Karlsruhe Institute of Technology

Sensitivity Analysis of the Oskarshamn-2 Stability Event Using the URANIE Software

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Content

- Description of the COBRA-TF code.
- Description of the URANIE and SUSA software.
- Application to the O2 -1999 Feedwater transient.
- O2 Core modeling with COBRA-TF.
- Comparison of results.
- Conclusion and Outlook.

NURESAFE COBRA-TF version

COBRA-TF is designed to simulate the thermal hydraulic phenomena of fuel assembly, core and RPV of Light Water Reactor (LWR).

It is being developed and improved by the Reactor Dynamics and Fuel Management Group (RDFMG) at the Pennsylvania State University (PSU).

COBRA-TF uses a two-fluid three fields formulation for the simulation of two phase flow (9 equation system for the conservation of mass, momentum and energy).

Within **NURESAFE EU project**, COBRA-TF is being delivered by GRS (Germany) to the partners. The same source is used as for the **CASL program (USA).**

URANIE Software (1)

URANIE is a software dedicated to uncertainty and optimization.

It allows to perform studies on uncertainty propagation, sensitivity analysis, model calibration in an integrated software environment.

It is based on ROOT, a software developed at CERN for particle physics data analysis. Hence, URANIE benefits from the numerous features of ROOT, among which:

- a C++ interpreter (CINT)
- a Python interface (PyROOT)
- access to SQL databases
- many advanced data visualization features

Open source project: **http://sourceforge.net/projects/uranie/**

URANIE Software (2)

At KIT, URANIE software has been applied to perform sensitivity analysis based on stochastic sampling (MC).

Advantages of a Statistical Methodology:

- Sound mathematical basis.
- Reduction of Expert Opinion to the minimum needed.
- There is no limit in the number of variables and models that can be used (No need for a previous PIRT).
- The actual BE Code is used for the calculations (No need for regression based surfaces to replace the code).
- The uncertainty can be quantified in transient analysis.

The methodology is concerned mainly with the uncertainty in:

- Code´s input variables.
- Code´s correlations and physical models.

Confidence level determined by **Wilk´s formula** (95% of probability with 95% confidence level with 93 runs).

URANIE Software (3)

The stochastic nature (PDF) of the uncertainty in the input variables and in the physical models induces a statistical nature in the results of the code.

The idea behind the statistical Methodology is quite simple

- Uncertainties in code inputs are treated as Stochastic Variables.

Input Sample of Size N

Random Sampling

Output Sample of Size N

$$\begin{pmatrix}(\boldsymbol{X})_1\\(\boldsymbol{X})_2\\\vdots\\(\boldsymbol{X})_N\end{pmatrix} \equiv \begin{pmatrix}(X_1,\dots,X_k)_1\\(X_1,\dots,X_k)_2\\\vdots\\(X_1,\dots,X_k)_N\end{pmatrix} \xrightarrow[\text{to Input}]{\text{Assign Values}} \begin{pmatrix}(x_1,\dots,x_k)_1\\(x_1,\dots,x_k)_2\\\vdots\\(x_1,\dots,x_k)_N\end{pmatrix} \to \begin{pmatrix}Code\left[(x_1,\dots,x_k)_1\right]\\Code\left[(x_1,\dots,x_k)_2\right]\\\vdots\\Code\left[(x_1,\dots,x_k)_N\right]\end{pmatrix} \to \begin{pmatrix}(y_1,\dots,y_m)_1\\(y_1,\dots,y_m)_2\\\vdots\\(y_1,\dots,y_m)_N\end{pmatrix} \equiv \begin{pmatrix}Code\left[(\boldsymbol{X})_1\right]\\Code\left[(\boldsymbol{X})_2\right]\\\vdots\\Code\left[(\boldsymbol{X})_N\right]\end{pmatrix} \to \begin{pmatrix}(\boldsymbol{Y})_1\\(\boldsymbol{Y})_2\\\vdots\\(\boldsymbol{Y})_N\end{pmatrix}$$

Input Multivariate
k stochastic input variables

Input Variables for N Code Executions

N Code Executions

Output Multivariate
m stochastic output variables

- Deterministic Code transforms Stochastic INPUT in Stochastic OUTPUT.
- Uncertainty in INPUT is PROPAGATED to OUTPUT.
- Statistical Methods extract uncertainty information from OUTPUT.

