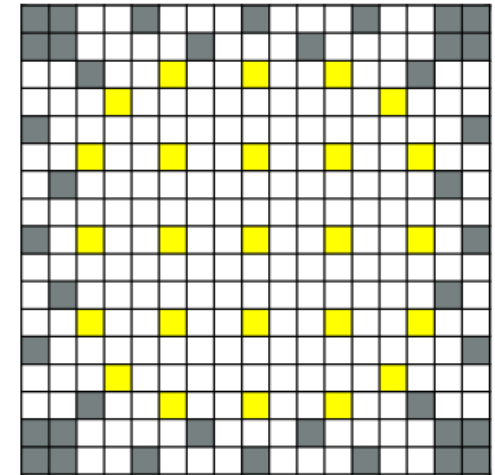


Analysis of partial defect capabilities: 15% of dummies

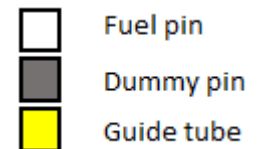
Analysis Diversion 11



Diversion 11 : 15% SS



→ **NO** able to detect the diversion either with
U-235 or with **U-238**



- In reference conditions
 - No sensitivity to detector type
 - Small influence of BU
- Influence of the storage rack
 - Guidetubes at the corner are the most sensitive to the burn up gradient within the rack
 - The more the pattern is asymmetric, the more the profile of the normalized detector response is distorted
- Analysis of partial defect capabilities
 - The combination of the normalized neutron signal detected with U-235 and U-238 can reveal diversion until 30% of the total active pins

**Thank you for your
attention!**

Copyright © 2015 - SCK•CEN

PLEASE NOTE!

This presentation contains data, information and formats for dedicated use ONLY and may not be copied, distributed or cited without the explicit permission of the SCK•CEN. If this has been obtained, please reference it as a "personal communication. By courtesy of SCK•CEN".

SCK•CEN

Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

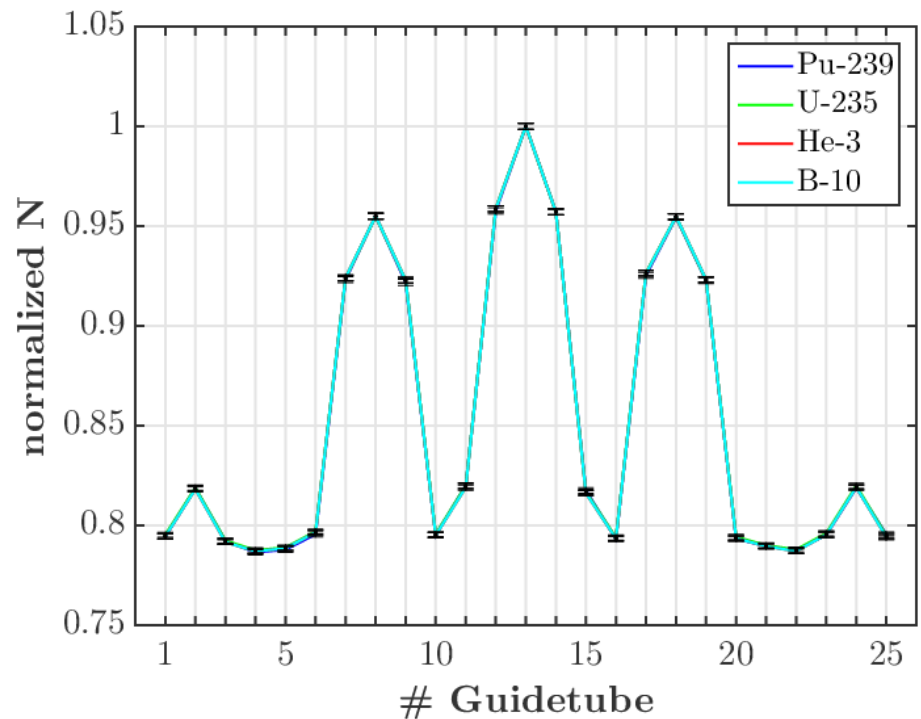
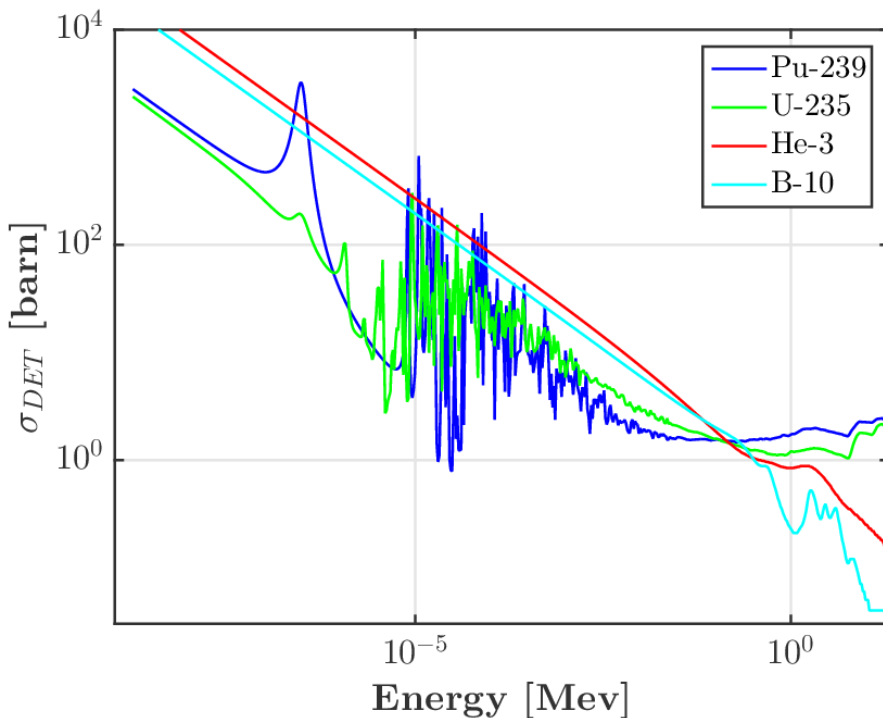
Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL



STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

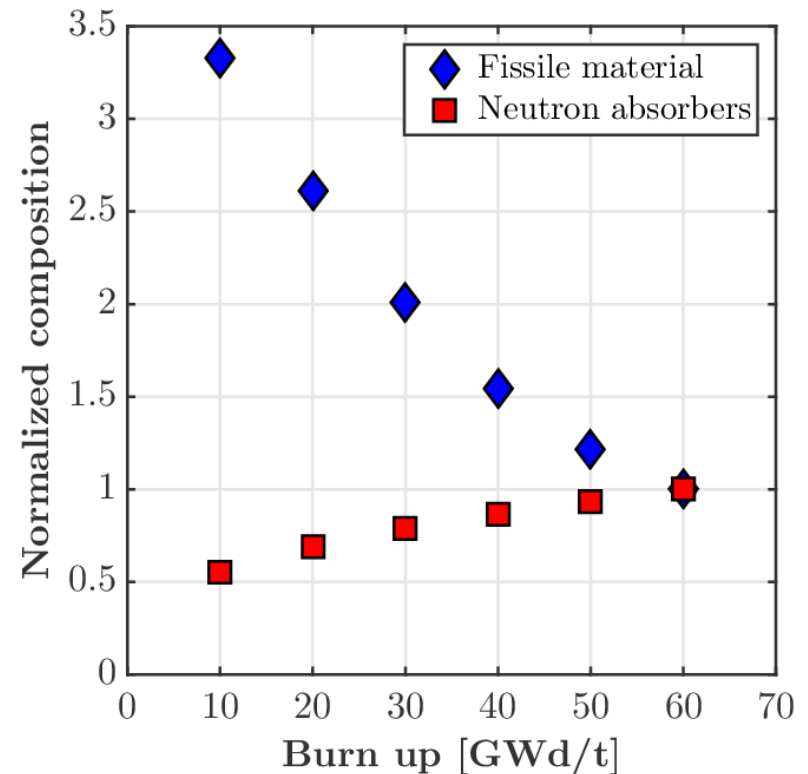
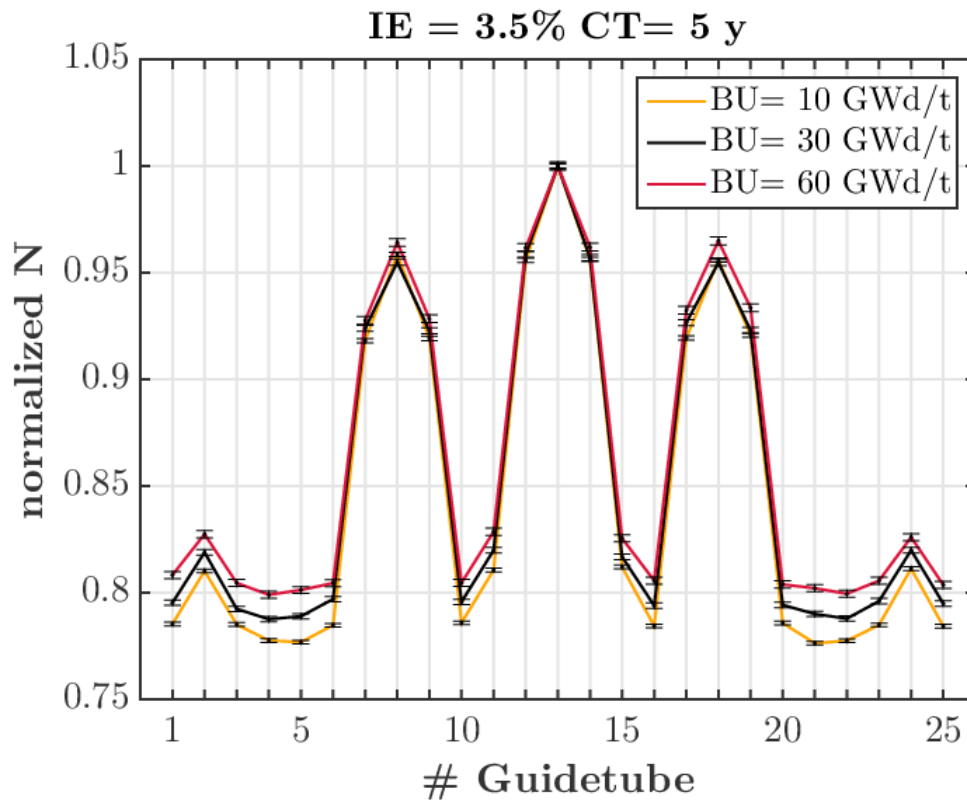
Additional slides: sensitivity to detector type



