Core-level analysis of ATF fuel rods performance under LBLOCA conditions in a PWR using TRACE and TRANSURANUS

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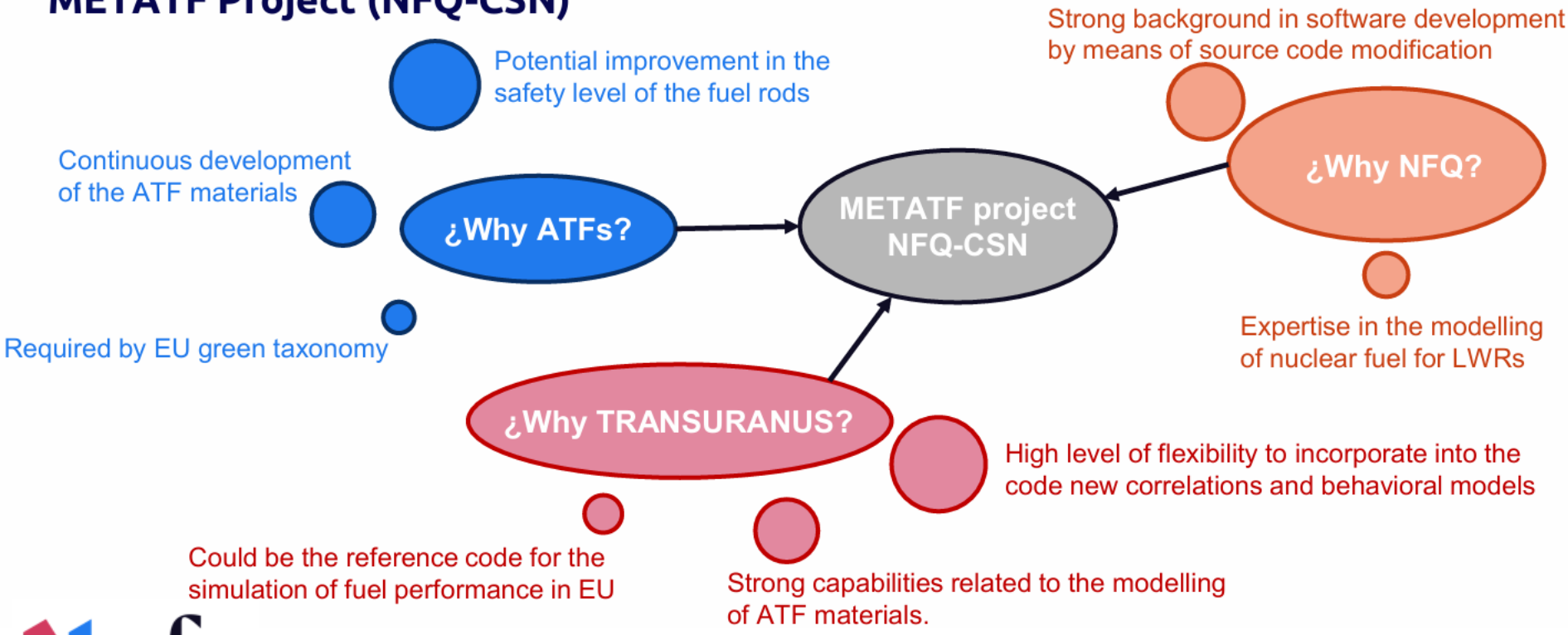
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1 Introduction

METATF Project (NFQ-CSN)



