Experimental data for **neutron transport & depletion** code validation

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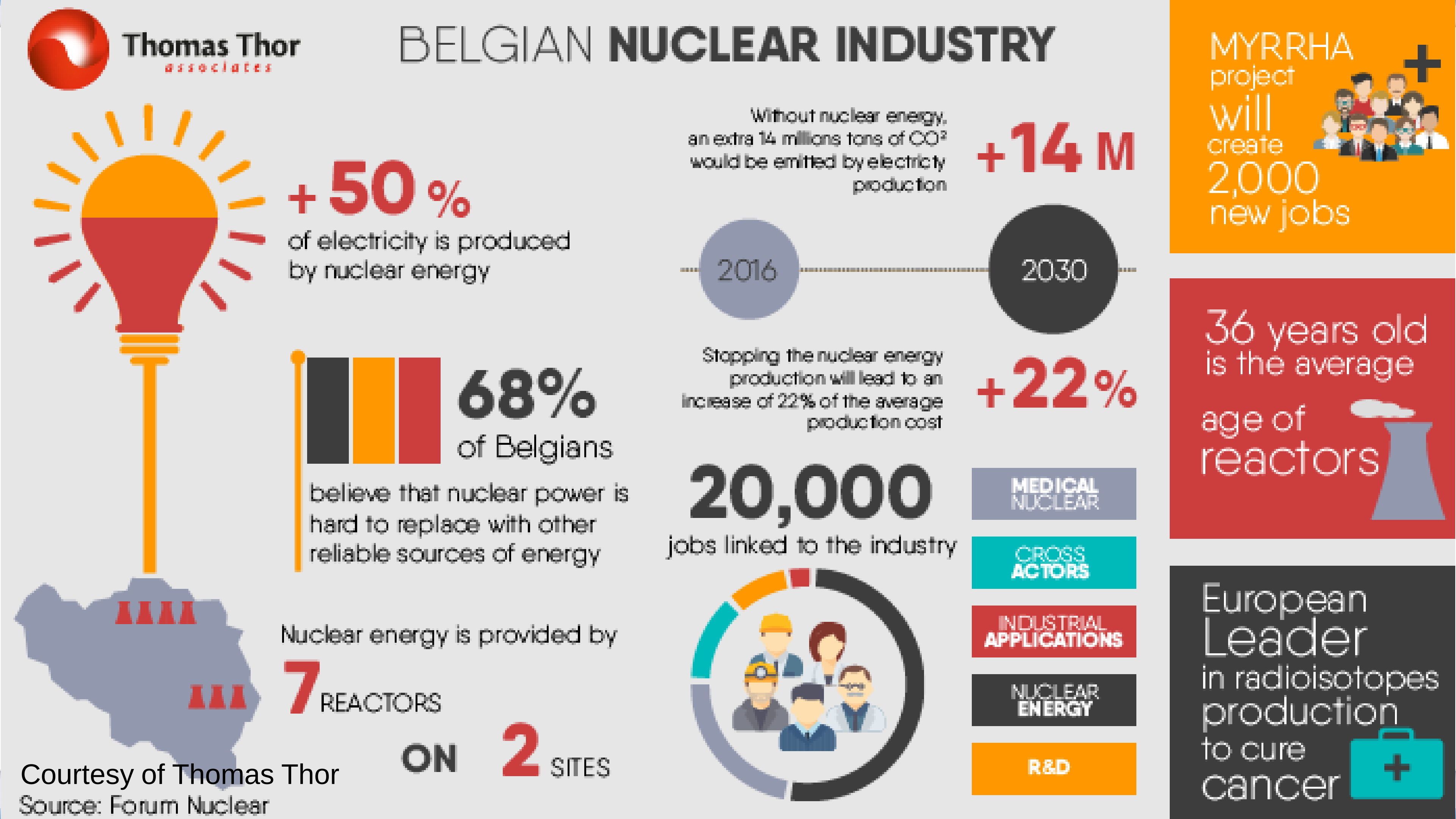
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE



Courtesy of Thomas Thor
Source: Forum Nuclear

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Belgian Nuclear Research Centre