- No sensitivity to the detector type is observed, so **U-235** cross section used for most of the work

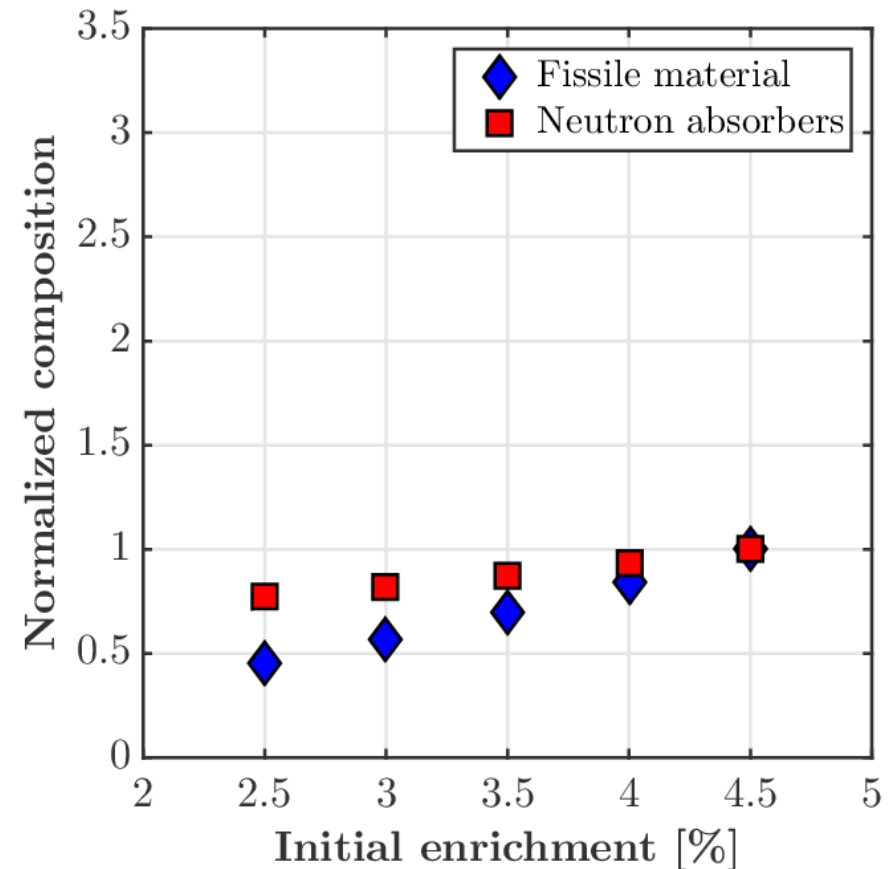
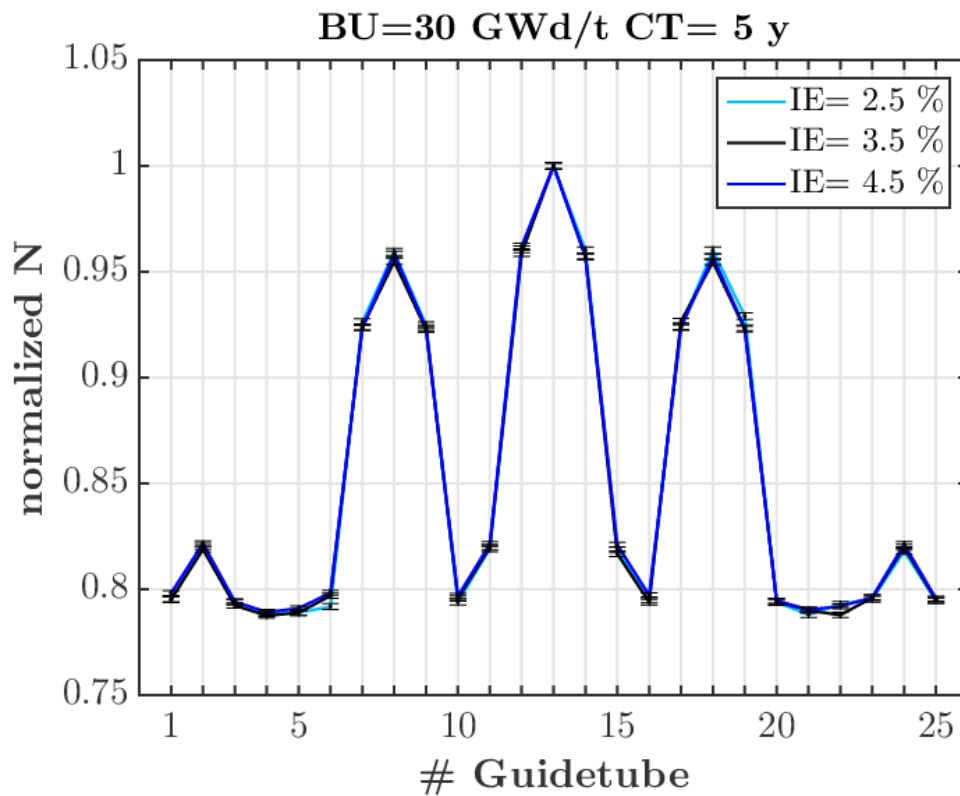
Additional slides: sensitivity to IE, BU, CT

- Small sensitivity to **burn up**



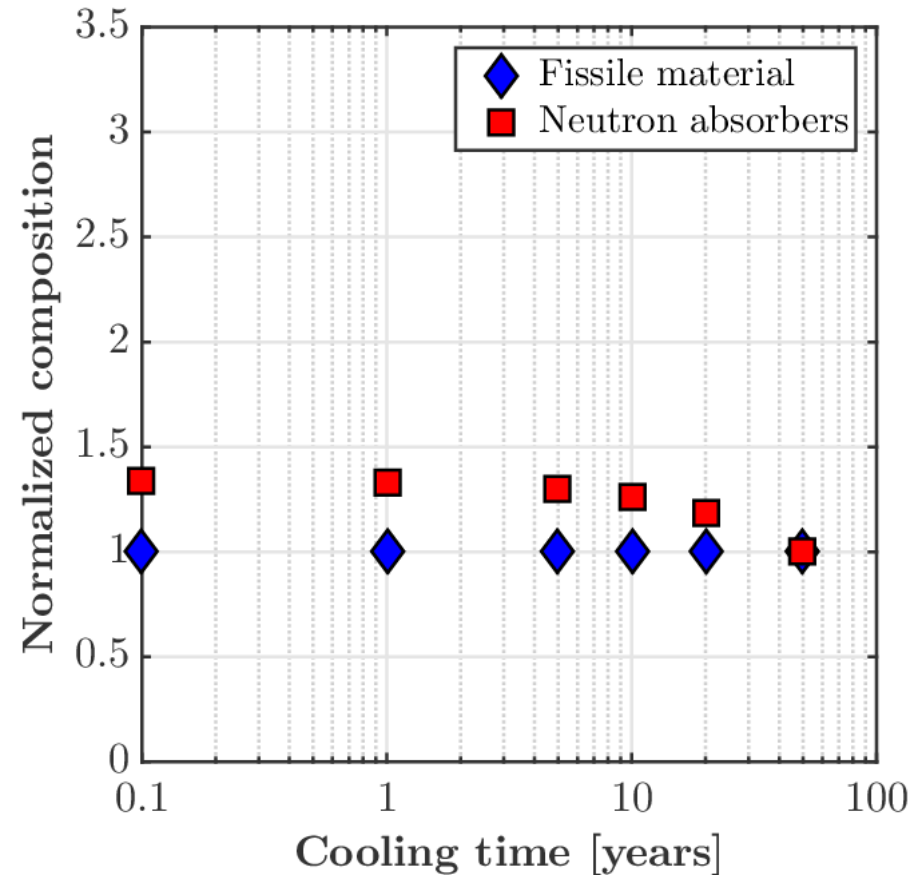
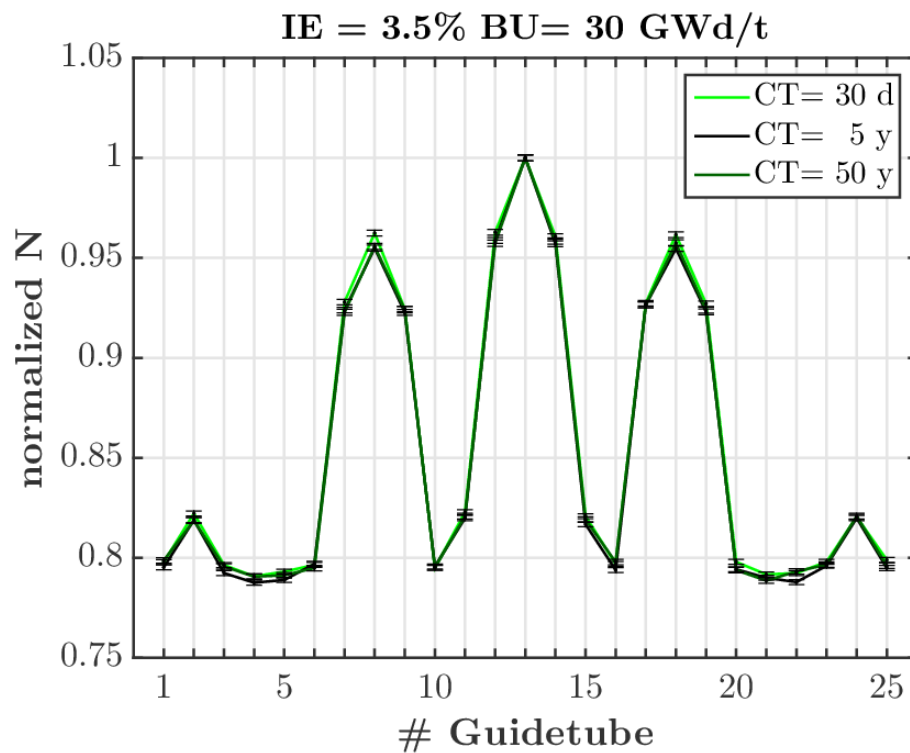
Additional slides: sensitivity to IE, BU, CT

