INSPYRE
Investigations Supporting MOX Fuel Licensing in ESNII Prototype Reactors

Case study: SUPERFACT Integral Irradiation Experiment
Fuel performance codes in fast reactors

Davide Pizzocri
Politecnico di Milano, Department of Energy, Nuclear Engineering Division, Milano

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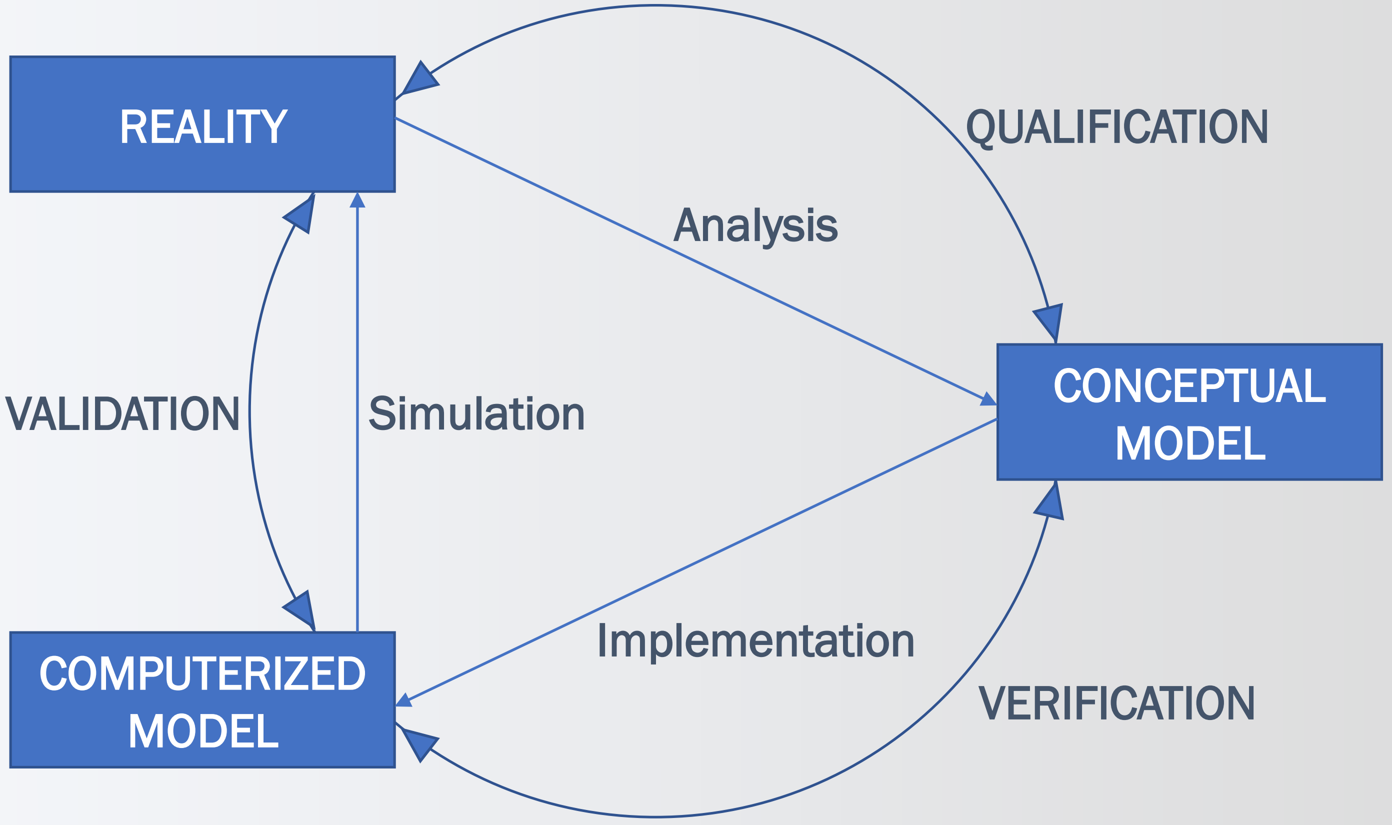
EERA European Energy Research Alliance JPNM JOINT PROGRAMME ON NUCLEAR MATERIALS

Framework: Do you trust scientific codes ?



Oberkampf and Trucano, 2002

Framework: Validation strategy

- A Fuel Performance Code contains a lot of **different models & material properties**!
- This calls for dedicated validation strategies

- STAND-ALONE VALIDATION
  - Each model should be validated on its own, outside of the framework of the fuel performance code
  - This is not always possible, since it requires the availability of separate effect experimental data

- INTEGRAL VALIDATION
  - The fuel performance code results HAVE to be compared with experimental results !
  - Importance of **code-to-code comparison** (benchmark, **w/** or w/o **experimental results**)

- **Importance of Sensitivity Analysis and Uncertainty Analysis !!!**

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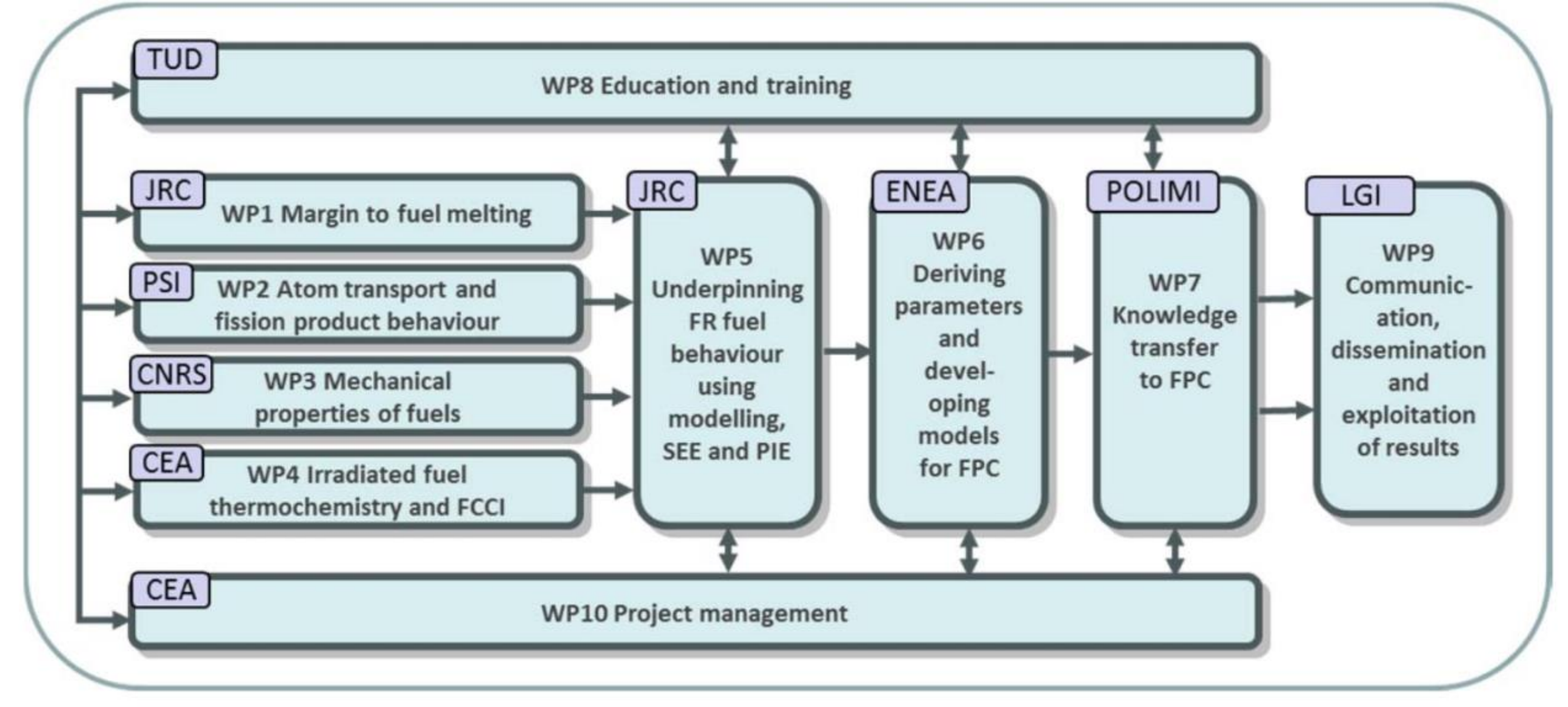
Framework: INSPYRE



