Italian National Agency for New Technologies, Energy and Sustainable Economic Developme

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Karlsruher Institut für Technologie

UNIVERSITÀ DEGLI STUDI DI PALERMO

DEVELOPMENT OF MELCOR v2.2 INPUT FOR THE SIMULATION OF QUENCH-06 EXPERIMENT

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CONTENTS

Framework:

IAEA CRP *«Advancing the State-of-Practice in Uncertainty and Sensitivity methodologies for Severe Accident Analysis in Water-cooled reactors»* is aimed to achieve significant improvement in sophistication and quality of SA analyses performed by the participants with well-developed knowledge, adequate simulation capabilities and long years of relevant practice. QUENCH-06 is one among the proposed exercises.

Goals of the work:

- Indipendent user validation of *Core Heat up*, *Zircaloy-Steam Oxidation* and *Degradation* models embedded into best estimate MELCOR code employing the experimental dataset provided by QUENCH-06 test;
- Sensitivity analysis (SA) adopting several Zircaloy-Steam oxidation reaction rates;
- Uncertainty analysis (UA).

Methodology:

1. QUENCH-06 experiment
- Description of QUENCH facility
- QUENCH-06 experiment

2. Dataset
- Geometry
- Boundary Conditions
- Experimental results

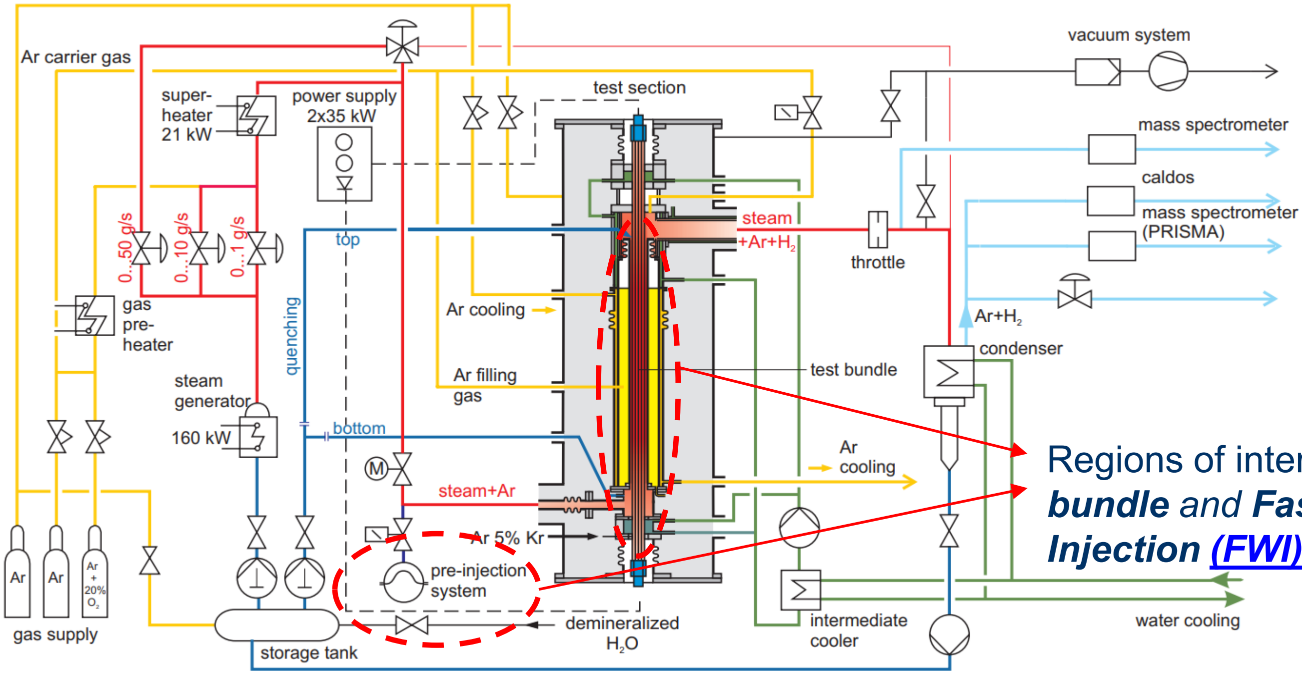
3. MELCOR Code
- Packages

4. QUENCH-06 Input
- Nodalization
- Sensitivity analysis

5. Results
- Reference case;
- SA outcome;
- UA outcome;
- Critical aspects and future efforts.

QUENCH facility

QUENCH is a series of scaled down, separate effect tests conducted at KIT



Regions of interest: ***Test bundle*** *and* ***Fast Water Injection*** ***(FWI) system.***

Goals of **QUENCH-06**:

- Evaluate the hydrogen build-up in a simulated Desing Basis Accident from Zircaloy oxidation during:
    1. a cool-down phase carried out by just steam and argon flows;
    2. quenching with subcooled water.

- Determine the behaviour of pre-oxidized LWR-like fuel rod on cooling down with water.

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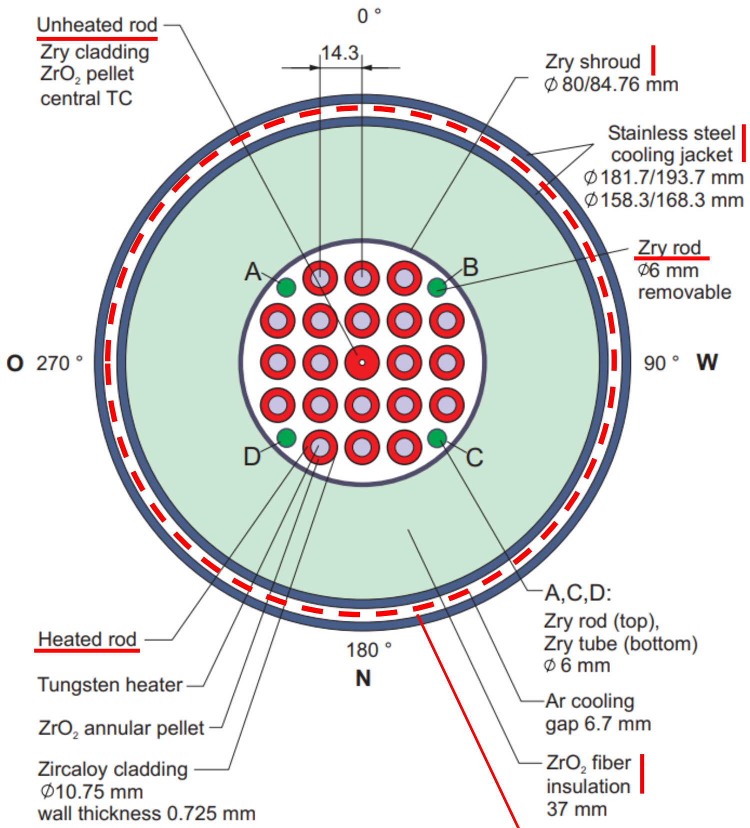
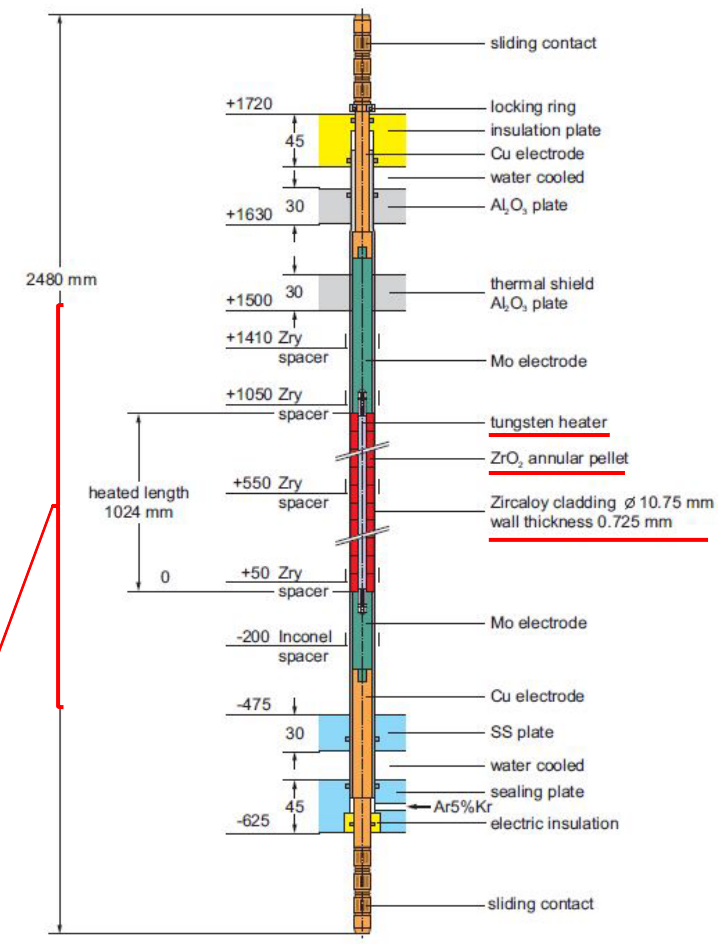
TEST BUNDLE AND FUEL ROD SIMULATORS



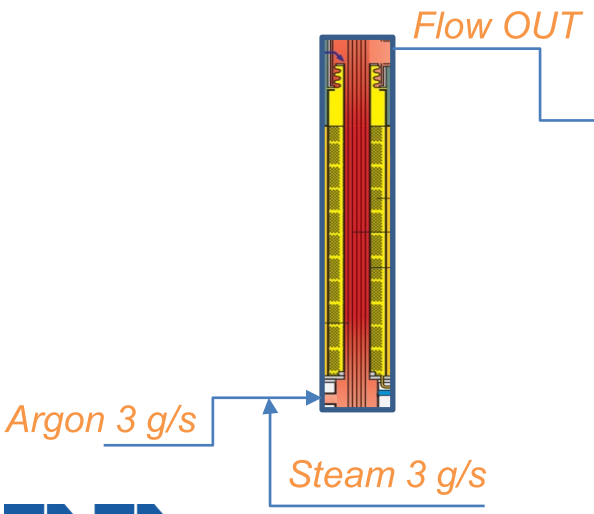


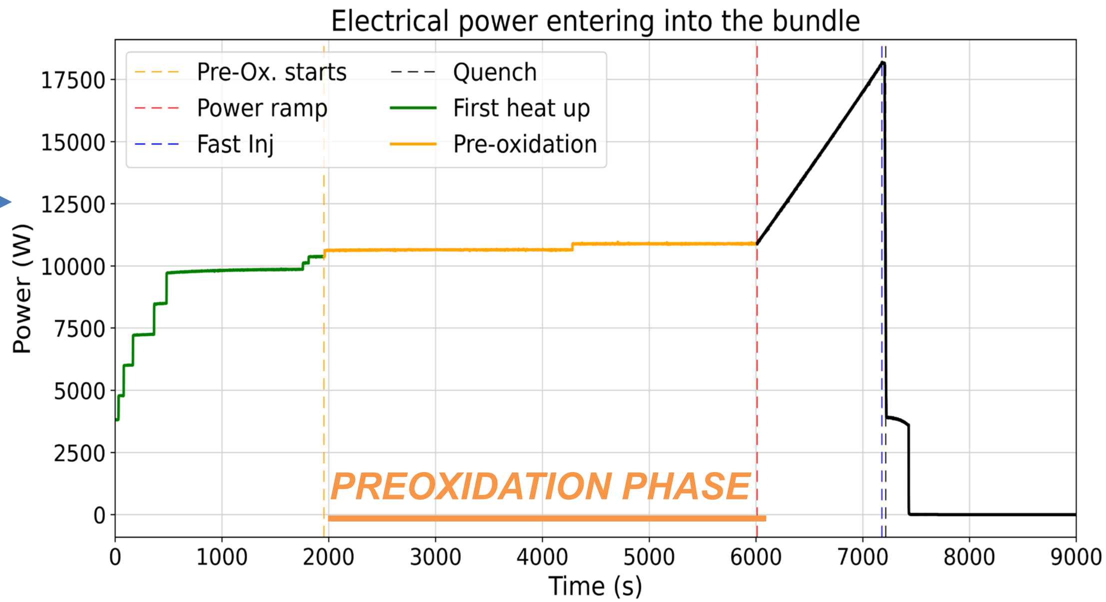
MELCOR QUENCH-06 Input Domain
ϕ: [0 m, 0.1683 m]
ΔH: [-0.47658 m, 1.5 m]

TEST PHASES: PREPARATION AND PREOXIDATION

Bundle is heated by a stepwise increase of electrical power from room temperature up to about ~873 K, while crossed by flowing argon (3 g/s) and steam (3 g/s) coming from the bottom. System status is kept for 7200 s.

After this stabilization period, (**t = 0 s**) measurements are turned on and power is ramped up from 4 kW to 11 kW without any changes in mass flow rates.
Once the bundle has reached ~ 1473 K (target value), **Preoxidation** of the Zry claddings and shroud occurs, while temperature is mantained by control systems for 4046 s.