- No sensitivity to **initial enrichment**



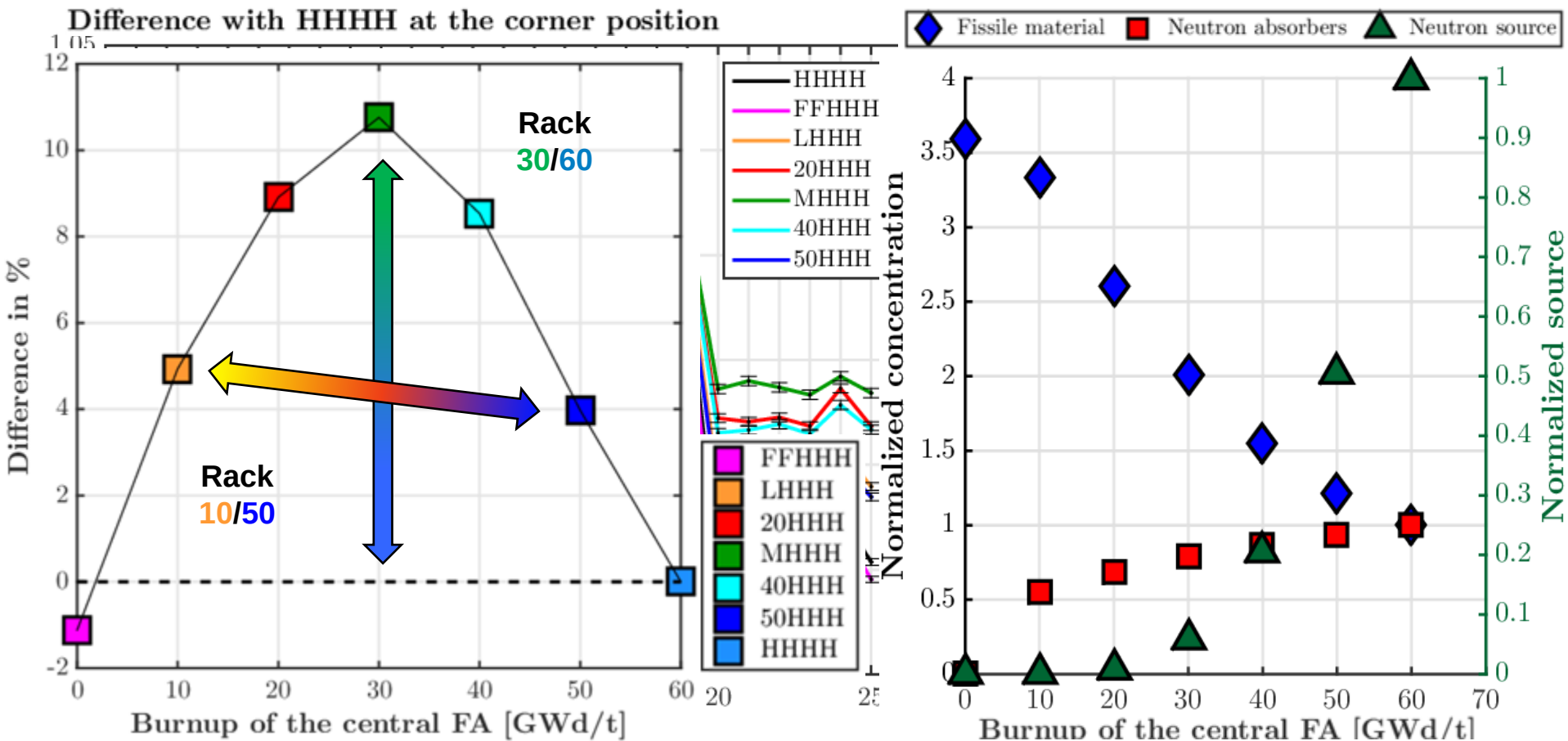
Additional slides: sensitivity to IE, BU, CT

- No sensitivity to **cooling time**



Additional slides: effect of the central FA

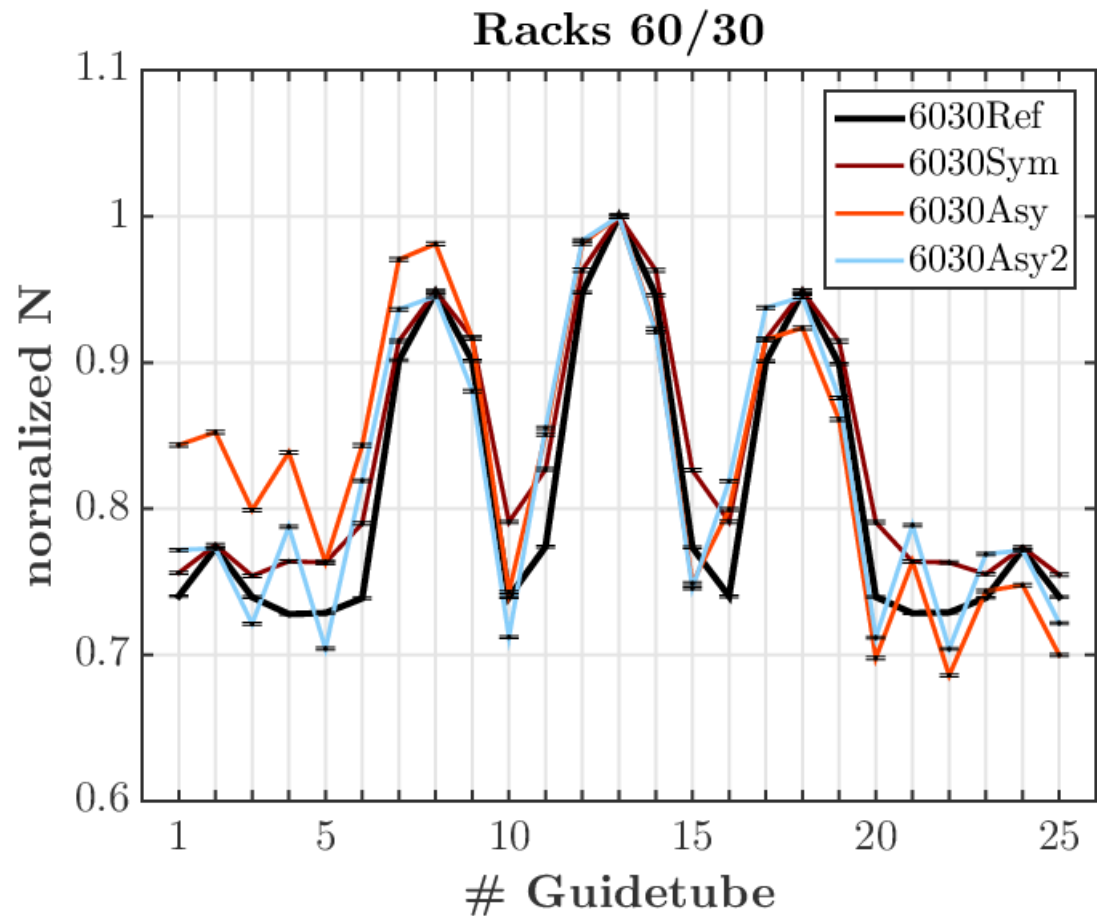
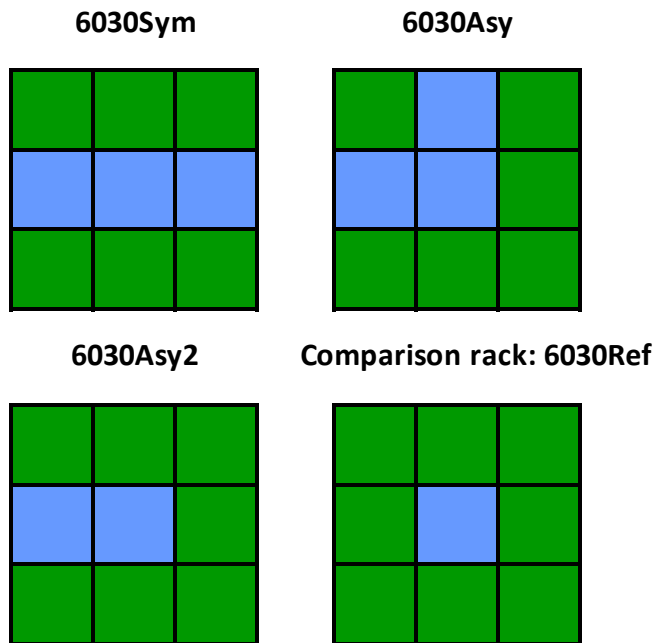
- BU variations in the central fuel assembly