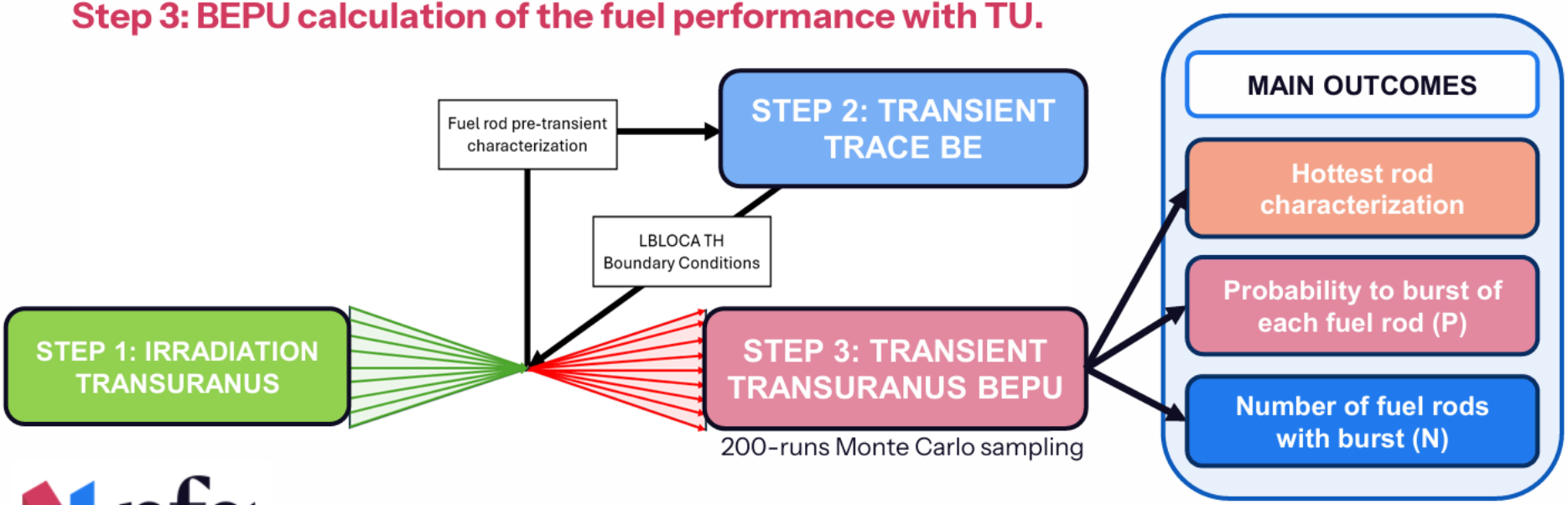
Core-level FSEM Methodology

2

Methodology

The Core-level FSEM is composed by three main steps:

Step 1: Base irradiation simulation with TU.
Step 2: Transient THBCs calculation with TRACE.
Step 3: BEPU calculation of the fuel performance with TU.



Simulations and Results

3

Modelling of ATF materials: Key Assumptions

Cr-doped UO2

- **Larger grain size**
  - 50 µm
- **Higher fuel density**
  - 97.10% TD
- **Initial pellet densification is not considered.**
- **Higher gas diffusivity in the matrix**
  - TU modification
  - Multiplicative factor of 1.59 applied to the intragranular diffusion coefficient of UO2

Cr-coated Zr-4

- **Mechanical behaviour assumed to be very similar to conventional Zr-4 cladding (conservative assumption)**
- **Coating thickness**
  - 15 µm
- **Oxidation correlations**
  - TRACE modification
  - Available in TU
- **Specific burst criterion**
  - Available in TU

FeCrAl

- **Cladding thickness**
  - 385 µm
  - Fuel rod geometry modified
- **Material physical properties**
  - TRACE modification
- **Oxidation correlations**
  - TRACE modification
- **Plastic deformation model**
  - TRACE modification
- **Specific burst criterion**
  - TRACE modification

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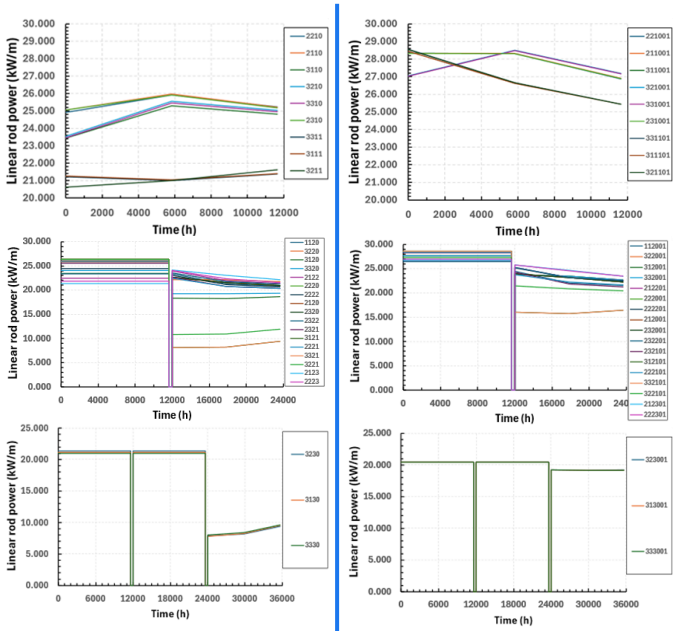
Step 1: Simulation of the operating period