- ## History
  - 1952: Gathers nuclear research & technology development in Belgium
  - > 60 years later: international player in nuclear R&D
    - 700 staff, >50% academic degree + 70 PhD students
    - 2017: ICERR certificate from AIEA
- ## Missions
  - 3 major **scientific research** areas
    - Nuclear materials sciences
    - Advanced nuclear systems
    - Environment, health and safety
  - **Services** towards industry, healthcare, government
  - **Education and training**

Unique infrastructure

- Research reactors
  - BR2: High Flux MTR – produces 25% of ^{99}Mo/^{99}Tc worldwide!
  - BR1: Activation studies / training
  - Venus: low power facility
  - Myrrha (in the future): ADS concept
    - Start with high current proton accelerator

- Nuclear laboratories
  - Hot cells: nuclear material science
  - Radiochemistry: renown laboratory for composition analysis
  - Animalarium: biology studies
  - Hades: underground lab for waste & disposal

Experimental data for **neutron transport & depletion** code validation

- Context
- REGAL
- SCALE analysis
- Perspectives

Context: Scarcity of (open!) depletion data

Context

REGAL

SCALE

Perspectives

- Gd rods
  - Low burnup
- Well-characterized conventional fuels
  - Detailed databooks
  - Follow design evolution

Flavour of past international programmes

A ctinide
R esearch
I n
A
N uclear
E lement

Radiochemical Analysis of
M OX
A nd UOX
L WR Fuels
I rradiated to High
Bu rnup

ARIANE
Fuel characteristics

EOI: 1992 to 1997

Reactor	Name	Fuel type	Enrichment (/ Pu content)	Burnup, GWd/t_{HM}	# of samples
PWR	Goesgen	UO_2	3.4–4.1%	30 – 56	4
PWR	Beznau	MOX	5.9 % Pu	50 – 60	6
BWR	Dode-waard	UO_2	4.9%	50	1
BWR	Dode-waard	MOX	6.4% Pu	50 – 60	4

- Laboratories
  - **ITU**
    - ICP-MS, TIMS
  - **PSI**
    - ICP-MS
    - γ- spectrometry
    - SIMS
  - **SCK•CEN**
    - TIMS, ICP-MS
    - A-, β-, γ- spectrometry

Base actinides

^{232}U , ^{234}U , ^{235}U , ^{236}U , ^{238}U

^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu

Minor actinides

^{237}Np

^{241}Am, ^{242m}Am, ^{243}Am

^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm

Fission Products

Volatile: ^{129}I , ^{133}Cs, ^{134}Cs, ^{135}Cs, ^{137}Cs

Metallic: ^{99}Tc, ^{90}Sr, ^{95}Mo, ^{101}Ru, ^{106}Ru, ^{103}Rh, ^{109}Ag, ^{125}Sb

Lanthanides: ^{144}Ce

^{142}Nd, ^{143}Nd, ^{144}Nd, ^{145}Nd, ^{146}Nd, ^{148}Nd, ^{150}Nd

^{147}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm

^{153}Eu, ^{154}Eu, ^{155}Eu

^{147}Pm, ^{155}Gd

MALIBU
Fuel characteristics

Reactor	Name	Fuel type	Enrichment (/ Pu content)	Burnup, GWd/t_{HM}	# of samples
PWR	Goesgen	UO_2	X%	45 - 70	2
PWR	Goesgen	MOX	X%	69	1
PWR	Ringhals	UO_2	3.7%	62 – 68	2
BWR	Gundrem-mingen	MOX	X%	50 - 81	3
BWR	Leibstadt	UO_2	3.9%	56 – 63	3

EOI: xxxx to 2005

- Laboratories
  - **CEA**
    - XX
  - **PSI**
    - HPLC-MC-ICP-MS, ICP-MS
    - γ- spectrometry
  - **SCK•CEN**
    - TIMS, ICP-MS
    - α-, γ- spectrometry
  - **Studsvik**
    - DRC-ICP-MS, HPLC-MC-ICP-MS, ICP-MS
    - α-, γ- spectrometry

Base actinides

^{234}U , ^{235}U , ^{236}U , ^{238}U

^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu

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^{142}Nd, ^{143}Nd, ^{144}Nd, ^{145}Nd, ^{146}Nd, ^{148}Nd, ^{150}Nd