Additional slides: effect of the lateral FA

- BU variations in lateral assemblies

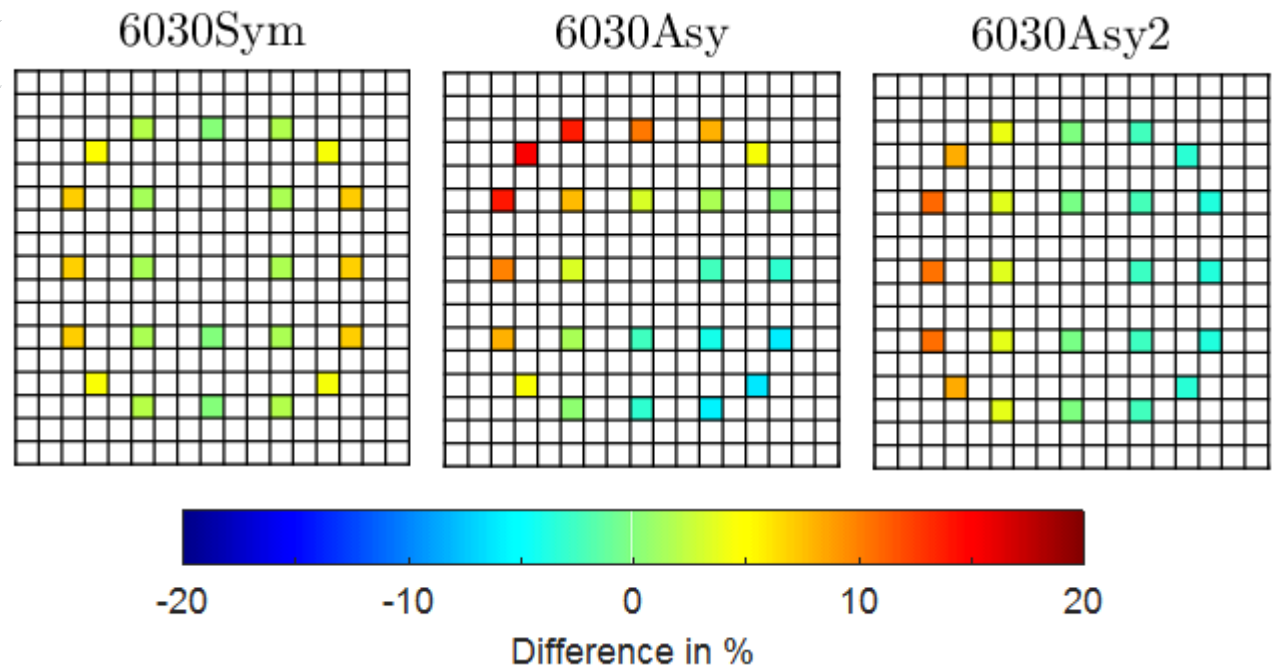
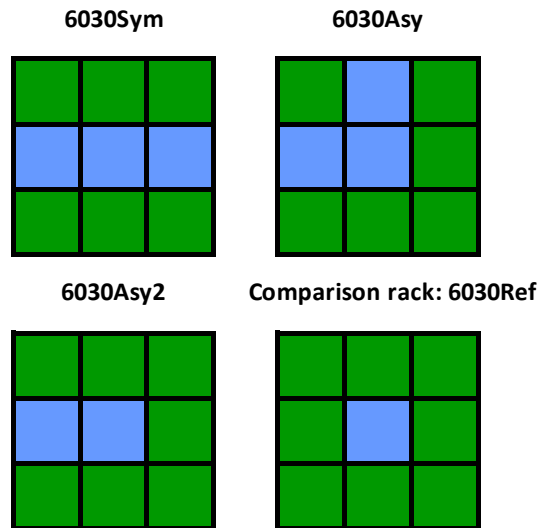
- Racks **60/30**



Additional slides: effect of the lateral FA

- BU variations in lateral assemblies

- Racks **60/30**



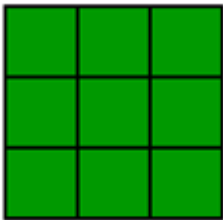
All the uncertainties are less than 0,2%.

Additional slides effect of the corner FA

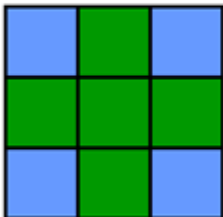
- BU variations in corner FA

- Racks **30/60**

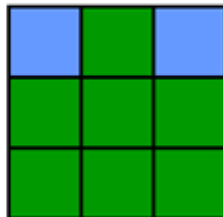
Comparison Rack:
REF350300501



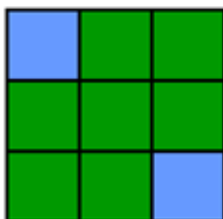
CorN3060Sym



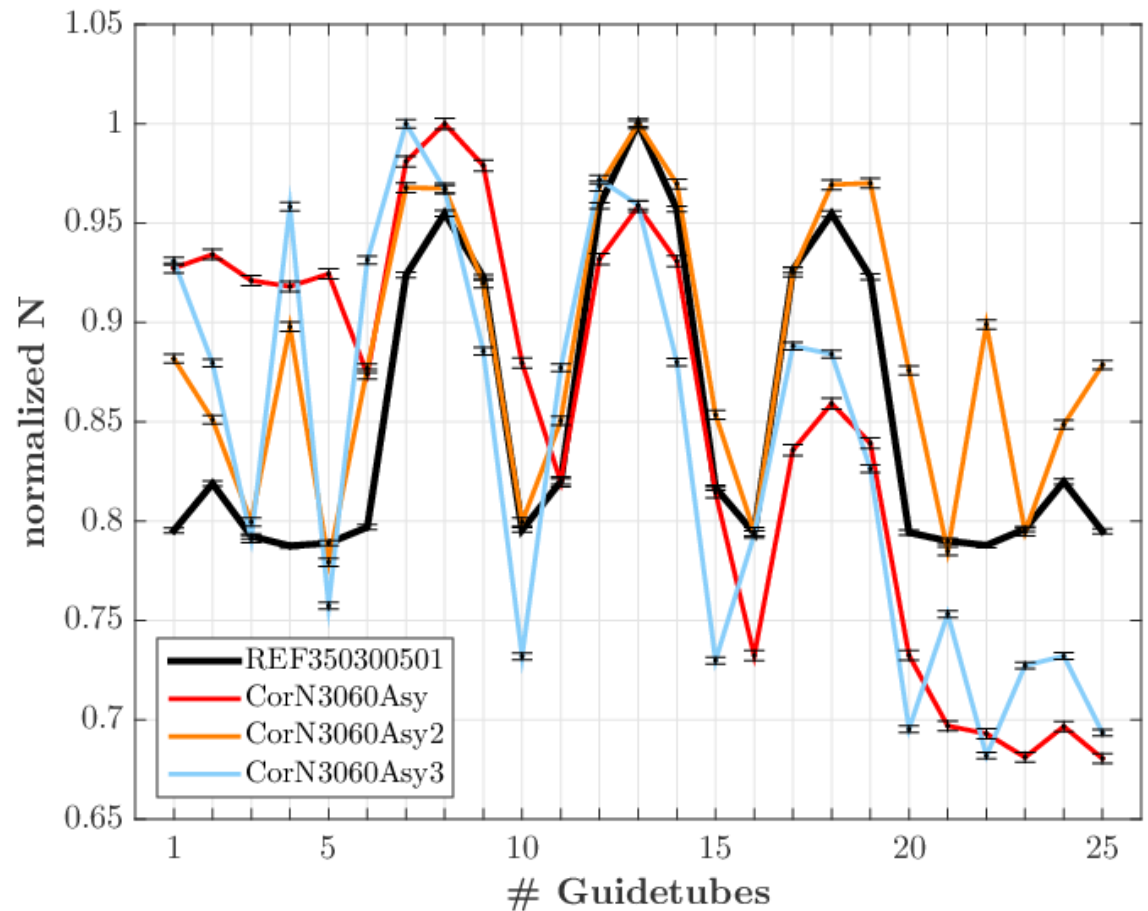
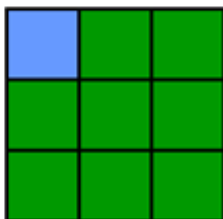
CorN3060Asy



CorN3060Asy2



CorN3060Asy3

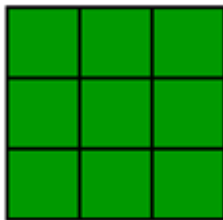


Influence of the spent fuel assemblies in the storage rack: effect of the corner FA

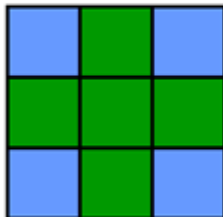
- BU variations in corner FA

- Racks **30/60**

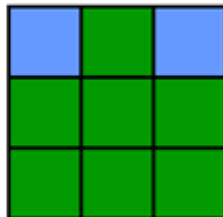
Comparison Rack:
REF350300501



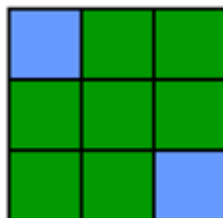
CorN3060Sym



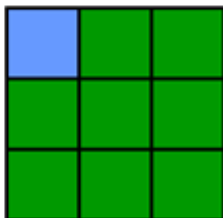
CorN3060Asy



CorN3060Asy2

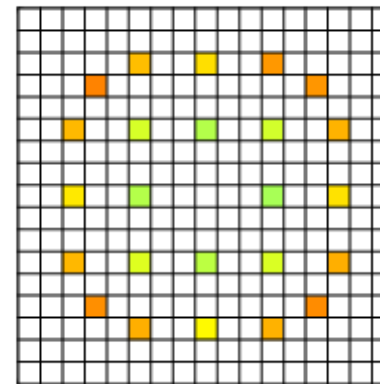


CorN3060Asy3

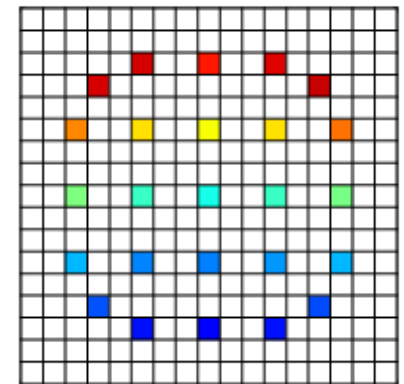


All the uncertainties are less than 0,4%.