SUSA Software system for Uncertainty and Sensitivity Analysis

- Under development at GRS (Germany).
- Probabilistic approach with input error propagation to the output.
- Minimal number of code runs defined by Wilk’s formula.
- Monte Carlo simple random and Latin Hypercube sampling (LHS).
- Widely used in nuclear community. Well validated.
- Used in this work as an independent tool for comparison purposes.

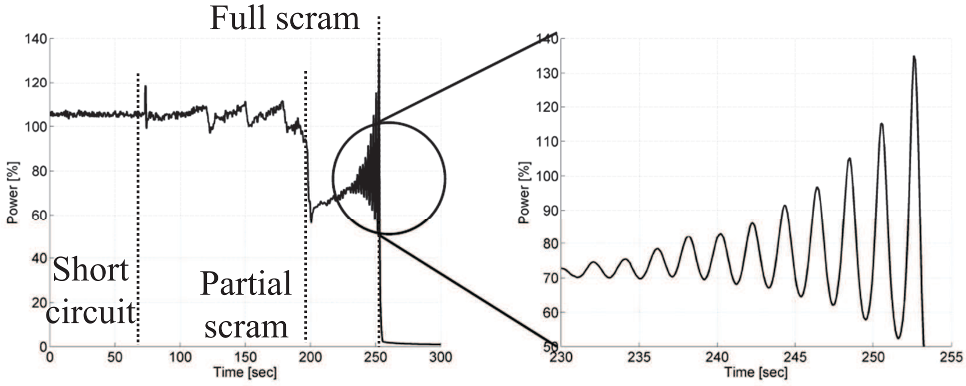
B. Krzykacs, E. Hofer and M. Kloos, “A software system for probabilistic uncertainty and sensitivity analysis of results from computer models”, Proceedings of the International Conference on Probabilistic Safety Assessment and Management, San Diego, California, USA, 1994.

R. Macian-Juan, “Uncertainty and sensitivity evaluation for Best Estimate coupled calculations,” FJOT Summer School 2011, Karlsruhe, Germany.

Application to the O2, 1999 FW transient

- On February 25, 1999, the **Oskarshamn-2 NPP** experienced a stability event, which culminated in diverging power oscillations with decay ratio greater than 1.3.
- Challenging to high-fidelity coupled TH/NK codes.

Power oscillation during the event (feedwater transient)



Oskarshamn-2 February 25, 1999 feedwater transient

T. Kozlowski, Analysis of the OECD/NRC Oskarshamn-2 BWR stability benchmark, Annals of Nuclear Energy, Volume 67, May 2014, Pages 4-12, ISSN 0306-4549

Characteristic and current limitations of the COBRA-TF O2 core model

The main features of this model are:

- The flow area, wetted perimeter and pressure loss coefficients are taken from the specifications (which are based on **real data from the NPP**).
- The 444 fuel assemblies are modelled in parallel (no flow between channels).

The current model has the following limitations:

- The bypass channel and the internal bundle water channel are not explicitly modelled.
- Only the active part of the core is modelled.
- Core averaged axial and radial power profiles are taken from a converged TRACE/PARCS simulation.

