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UNCERTAINTY AND SENSITIVITY ANALYSIS OF THE PHEBUS FPT1 TEST SIMULATION RESULTS

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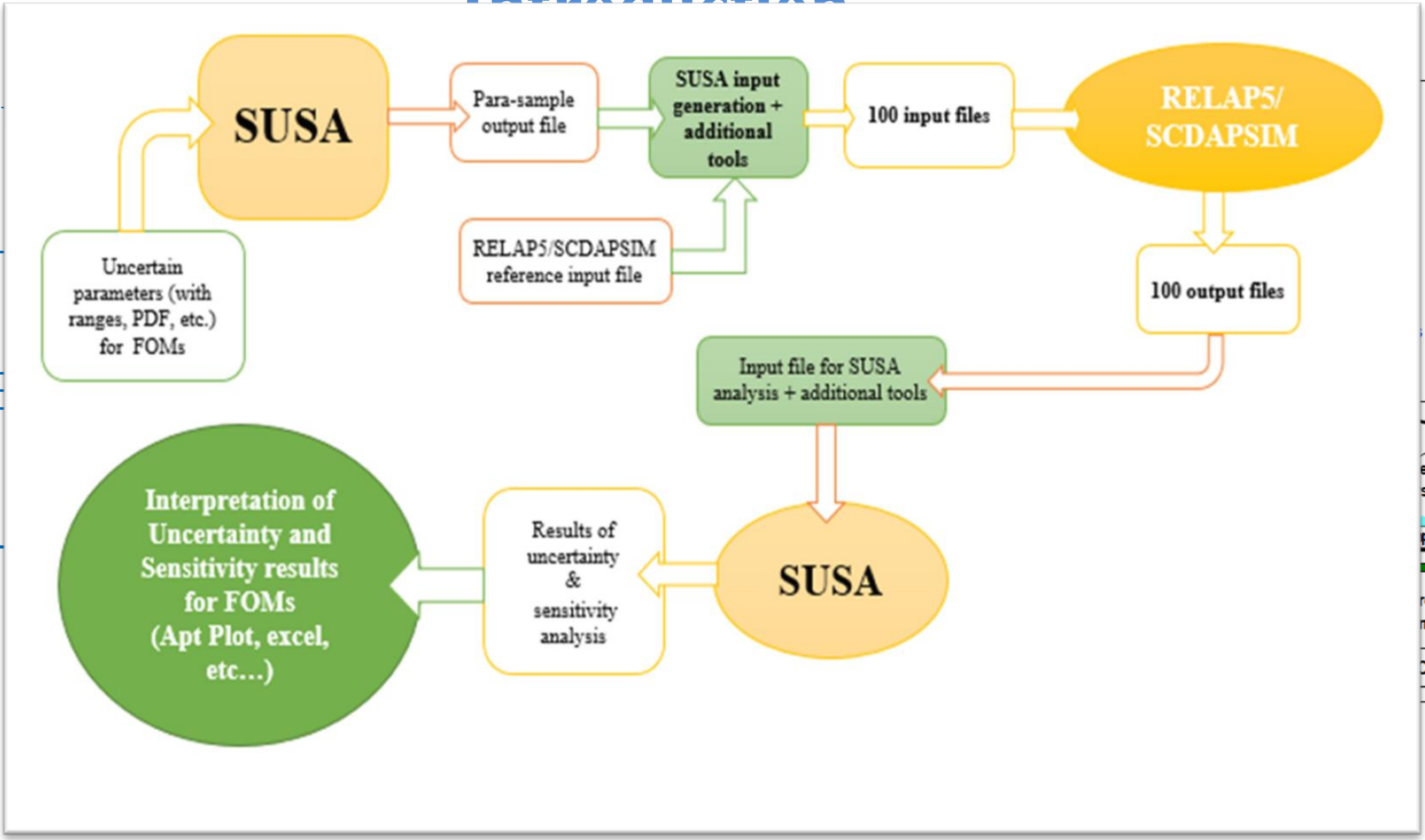
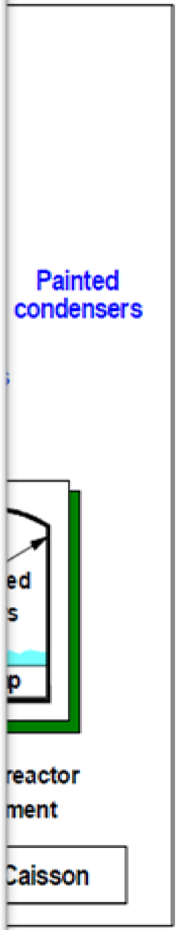
Content

- Introduction
  - PHEBUS FPT-1 test
  - RELAP/SCDAPSIM code
  - SUSA tool
  - Method of analysis
- Uncertainty quantification of PHEBUS FPT-1 test
  - Uncertainty analysis
  - Sensitivity analysis
- Conclusions, future work