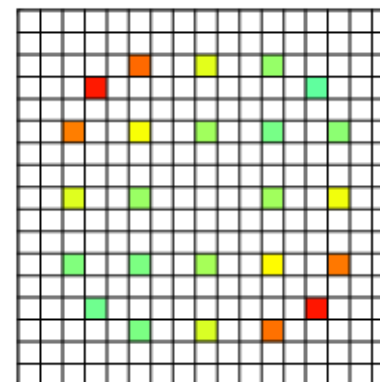
CorN3060Sym



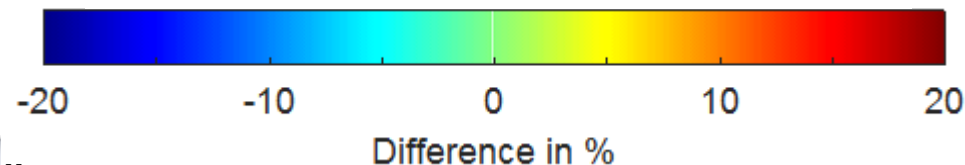
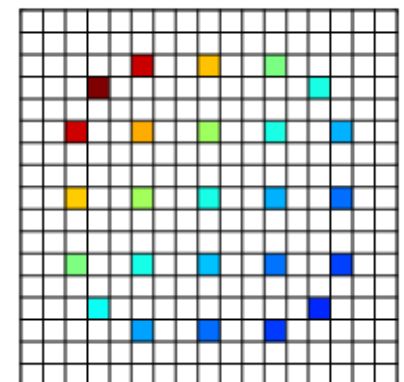
CorN3060Asy



CorN3060Asy2

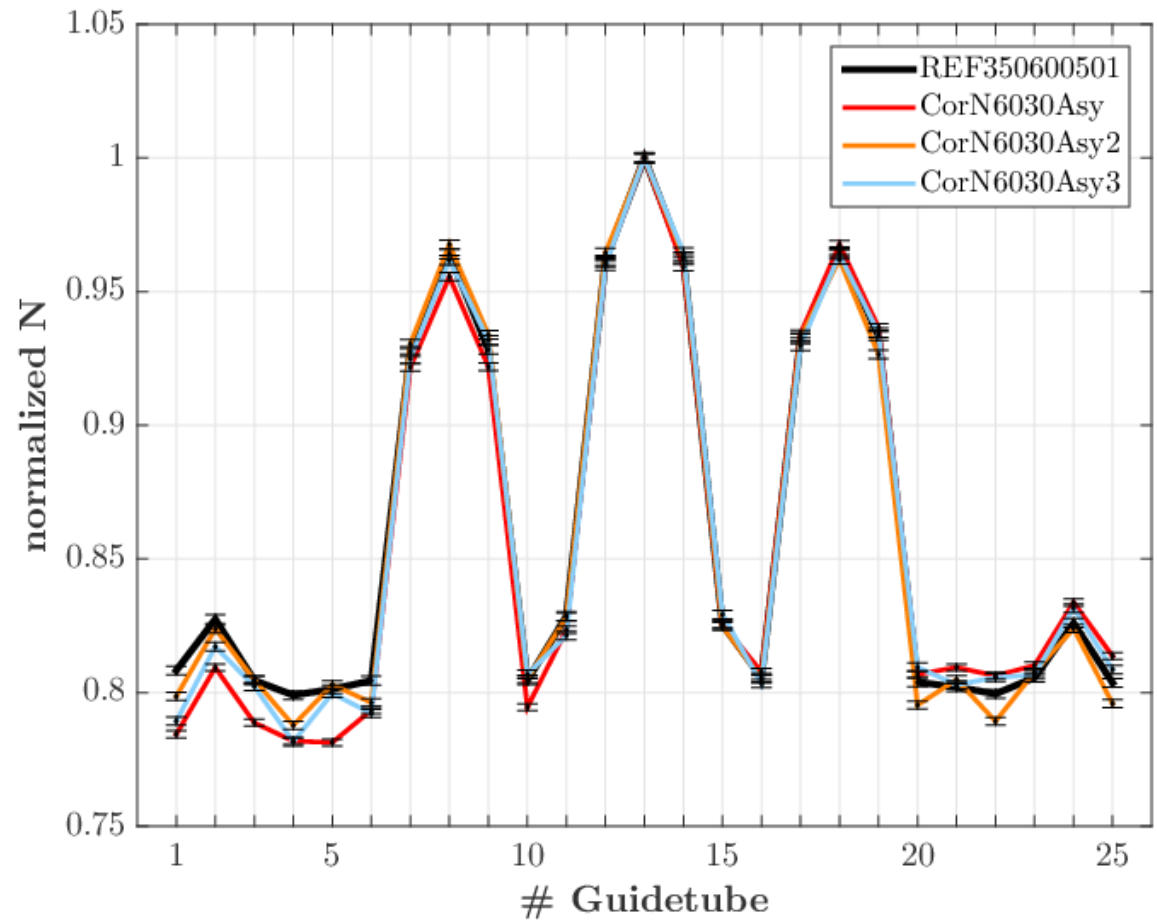
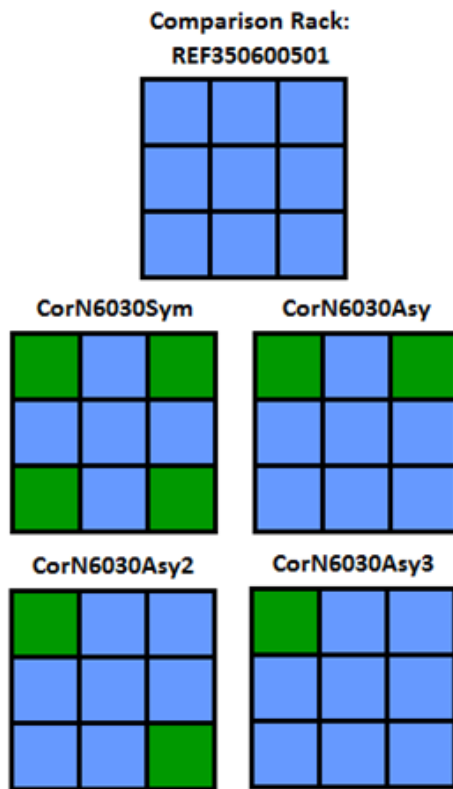


CorN3060Asy3



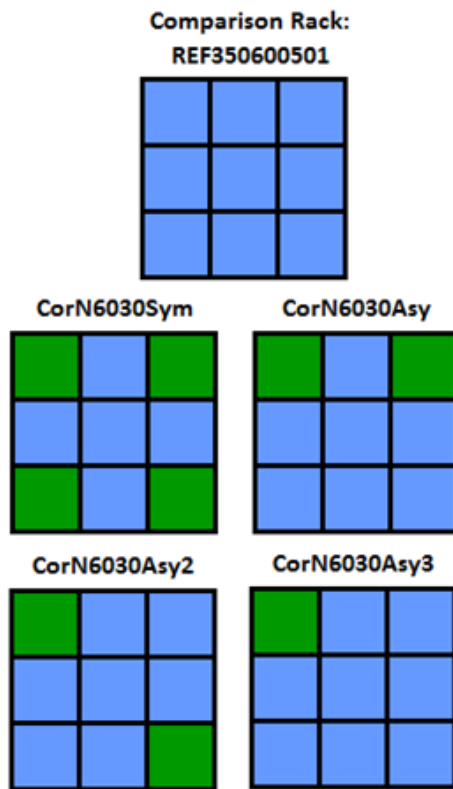
Additional slides effect of the corner FA

- BU variations in corner FA
 - Racks **60/30**

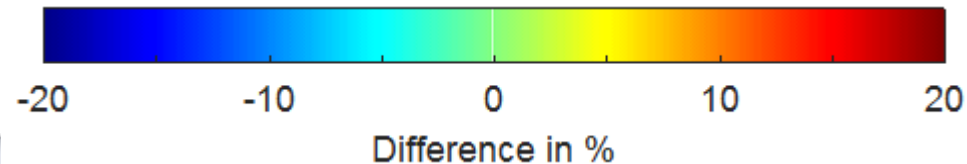
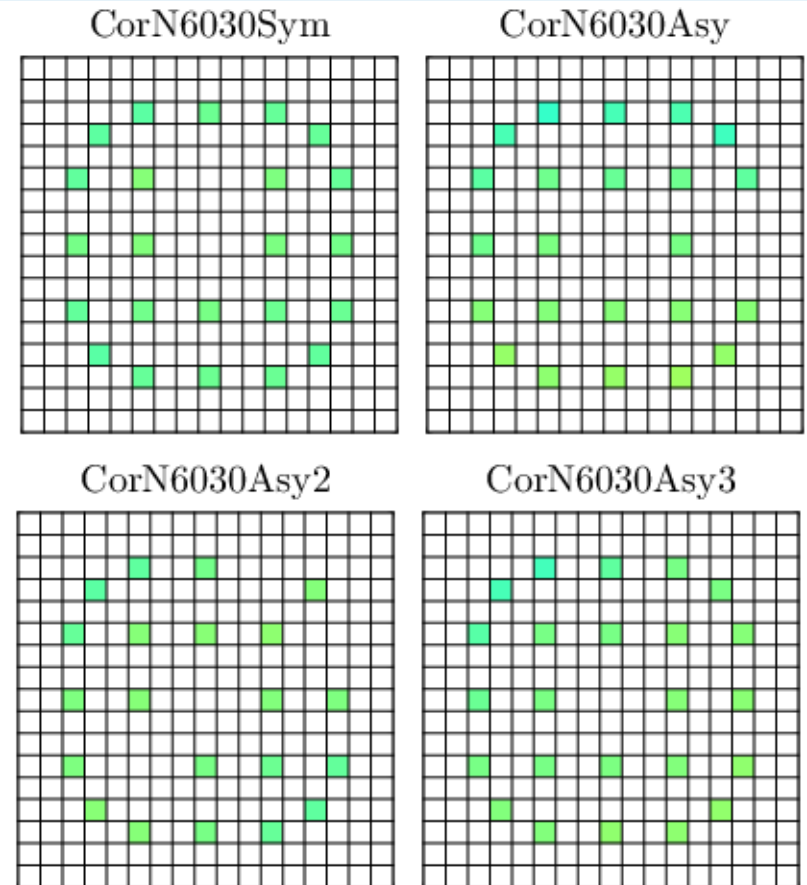