^{147}Sm, ^{148}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm, ^{154}Sm

^{151}Eu, ^{153}Eu, ^{154}Eu, ^{155}Eu

Next step

Ariane

Malibu

Purposes

Context

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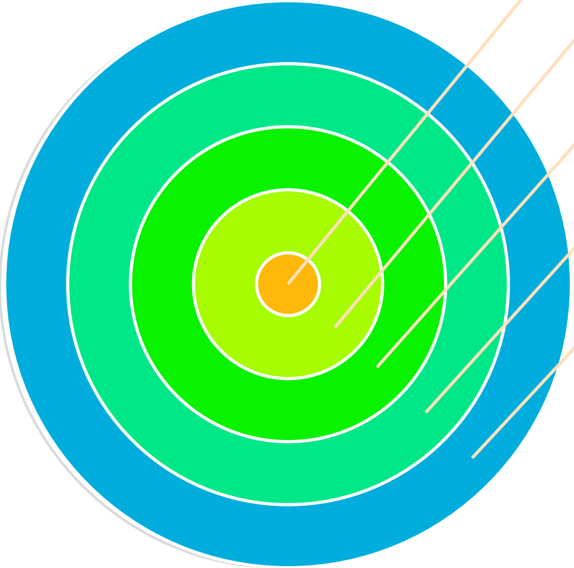

Analytical work (RCA)

+Techniques cross-check

+ Laboratory cross-check

+ Reduction of uncertainties

+Interpretation

= High quality data

Material available

'Databooks'

High duty UO_2 rods | Gado rod

Fabrication data | Irradiation data | Macro-cell data | Thermo-mechanical evaluation

Essential for interpretation of the results!

Internal "exercise" to **check for coherence** !

UO$_2$ fuel rods

- Context
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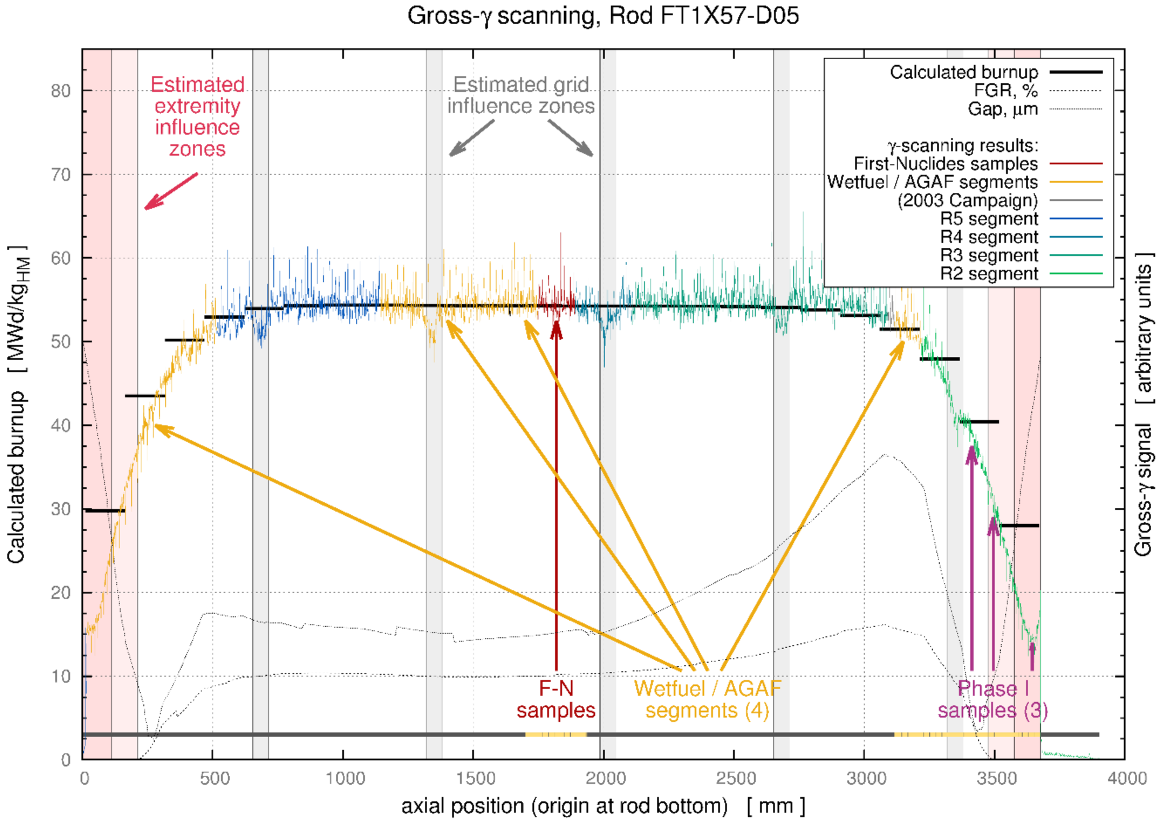