O2 HFP nominal operating conditions

- Core boundary conditions taken from TRACE/PARCS calculation (KIT model with 444 channels).
- Power distribution is imposed from the TRACE/PARCS SS.
- COBRA-TF standalone results:

$$\text{Deviation} = \frac{Messured - CODE}{Messured} * 100$$

Parameter at HFP	Benchmark	CTF
Core outlet Temperature (K)	Ref.	+0.138%
Average void fraction (-)	Ref.	-11.9%
Void fraction at core outlet (-)	-	0.7080
Presure drop in the core (kPa)	Ref.	+16.34%
Average flow velocity in the core (m/s)	-	3.21

NON DISCLOSURE AGREEMENT

Sensitivity study, PDFs determination

Sensitivity analysis with parameters taken from the NURESAFE benchmark specifications (D13.11).

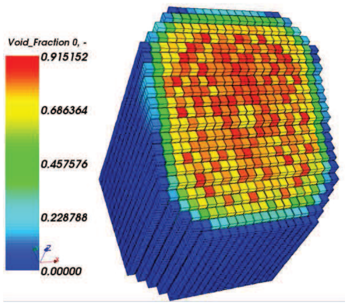
No.	Parameter	Range	Distribution
1	Outlet pressure	**± 0.5 %**	**Uniform**
2	Mass flow rate	**± 0.5 %**	**Uniform**
3	Inlet temperature	**± 2.0 %**	**Normal**
4	Power	**± 0.75 %**	**Normal**
5	Cladding Wall Roughness	**± 30.0 %**	**Normal**
6	Spacer grid pressure drop coefficient	**± 5.0 %**	**Uniform**
7	Gap Conductance	**± 35.0 %**	**Uniform**
8	Fuel Conductivity	**± 10.0 %**	**Uniform**
9	Cladding Conductivity	**± 6.25 %**	**Uniform**

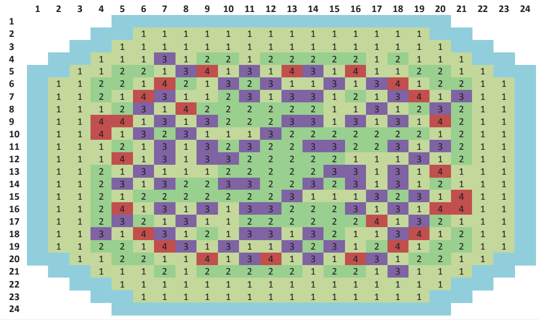
I. Gajev, Sensitivity analysis of input uncertain parameters on BWR stability using TRACE/PARCS, Annals of Nuclear Energy, Volume 67, May 2014, Pages 49-58, ISSN 0306-4549

O2 nominal steady state results (1)

- **Axial pressure drop** and **Outlet void fraction** are the output parameters studied (200 runs were used - 97.3% confidence level).
- The computed Pearson sensitivity coefficients by URANIE corresponding to a steady state at nominal operating conditions using COBRA-TF.

	Mass flow rate	Inlet enthalpy	Pressure	Heat flux	Spacer	Gap conductivity
Axial pressure loss	0.259488	0.384382	-0.52228	0.410298	0.597949	-0.0036
Void Fraction	-0.198526	0.673415	-0.660979	0.275753	-0.0077247	0.02582