Additional slides : effect of the corner FA

- BU variations in corner FA
 - Racks **60/30**

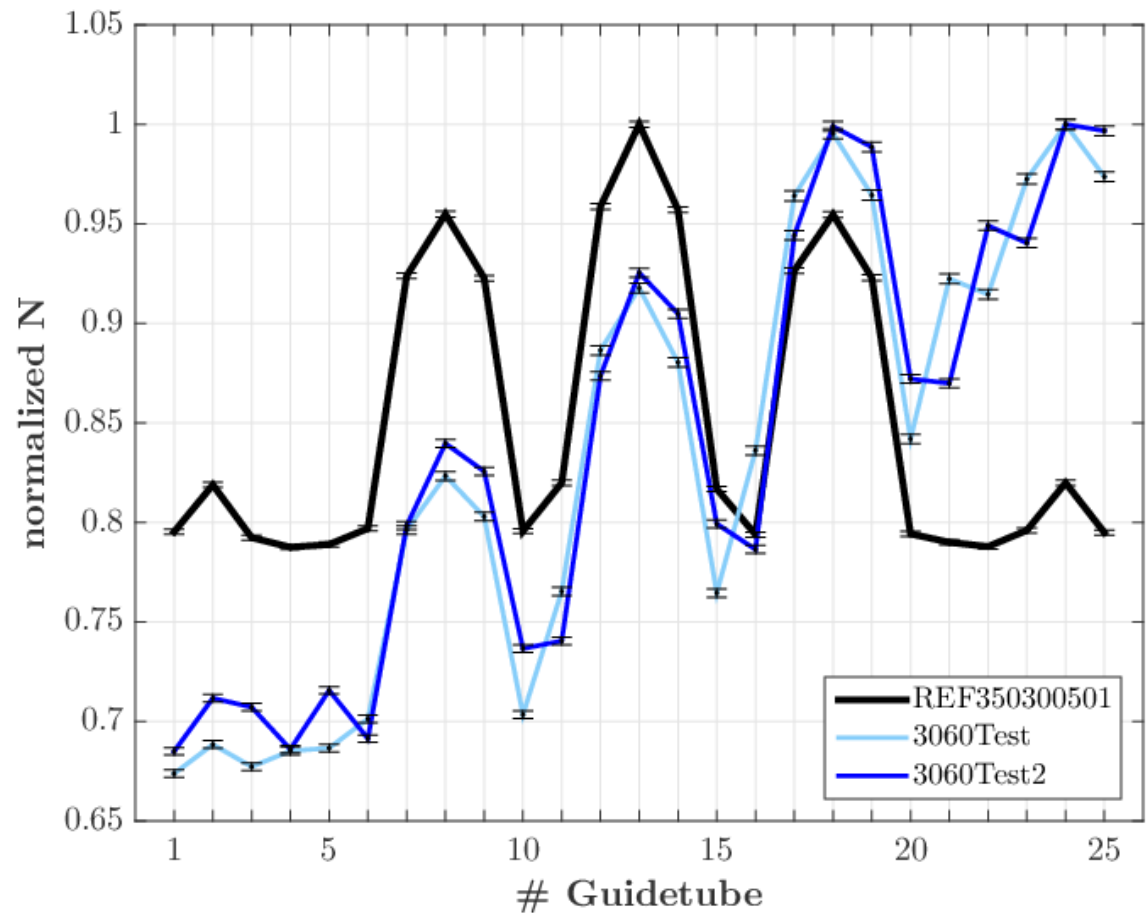
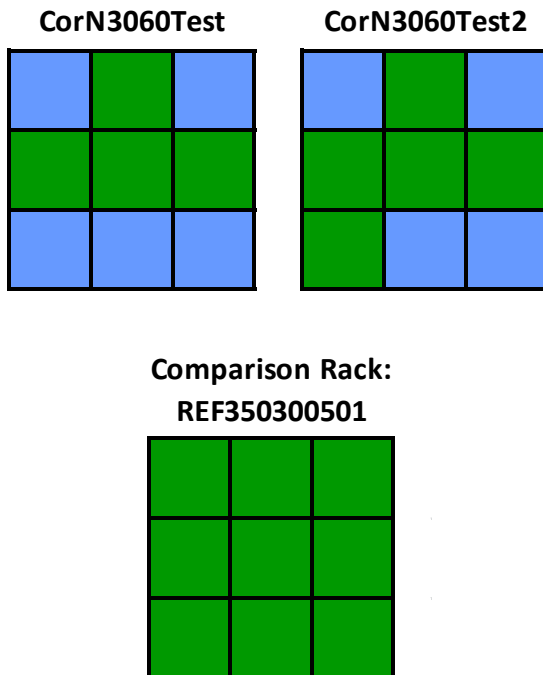


All the uncertainties are less than 0,3%.



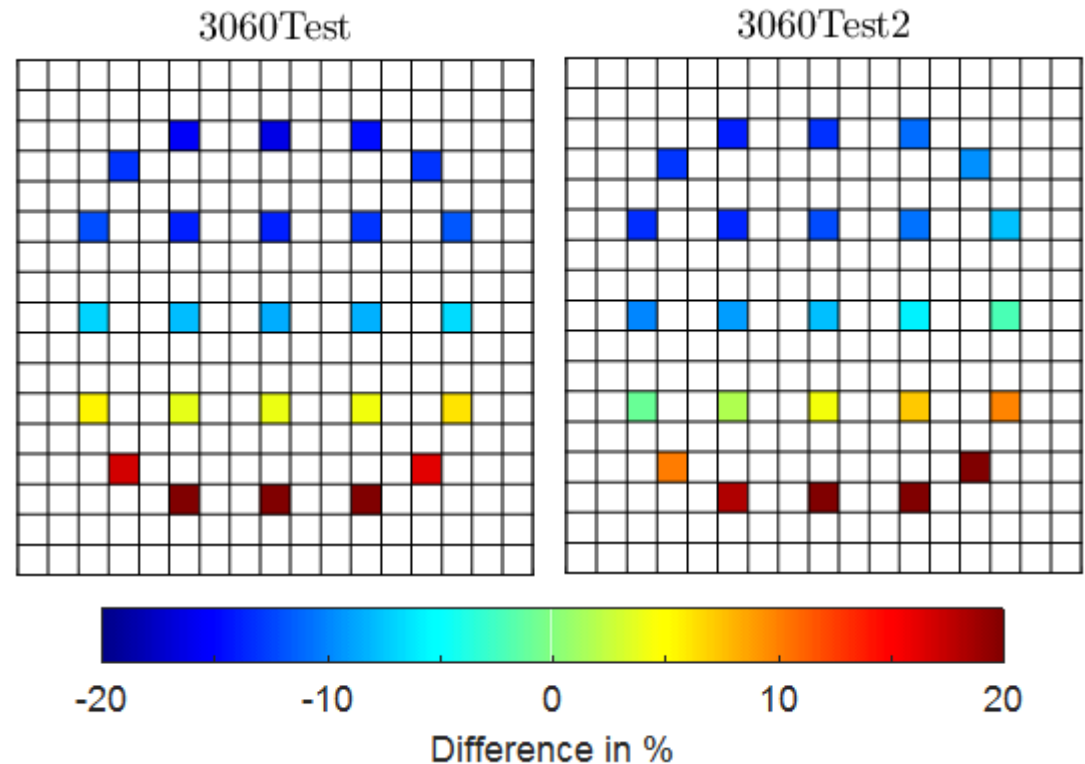
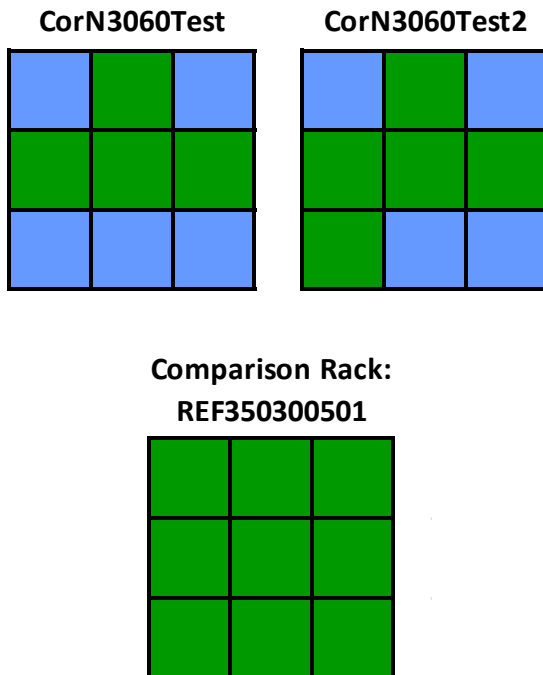
Additional slides generic storage rack pattern