$(U,Gd)O_2$ fuel rod

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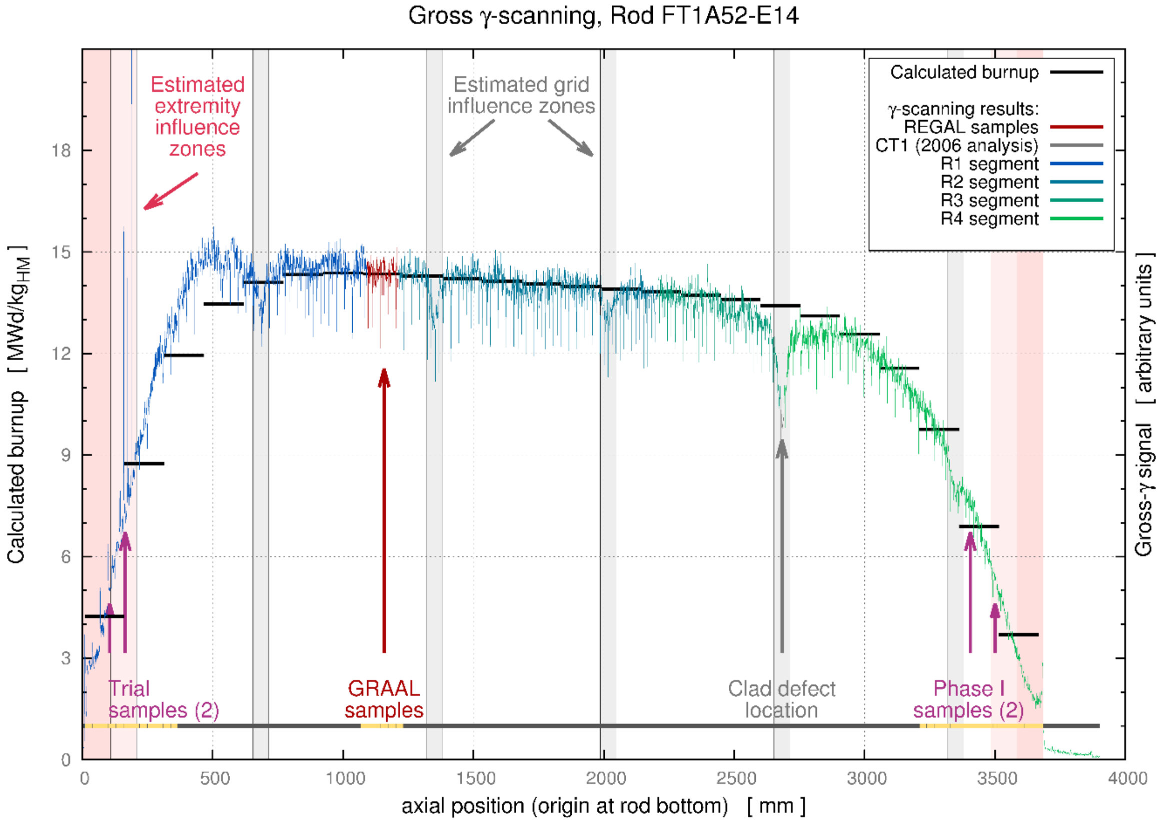

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ReGaL

Comprehensive assessment

- Context
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- Already performed:
  - FGR
  - **RCA**
  - OM
  - **EPMA**
  - Leaching
  - Gas axial communication

- Currently ongoing:
  - **RCA (additional samples)**
  - Leaching (additional samples)

- Foreseen in the near future:
  - **Neutron emission (early 2018)**
  - **Calorimetry (2019)**

Context

REGAL

SCALE analysis

Perspectives

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ReGaL

SCALE Model

- Context
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Triton depletion sequence