Introduction

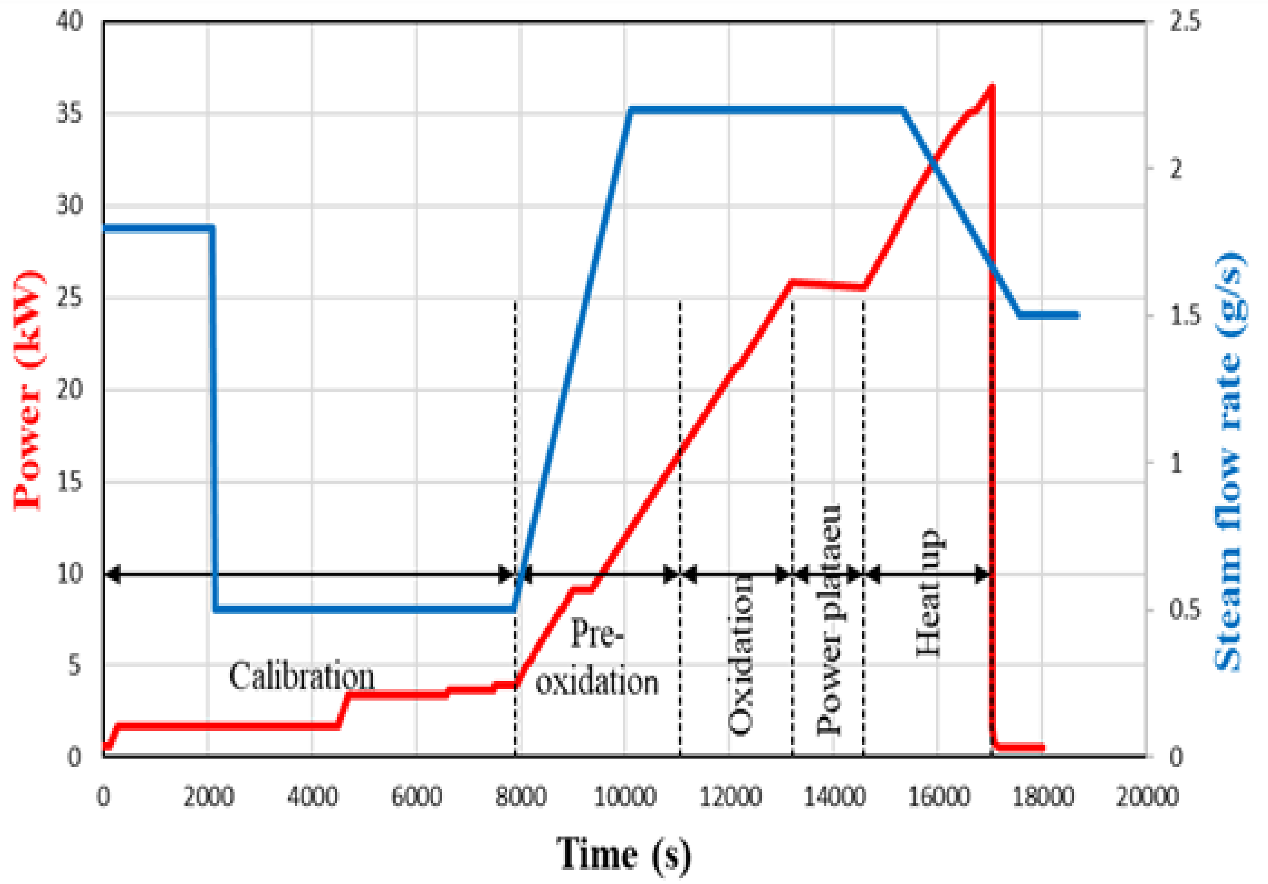
- M
- PH
- RE
- SU





Phases & processes of FPT1 test

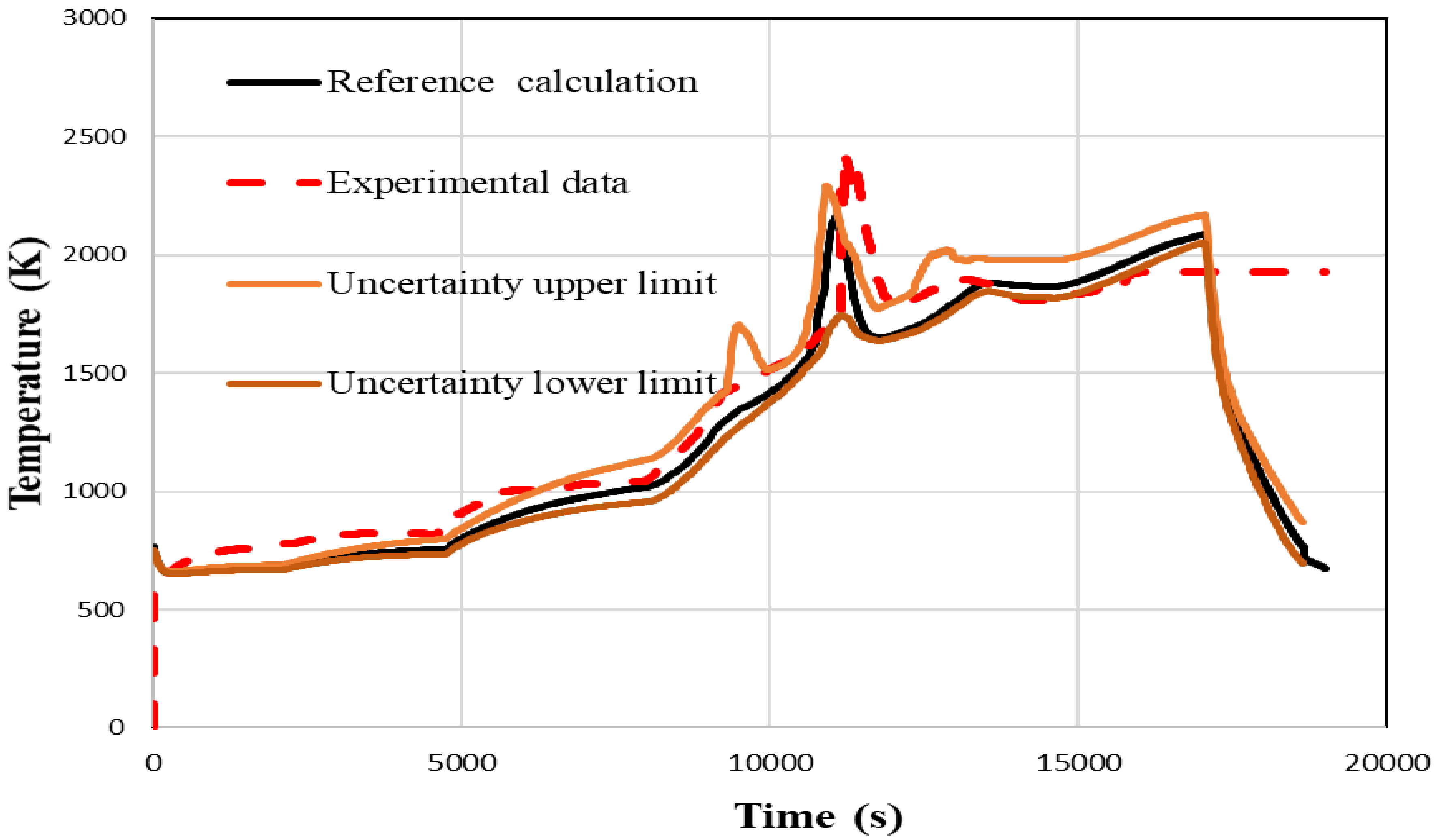
- **Calibration phase** ends at 7900 s;
- **Pre-oxidation phase** from 7900 s to 11060 s;
- **Oxidation phase** from 11060 s to 13200 s;
- **Power plateau phase** from 13200 s to 14580 s;
- **Heat up phase** from 14580 s to 17039 s.



Uncertainty parameters used in the calculations of PHEBUS FPT-1 experiment for cladding temperature & total hydrogen generation