- Test pattern: racks **30/60**



Additional slides: generic storage rack pattern

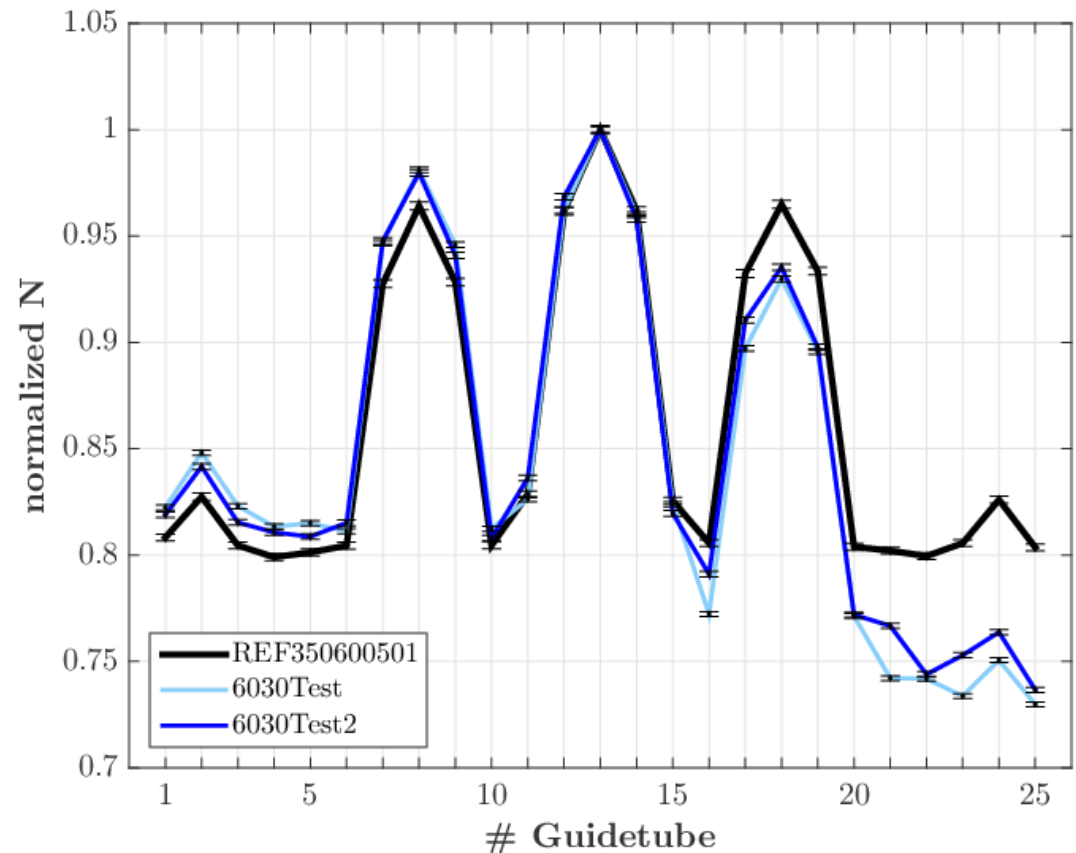
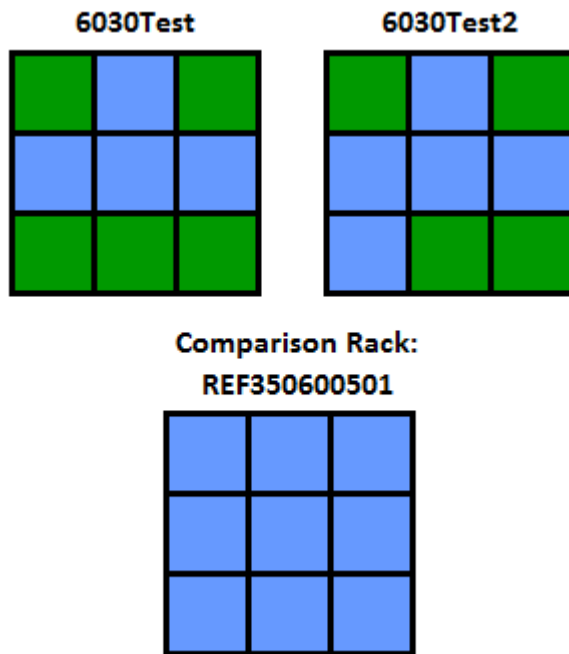
- Test pattern: racks **30/60**



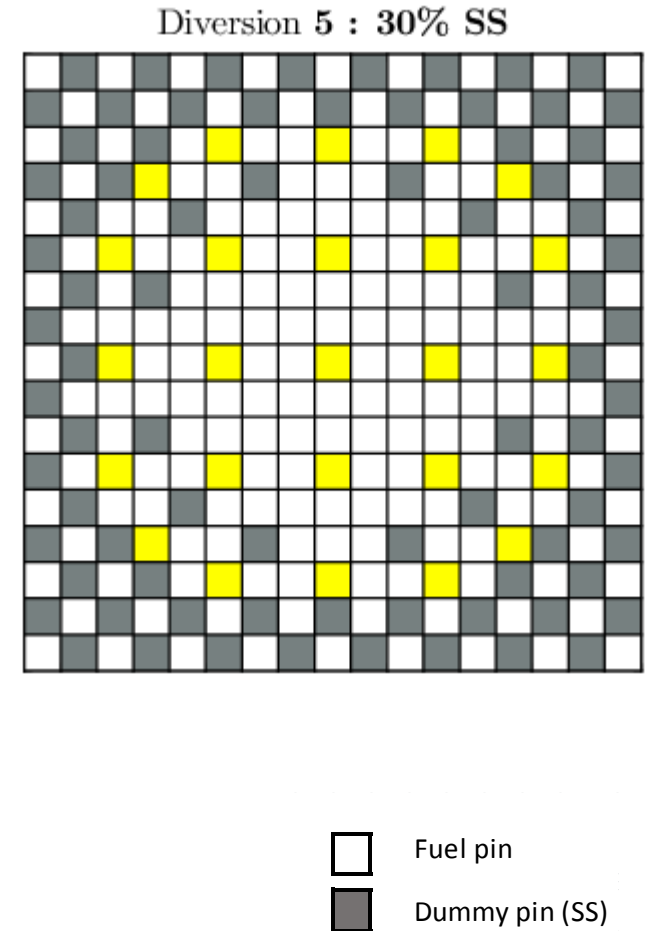
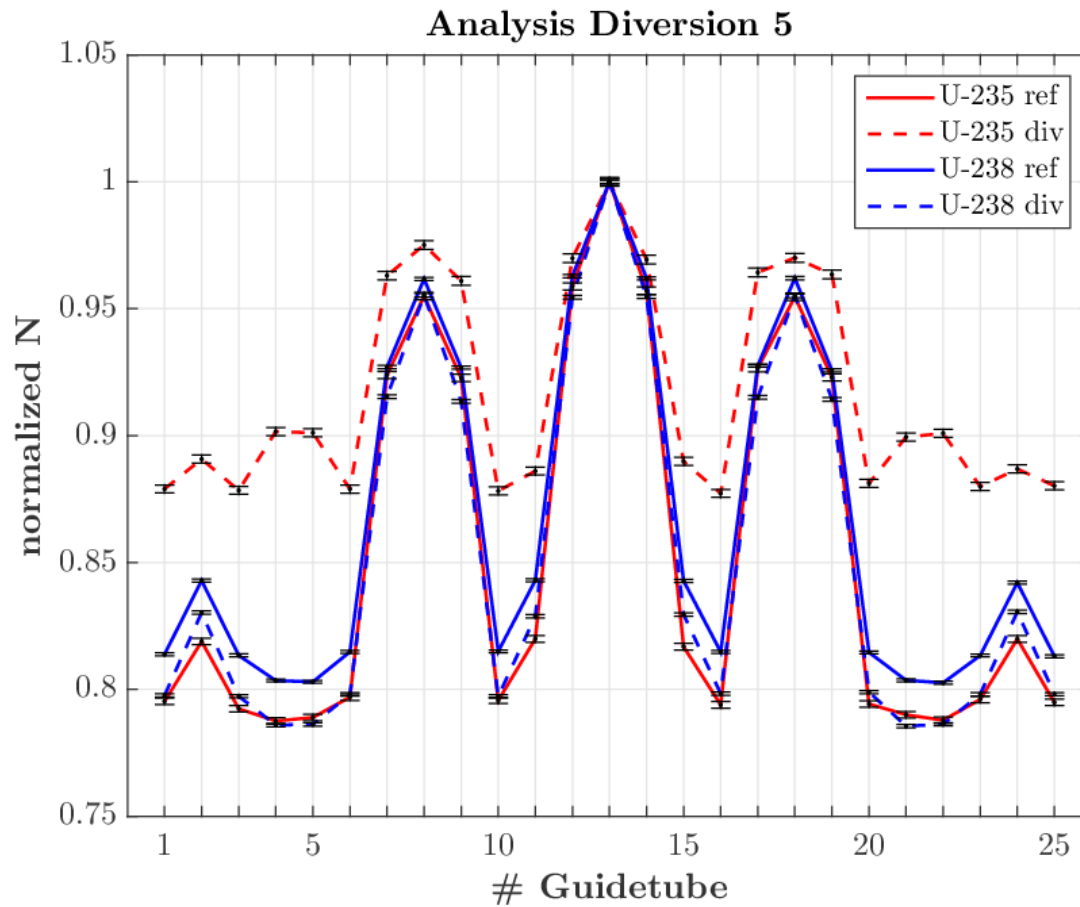
All the uncertainties are less than 0,4%.