Transport: Keno Va module	Origen-S for depletion

Cross-sections

ENDF/B-VII.0	Problem-dependant 238g MC

Discretization

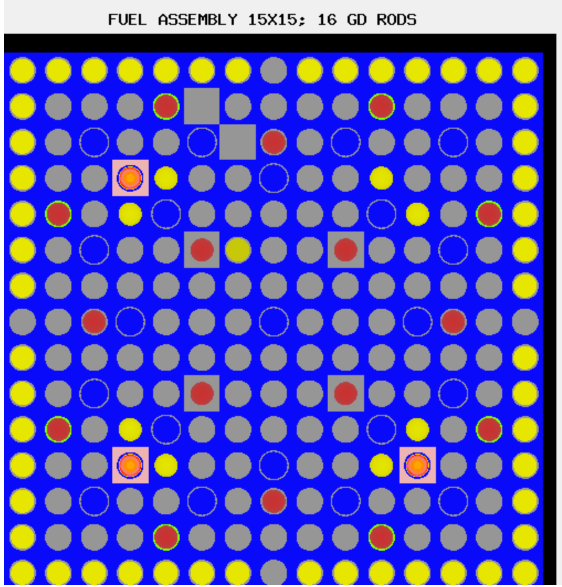
Each rod depleted separately	Gd rod in 16 - 20 radial nodes

Materials / composition

Fuel: nominal values	Water: density & boron

Operator power history

Blind calculations



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Pellet-average C/E
D05 rod (High duty UO_2)

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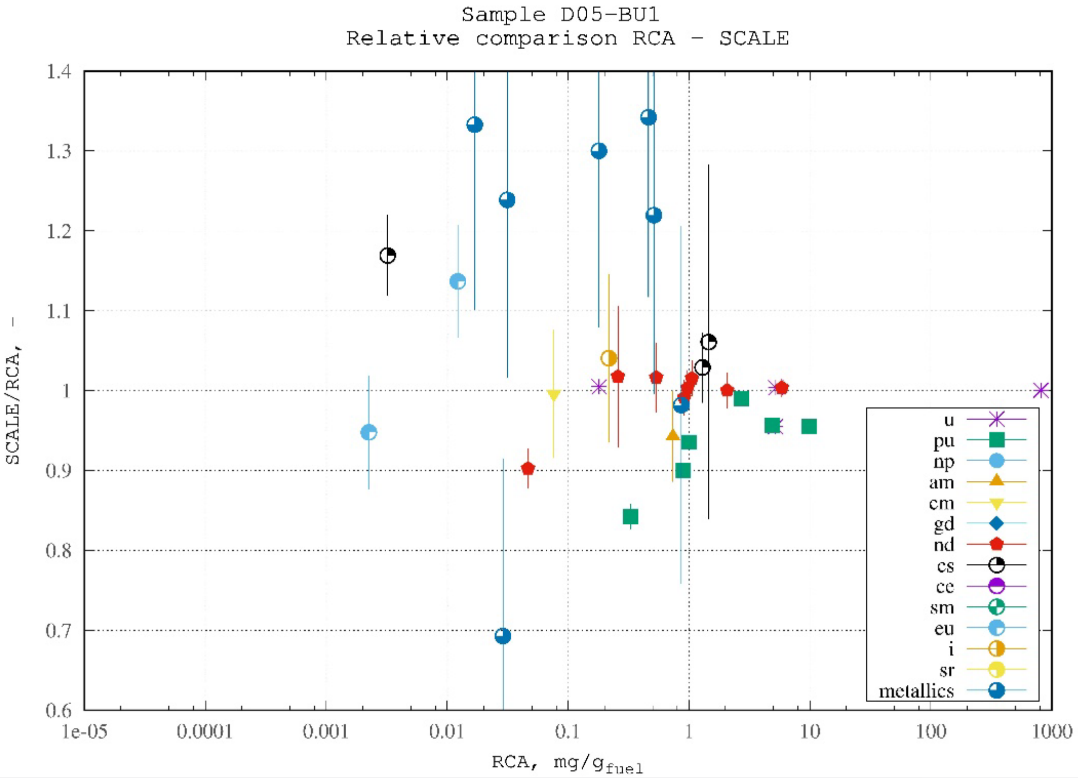