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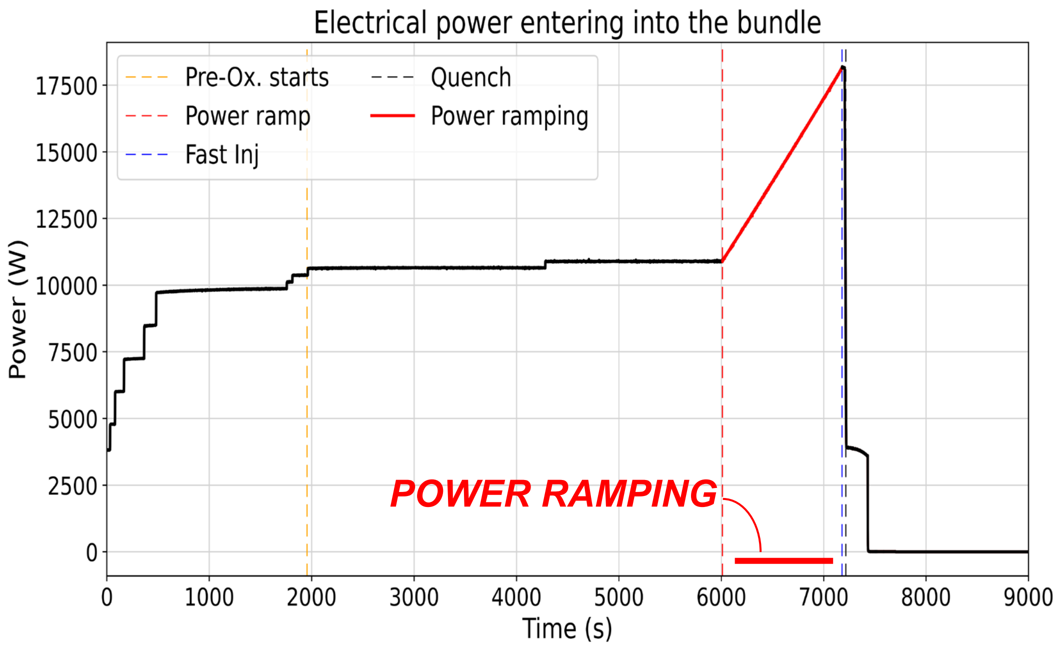
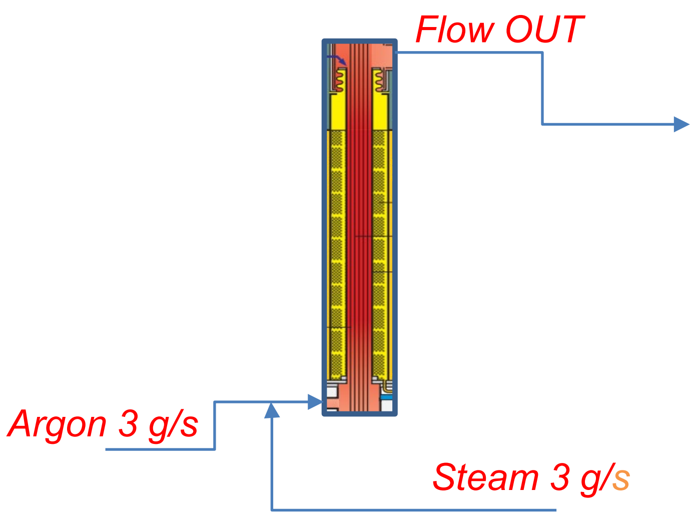
TEST PHASES: POWER RAMPING

At the end of pre-oxidation period, a **Power ramping** begins, where power is steeply increased until the **quenching condition** is satisfied (**t = 7179 s**):

- a minimum of three rod thermocouples should have exceeded ~1973 K, and the central rod thermocouple should have reached ~1873 K at this time.

This phase is characterized by the highest hydrogen production rate of all the experiment.

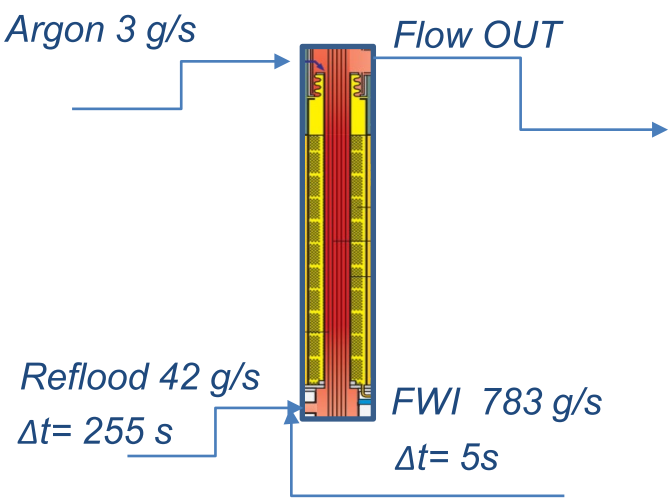


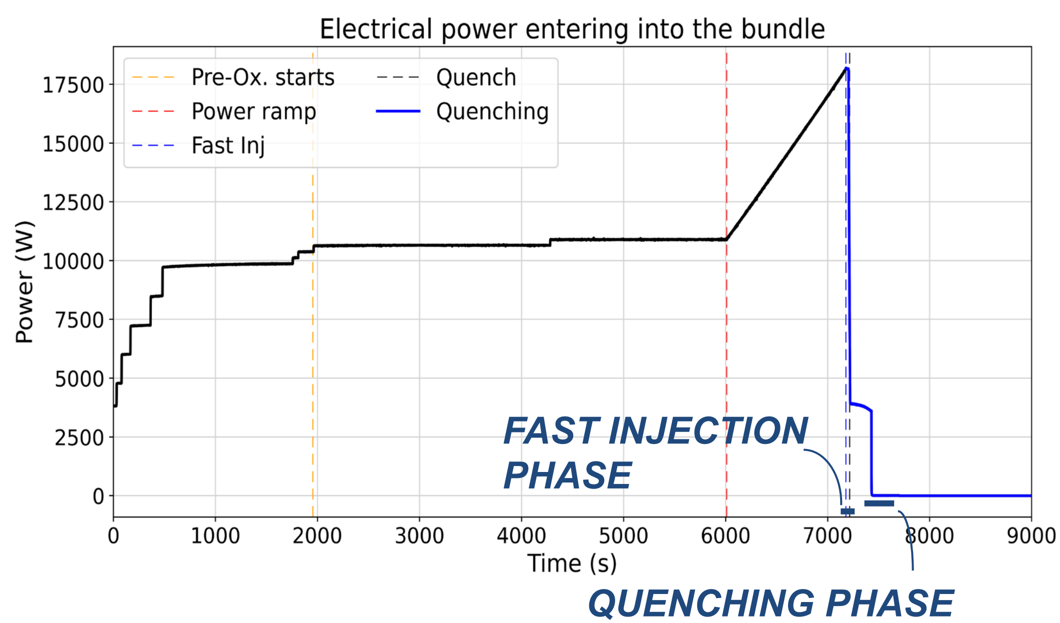


TEST PHASES: QUENCHING

Quenching phase begins by turning off bottom injections and switching the argon flow rate to the head of the bundle.
Fast injection (FWI) system is activated at **t = 7179.5 s** for 5 s allowing 4 l of quench water (6 bar, 397 K) for pre-filling the pipes and the lower plenum.

With 30 s of delay (**t = 7215 s**), quenching water is pumped at a flowrate of 42 g/s for 255 s.
At **t = 7205 s** power is reduced to 4 kW to simulate decay power.
Around **t = 7470 s**, quenching is concluded, and power is set to zero.





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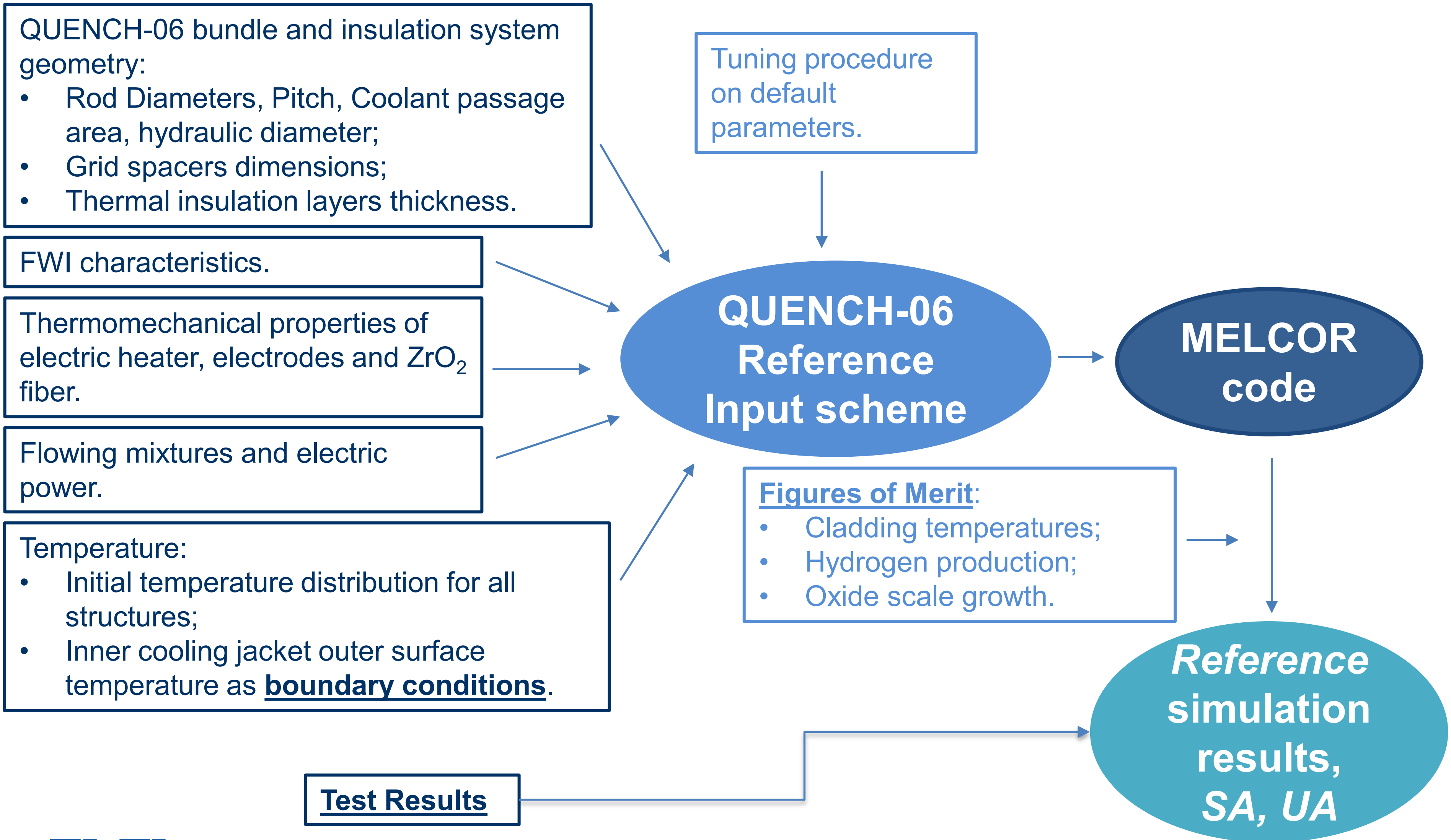
QUENCH-06 EVENTS

Time [s]	Event	Flowing mixture
0	Test starts, heat up from 873 K to 1473 K	• 3 g/s steam [2 bar, 640 K] • 3 g/s argon [2 bar, 640 K]
1965	Preoxidation stage onset, power at 11 kW	‘’
6011	Power ramping	‘’
6620	Corner rod B withdrawal for metallographic analysis	‘’
7179.5	Reflood on-set	• 783 g/s FWI [6 bar, 370 K] • 3 g/s argon in bundle head [2 bar, 298 K]
7184.5	FWI ends	• 3 g/s argon in bundle head [2 bar, 298 K]
7215	Main quench, power to 4 kW	• 42 g/s water [2 bar, 397 K] • 3 g/s argon in bundle head [2 bar, 298 K]
7431	Power shutoff, quench ended	• 3 g/s argon in bundle head [2 bar, 298 K]
11420	Test termination	-

DATASET AND INPUT DEVELOPMENT



QUENCH-06 INPUT NODALIZATION

QUENCH-06 CVH-FL NODALIZATION (1)

TEST Control Volumes (CV)