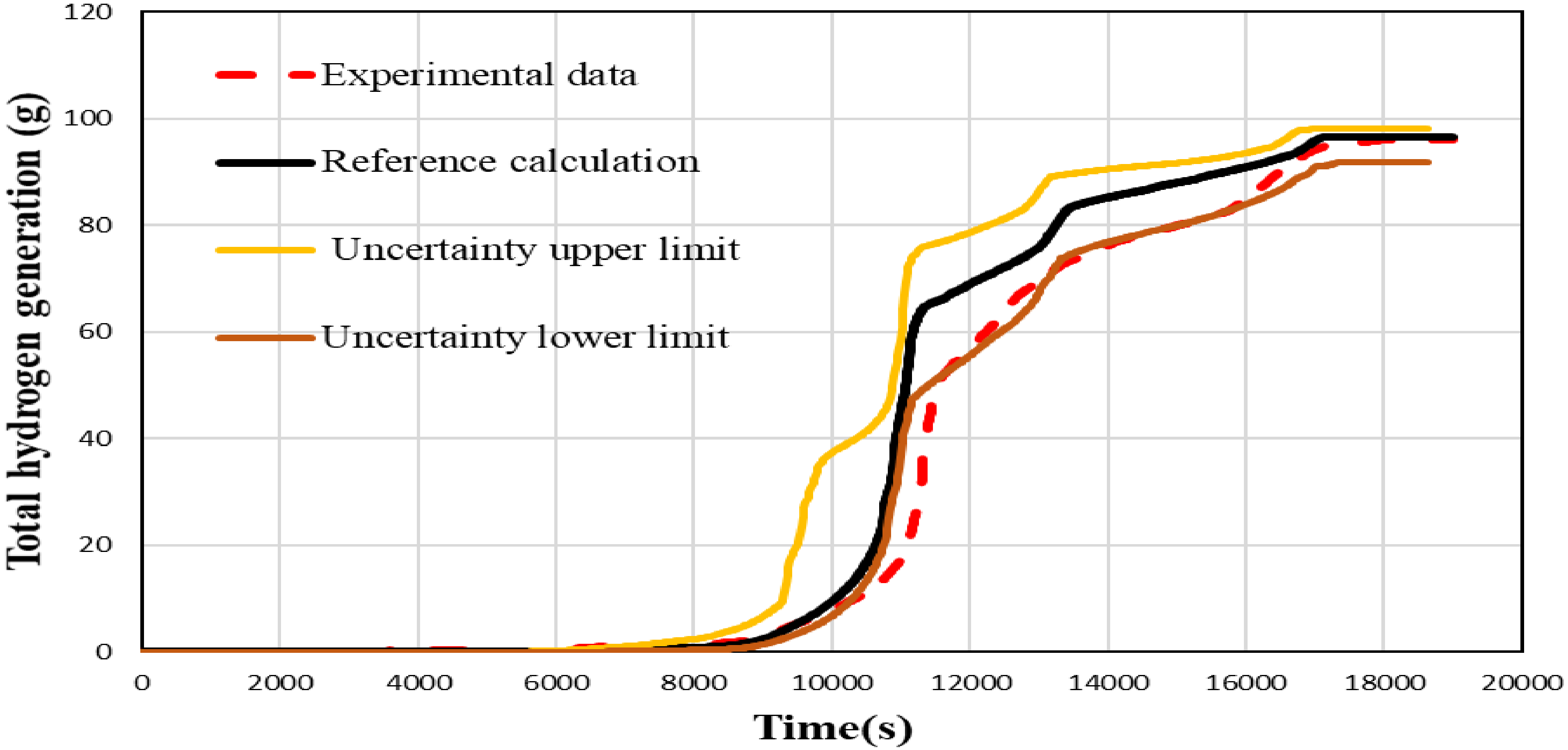
No	Parameter	Reference value	Ranges	PDF
	Thermal properties of materials			
P1	Zircaloy-4, Specific heat (J/kgK)	Reference value according to ISP-46 [5]	±20% [1, 2]	Normal
P2	Zircaloy-4, Density (kg/m^3)			
P3	Zircaloy-4, Thermal conductivity (W/mK)			
P4	Gap, Specific heat (J/kgK)			
P5	Gap, Density (kg/m^3)			
P6	Gap, Thermal conductivity (W/mK)			
P7	Thoria (ThO_2), Specific heat (J/kgK)			
P8	Thoria (ThO_2), Density (Kg/m^3)			
P9	Thoria (ThO_2), Thermal conductivity (W/mK)			
P10	ZrO_2, Specific heat (J/kgK)			
P11	ZrO_2, Density (kg/m^3)			
P12	ZrO_2, Thermal conductivity (W/mK)			
P13	Gap (inner and outer), Specific heat (J/kgK)			
P14	Gap (inner and outer), Density (kg/m^3)			
P15	Gap (inner and outer), Thermal conductivity (W/mK)			
P16	Spray coating, Specific heat (J/kgK)			
P17	Spray coating, Density (kg/m^3)			
P18	Spray coating, Thermal conductivity (W/mK)			
P19	Inconel^{625}, Specific heat (J/kgK)			
P20	Inconel^{625}, Density (kg/m^3)			
P21	Inconel^{625}, Thermal conductivity (W/mK)			
	SCDAP parameters			
P22	Temperature for failure of oxide shell on outer surface of fuel and cladding (K)	2500	±10%	Uniform
P23	Fraction of oxidation of fuel rod cladding for stable oxide shell	0.6	±50%	Uniform
P24	Hoop strain threshold for double-sided oxidation	0.07	±50%	Uniform
P25	Cladding rupture strain	0.18	0.1<x<0.2	Uniform
P26	Cladding transition strain	0.2	0.1<x<0.2	Uniform
P27	Limits strain. Strain limit for rod-to-rod contact	0.245	0.2<x<0.245	Exponential Lambda = 1
P28	Pressure drop caused by ballooning	Modelled	Modelled / not modelled	Discrete 0-0.5 prob 1-0.5 prob
P29	Fraction of surface area covered with drops that results in blockage that stops local oxidation	0.2	±50%	Uniform
P30	Velocity of drops of cladding material slumping down outside surface of fuel rod (m/s)	0.5	±50%	Uniform
P31	Gamma heat fraction. The fraction of power used to directly heat the coolant by gamma heating	0.026	±50%	Uniform
P32	Mass of grid spacer, kg	3.724E-3	±20%	Normal
P33	Height of grid spacer, m	0.043	±20%	Normal
P34	Plate thickness of grid spacer, m	0.004	±20%	Normal
P35	Definition of Core Slumping Model	0	0: latest possible; 1: earliest possible;	Discrete. 0 – 0.5 prob. 1 – 0.5 prob.
P36	Minimum flow area per fuel rod in cohesive debris in core region, m^2	4.4E-5	±50%	Normal

Uncertainty Results (1)



Uncertainty upper and lower limits with experimental data and reference calculation for cladding temperature at 950 mm elevation.