Radial profile
D05 rod (High duty UO_2)

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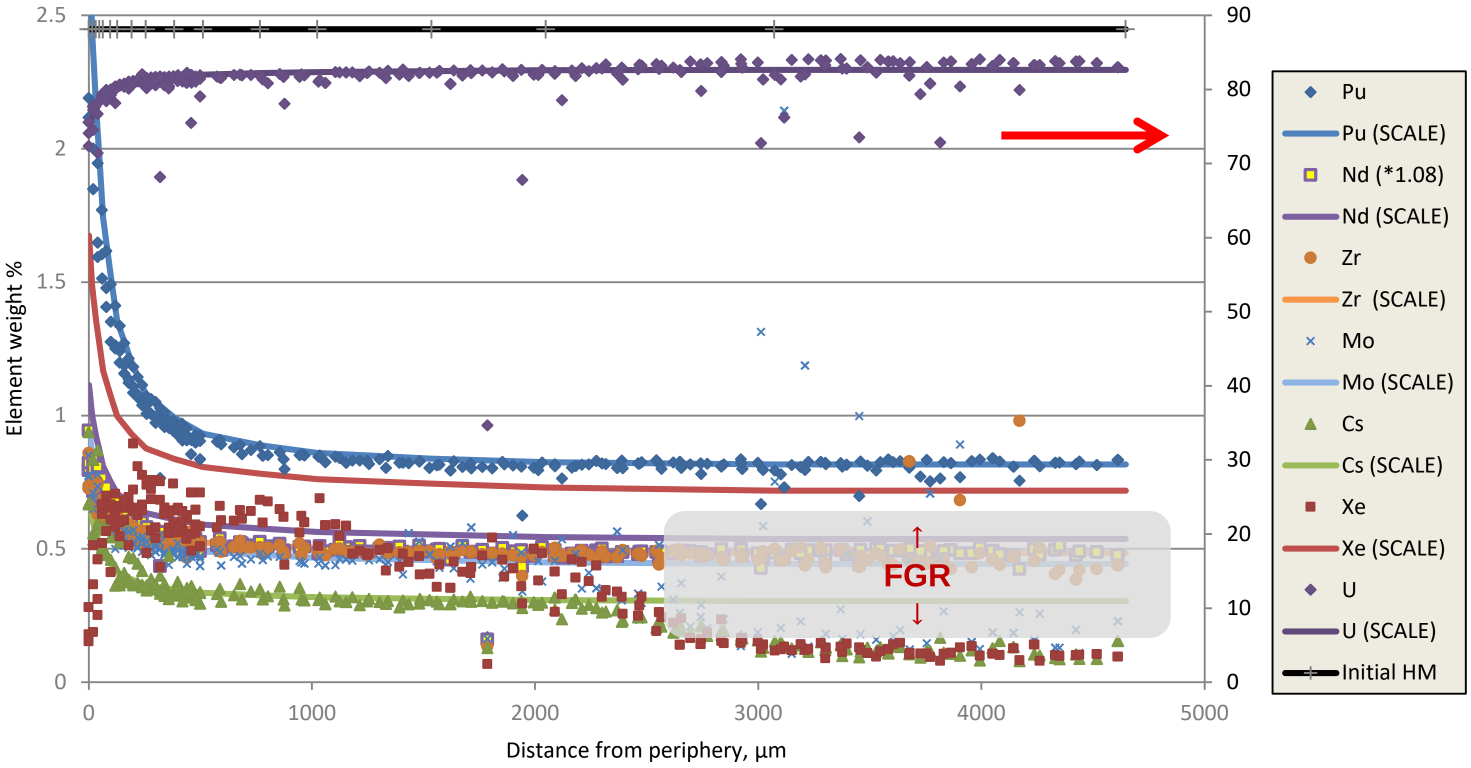

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ReGal

Radial profile
E14 rod (Gado rod)