Parámetro	Valor
Outer Fuel Pellet Radius (mm)	4.095
Inner Cladding Radius (mm)	4.18
Outer Cladding Radius (mm)	4.75
Cladding Thickness (mm)	0.57
Fuel Rod Active Height (mm)	3658.0
Fill Gas Pressure (MPa)	2.35
Fuel Grain Size (μm)	10.0
Fuel density (%)	95.00

Geometric data (reference fuel rod)

Rod Power Histories

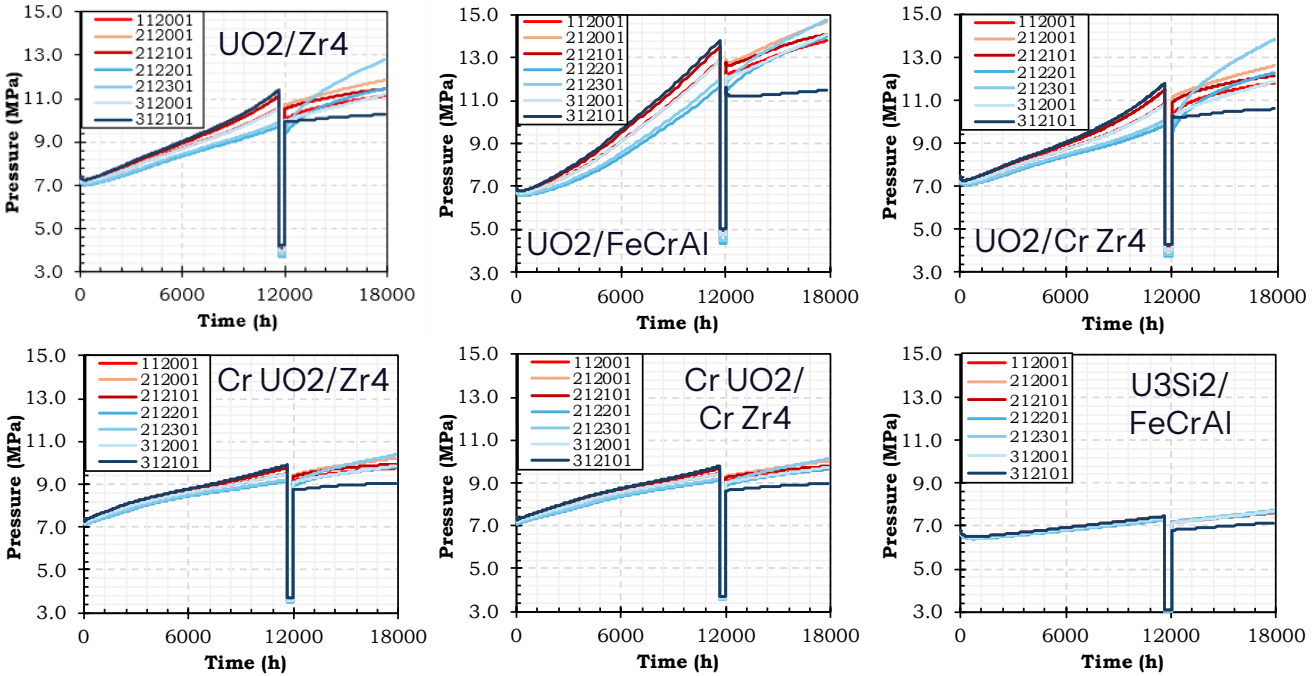
Average Rods | Hot Rods



Step 1: Simulation of the operating period

Second cycle – Hot rods

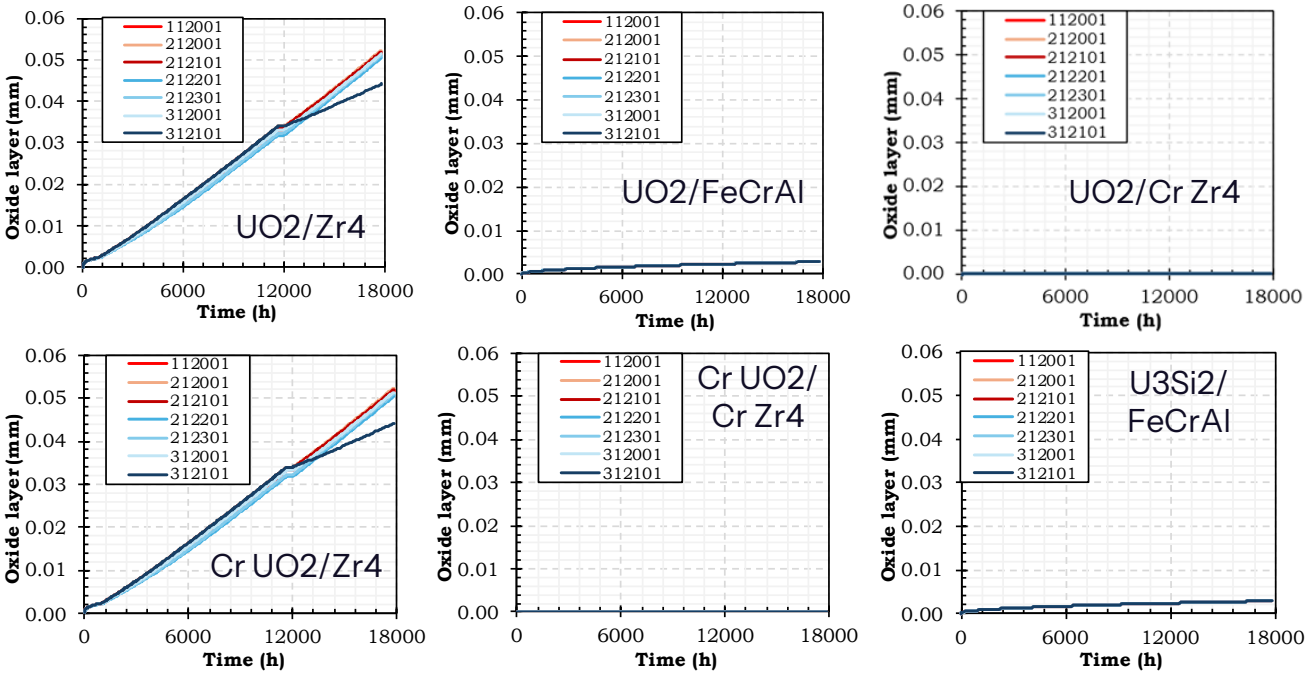
Rod Internal Pressure



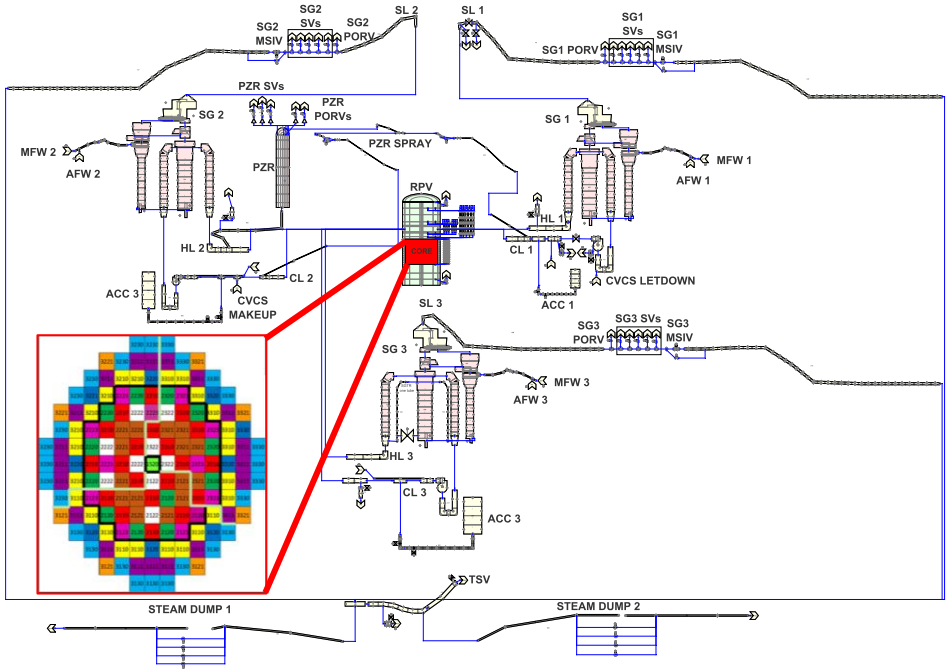
Step 1: Simulation of the operating period