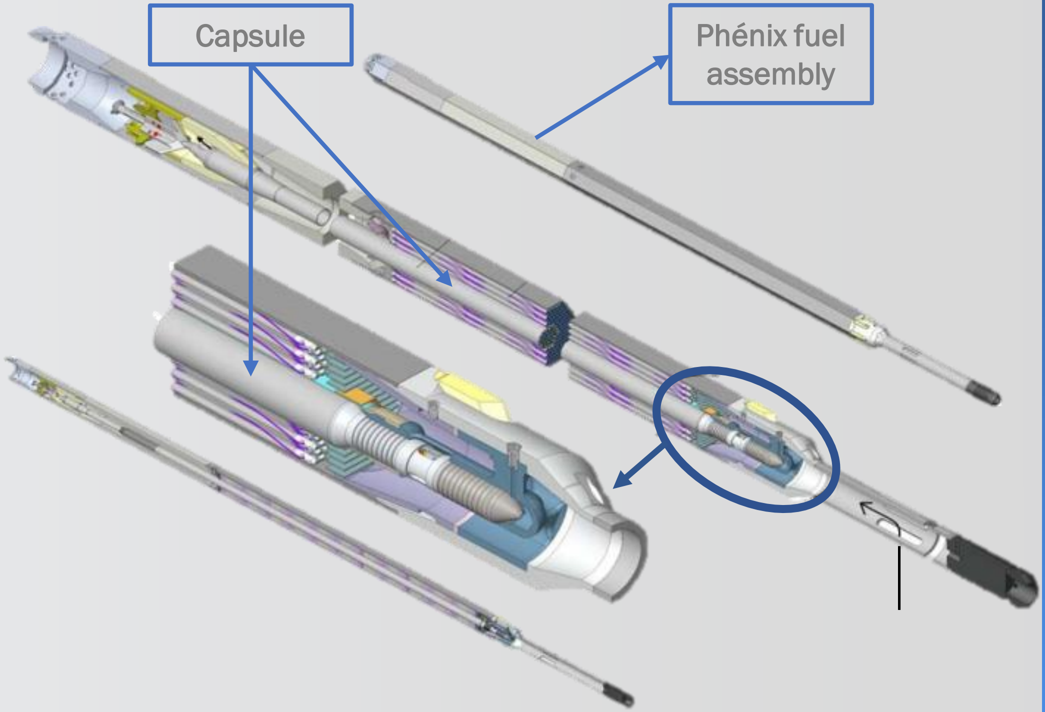
The SUPERFACT irradiation experiment in a nutshell

- Conducted jointly by **CEA** and **JRC-Karlsruhe** between 1984 and 1993.

- Goal: demonstrate technical feasibility of transmutation of M.A. through homogenous (i.e., low content M.A. fuel) and heterogenous concepts (i.e., high M.A. content).

- Irradiation took place in the **Phénix** reactor (Marcoule, France) between the 38th and 42nd cycles (October, 1986 – January, 1988), in a standard capsule containing 19 pins.

- The pins selected from this database are representative of the **homogenous** strategy:
  - **SF6** and **SF13** bearing 2.0 wt.% of ^{237}Np
  - **SF4** and **SF16** bearing 1.8 wt.% of ^{241}Am