Additional slides generic storage rack pattern

- Test pattern: racks **60/30**

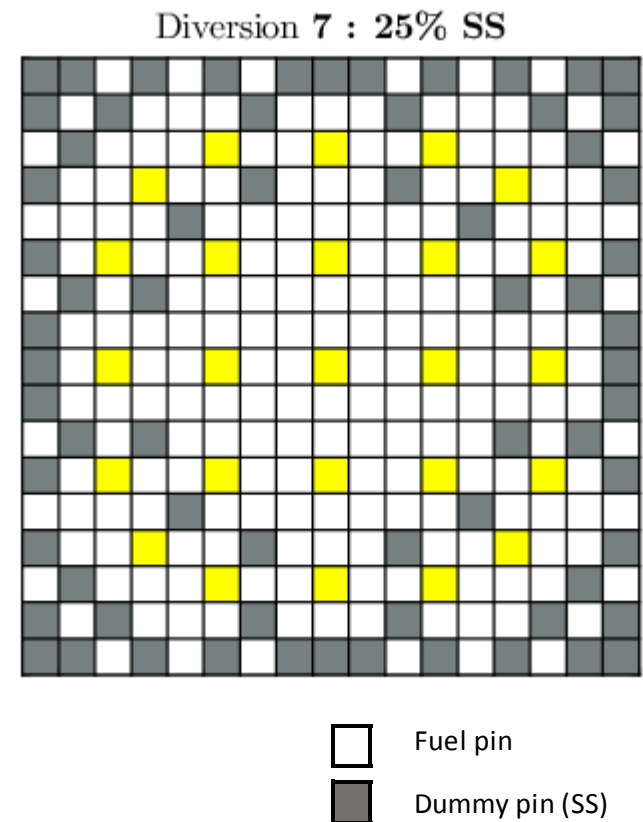
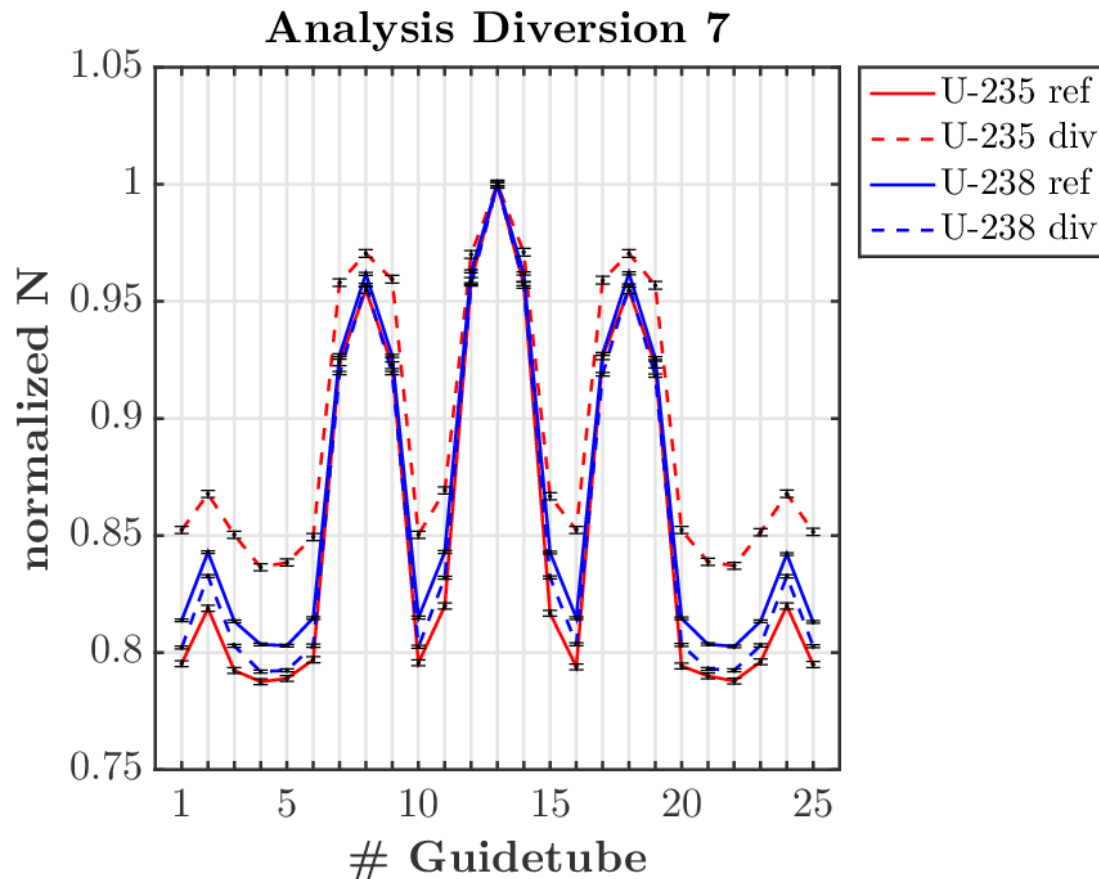


Additional slides: diversion with 30% dummies



Additional slides: diversion with less than 30% dummies

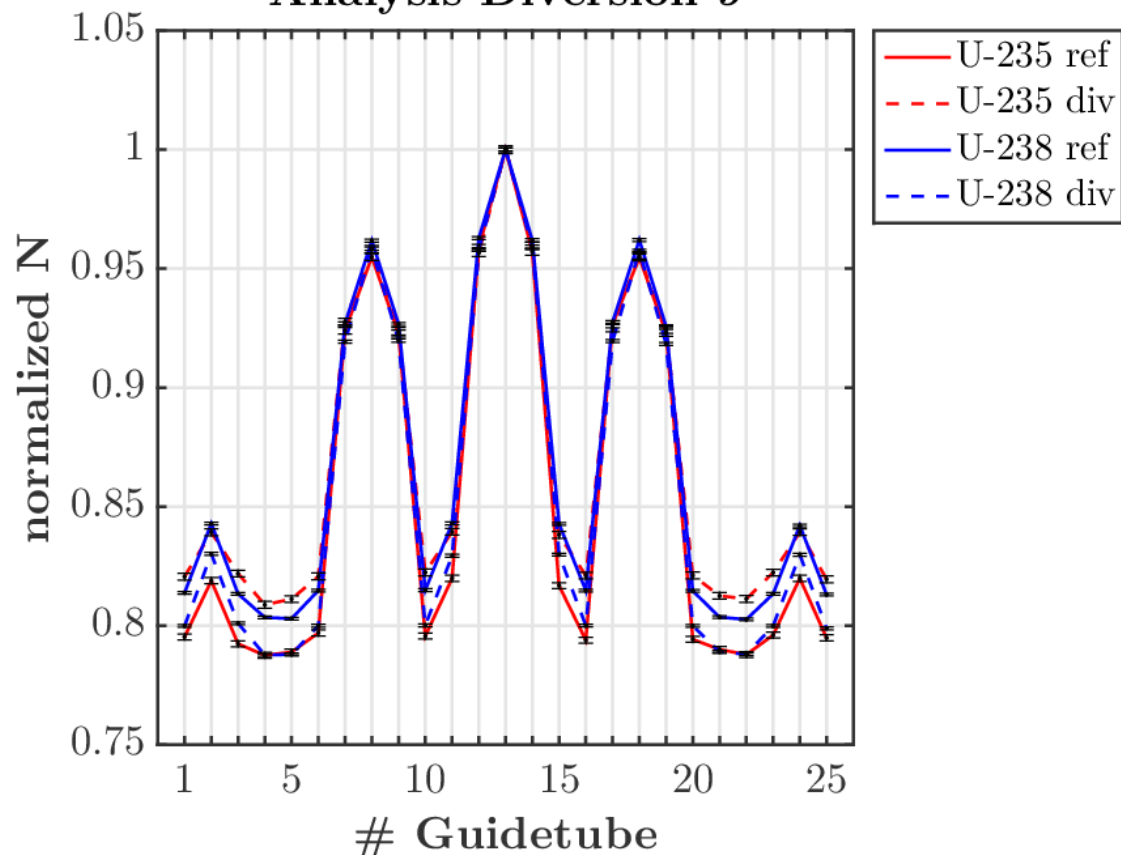
- 25% of fuel pins in SS



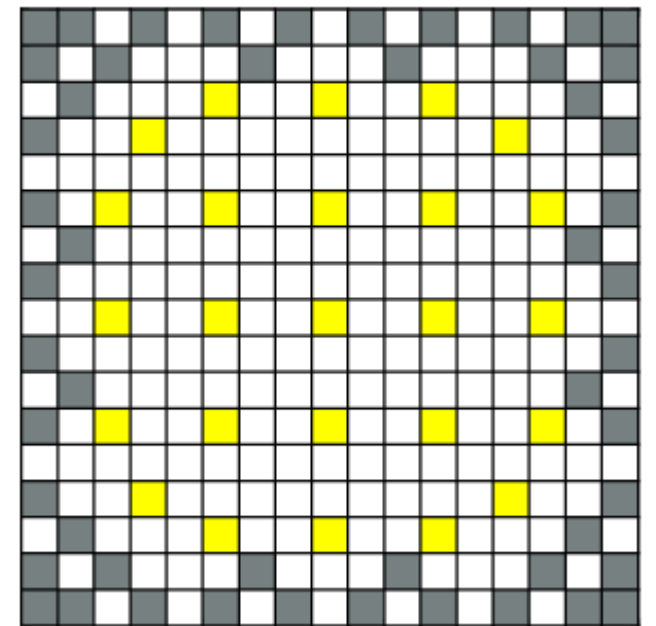
Additional slides: diversion with less than 30% dummies

- 20% of fuel pins in SS

Analysis Diversion 9



Diversion 9 : 20% SS



□ Fuel pin
■ Dummy pin (SS)

Additional slides: diversion with less than 30% dummies

- 15% of fuel pins in SS