Second cycle – Hot rods

Maximum Oxide Thickness



Step 2: Calculation of thermal-hydraulic boundary conditions

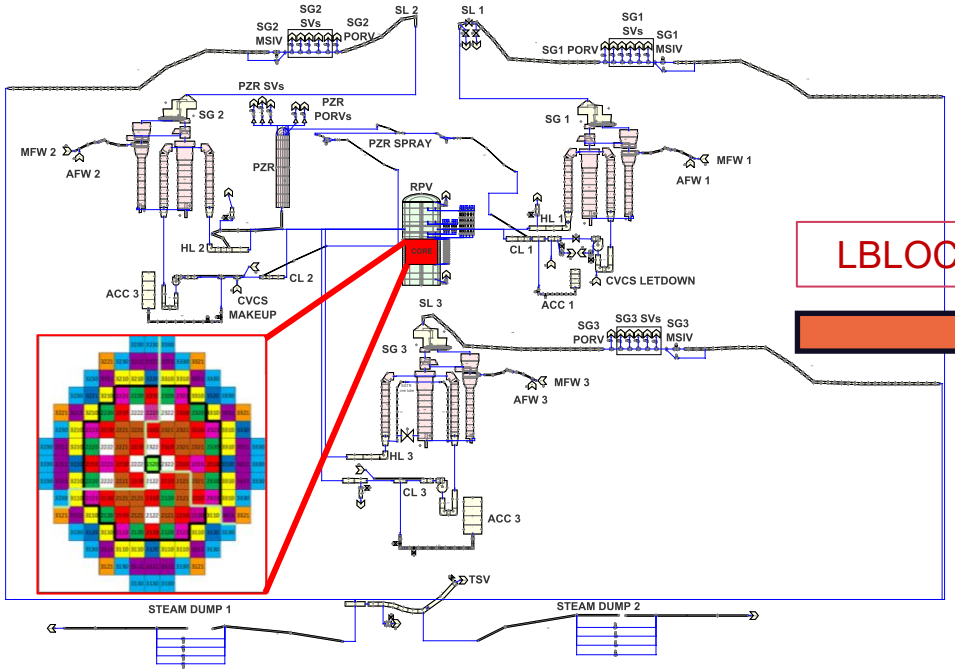


Steady-state calculation
(100% - MOC)

PARAMETER	Reference	TRACE	Error(%)
Thermal Power (MW)	2947.00	2947.00	0.00
PZR Pressure (bar)	155.37	155.38	0.01
PZR Level (%)	57.00	57.90	1.58
RCS Massflow per loop (kg/s)	4531.41	4520.40	-0.24
Av. RCS Temperature (K)	580.95	580.92	-0.01
SGs Pressure (bar)	66.87	67.05	0.27
MS Massflow (kg/s)	1626.07	1633.37	0.45
SGs NR Level (&)	50.60	50.58	-0.05

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Step 2: Calculation of thermal-hydraulic boundary conditions