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3					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
4				1	1	1	3	1	2	2	1	2	2	2	2	2	1	2	1	1	1			
5			1	1	2	2	1	3	4	1	3	1	4	3	1	4	1	1	2	2	1	1		
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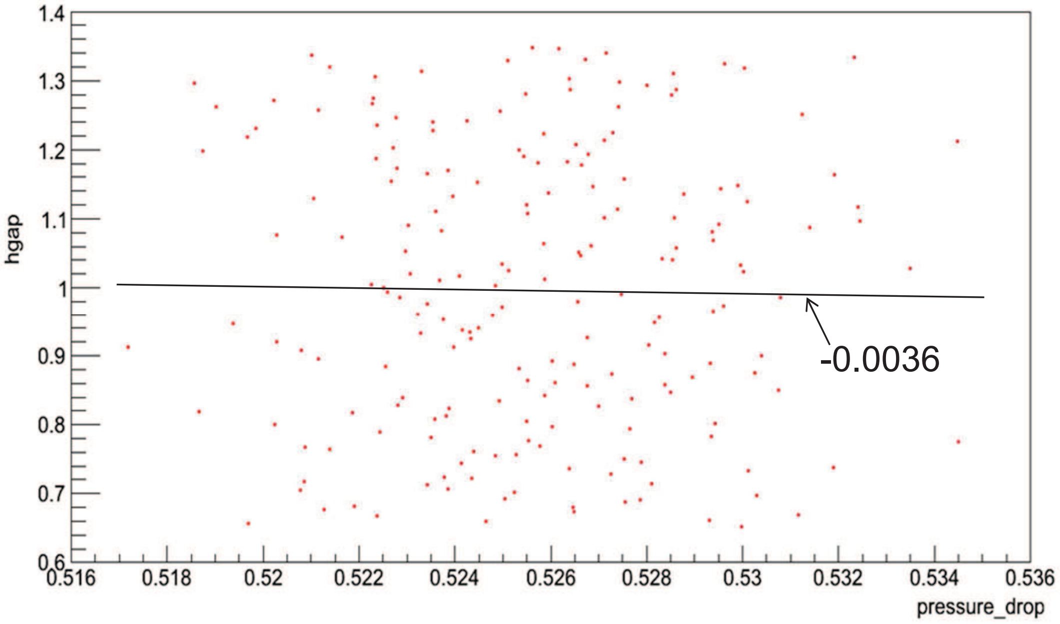
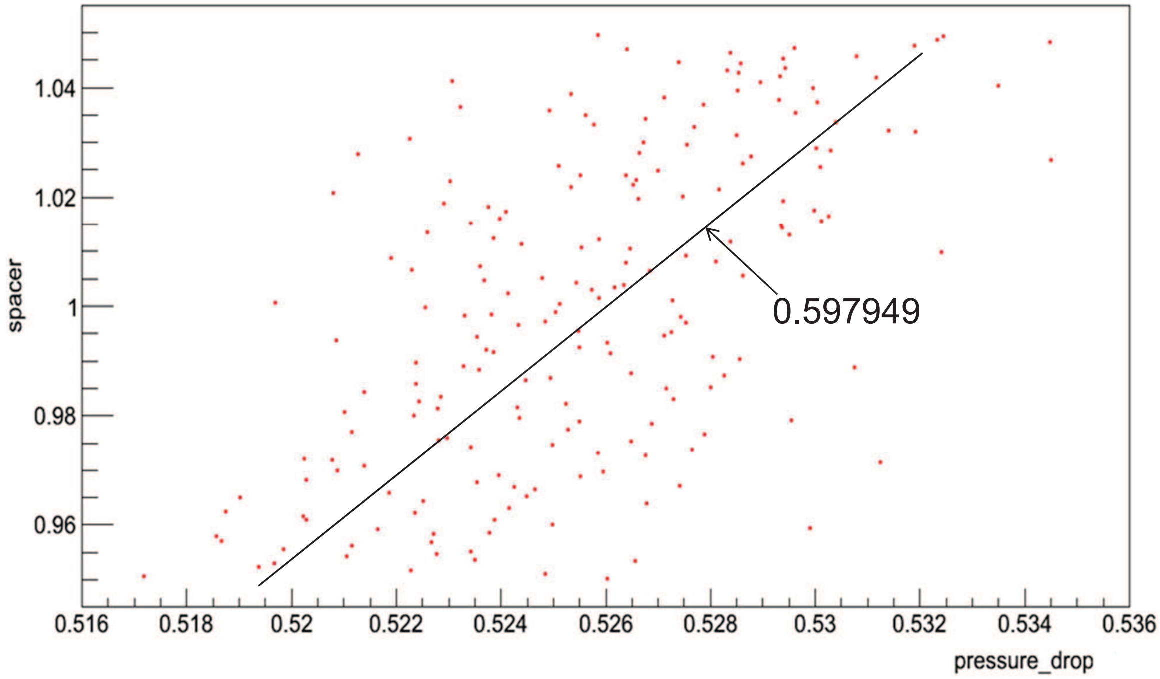
24																								