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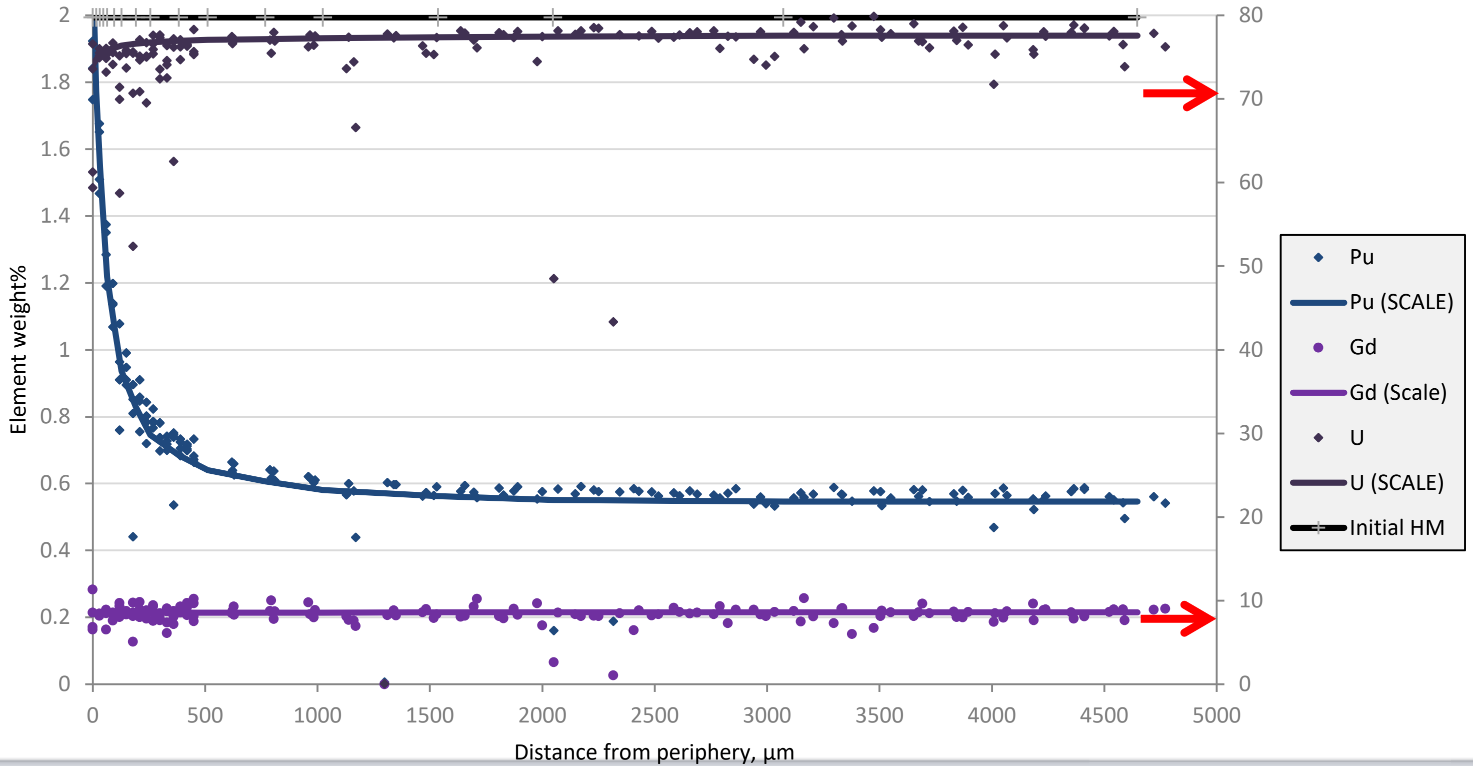

Radial profile
E14 rod (Gado rod)