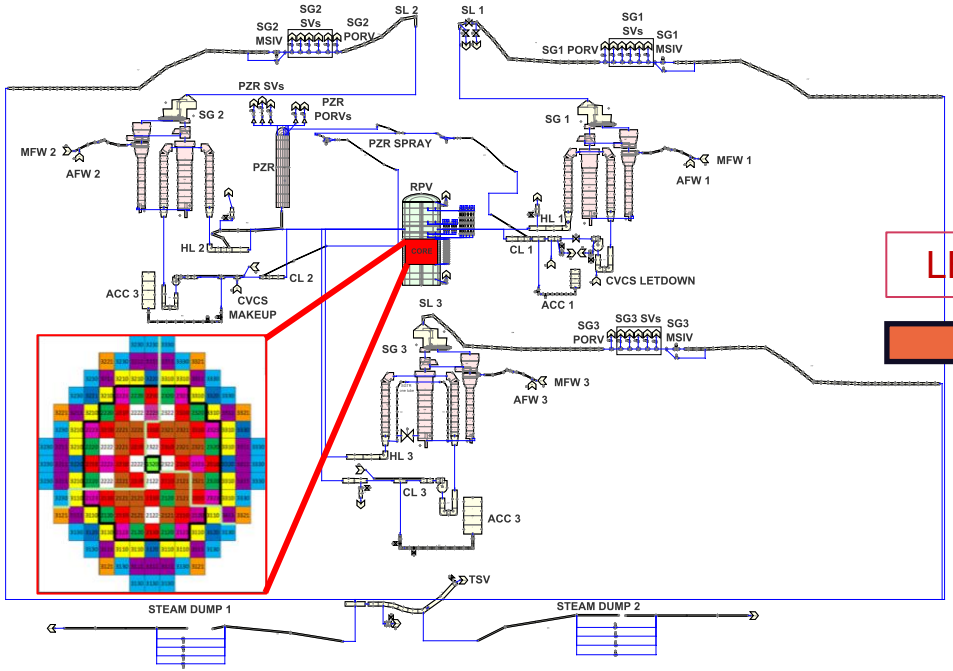


LBLOCA

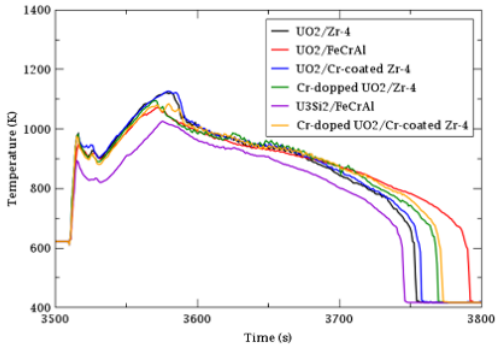
Key Assumptions:

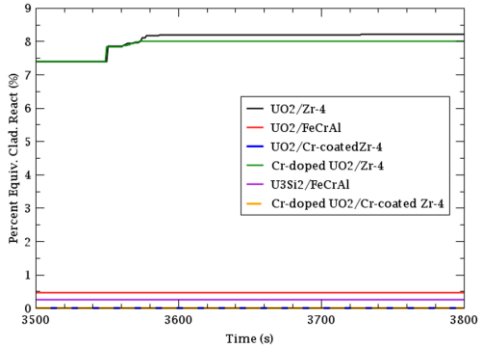
- LBLOCA + LOOP
- One safety-injection (SI) train available.
- Decay heat increased by 20%.
- Void reactivity feedback not considered.
- Discharge from the ACC in the broken loop is neglected.

Step 2: Calculation of thermal-hydraulic boundary conditions



LBLOCA

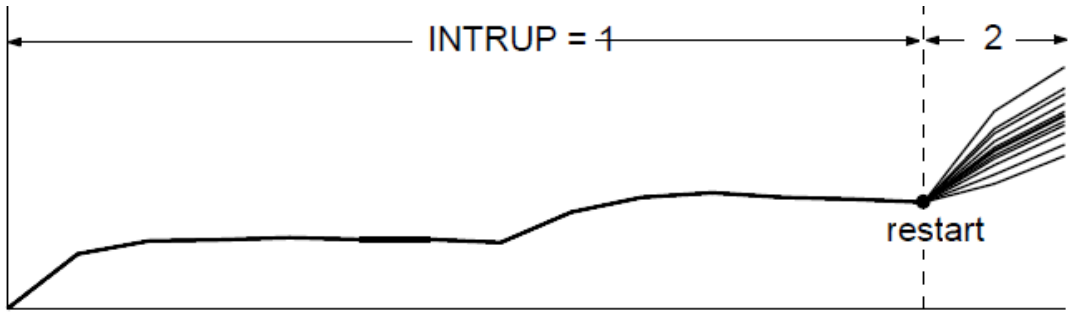




Step 3: Simulation of fuel rod behaviour

LBLOCA – TU (BEPU)