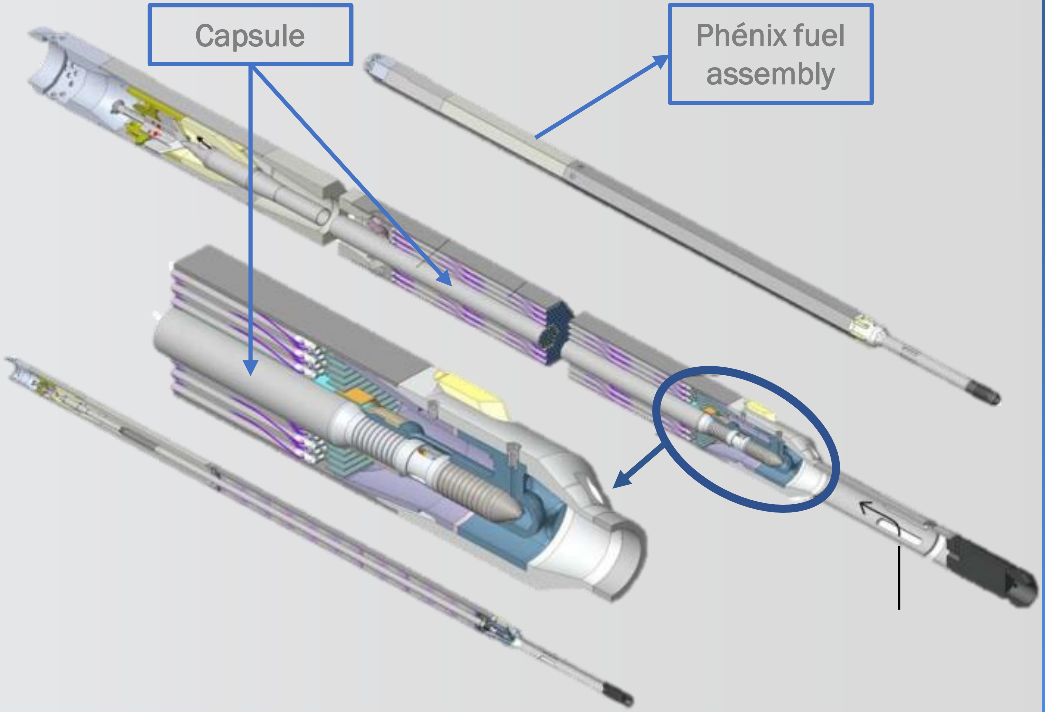


The SUPERFACT irradiation experiment in a nutshell

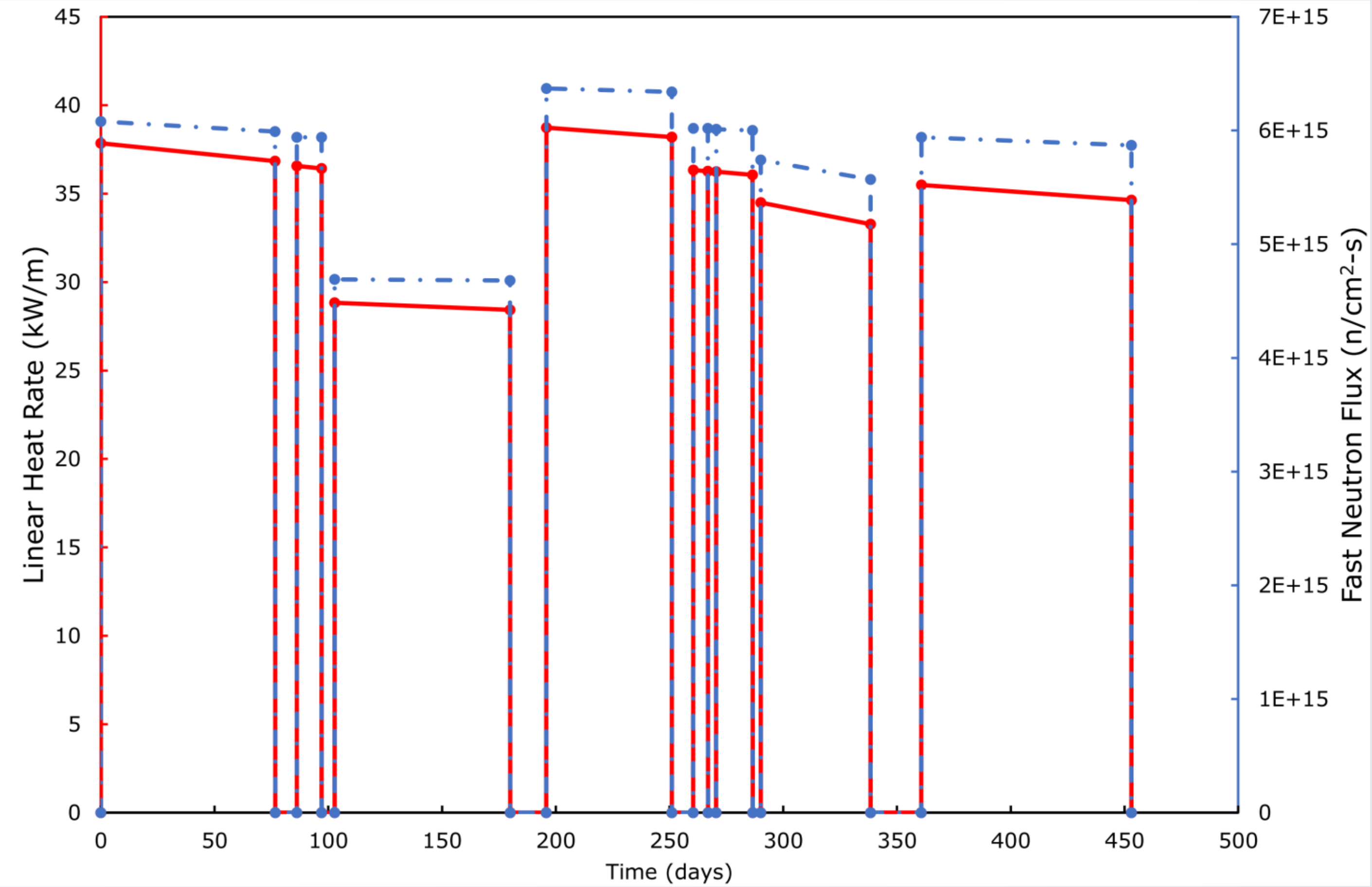
Parameter	SF6 and SF13	SF4 and SF16
Pellet radius (mm)	2.68	2.71
Radial gap (mm)	0.143	0.116
Pellet density (%TD)	97.5	96.3
U[a]/M	0.741	0.745
M.A. / M	**0.02, ^{237}Np**	**0.018, ^{241}Am**
Pu[b]/M	**0.244**	**0.237**
O/M	**1.943**	**1.957**
Fissile column length (mm)	850	850
Cladding material	15-15, Ti stabilized, CW SS	
Cladding thickness (mm)	0.45	0.45
He pressure (MPa)	0.1	0.1

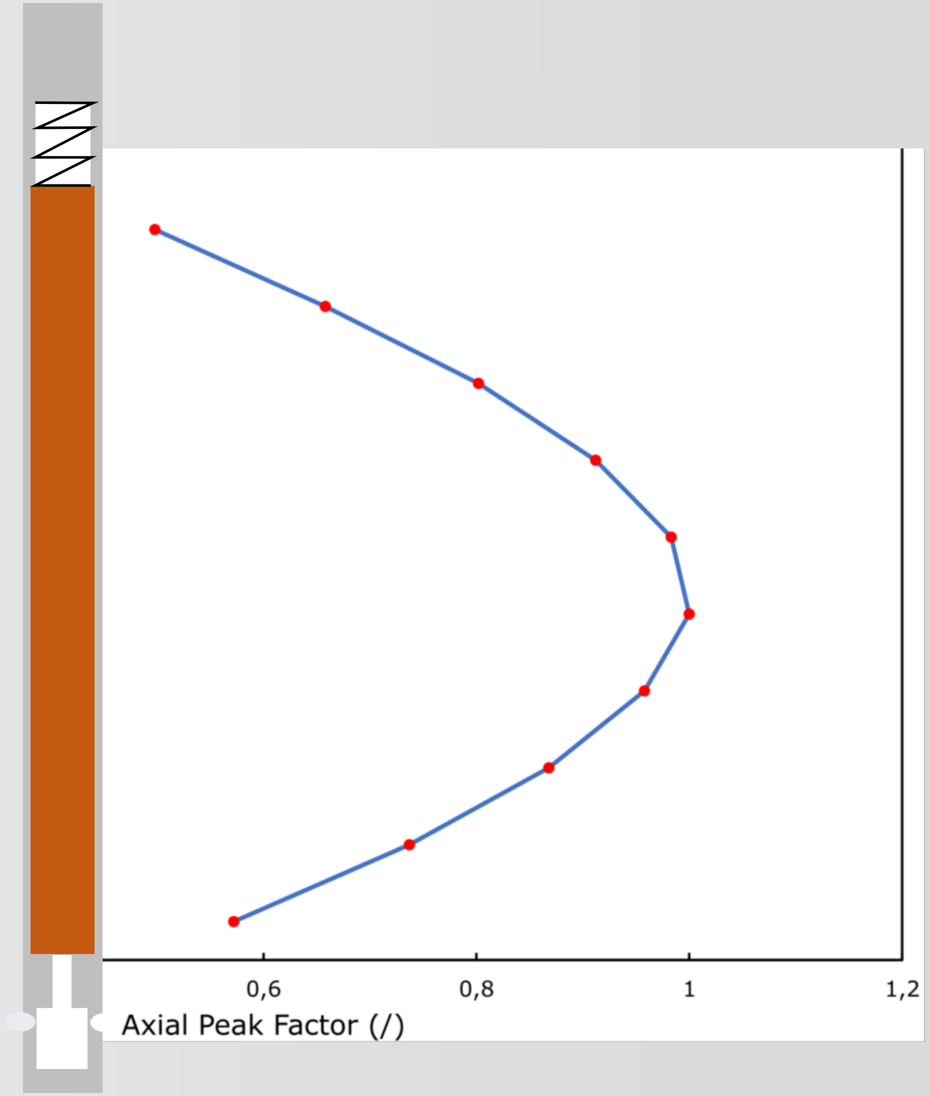
[a] U nat

[b] ^{238}Pu 1.3%, ^{239}Pu 60.4%, ^{240}Pu 23.4%, ^{241}Pu 10.4%, ^{242}Pu 4.5%



Peak LHR vs time and Axial Peaking Factor





SUPERFACT irradiation experiment: The tools

- The SUPERFACT irradiation experiment has been simulated by four of the institutions involved in the TF, with three different codes:
  - **GERMINAL** (v2.2.3) – CEA
  - **MACROS** – SCK•CEN
  - **TRANSURANUS** – JRC-Karlsruhe (v1m2j17) and Polimi (v1m1j14)
- The input power histories, axial peaking profile and discretization were aligned between the participants, coherently with the specifications of the irradiation experiment.
- The codes are as-they-were **before** the project, to provide a suitable reference state for developments coming from INSPYRE.