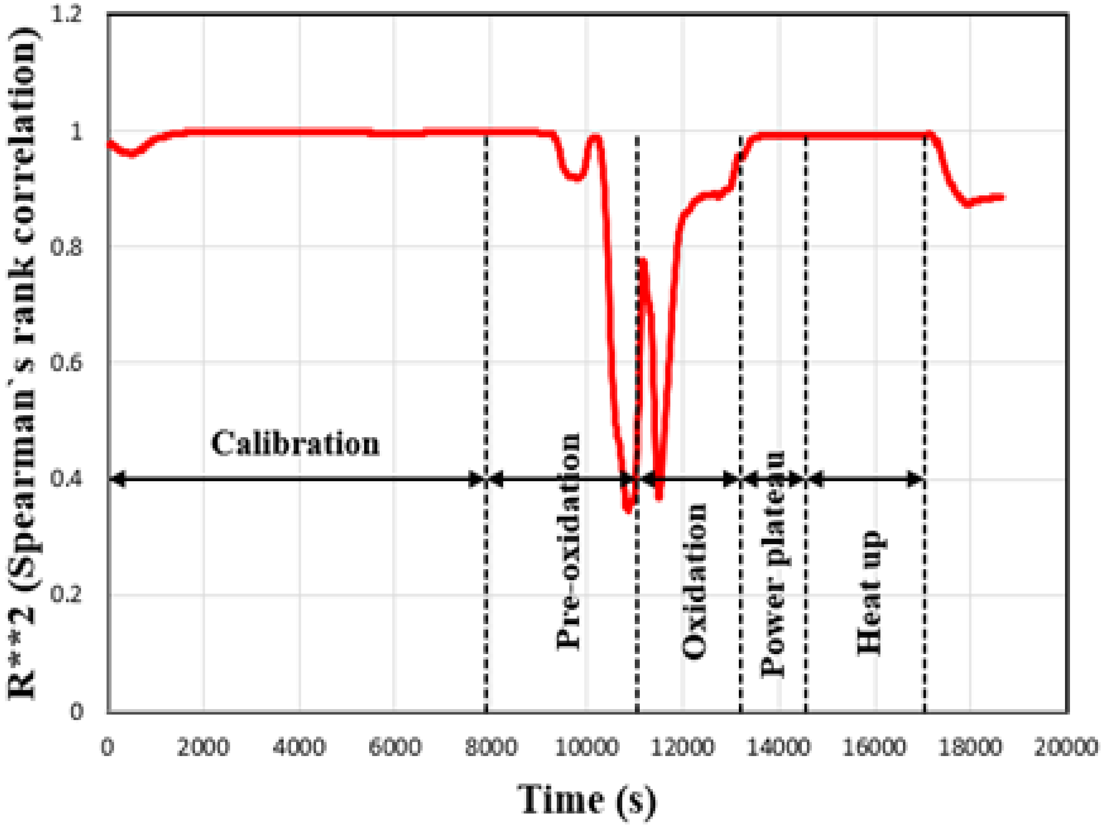
Uncertainty Results (2)



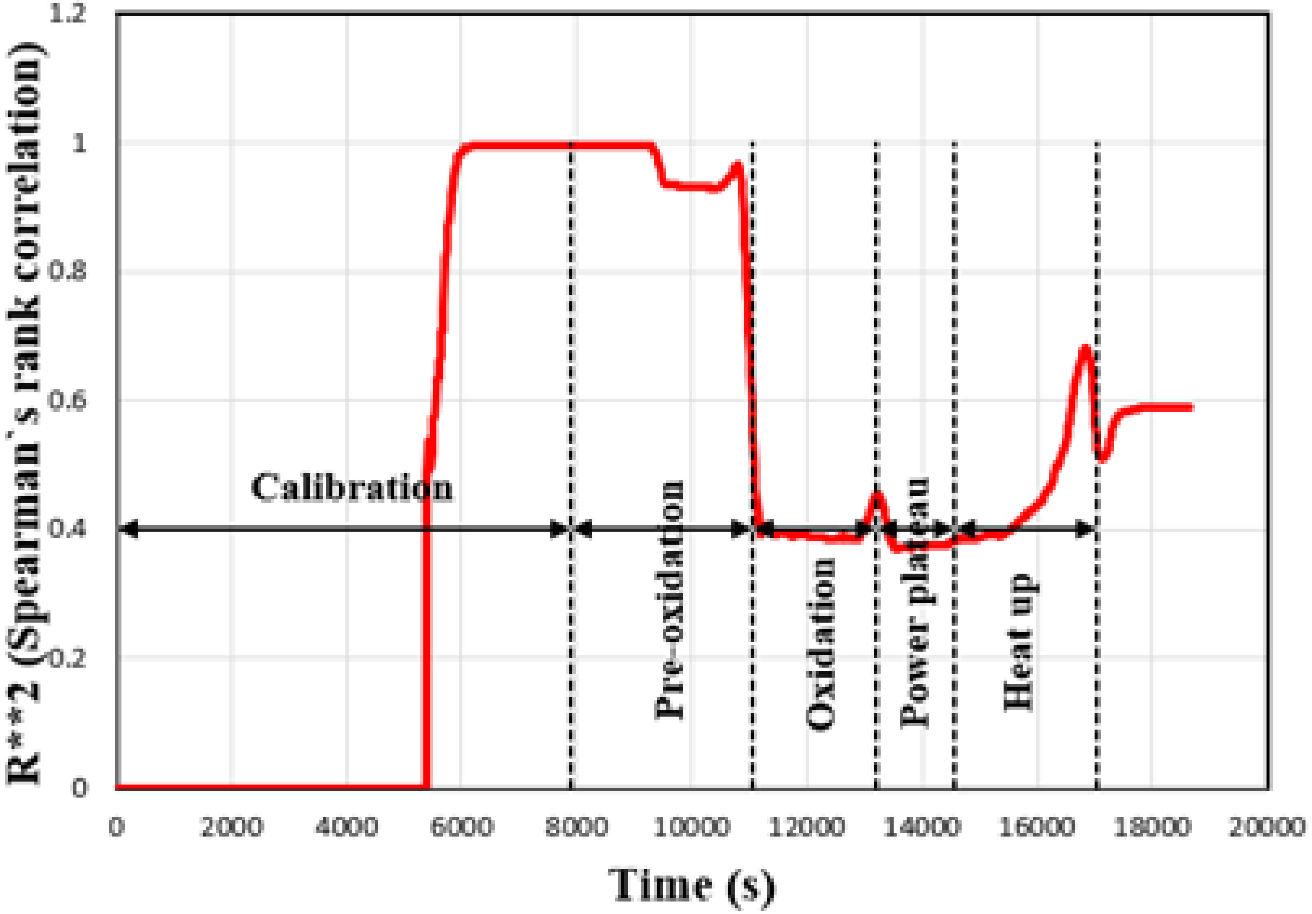
Uncertainty upper and lower limits with experimental data and reference calculation for total hydrogen generation.