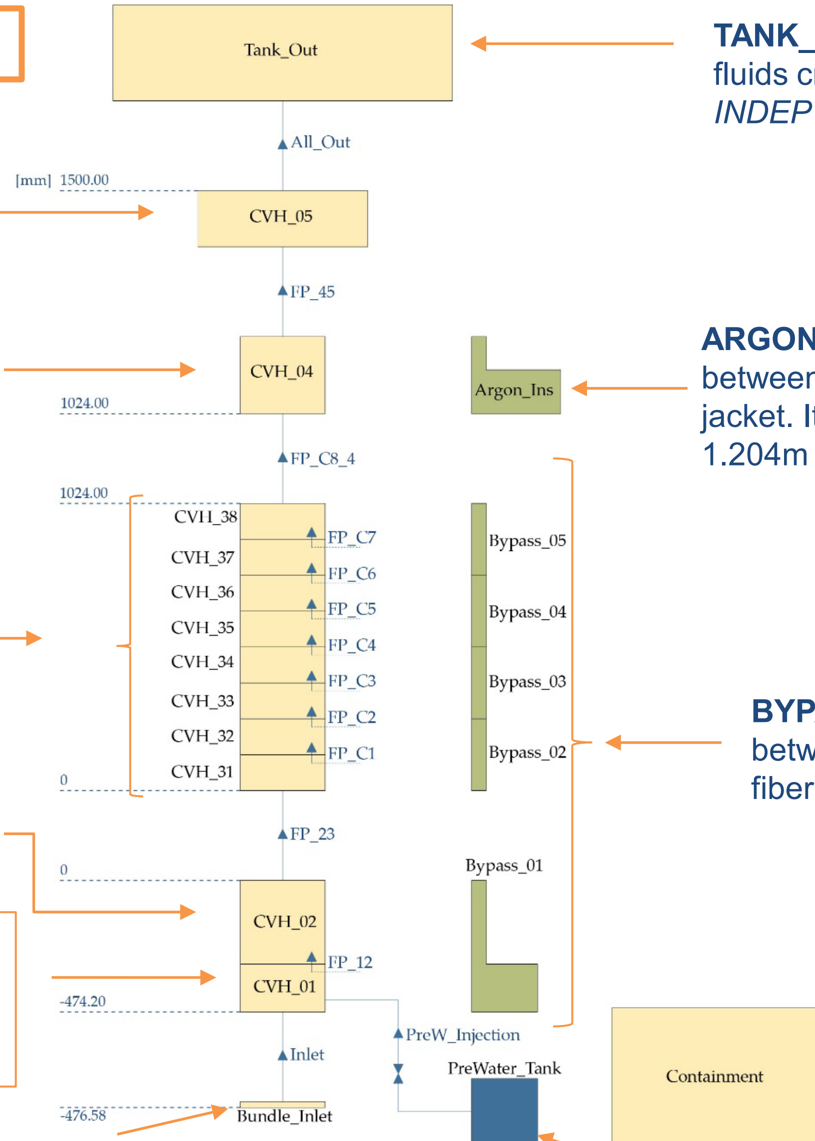
CVH_05: : CV in corrispondence of upper Mo electrode.
- Post FWI Argon mass flow rate source

CVH_04: : CV in corrispondence of upper Mo electrode

CVH_31-38: : CVs in active region

CVH_02: : CV in correspondence of lower Mo electrode

CVH_01: CV in correspondence of Cu electrode
- Steam, Argon and quenching water flow rates sources



TANK_OUT: it acts as a sink for all fluids crossing the test section (*TIME – INDEP* at 2 bar, 600 K)

ARGON_INS: argon insulation between the shroud and the cooling jacket. It acts also as bypass between 1.204m and 1.3m.

BYPASS: 5 thin dummy annuli between the Zry shroud and the ZO fiber (thickness 0.5 mm).

CONTAINMENT: Argon filled *TIME-INDEP* volume at 415 K.

BUNDLE INLET: for COR lower head

PREW_TANK: FWI system

QUENCH-06 CVH-FL NODALIZATION (2)

- Every **Test Section CV** is initialized as Both Pool and Atm, Active and with Non-equilibrium:
  1- Pool saturated (2 bar);
  2- Atm superheated (2 bar, 607 K).

- CVH_01: mass and temperature sources (steam, argon and quenching water) as TFs;
- CVH_05: mass and temperature sources of post quenching argon in-head injection as TFs;

As concerns flow paths linking **TEST CVs**:

$$cross\ sectional\ area = 3.007 * 10^{-3}\ m^2$$
$$hydraulic\ diameter = 0.01161\ m$$

- Fast preinjection is triggered by the opening of a valve:
  1. Length, diameter and friction coefficent of the FL are determined after a sensitivity analysis in order to inject into the system 4 l of subcooled water in 5 s;
  2. **PreW_tank** CV is *TIME-INDEP* at 6 bar, *Only Pool.*

- **BUNDLE_INLET** is merely a dummy control volume that acts as lower plenum to match the COR nodalization of the lower head (it is *Active*, *Non Equilibrium* with *Both Pool and Atmosphere*).

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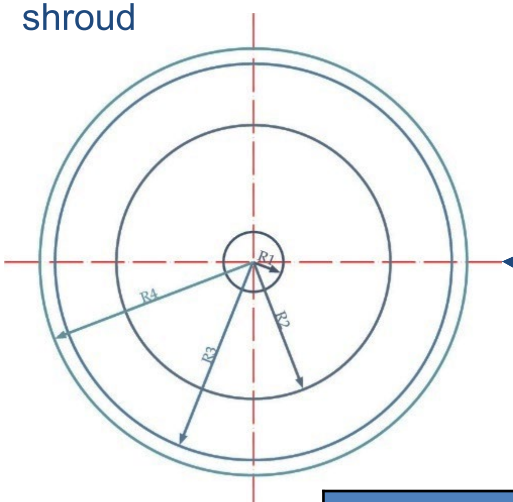
QUENCH-06 COR NODALIZATION (1)

Test Bundle up to zircaloy shroud is nodalized in *4 concentric rings and 42 axial levels*.

RADIAL NODALIZATION

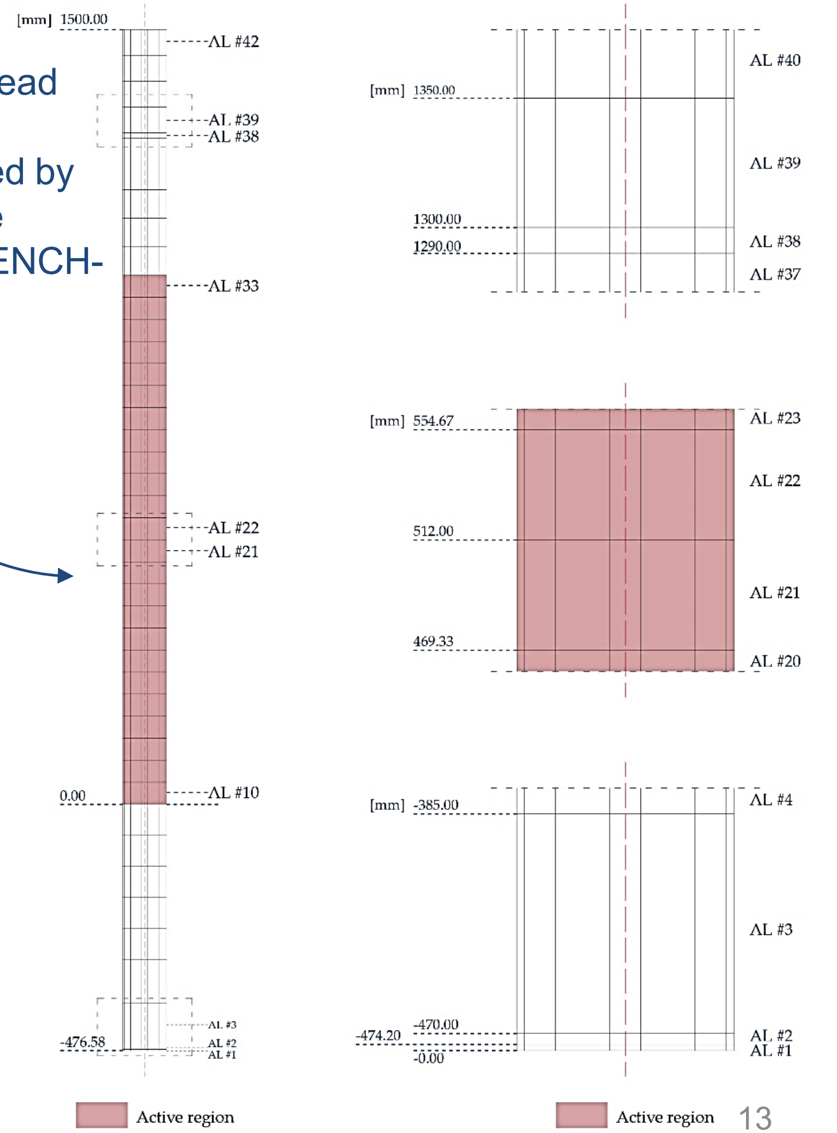
- *Ring 1*: unheated rod + grids
- *Ring 2*: 8 inner heated rods + grids
- *Ring 3*: 12 outer heated rods + grids
- *Ring 4*: 4 corner rods + grids + shroud



Ring	Radius
Ring #1	6 mm
Ring #2	27.975 mm
Ring #3	39 mm
Ring #4	42.38 mm

AXIAL NODALIZATION

- *Axial level 1*: lower head (dummy)
- *Axial level 2*: occupied by core supporting plate
- *Axial level 3-42*: QUENCH-06 test bundle



QUENCH-06 COR NODALIZATION (2)

COR type: PWR

Core radius = 0.04238 m → shroud outer radius
Vessel radius = 0.039 m → R_3 of COR nodalization
Vessel thickness = 0.00238 m → shroud thickness
Flat transition vessel-lower head
Lower elevation of COR support plate = - 0.4742 m
Thickness of COR supporting plate = 0.0042 m → equal to grid thickness

Cladding: all rods cladding, corner rods.
ZrO2 Pellets: supporting ZrO2 structures (ring: 1,2,3).
Grids: supporting (SS, Zry) structures + supporting core grid (COR_PLATE) in axial level 2.
Fuel: ELHEAT option on (ring: 2,3)
Shroud: SH component

- W as MATHT
- Mo as ELM1
- Cu as ELM2

In ELPOW voltages, outer resistance (~0.5mΩ/ring, variable in time) and electric power supplied to each heated ring are inserted.

In ELMAT resistivity options DEFW, DEFMO and DEFCU are turned on.

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QUENCH-06 COR NODALIZATION (3)

```
!               fcncl         fsscn         fcelr         fcela         flpup
COR_RF           0.25          0.25           1.0           0.1          0.25
!              ntpcor       rntpcor        icfgap        icffis
COR_TP             NO            NO            NO            NO
!            zr     zx     uo     ss     sx     cp
COR_CHT  7500.0 7500.0 7500.0 2500.0 2500.0 2500.0
!              ieumod         ihsdt          idtdz          icorcv
COR_MS       INACTIVE           REQ            CVH          NOCONS
!        mtuozr mtzxzr mtsxss mtcpss fuozr fzxzr fsxss fcpss
COR_CMT       1      1      2      2   0.2   0.0   1.0   0.0
!              drclmn        drssmn
COR_CCT        1.0E-5           0.0
!       size
COR_SS     7 !n  ia      ir issmod issfai tssfai ssmetal
             1    2     1-4 PLATEG TSFAIL 2400.0 STEEL
             2   10       1 PLATEG TSFAIL 2400.0 STEEL
             3    6     2-3 PLATEG TSFAIL 2400.0 STEEL
             4   11     2-3 PLATEG TSFAIL 2400.0  ZIRC
             5   22     2-3 PLATEG TSFAIL 2400.0  ZIRC
             6   34     2-3 PLATEG TSFAIL 2400.0  ZIRC
             7   41     2-3 PLATEG TSFAIL 2400.0  ZIRC
```

Best estimated through sensitivity analysis. They tune radial heat exchange

- No critical stainless steel structure diameter
- Critical diameter for Zry structures has been lowered

COR supporting plate

Structure to support the Zirconia stack in the dummy rod (lower elevation 0 mm)

Inconel lower grid → modeled as stainless steel

Zry spacer grids placed at different altitudes

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QUENCH-06 COR NODALIZATION (4)

```
              !              iaxsup       hdbh2o       ppfail        vfall        ntlp
COR_LP                2       100.0        2.0E7        1.0E-5           1
!                 nlh        ninslh
COR_LH                6           0
!                 nlht        nlhta
COR_LHD               5           4
!          is    tlh     radlh        icvcav ihscav hsside vflhhs icfelh icfelhs icfcnv
            1 300.0   6.0E-3      'CONTAINMENT'
            2 300.0   0.027975    'CONTAINMENT'
            3 300.0   0.039        'CONTAINMENT'
            4 300.0   0.04238     'CONTAINMENT'
            5 300.0   0.04238     'CONTAINMENT'
!                hdbpn          hdblh        mdhmpo        ihmpmlh       tpfail        cdispn
COR_LHF          100.0          1.0E6         MODEL         MODEL        9999.0          1.0
!                shmat
COR_SHM           SS
!
COR_MAT       1 ! cormat              matnam
              1   SS              ZIRCALOY
```

Stainless steel in COR description has been modified and substituted with Zircaloy. Mandatory operation since **it is not possible to define SH component made directly as Zircaloy**

In this way also Supporting Structures are altered.

Not a big concern..

Lower head default properties has been kept.

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QUENCH-06 HS NODALIZATION

In the HS package thermal insulation system is modeled.

Heat structures [1-42] have: To reflect COR axial structure

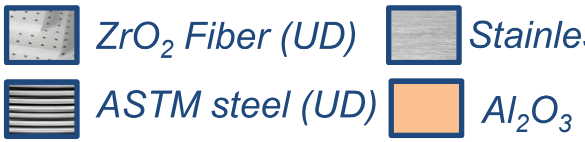
- LHS: *CalcCoefHS* option with the relative CV/Bypass + enabled radiation option

1. $\varepsilon_{Zry} = 0.8\,, \varepsilon_{SS} = 0.07$
2. $Rad.Path = Bypass\ thickness,$
3. $Heated\ diameter = 0.001\ m].$

- RHS: boundary *TempCF* (from experimental data or reasonably guessed) or *CalcCoefHS* with CONTAINMENT.

Heat structure [43] UPPER_PLATE for the upper thermal shield.