O2 nominal steady state results (2)



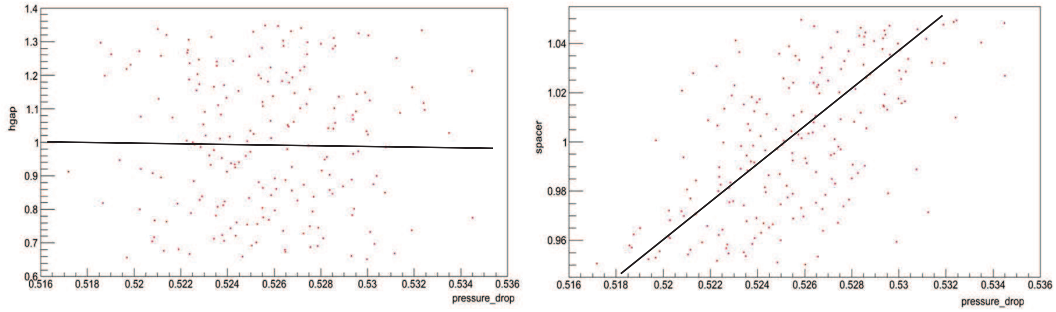
Axial pressure drop sensitivity with regards to fuel gap conductivity.

O2 nominal steady state results (3)

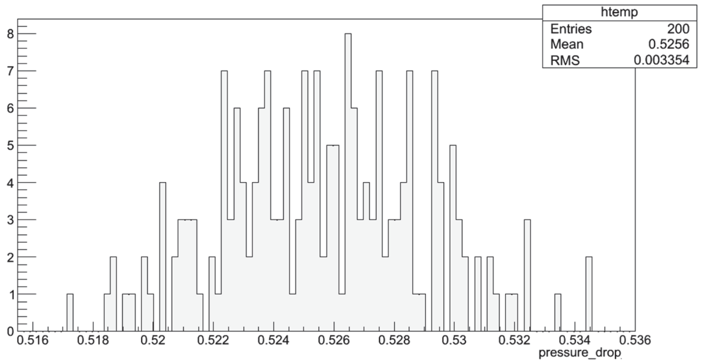


Axial pressure drop sensitivity with regards to spacer grids pressure loss coeff.

O2 nominal steady state results (4)



Axial pressure drop sensitivity for spacer grids and fuel gap conductivity.

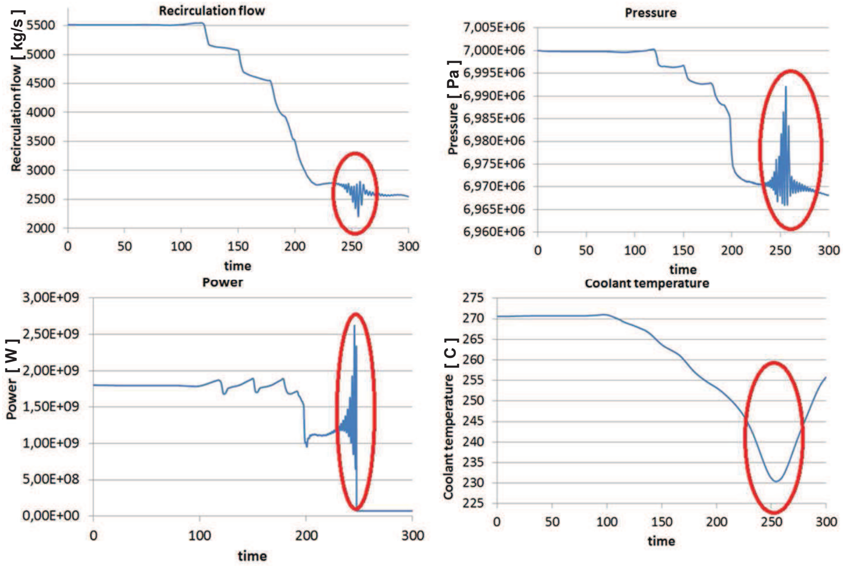


Pressure drop distribution over all COBRA-TF runs

BWR O2 Transient simulation (1)