Sensitivity results (1)

Determination coefficient (R^2)



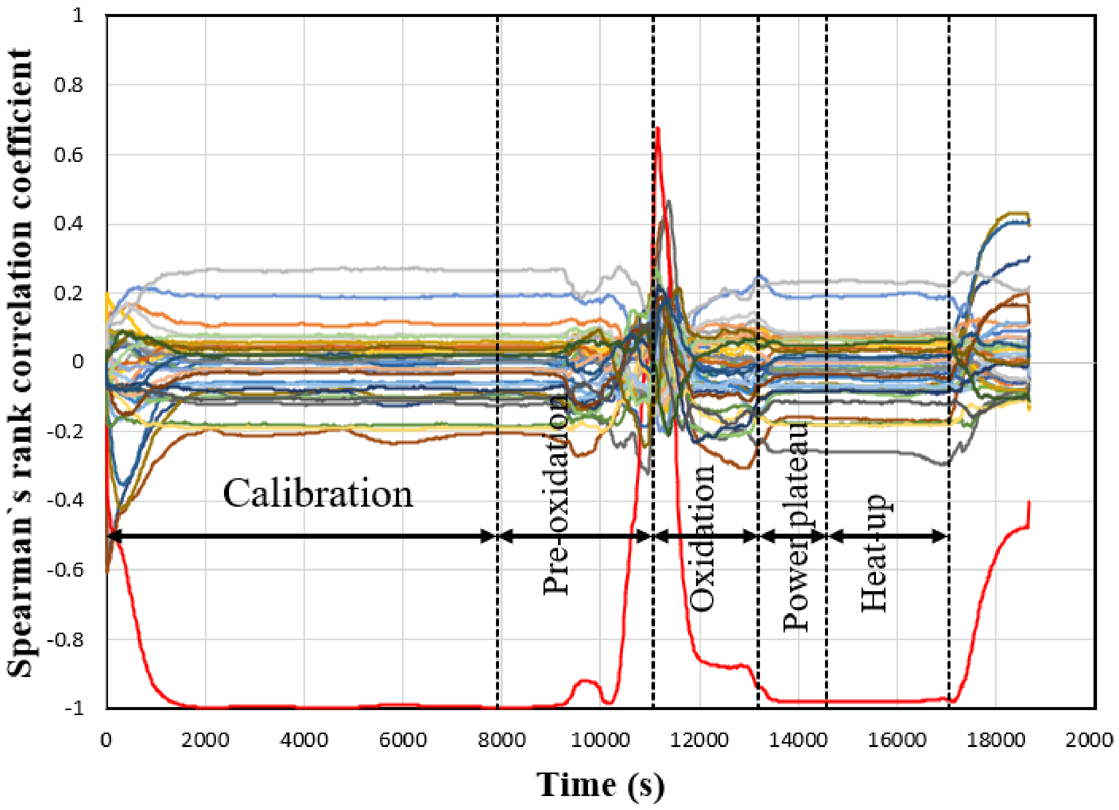
Cladding temperature at 950 mm elevation