Heat structure materials:



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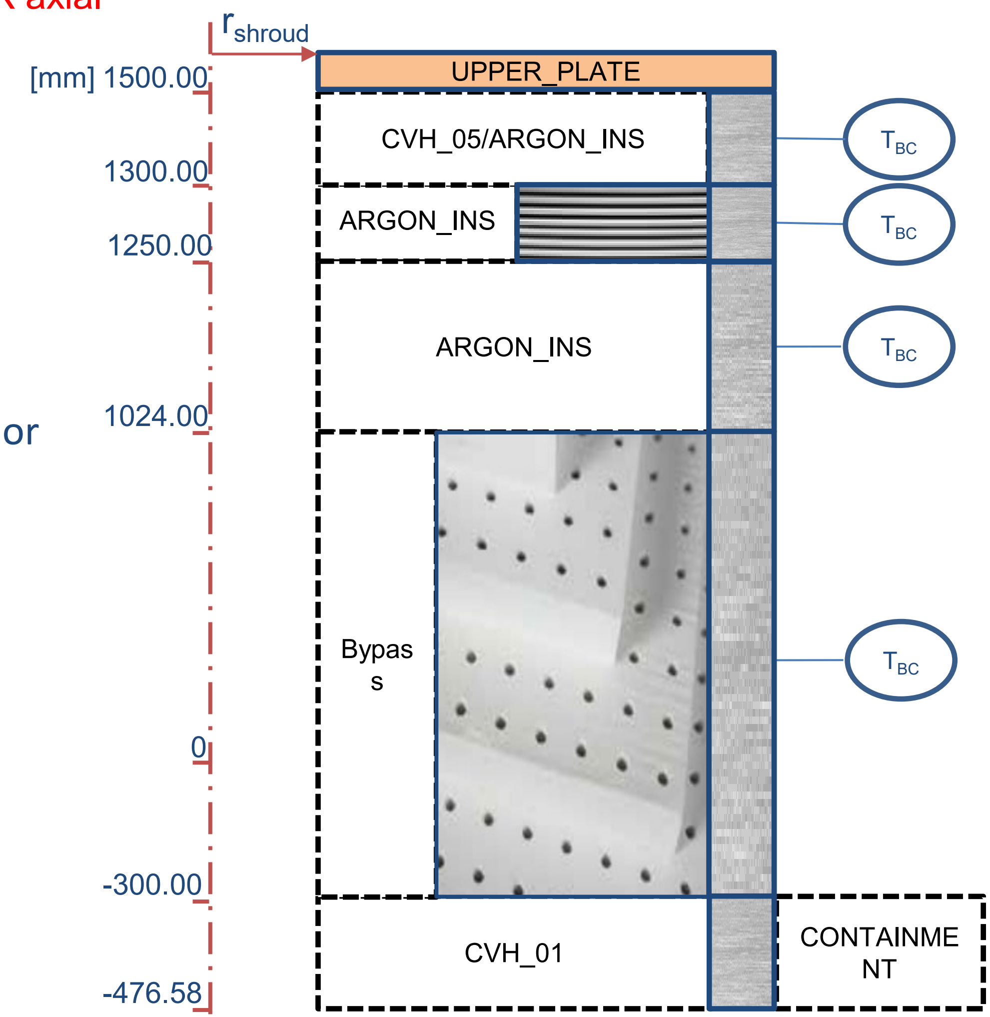
Cylindrical geometry



QUENCH-06 SENSITIVITY COEFFICENTS

Some sensitivity coefficients have been modified to better describe specific phenomenologies, unusual geometry and to solve some numeric issues arising from the fine nodalization of the input.

CVH_SC:
1. 4415(2) = 1.0E-5
2. 4415(3) = 1000.

One of the most occuring errors was
ERROR IN CVHMOM: ERROR SOLVING MATRIX IN SPARSE FORM
Hence with those modifications, error tolerance is enhanced and an higher n° of allowed iterations per cycle are permitted.

HS_SC:
1. 4205(1) = 1.0E-5 [kg]

This SC referres to the minimum mass of unmelted steel on which an HS could still run without being deactivated.
This attempts was devoted to preventing the following error:
UPPEST 4 HS BEING DEACTIVATED (made just by a thin slab of steel).

COR_SC:
1. 1004(1) = 1100 [K] default
2. 1132(1) = 2990.0 [K]
3. 1132(2) = 3695 [K]
4. 1502(1) = 1.0E-9 [kg]
5. 1502(2) = 1.0E-7 [kg]

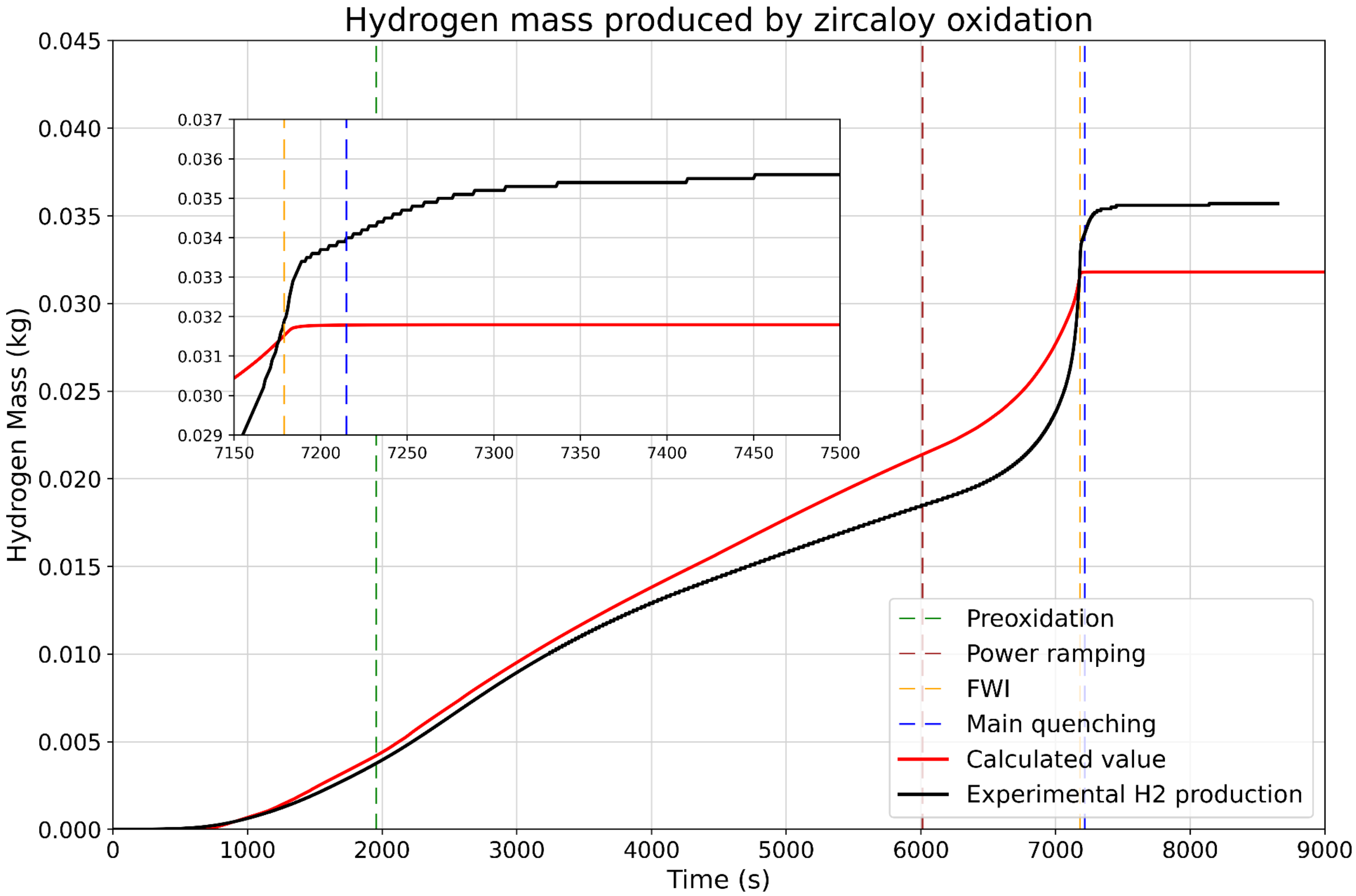
Some SC are needed while dealing with so light-weight component

COR_SC 1401 instead is devoted to control the DT(COR).