Integral results for the Np-bearing pin

	Measured	Calculated - POLIMI (% error)	Calculated - JRC (% error)	Calculated - CEA (% error)	Calculated - SCK●CEN (% error)
Final burnup at ppn (at. %)	6.4	6.41 (0.15)	6.9 (7.8)	6.6 (3.13)	6.75 (5.47)
Fission gas (Xe + Kr) produced (cm^3)	**226.68**	**230.96 (1.89)**	**231.6 (2.17)**	**227.24(0.25)**	**237.1 (4.60)**
Fission gas release (%)	**66.5**	**73.4 (10.38)**	**75.3(13.23)**	**60.6 (-8.87)**	**55.2 (-16.7)**
Kr / (Kr + Xe) (%)	6.89	7.09 (2.9)	7.1 (3.05)	7.2 (4.50)	7.02 (1.89)
He released (cm^3)	14.2*	14.2 (0)	13.3 (-6.33)	23.8†(67.6)	7.19 (-49.36)
Central hole length (mm)	**624-643**	**850 (34)**	**850 (34)**	**598 (-5.6)**	**541 (-14.60)**
Fuel elongation (mm)	9.5 – 10.2	23.1 (134)	24.6 (149)	3.16 (-67.9)	39.31 (299)
Clad elongation (mm)	1.6	1.42 (-11.25)	1.4 (12.5)	0.01 (-99)	1.63 (1.88)

* Measurement after 20 months from shutdown

† Result with a 100% release assumption

Integral results for the Am-bearing pin

	Measured	Calculated - POLIMI (% error)	Calculated - JRC (% error)	Calculated - CEA (% error)	Calculated - SCK●CEN (% error)
Final burnup at ppn (at. %)	6.4	6.23 (-2.66)	6.7 (4.68)	6.6 (3.13)	6.6 (3.13)
Fission gas (Xe + Kr) produced (cm^3)	**225.03**	**225.98 (0.42)**	**226.7(0.74)**	**226 (0.43)**	**236.4 (5.05)**
Fission gas release (%)	**68.5**	**57 (-16.8)**	**61.5 (-10.2)**	**53.3 (-22.2)**	**53.8 (-21.4)**
Kr / (Kr + Xe) (%)	6.85	6.9 (0.73)	6.9 (0.73)	7.13 (4.09)	6.94 (1.31)
He released (cm^3)	39.7*	36.3 (-8.56)	51.9(30.73)	63.9†(60.9)	38 (-4.28)
Central hole length (mm)	**550-619**	**850 (45.4)**	**850 (45.4)**	**595 (1.79)**	**541 (-7.44)**
Fuel elongation (mm)	5.6 – 6.2	21.2 (259)	24.2 (310)	1.88 (-68)	39.13 (563)
Clad elongation (mm)	1.5 – 2.3	1.44 (-24.2)	1.4 (-26.3)	0.06 (-96.8)	1.76 (-7.37)

* Measurement after 20 months from shutdown

† Result with a 100% release assumption

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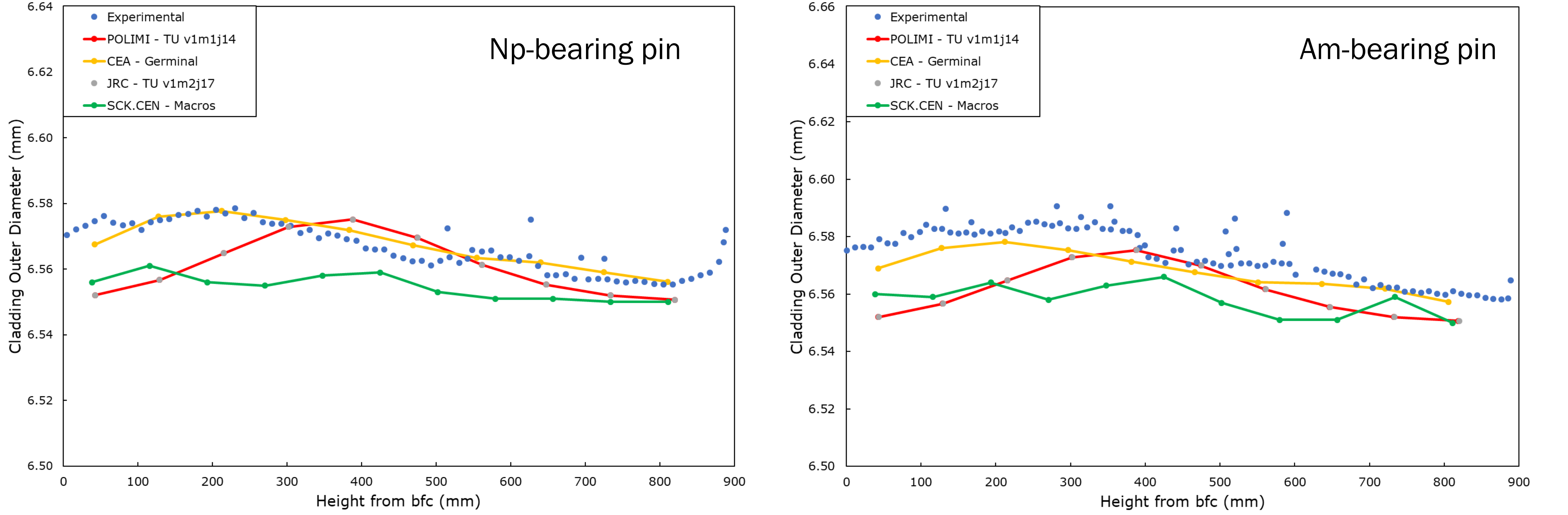
Comparison against local PIE: cladding profilometry



Agreement in line with SotA for all the codes, deviations likely due to different correlations for cladding steel swelling and creep, secondly to **fuel swelling** and **creep models**.