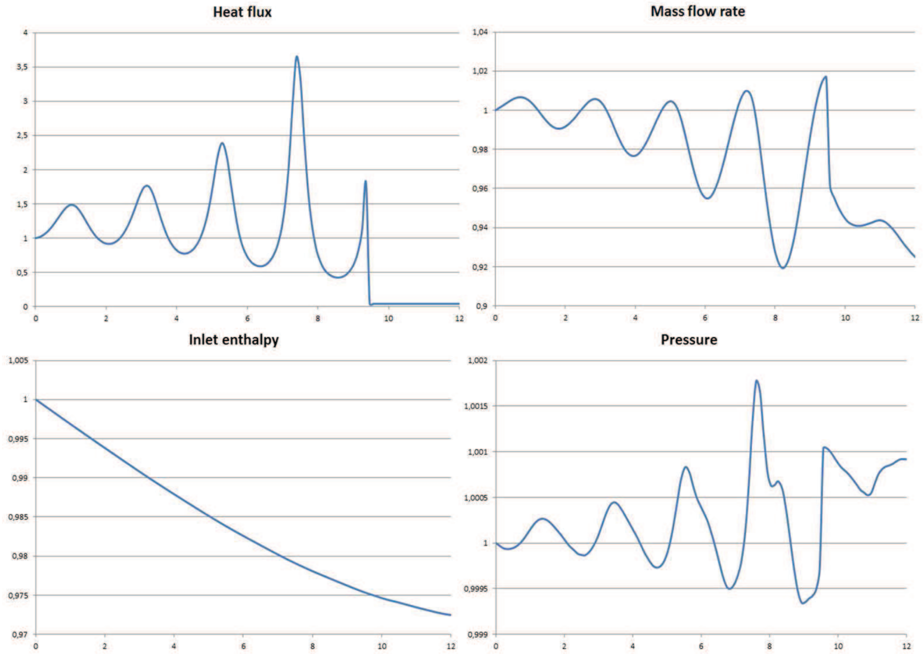
- Boundary conditions: extracted from a TRACE5P3/PARCS calculation (only 12s are analyzed).

Power, inlet temperature, pressure, mass flow rate vs. time.



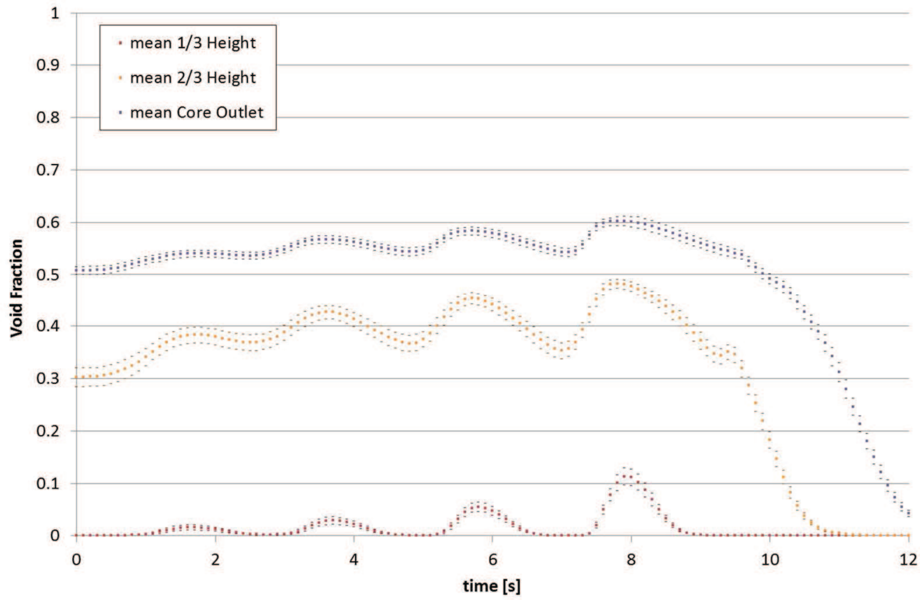
BWR O2 Transient simulation (2)