RESULTS

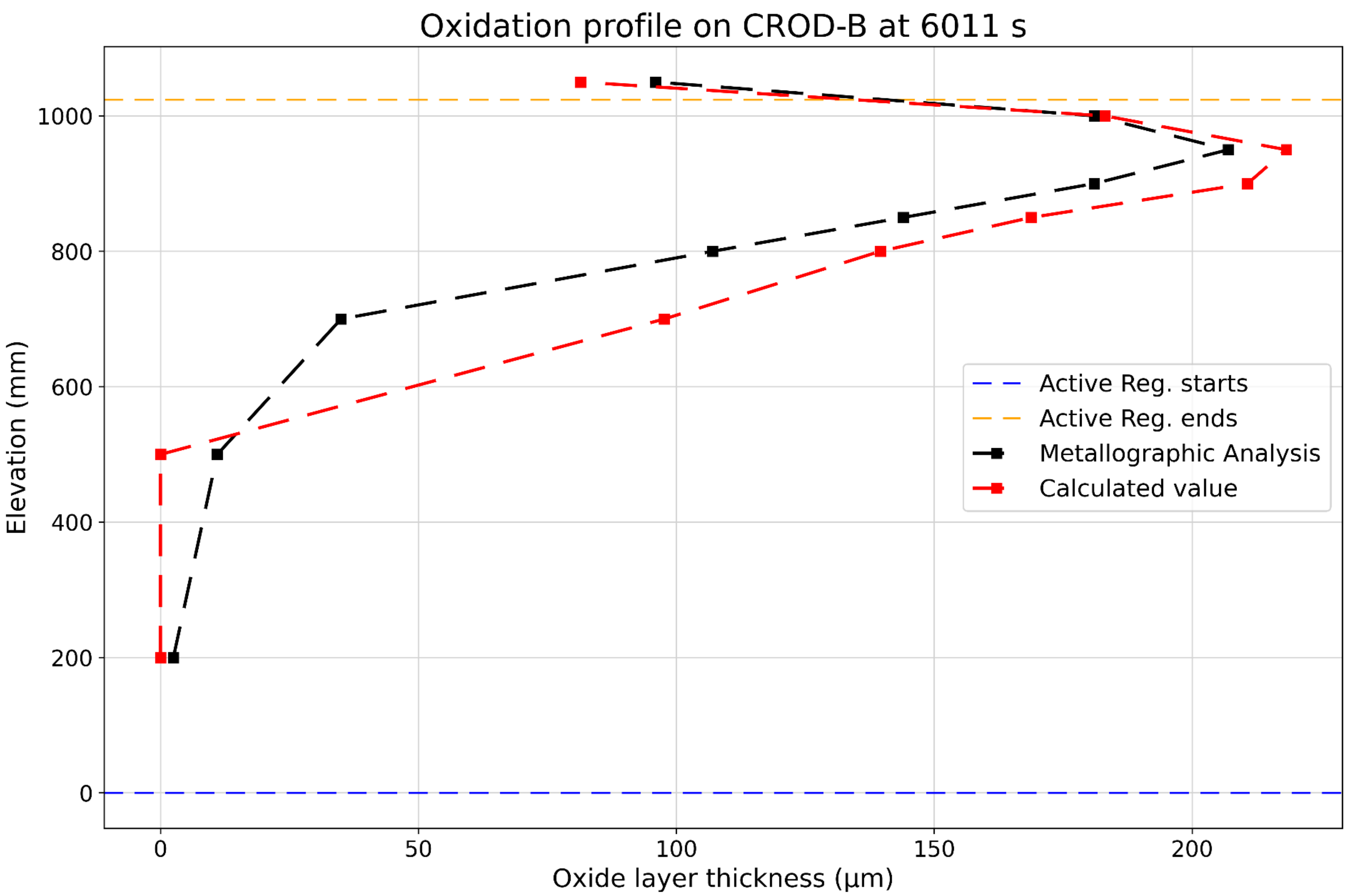
REFERENCE CASE RESULTS AND COMPARISON WITH EXPERIMENTAL DATA

RESULTS



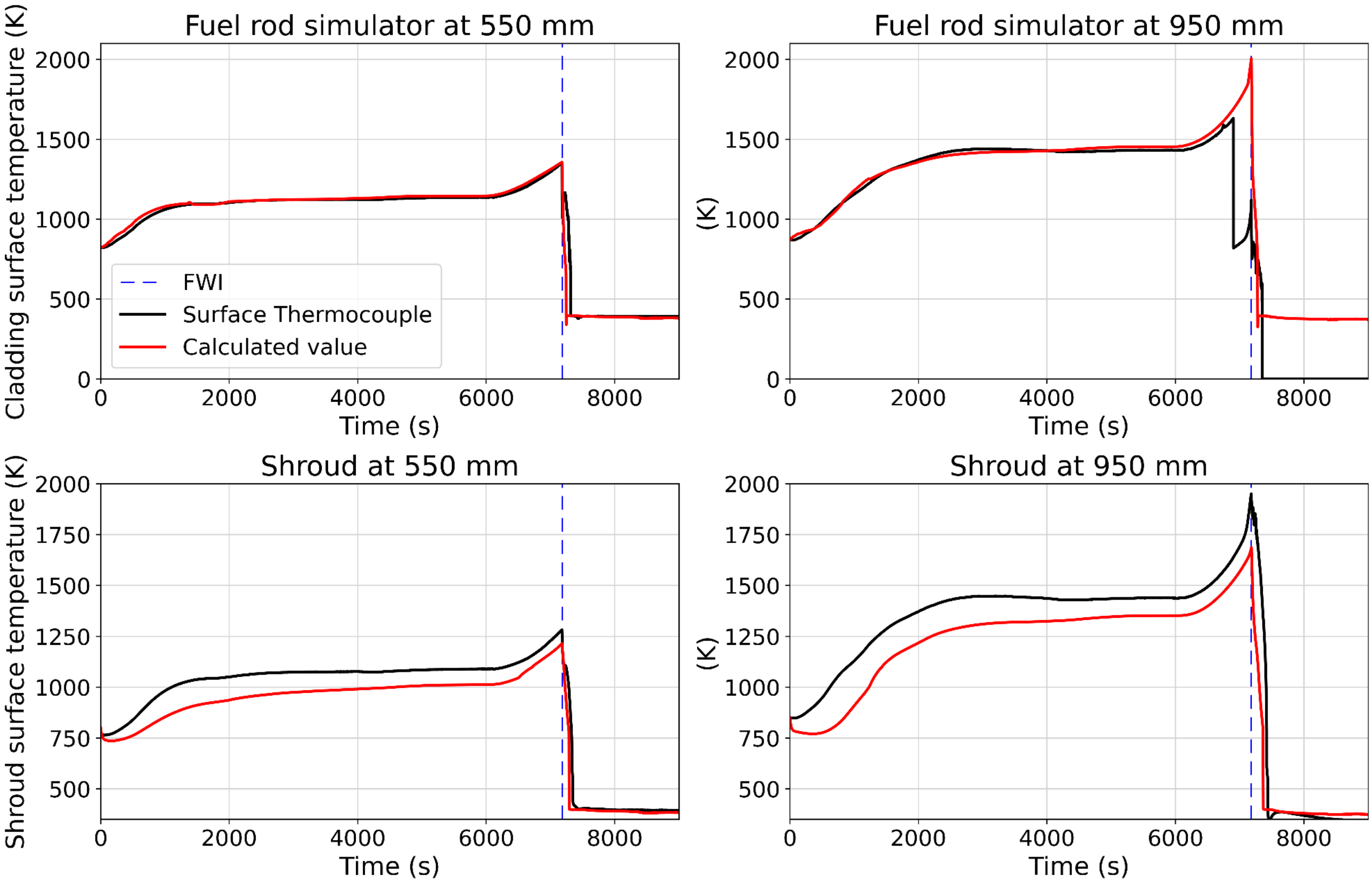
Hydrogen mass produced by zircaloy oxidation
Hydrogen Mass (kg)
Time (s)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0.037
0.036
0.035
0.034
0.033
0.032
0.031
0.030
0.029
7150
7200
7250
7300
7350
7400
7450
7500
Preoxidation
Power ramping
FWI
Main quenching
Calculated value
Experimental H2 production

RESULTS

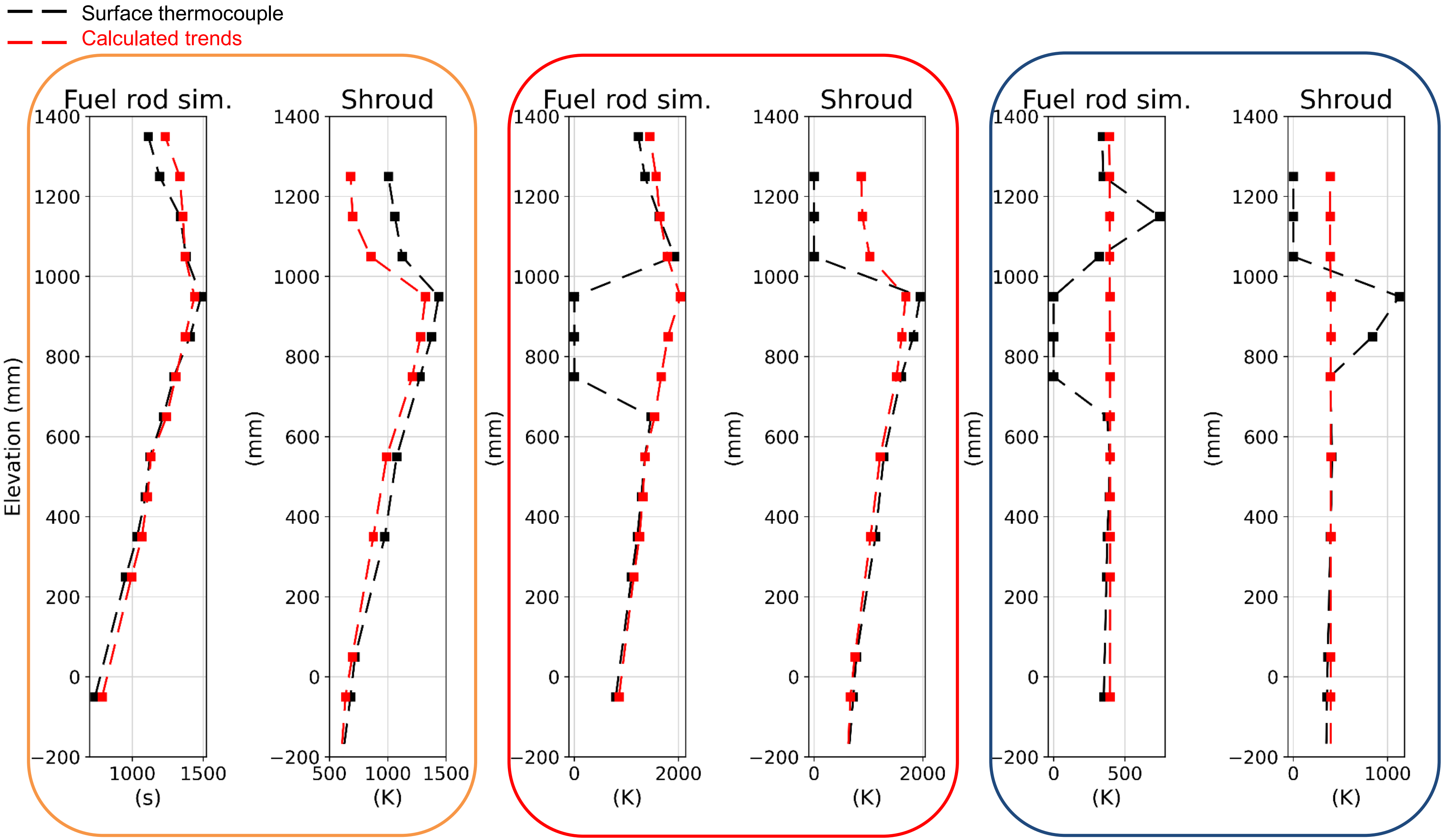


Oxidation profile on CROD-B at 6011 s
Elevation (mm)
Oxide layer thickness (μm)
0
200
400
600
800
1000
0
50
100
150
200
Active Reg. starts
Active Reg. ends
Metallographic Analysis
Calculated value

RESULTS


Fuel rod simulator at 550 mm
Fuel rod simulator at 950 mm
Shroud at 550 mm
Shroud at 950 mm
Cladding surface temperature (K)
Shroud surface temperature (K)
(K)
Time (s)
FWI
Surface Thermocouple
Calculated value
2000
1500
1000
500
0
1750
1250
750
4000
6000
8000

RESULTS



Preoxidation
t = 4000 s

Power ramping
t = 7179 s

Quenching
t = 7400 s

RESULTS

Fast Fourier Based Transform Method (FFBTM) tool delivers in output a **dimensionless indicator AA** for each variable in each phenomenological windows that acts **as indicator of the quantitative accuracy of the code results**.

Variables	Preoxidation	Power ramping	Quench and rest
Hydrogen Prod.	0,15	0,20	0,23
Rod Temperature 950 mm	0,03	-	-
Shroud Temperature 950 mm	0,13	0,14	0,33
Rod Temperature 1250 mm	0,31	0,21	0,73
Shroud Temperature 1250 mm	0,57	-	-
Rod Temperature 50 mm	0,21	0,21	0,80
Rod Temperature 550 mm	0,03	0,02	0,49
Collapsed Liquid level	0,14	0,07	0,94

- AA ≤ 0.3: very good code prediction;
- 0.3 < AA ≤ 0.5: good code prediction;
- 0.5 < AA ≤ 0.7: poor code prediction;
- 0.7 < AA: insufficient.

Issues:

1. Elevation 1250 mm is critical in the input.
2. Difficult to catch evaporation after FWI at 50 mm and 550 mm (affecting Liquid Level).

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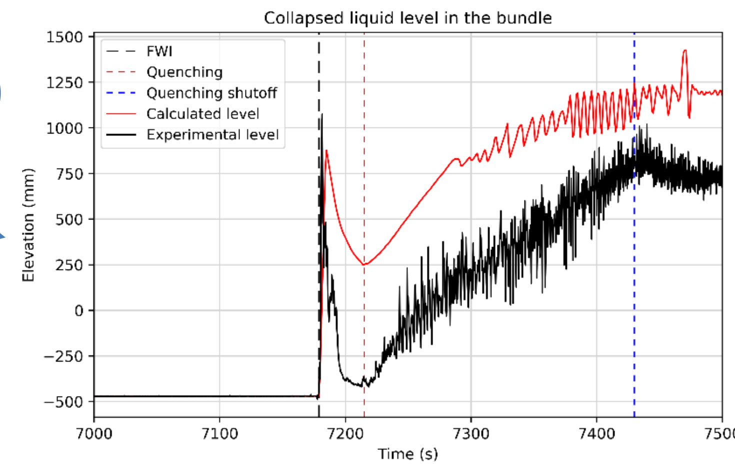
INPUT ISSUES

Reference Input does not predict evaporation of FWI water

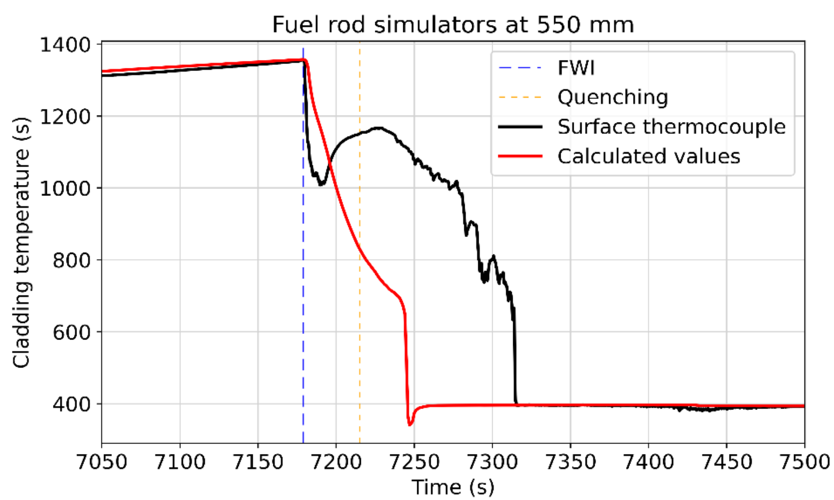
Waterfront is located at higher altitude

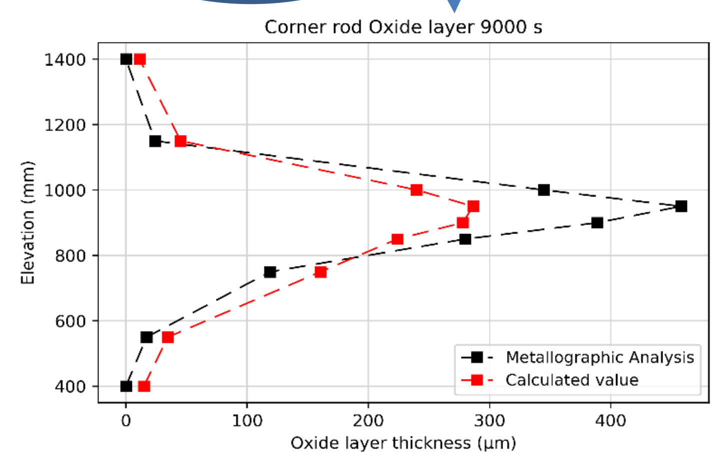


Rod temperature does not increase again in between the two quenching

No further 4 g of H_2 generation

Final oxide thickness is underestimat ed





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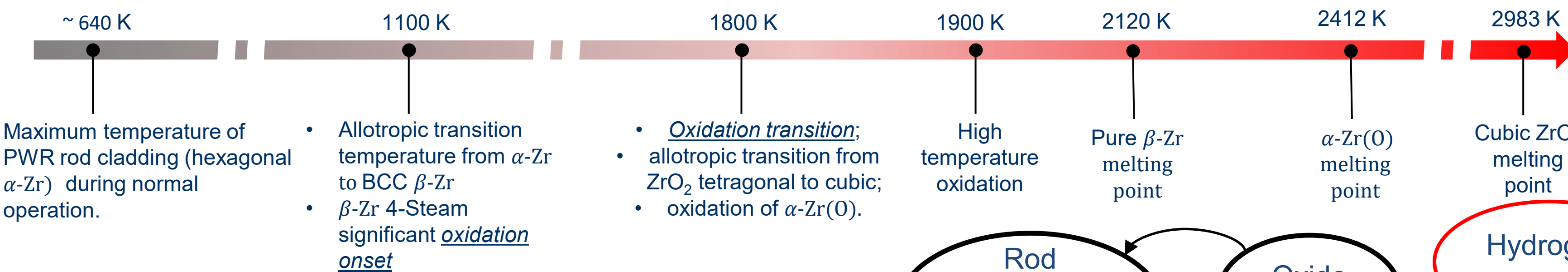
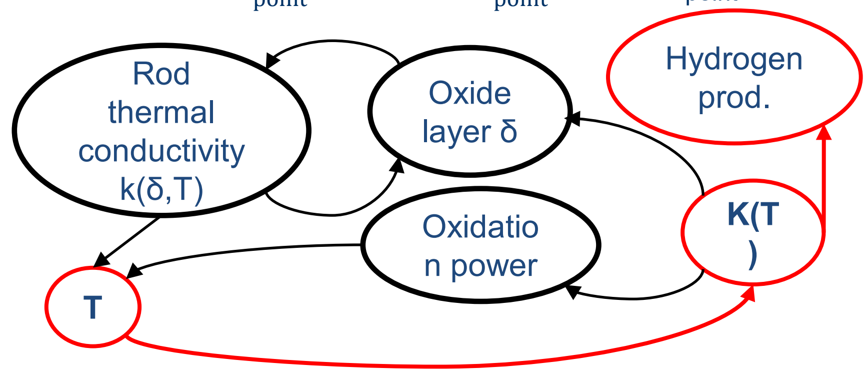
RESULTS