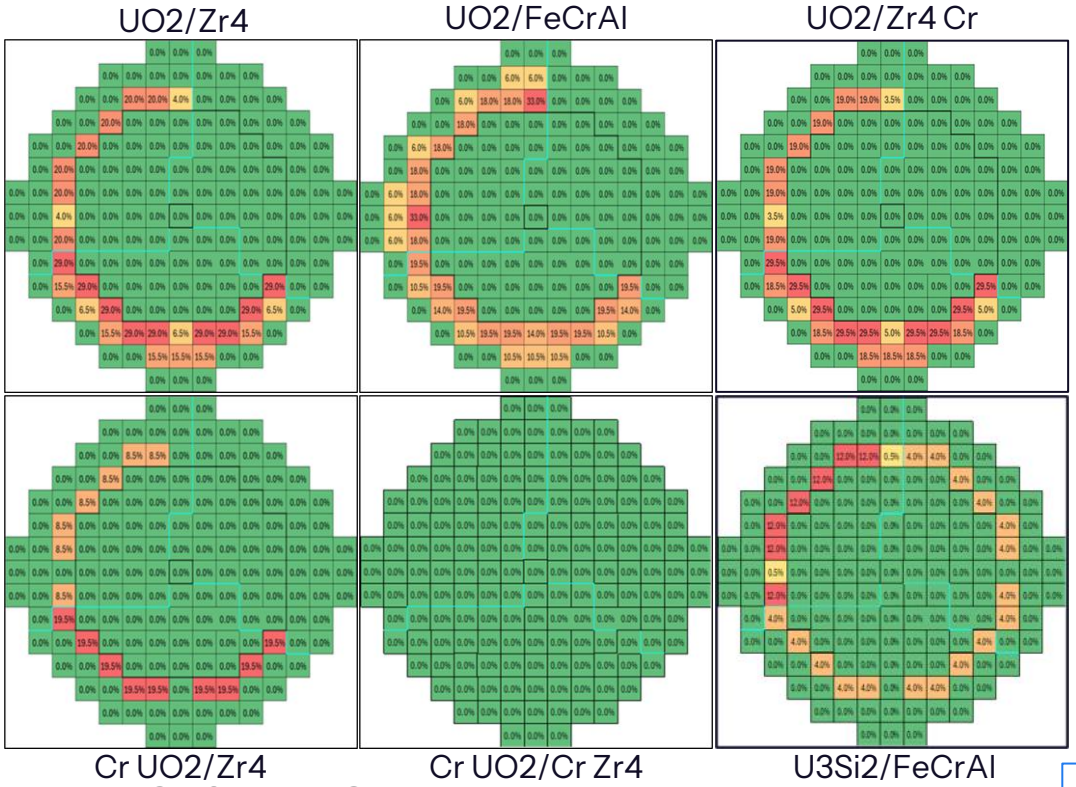
- Resuming the previous simulation of normal operation.
- 66 BEPU analyses per material.
- 200 runs Monte Carlo sampling for each rod model.
- Typical uncertain parameters of LOCA analyses were selected.
- Sensitivity analysis were performed.



Step 3: Simulation of fuel rod behaviour

LBLOCA – TU (BEPU)

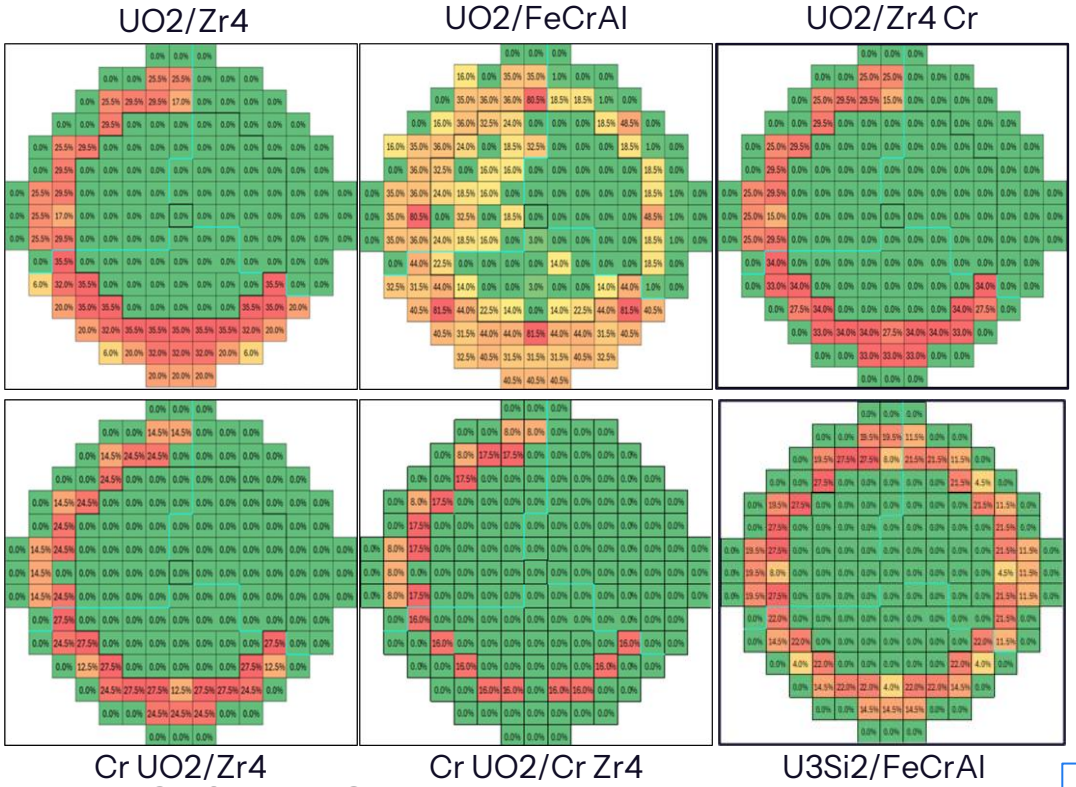
Probability to burst
Radial Distribution in the core
(Average rods)