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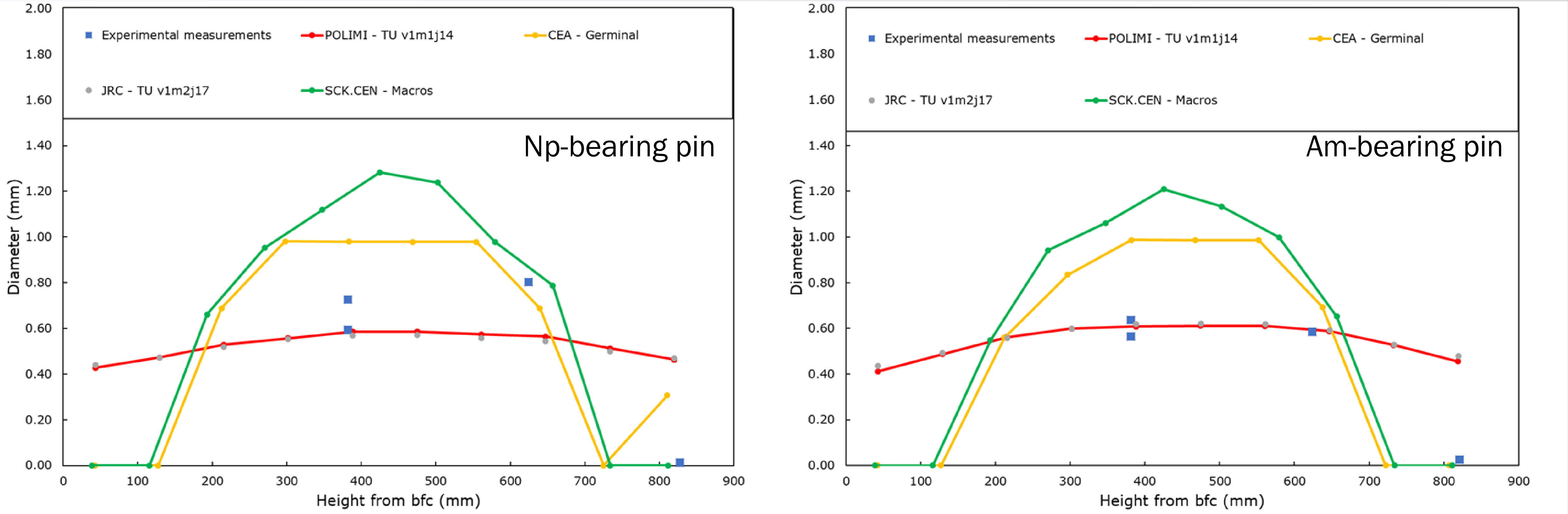
Comparison against local PIE: fuel inner diameter



Good agreement with respect to the measured values, very different trends between TRANSURANUS and MACROS&GERMINAL calculations. Many reasons could be behind those integral differences (fuel creep, gap conductance, restructuring models, relocation, cladding behavior…).

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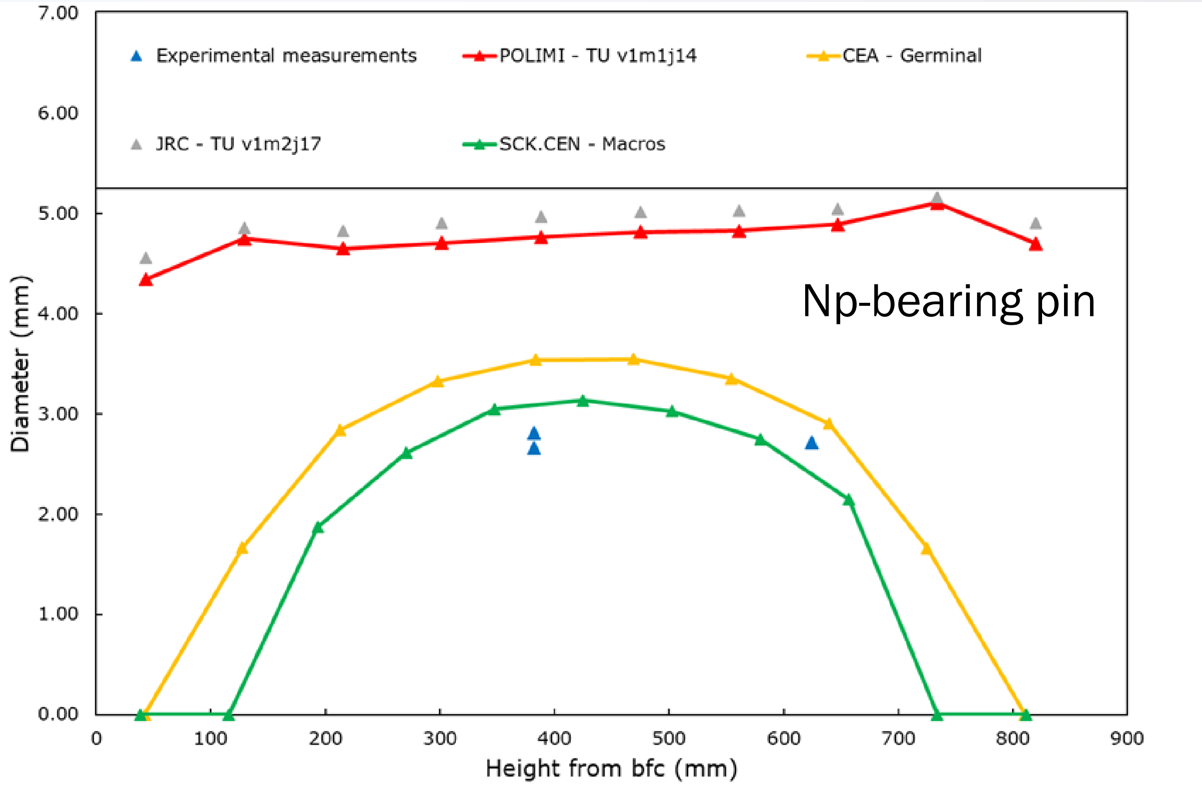
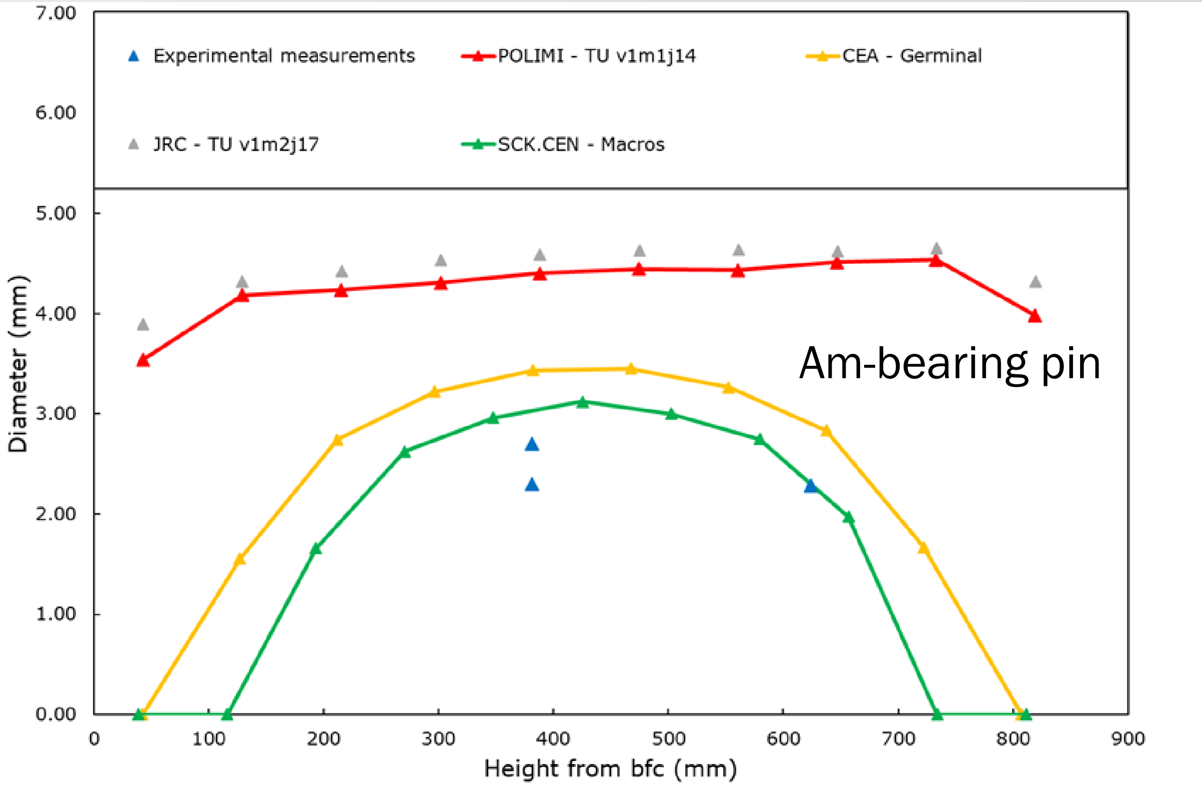
Comparison against local PIE: columnar grains region