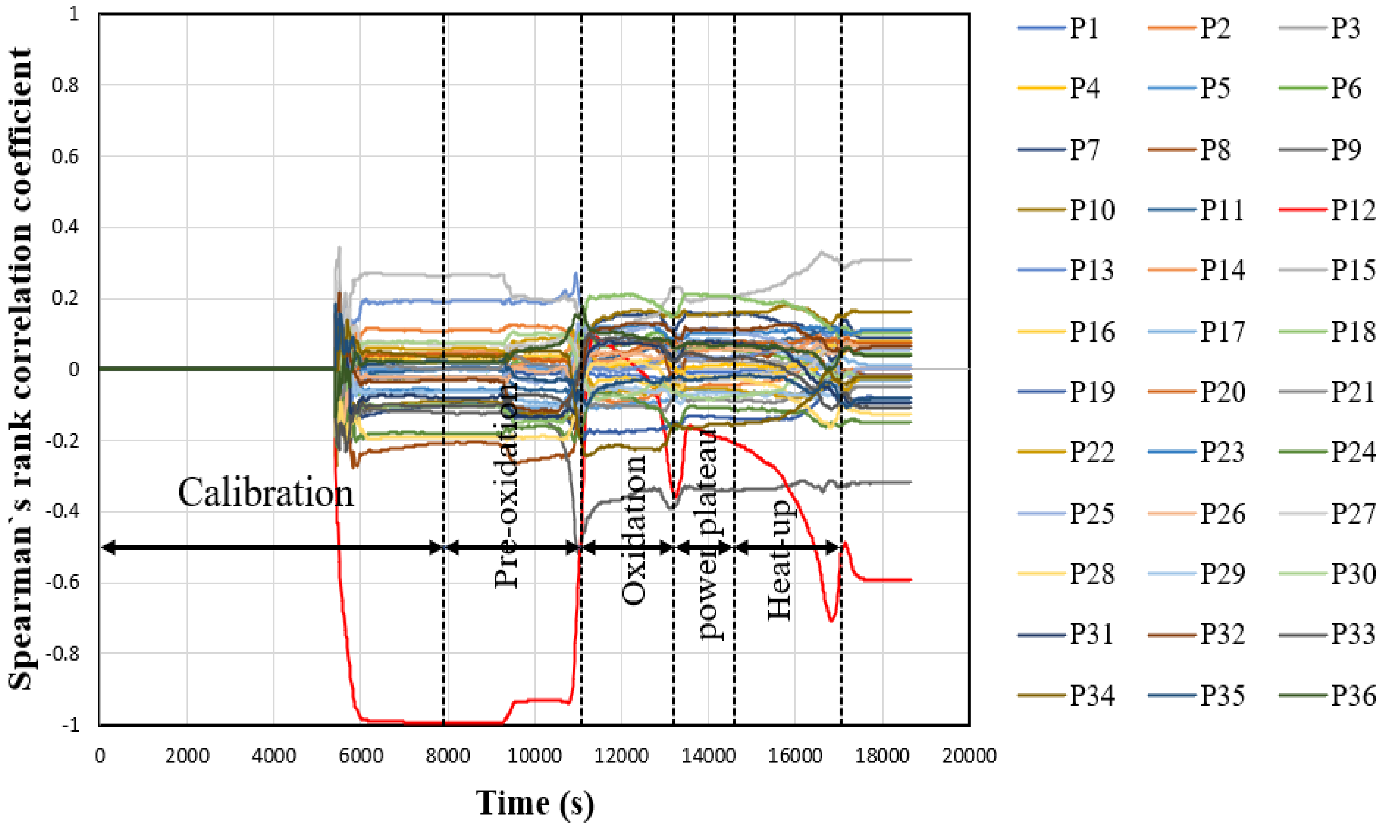
Total hydrogen generation

Sensitivity Results (2)

Spearman's rank correlation



Cladding temperature at 950mm elevation



Total hydrogen generation

Sensitivity results (3)

Cladding temperature at 950mm elevation calculations

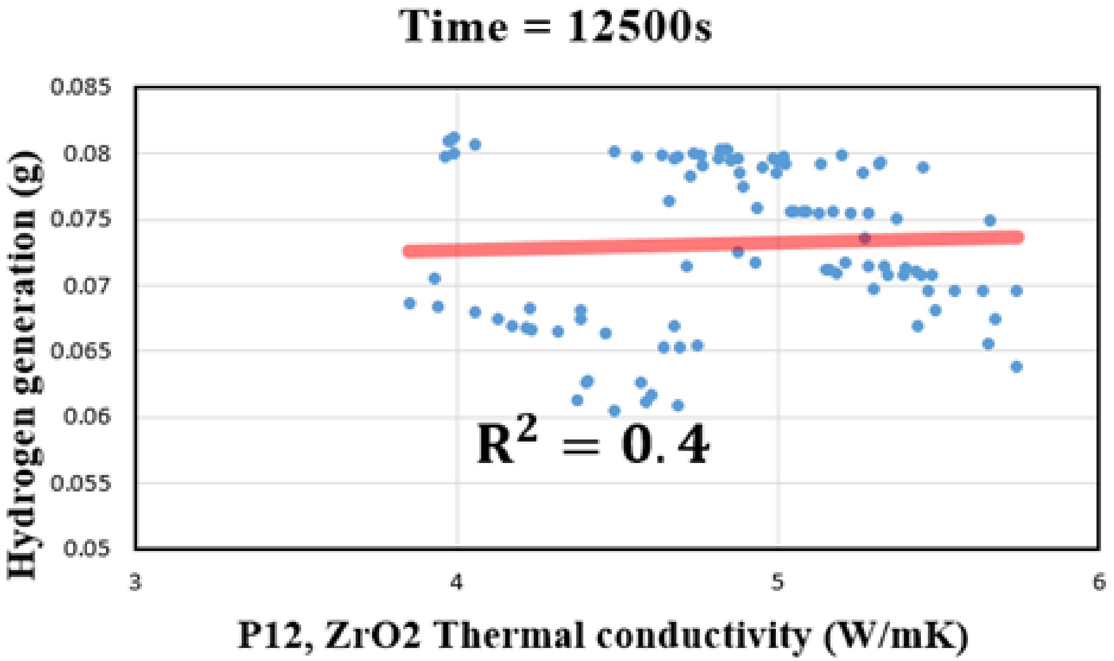
Phases				
Calibration (6000s)	Pre-oxidation (9000s)	Oxidation (12500s)	Power plateau (14000s)	Heat up (16000s)
P12, ZrO_2, Thermal conductivity, influence (-0.98).	**P12**, ZrO_2, Thermal conductivity, influence (-0.85); **P15**, Gap thermal conductivity, influence (0.25).	**P12**, ZrO_2, Thermal conductivity, influence (-0.83); **P8,** ThO_2 density, influence (-0.32); **P18**, Spray coating thermal conductivity influence (0.21).	**P12,** ZrO_2, Thermal conductivity, influence (-0.88); **P9**, ThO_2 Thermal conductivity, influence (-0.25);	**P12,** ZrO_2, Thermal conductivity, influence (-0.98); **P10**, ZrO_2, Specific heat, influence (-0.6); **P9**, ThO_2 Thermal conductivity, influence (-0.22).