Step 3: Simulation of fuel rod behaviour

LBLOCA – TU (BEPU)

Probability to burst
Radial Distribution in the core
(Hot rods)



Step 3: Simulation of fuel rod behaviour

LBLOCA – TU (BEPU)

	Average rods			Hot rods		
Fuel Rods Concepts	**Mean time to cladding burst (s)**	**P_5**	**P_{95}**	**Mean time to cladding burst (s)**	**P_5**	**P_{95}**
UO2/Zr-4	63.29	51.69	72.04	61.43	48.55	70.46
UO2/FeCrAl	47.35	36.12	60.01	49.18	32.67	60.57
UO2/Cr Zr-4	62.31	55.99	68.45	58.34	50.29	68.05
Cr UO2/Zr-4	57.12	55.31	58.50	55.22	50.54	58.58
Cr UO2/Cr Zr-4	-	-	-	55.49	52.83	60.95
U3Si2/FeCrAl	63.72	61.84	65.33	61.72	58.25	64.50

Step 3: Simulation of fuel rod behaviour: SA for the Hot Rods

LBLOCA – TU (BEPU)

Figures of Merit analyzed:

Pre-burst:
- Cladding Outer Diameter.
- Gap Pressure.

End of simulation:
- Cladding Oxide Thickness .
- Time to burst.

Spearman's CCs computed.

	UO2/Zr-4	UO2/FeCrAl	UO2/Cr Zr-4	Cr UO2/Zr-4	Cr UO2/Cr Zr-4	U3Si2/FeCrAl
Linear Heat Rate	0.04	0.06	0.02	0.00	-	0.08
Cladding Temperature	0.84	0.35	0.62	0.57	-	0.73
Heat Tr. Coef. Fuel-Clad.	0.07	0.08	0.13	0.07	-	0.04
Fission Gas Diffusion Coef	0.08	0.11	0.03	0.08	-	0.00
Cladding Corrosion Rate	0.08	0.08	0.01	0.01	-	0.05
Fuel Thermal Strain	0.06	0.02	0.02	0.01	-	0.04
Fuel Thermal Conductivity	0.01	0.12	0.13	0.14	-	0.08
Fuel Density	0.09	0.13	0.08	0.03	-	0.01
Cladding Elasticity const	0.00	0.05	0.02	0.02	-	0.11
Cladding Thermal Strain	0.16	0.04	0.17	0.22	-	0.08
Cladding Thermal Conductivity	0.04	0.08	0.02	0.02	-	0.12
Cladding Yield Stress	0.03	0.12	0.11	0.03	-	0.04
Fuel Outer Radius	0.46	0.28	0.36	0.31	-	0.42
Cladding Inner Radius	0.46	0.29	0.36	0.31	-	0.47
Cladding Outer Radius	0.52	0.28	0.40	0.35	-	0.47

Spearman's CCs for the Time to burst

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Conclusions

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Conclusions

- The behavior of ATF materials under LBLOCA conditions has been successfully analyzed using an advanced methodology combining TRACE and TRANSURANUS codes. The results obtained for each material are consistent with expectations.

- In-house versions of TRACE and TRANSURANUS have been developed to extend their simulation capabilities for FeCrAl, Cr-coated Zr-4 and Cr-doped UO2.

- The results of the simulations demonstrate a significant reduction in the number of failed rods and their failure probability when ATF materials are used, particularly when fuel and cladding improvements are combined.

- Sensitivity analyses confirm that the selected Figures of Merit depend not only on cladding temperature but also on the pre-transient fuel rod geometry, highlighting the importance of accurately characterizing the initial fuel state in LOCA analyses. These findings are consistent with the simulation results and underscore the benefits of Cr-doped UO_2 fuel concepts under LOCA conditions.

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Thank you!

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