- Boundary conditions: representative of a stability event.
- 500 COBRA-TF runs were used - 98.7% confidence level



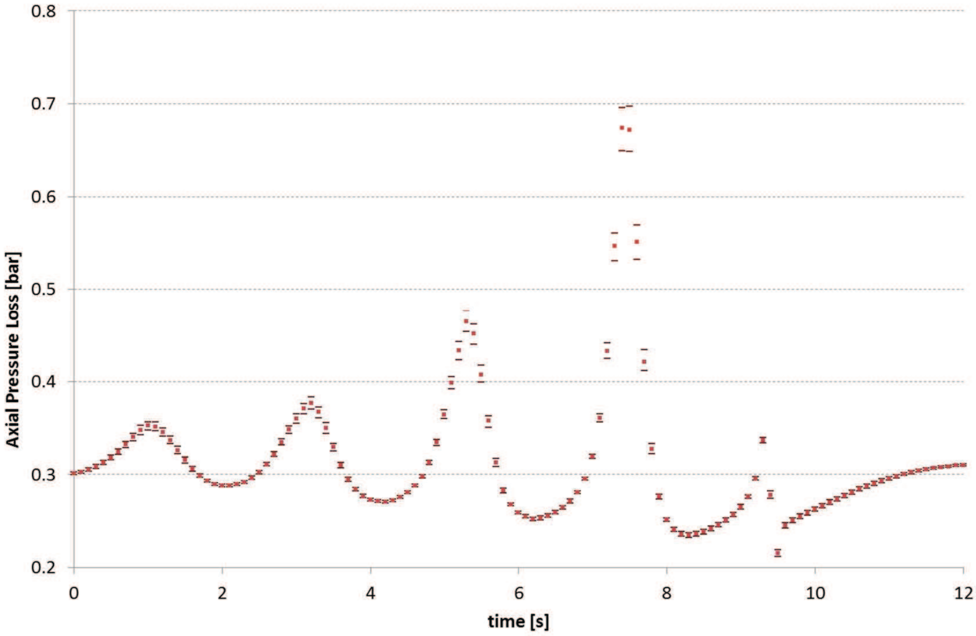
URANIE results in the zooming area (1)

Mean, min and max values of the **void fraction** at three different elevations: 1/3, 2/3 and core outlet