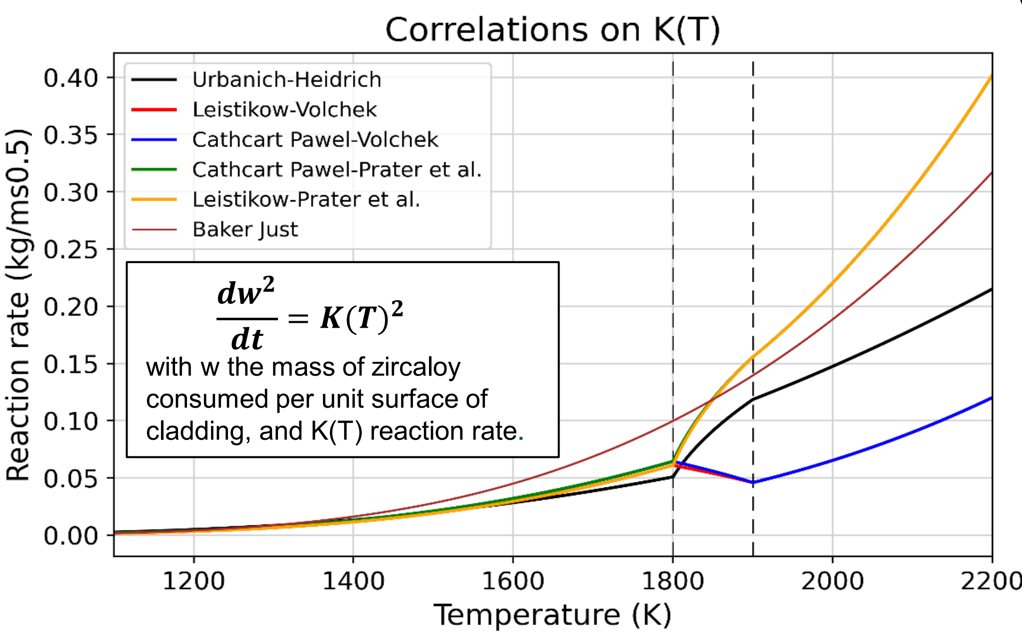
SENSITIVITY ANALYSIS ADOPTING DIFFERENT ZIRCALOY-STEAM OXIDATION CORRELATIONS

ZIRCALOY-STEAM OXIDATION

Zry oxidation kinetics

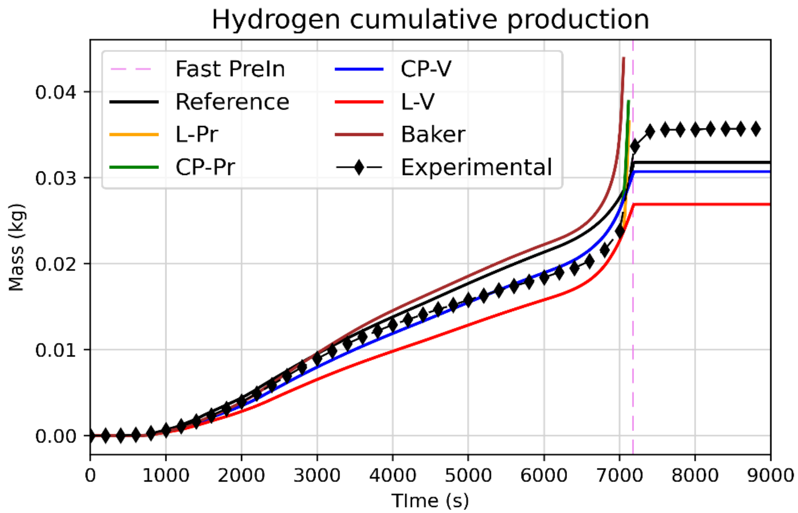




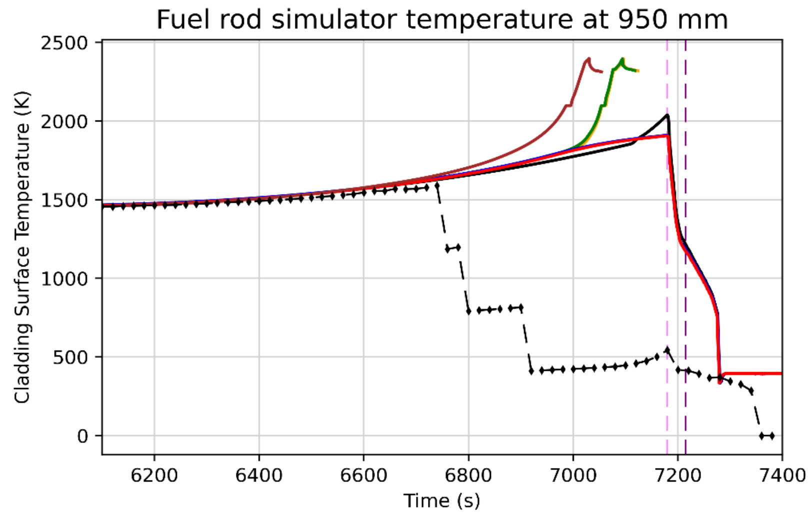


Simulations	K(T) T: [1100 K-1800 K]	K(T) T > 1900 K
1. Reference	Urbanich-Heidrich (default)	
2. Baker	Baker-Just	
3. L-V	Leistikow-Schanz	Volchek [1]
4. CP-V	Cathcart-Pawel	Volchek [1]
5. L-Pr	Leistikow-Schanz	Prater-Courtright
6. CP-Pr	Cathcart-Pawel	Prater-Courtright

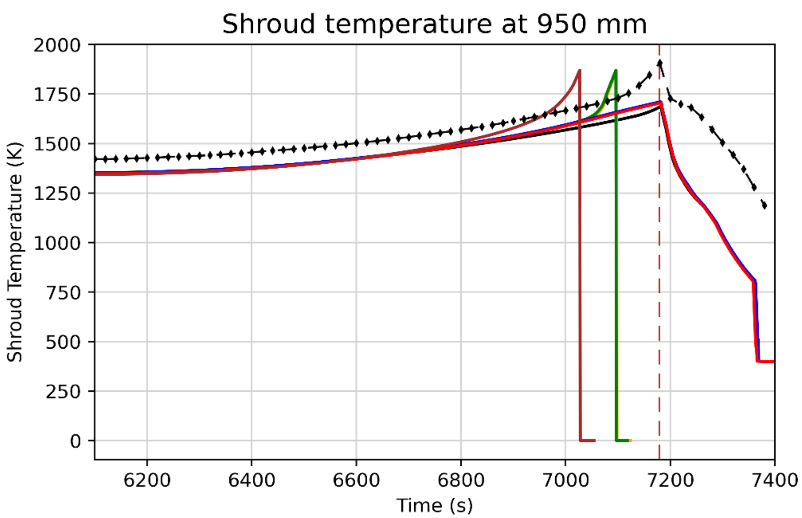
SA RESULTS



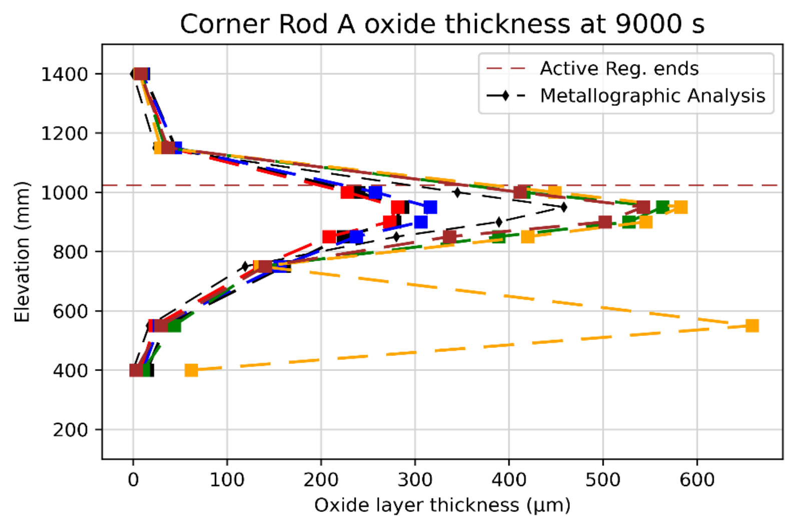
Hydrogen cumulative production
Fast PreIn
Reference
L-Pr
CP-Pr
CP-V
L-V
Baker
Experimental
Mass (kg)
0.00
0.01
0.02
0.03
0.04
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
TIme (s)



Fuel rod simulator temperature at 950 mm
Cladding Surface Temperature (K)
0
500
1000
1500
2000
2500
6200
6400
6600
6800
7000
7200
7400
Time (s)



Shroud temperature at 950 mm
Shroud Temperature (K)
0
250
500
750
1000
1250
1500
1750
2000
6200
6400
6600
6800
7000
7200
7400
Time (s)



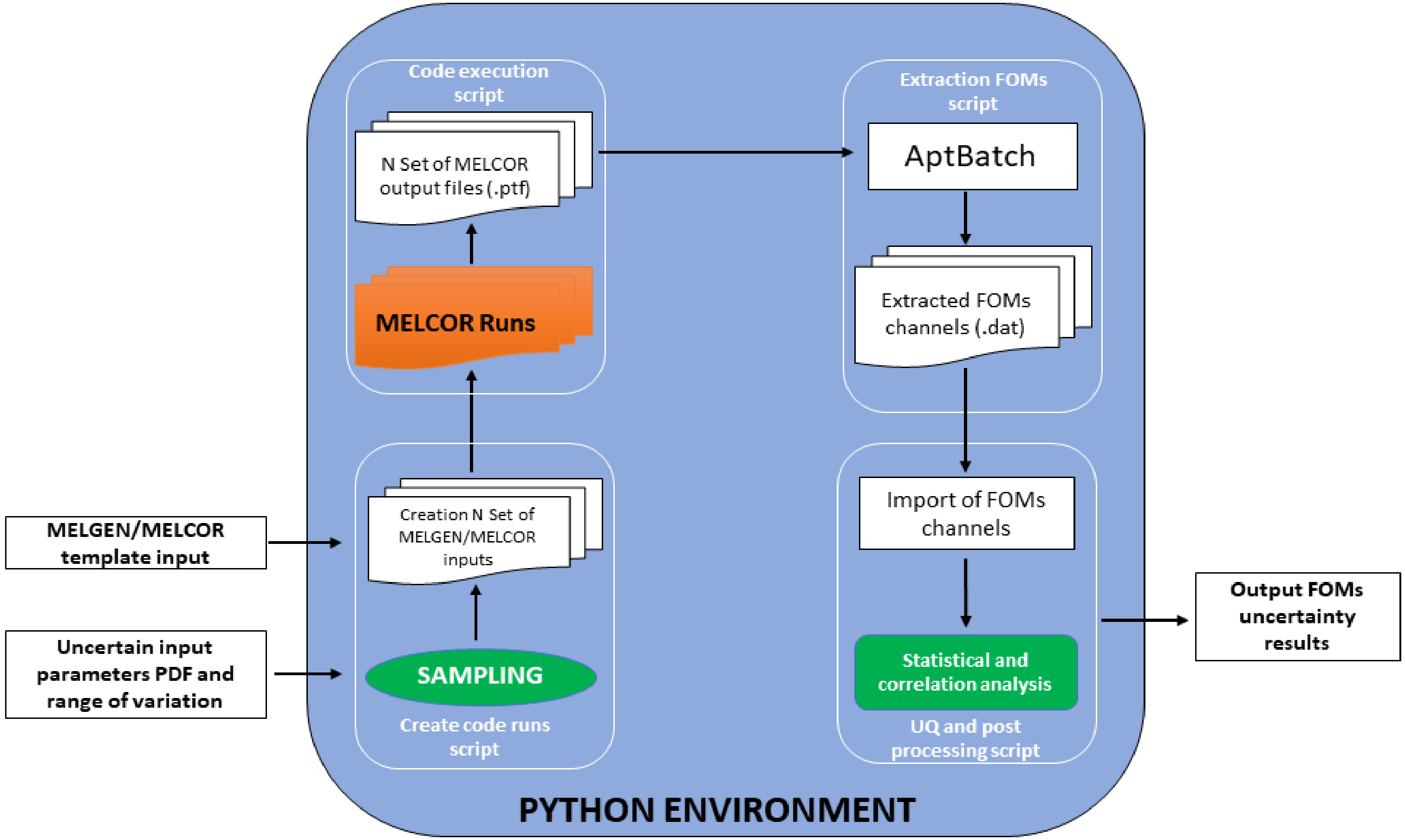
Corner Rod A oxide thickness at 9000 s
Active Reg. ends
Metallographic Analysis
Elevation (mm)
200
400
600
800
1000
1200
1400
0
100
200
300
400
500
600
Oxide layer thickness (μm)

UNCERTAINTY ANALYSIS ADOPTING INPUT WITH CATHCART-PAWEL & VOLCHEK OXIDATION CORRELATIONS

UA TOOL

- The probabilistic method to propagate input uncertainty has been chosen to conduct the Uncertainty Analysis (UA).
- A tool in Python has been developed to conduct the UA. The Uncertainty Tool permits to set the UA in terms of uncertainty input parameters Probabilistic Density Functions (PDFs), sampling methods (e.g. Random Sampling, Latin Hypercube, etc.) and response data.
- The in-house tool, substitute the sampled uncertain input parameters in the sets of MELGEN/MELCOR inputs, run MELCOR simulations and extract the desired FOMs channels through the AptBatch executable.
- In this present UQ application, the **hydrogen cumulative mass production** has been selected as FOMs.
- Based on Wilks theory, a minimum of 59 code runs are required for one-sided confidence level of 95% in the case one FOM is selected.