Substantial spreads in the predictions between the codes, both on predicted values and axial trends. Transuranus overprediction may be linked to a general overprediction of the temperature profile along the fuel column (with no on-line measurements, columnar region extent can be thought in principle to be linked to the max. local temperature).

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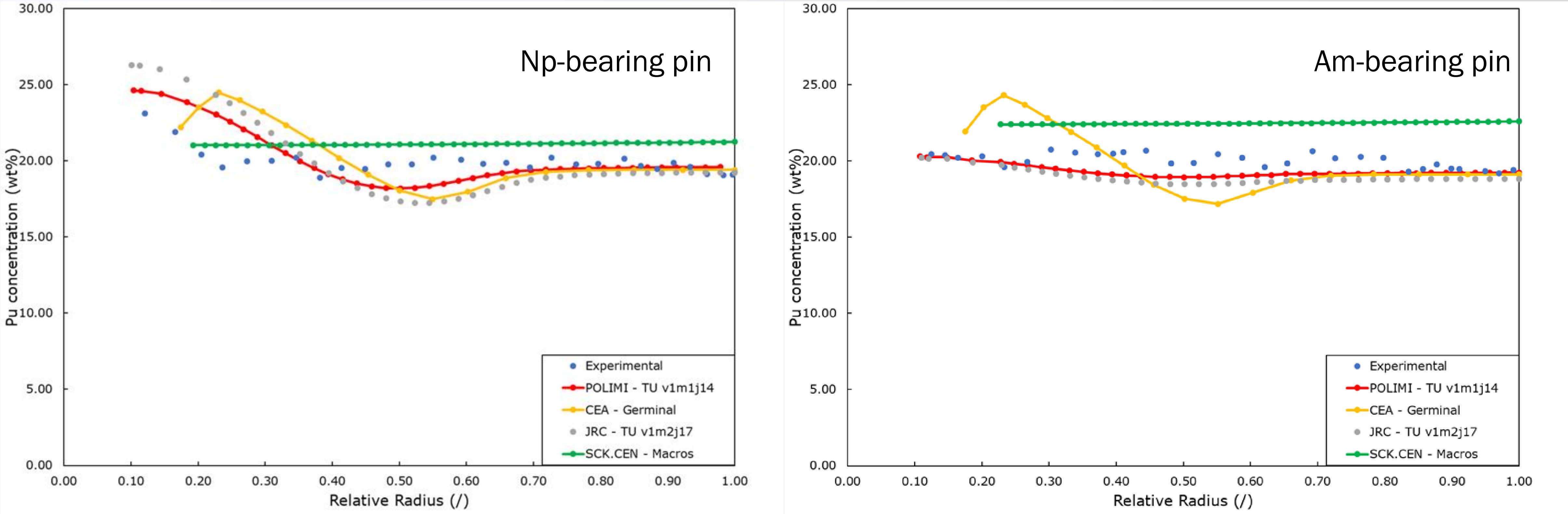
Comparison against local PIE: Pu concentration



Local Pu concentration is linked to fuel restructuring and actinides redistribution. Satisfactory agreement for TRANSURANUS and GERMINAL predictions, MACROS does not to redistribute the actinides. Results are suggesting modeling improvements on redistribution and restructuring model parameters.