Sensitivity results (4)

Total hydrogen generation calculations

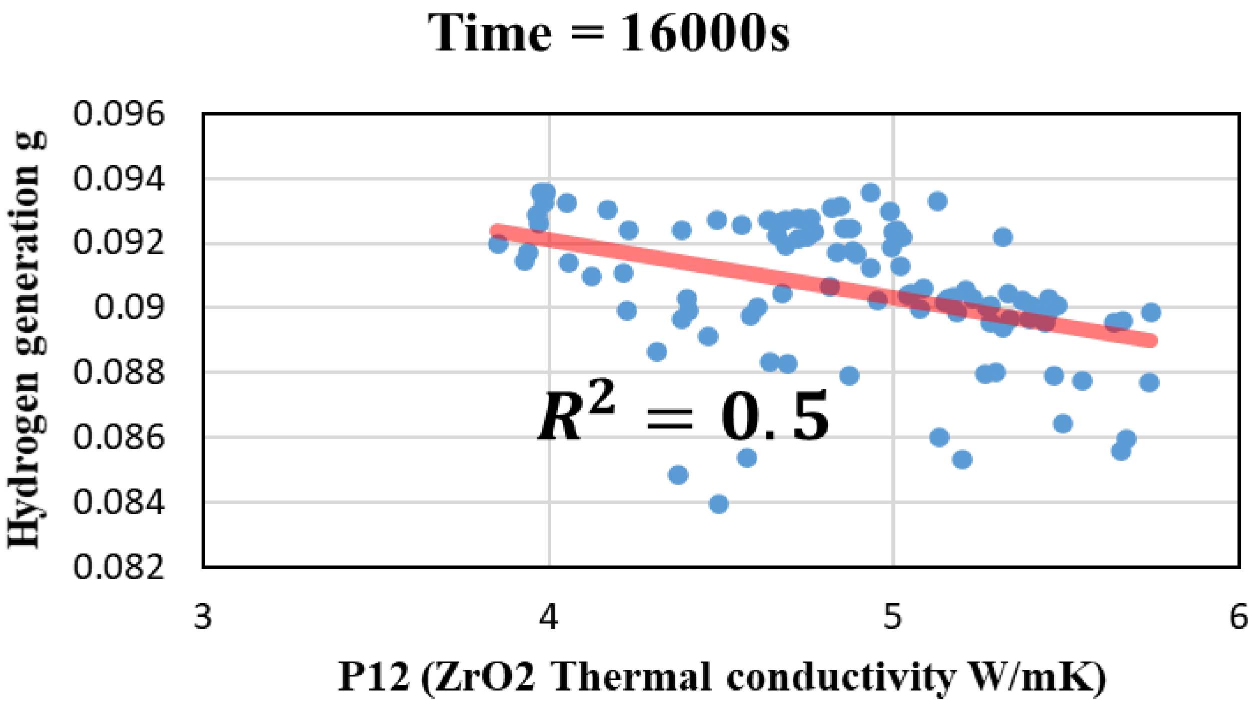
Phases				
Calibration (6000s)	Pre-oxidation (9000s)	Oxidation (12500s)	Power plateau (14000s)	Heat up (16000)
P12, ZrO_2, Thermal conductivity, influence (-0.98)	**P12**, ZrO_2, Thermal conductivity, influence (-0.92); **P8**, ThO_2 density, influence (-0.22).	Weak linear correlation between uncertain parameters		

Sample scatter plot and regression line for linear regression



Oxidation Phase

Heat up phase



CONCLUSIONS

- Uncertainty and sensitivity analysis were provided for cladding temperature at 950mm elevation and total hydrogen generation calculation results for FPT1.

- Results of uncertainty analysis showed that in the case of cladding temperature upper and lower uncertainty limits bounded the experimental data, but in the case of total hydrogen generation, they were in a good agreement in the late phases.

- Results of sensitivity analysis showed that ZrO_2 thermal conductivity has the dominant influence on cladding temperature at 950 mm elevation and hydrogen generation calculation results.

Future work

- It is planned to reduce the number of uncertain parameters fixing them at reference values and to provide uncertainty and sensitivity analysis once again to see how changes the uncertainty quantification of results.
- Sensitivity analysis showed a weak linear correlation of uncertain parameters to calculation results in the case of total hydrogen generation at the late phases of the experiment. This means that the applied sensitivity method could give not exact results of the sensitivity analysis.
- Another possibility for such phases to use different sensitivity methods which are not based on the linearity of input parameters to result. However, these methods require a huge amount of calculation cases.

Thanks for your attention

Acknowledgement

Work provided in this article was done in the frame of MUSA project. MUSA project has received funding from the Euratom research and training program 2014-2018 under grant agreement No 847441.

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