UA WORKFLOW



MELGEN/MELCOR template input
Uncertain input parameters PDF and range of variation
Code execution script
N Set of MELCOR output files (.ptf)
MELCOR Runs
Creation N Set of MELGEN/MELCOR inputs
SAMPLING
Create code runs script
Extraction FOMs script
AptBatch
Extracted FOMs channels (.dat)
Import of FOMs channels
Statistical and correlation analysis
UQ and post processing script
PYTHON ENVIRONMENT
Output FOMs uncertainty results

UNCERTAINY QUANTIFICATION HYPOTHESES (1)

- The uncertain input parameters, their ranges and PDFs have been provided by KIT leader of task 1 (QUENCH-06 experiment) of IAEA CRP I31033.

Name	Distribution Type	Mean	Parameters	
Steam_flow_rate, Argon_flow_rate, Quench_flow_rate [-]	Normal	1	low	0.98
			up	1.02
			St.dev	0.0133
Steam_temperature, Argon_temperature, Quench_temperature[-]	Normal	1	low	0.98
			up	1.02
			St.dev	0.0133
Outler_pressure [bar]	Normal	2E5	low	1.8E5
			up	2.1E5
			St.dev	1E4
FWI_pressure [bar]	Normal	6E5	low	5.7E5
			up	6.3E5
			St.dev	2E4
FWI_area [m^2]	Uniform	9.9E-5	min	8.91E-5
			max	1.09E-4
FWI_Friction [-]	Uniform	11	min	7.7
			max	14.3
Res_In, Res_Out [-]	Uniform	1	min	0.85
			max	1.15
Radial_Factor [-]	Uniform	1	min	0.8
			max	1
Biot_HTC [W/m^2K]	Uniform	1.5E5	min	1E5
			max	2E5
Max_Wall_Superheating [K]	Uniform	600	min	500
			max	700

Out of bundle wire R

Fcelr coeff.

For the QUENCH Model

UNCERTAINY QUANTIFICATION HYPOTHESES (2)

- In addition, also the oxidation onset temperature and the parameters of the Arrhenius formulation ofr the Zircaloy-Steam reaction rates (regarding both Cathcart-Pawel and Volchek formalisms) have been varied.

Name	Distribution Type	Mean	Parameters	
Onset_Ox_Temperature [K]	Uniform	1100	low	900
			up	1200
Ox. Par1 [K]	Normal	294.2	low	256.54
			up	331.85
			St.dev	25.1
Ox.Par2 [J]	Normal	20100	low	19768.35
			up	20431.65
			St.dev	221.1
Ox. Par3 [K]	Normal	107.4	low	102.03
			up	112.77
			St.dev	3.58
Ox.Par4 [J]	Normal	26822.2	low	26607.62
			up	27036.77
			St.dev	143.05

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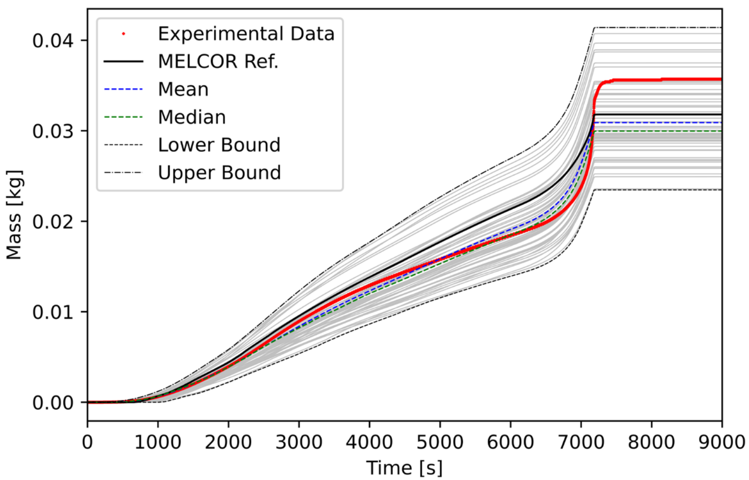
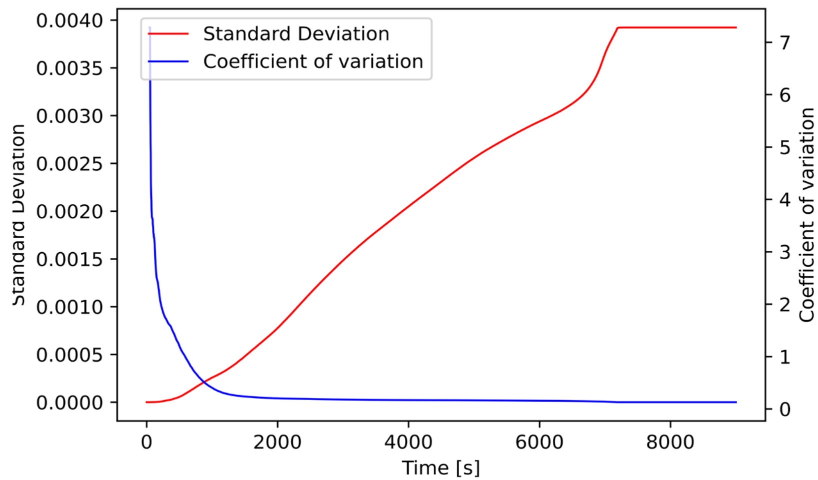
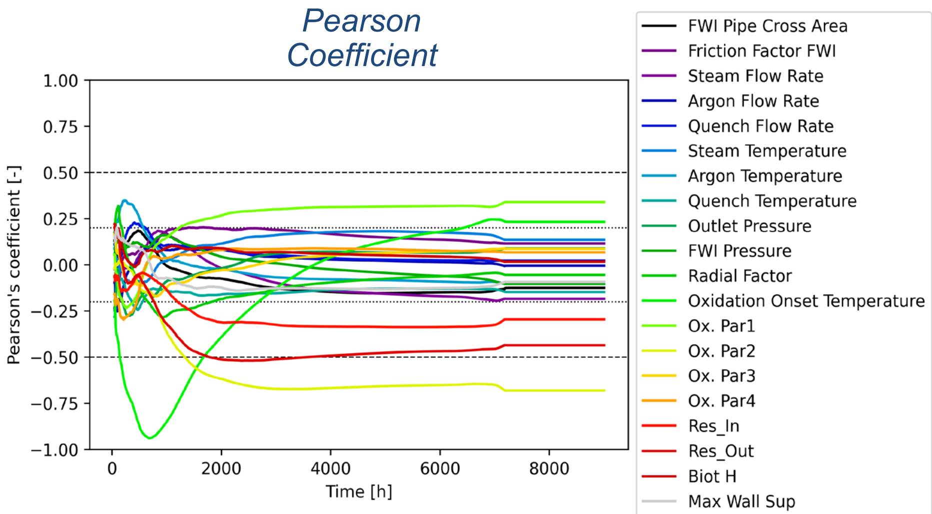
UA RESULTS

Hydrogen Production

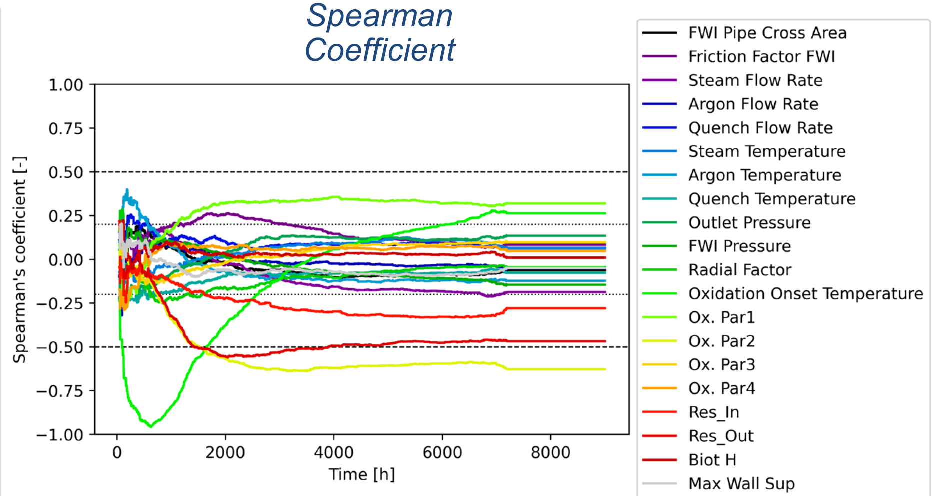




Pearson Coefficient

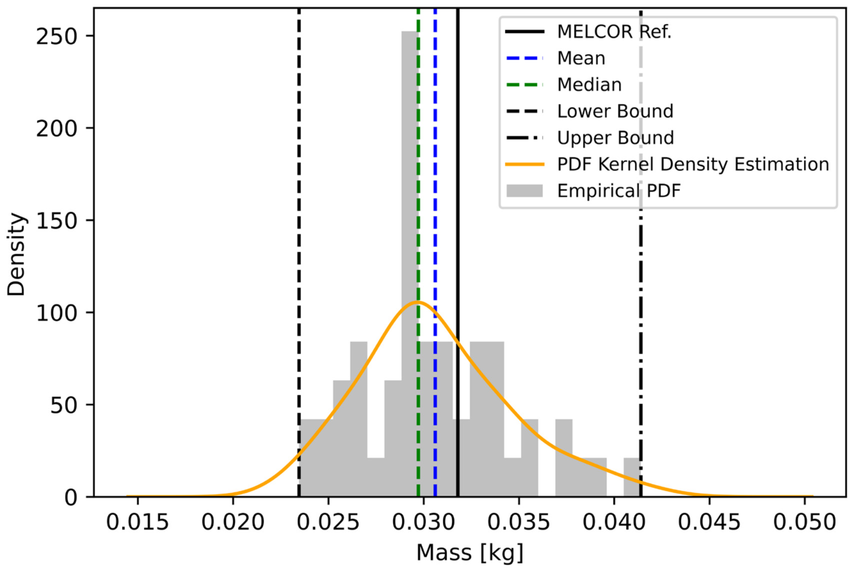


Spearman Coefficient



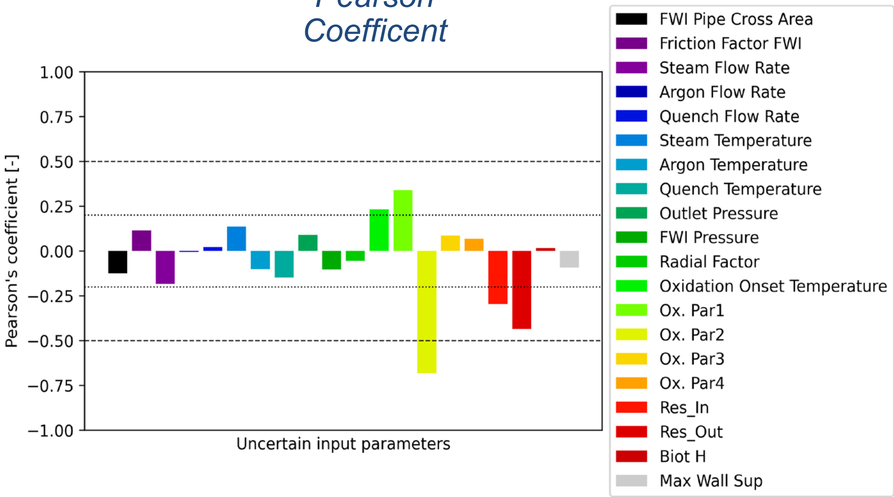
UA SCALAR ANALYSIS ON THE FINAL AND MAXIMUM VALUE OF THE FOM

Estimated Hydrogen production pdf

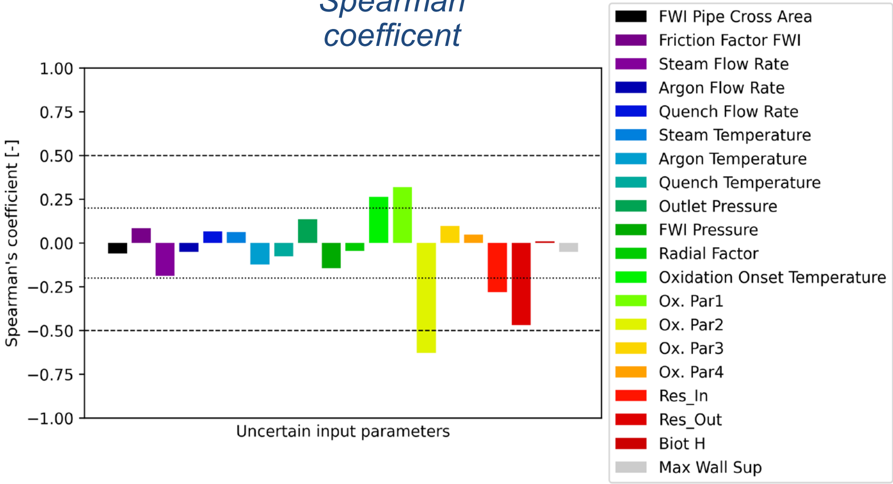


Uncertainty outcome	
Mean FOM	0,0306 kg
Median FOM	0,0297 kg
Lower Bound FOM	0,0235 kg
Upper Bound FOM	0,00414 kg

Pearson Coefficent



Spearman coefficent



UA REMARKS

The parameters with higher correlation with the FOM are:

- **Oxidation onset temperature**: as expected, by lowering it, the hydrogen mass predicted by the simulation increases;
- **Oxidation parameters 1 & 2**: they define the Arrhenius type reaction rate of *Cathcart-Pawel correlation* for the zircaloy oxidation when zircaloy structures temperature is under 1800 K.

$$K(T) = Ox.Par1 * e^{-\left(\frac{Ox.Par2}{RT}\right)}$$

- **Res_In** and **Res_Out**: they model the out-of-bundle wire resistances for the two rings of heated rods.