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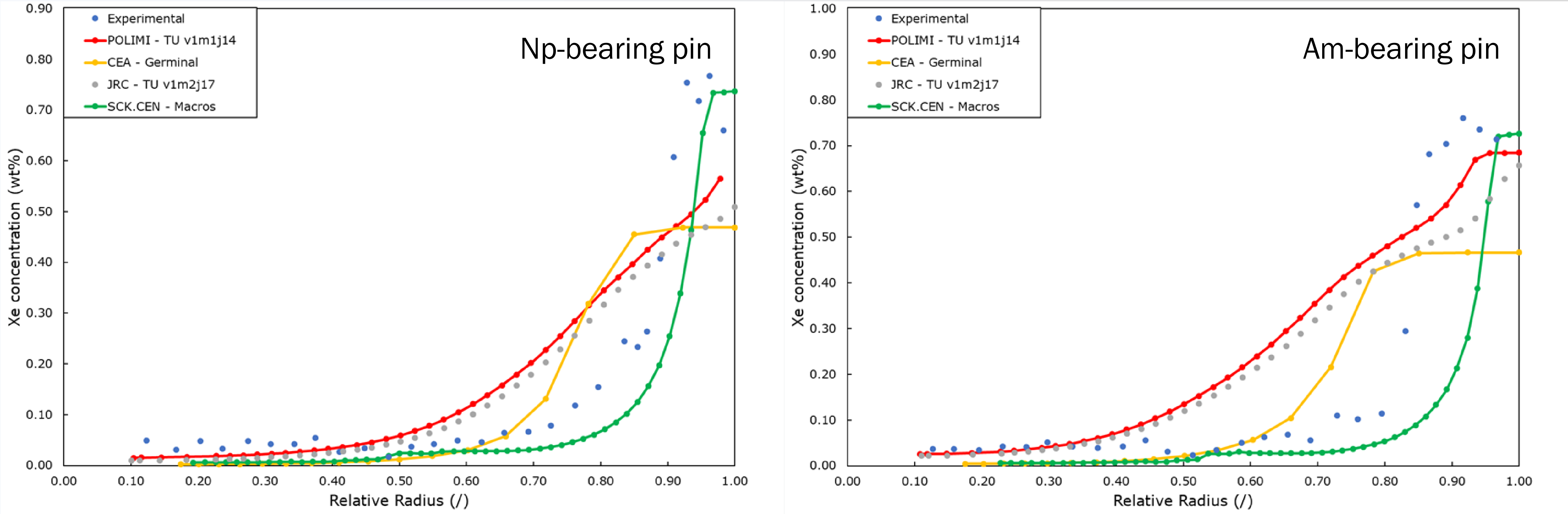
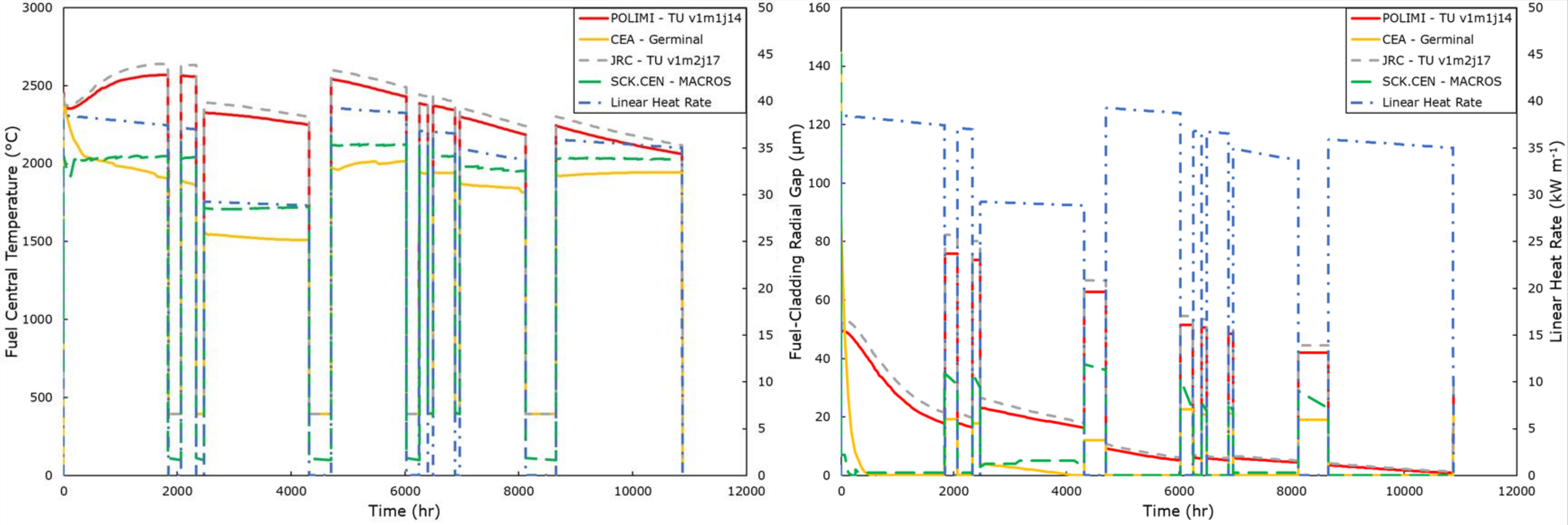
Comparison against local PIE: Xe concentration



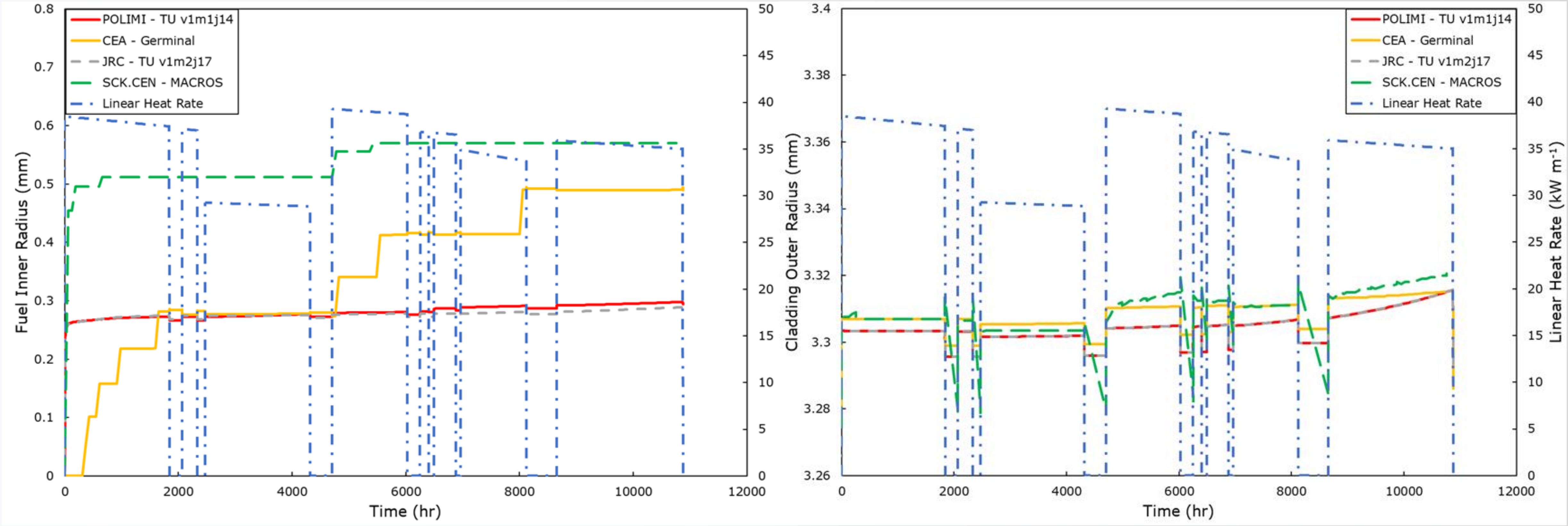
Predictions are good in the central part (i.e., high temperatures), but suggest modeling improvements from intermediate radii, where temperatures are low and the current, simplified models employed in the codes cannot describe properly the behavior of xenon.