- Context
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- SCALE
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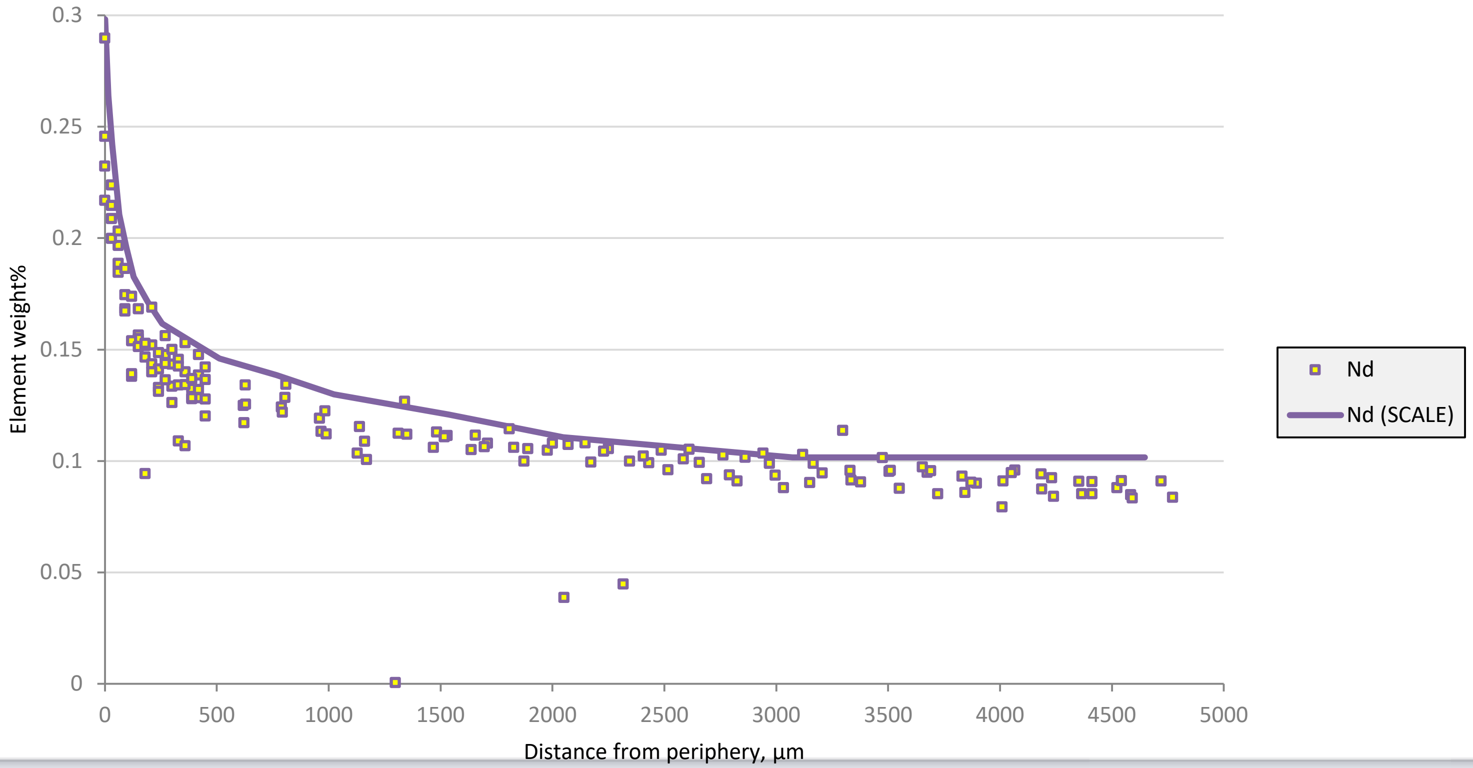

Performance of SCALE versions

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- SCALE 6.1.x
  - 28 ‘regular’ UO_2 rods
  - Meshed rods: 16 rings
    - 2 UO_2 rods
    - 3 Gd rods
  - 4 10^8 neutrons (npg x gen)

9 – 10 h / timestep (25% Σ, 75% transport)

- SCALE 6.2(.1)
  - Memory(?) crash after few timesteps
  - Need to down-size the problem (e.g. 6-2-1 rods)

- SCALE 6.2.2
  - Works fine!

~7h / timestep (5% Σ, 95% transport)

Context

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Code benchmark exercise

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- Gd depletion: challenge for neutron transport / depletion codes
  - Huge resonant capture cross-section
  - Important self-shielding effects
- First code-to-code comparison
  - Some codes fail to reproduce experimental values
  - Vesta: revised procedure to properly address the issue
  - Further assessment after bias reduction
- Open to non-REGAL partners
  - No access to experimental values
  - NDA for other aspects

Experimental data for neutron transport & depletion code validation

Highlights

- High quality characterization of UO_2 and Gado fuel rods
  - Improved RCA procedures for Gd & burnup
- Rods also used in other projects, with possibly publications
  - Comprehensive characterization of a UO_2 fuel pin
- SCALE analysis
  - Encouraging results, good C/E
- Code benchmark exercise for UO_2 and Gado pin was set up
  - Open for external partners

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