Standard deviation of the final distribution of the FOM is 12% of the mean value.

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CONCLUSIONS

QUENCH-06 nodalization may be employed, just modifying the boundary conditions, in every QUENCH test where fuel rod simulators are sheathed by zircaloy cladding.

QUENCH-06 *Reference Input:*

- Ability to reproduce the main phenomenologies occuring during **preoxidation** and **power ramping** phases
  - hydrogen build up and oxidation are in agreement with the experimental trend;
  - temperature reconstruction matches closely the experimental evolution.

- During **quenching**, it does not reproduce FWI evaporation:
  - no further hydrogen production and no thickening of oxide layers;
  - collapsed liquid level is overerstimated.

Sensitivity analysis has provided interesting insights:

- The ***CP-V*** simulation (Cathcart-Pawel and Volchek oxidation correlations) is suggested for future calculations;

- Shroud is predicted to fail while adopting Baker and Prater at el. Correlations

Uncertainty analysis has provided interesting insights:

- The experimental data is comprised in the uncertainty band;
- The uncertain input parameters with higher correlation with the FOM are: oxidation onset temperature, Oxidation parameters 1 & 2, Res_In and Res_Out.

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CONCLUSIONS

Thank you very much for your attention!

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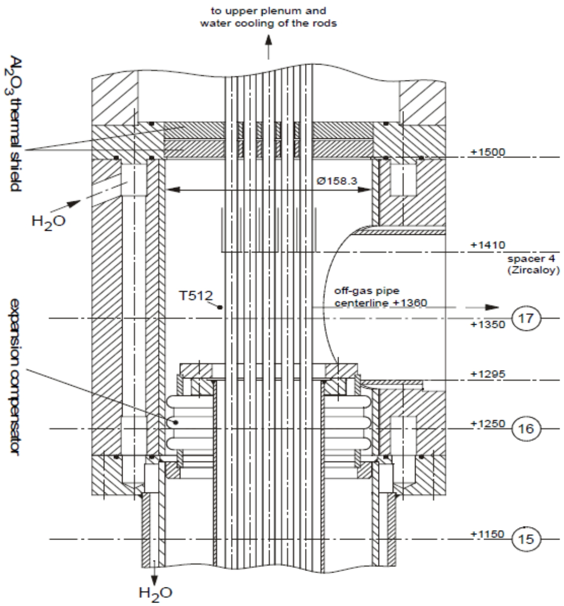
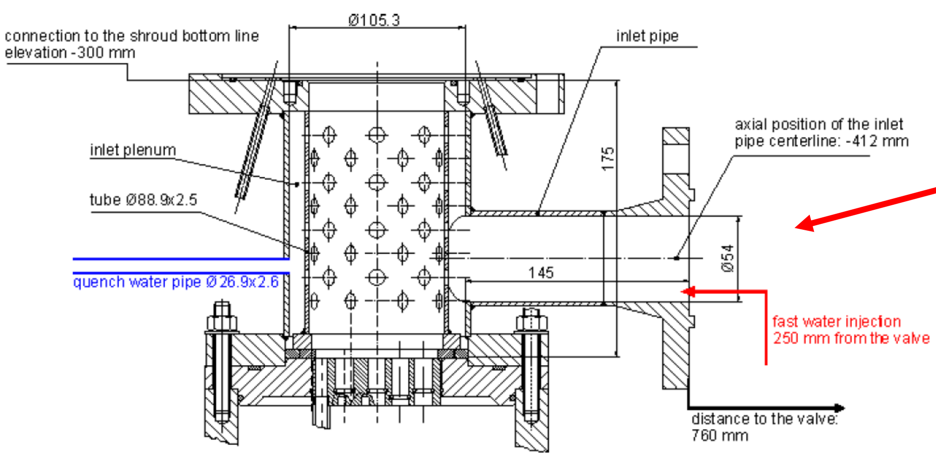
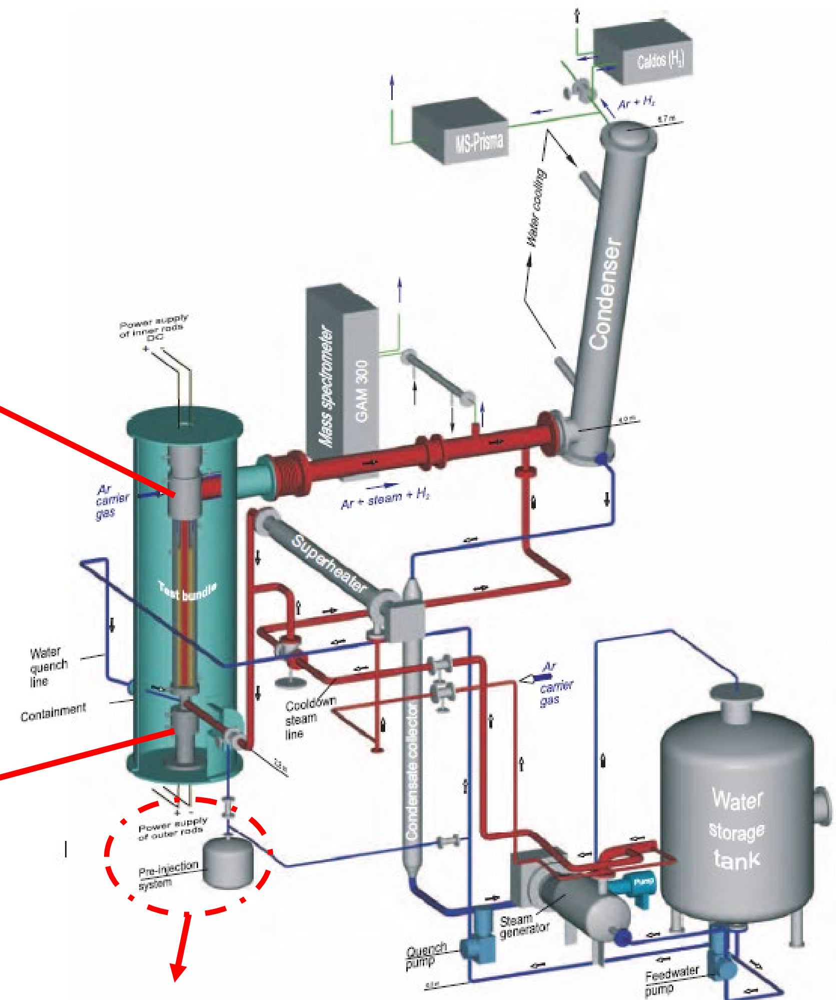
REFERENCES

[1] A. Volchek, Y. Zvonarev e G. Schanz, «Advanced treatment of zircaloy cladding high-temperature oxidation in severe accident code calculations. Part II. best-fitted parabolic correlations,» *Nuclear Engineering and Design,* pp. 85-96, 2003.

APPENDIX I: WATER LOOP AND PLENA







Fast Water Injection system

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APPENDIX II: SC QUENCH-06

Some SCs were added in order to solve timestep issues. In the following analyses, non mandatory parameters will be discarded.

Criteria for solving the Flow Eqts in Sparse Form [CVH]

- 4415(2): Convergence tolerance for iterative solver (Criteria for solving the Flow Eqts in Sparse Form)
- 4415(3): Max number of iterations permitted for the iterative solver

Stainless Steel Melting (Degassing) Parameters [HS]

- 4205(1): mass of unmelted steel below which the HS is deactivated and the remaining mass is relocated to the COR package

Core components failure parameters [COR]

- 1132(1): temperature to which oxidized fuel rods can stand in the absence of unoxidized Zr in cladding
- 1132(2): temperature at which fuel rods fail, regardless the composition of the cladding

Minimum Component Masses [COR]

- 1502(1): minimum total mass of a component
- 1502(2): minimum mass of a component subject to the max temperature change criterion for dt control

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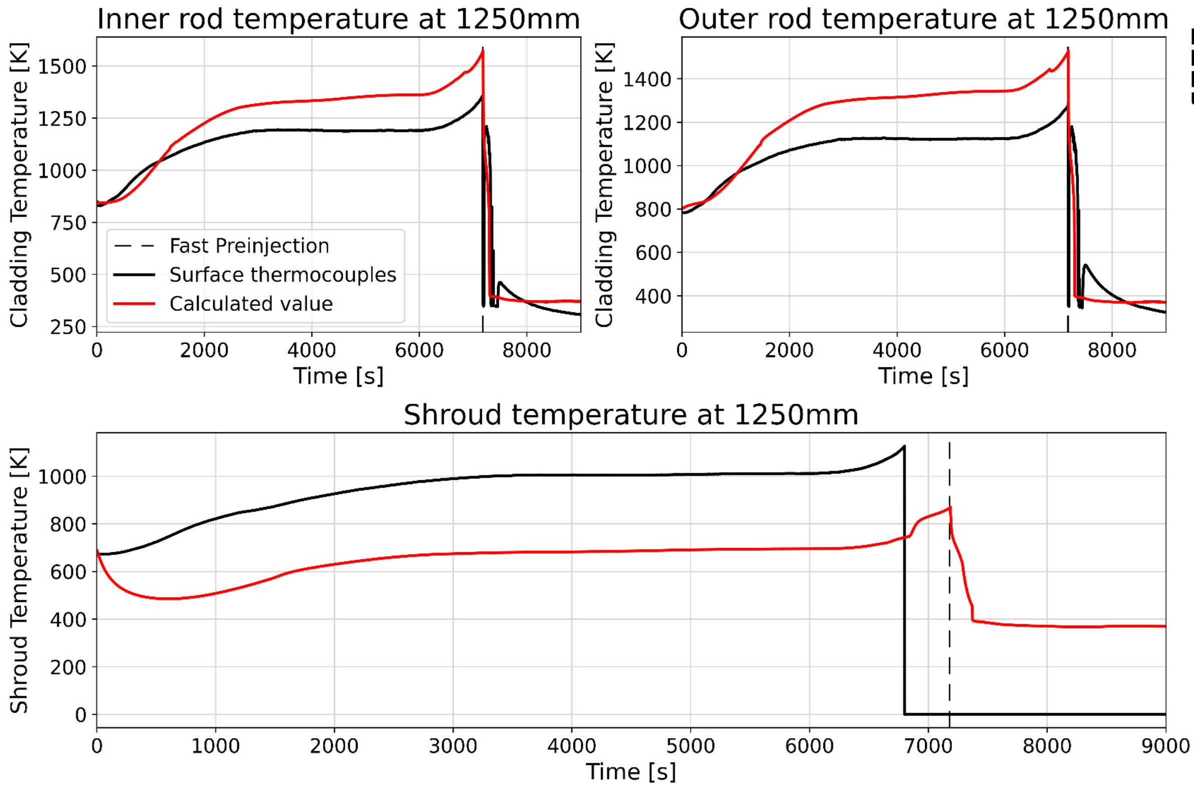
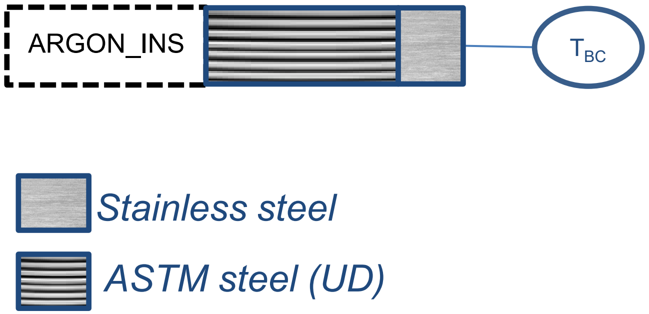
APPENDIX III: ELEVATION 1250 mm





Argon_Ins control volume and the heat structure (composed of the expansion compensator and the inner wall cooling jacket) are not correctly modeling radiative heat loss.