Code-to-code comparsion on SF13: Fuel central temperature & gap size



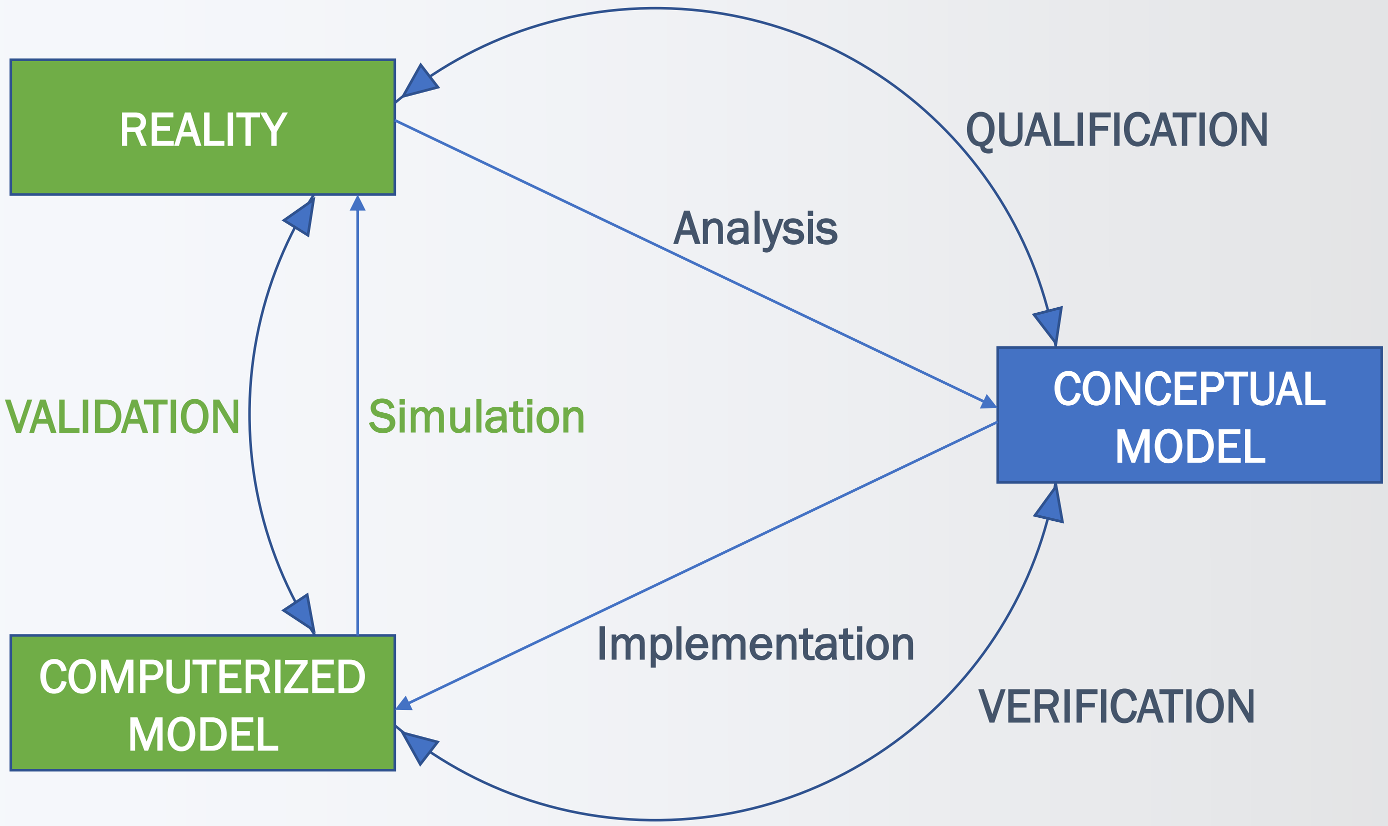
Different temperatures as a function of irradiation predicted by the code, especially in the first cycles. This can be partly ascribed to the different gap sizes, thus to the different gap conductance and relocation models, plus the thermal conductivity correlation employed.

Code-to-code comparsion on SF13:
Fuel inner radius & cladding outer radius



Different evolution of the inner fuel void radius, due to the different restructuring model structure and parameters. Cladding evolution seems to suggest also differences in the material properties (e.g., differences in first rise to power).

Do you trust fuel performance codes ?

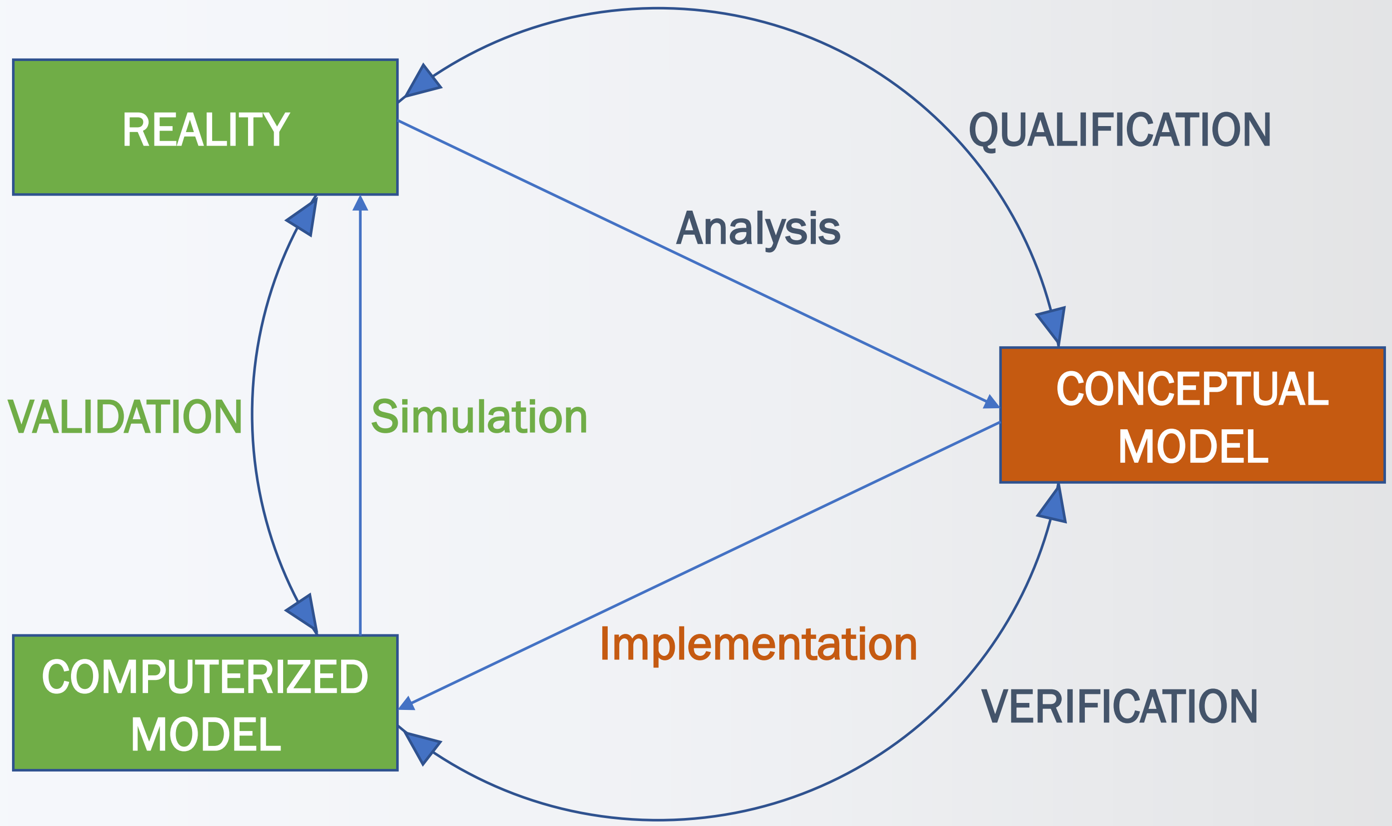


Yes, but be aware that

- They are <u>predictive tools</u>!
  - Errors cannot be cancelled by tuning...
  - They model the engineering scale of fuel pins (multi-scale...)
- Several actions HAVE to be taken to improve their confidence level
  - V & V
  - UA & SA

Conclusions

Do you trust fuel performance codes ?



Yes, but be aware that

- They are predictive tools!
  - Errors cannot be cancelled by tuning…
  - They model the engineering scale of fuel pins (multi-scale…)
- Several actions HAVE to be taken to improve their confidence level
  - V & V
  - UA & SA

Acknowledgments

The results here summarized have been obtained in the framework of the Task Force activities in WP7. The partners involved in the simulations (and analyses) of the presented irradiation experiment are:

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- **Brian Boer and Sergei Lemehov** (MACROS, SCK●CEN)
- **Alessandro Del Nevo** (ENEA)
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Thank you for your kind attention :)

davide.pizzocri@polimi.it

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