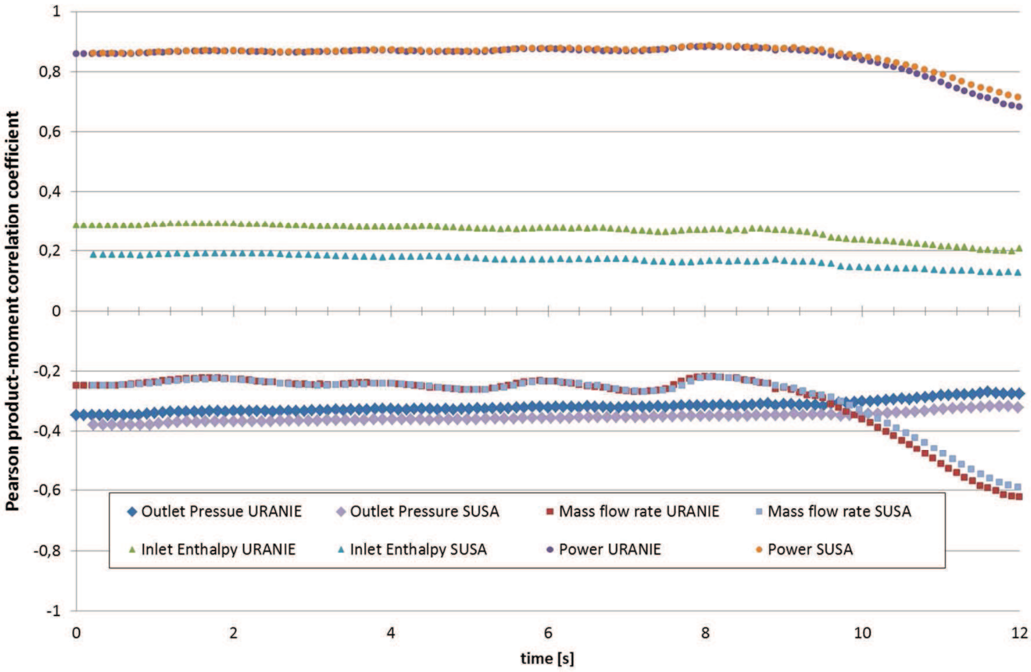
URANIE results in the zooming area (2)

Mean, min and max values of the **axial pressure loss** of the bundle average



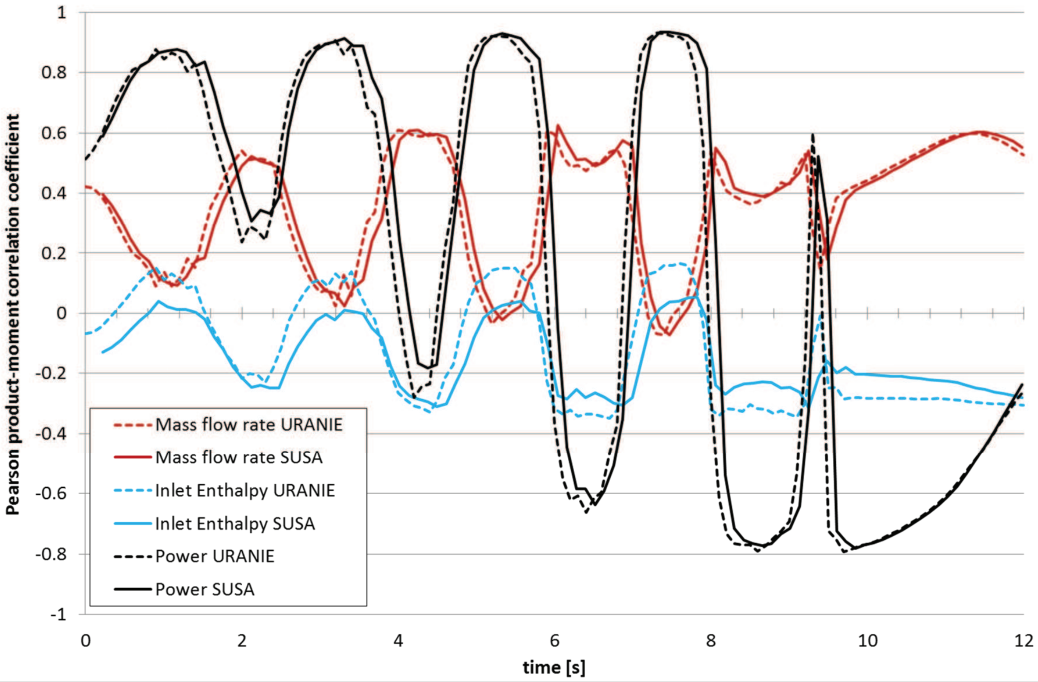
Comparison of URANIE against SUSA (1)

Pearson sensitivity coefficients of the **void fraction**



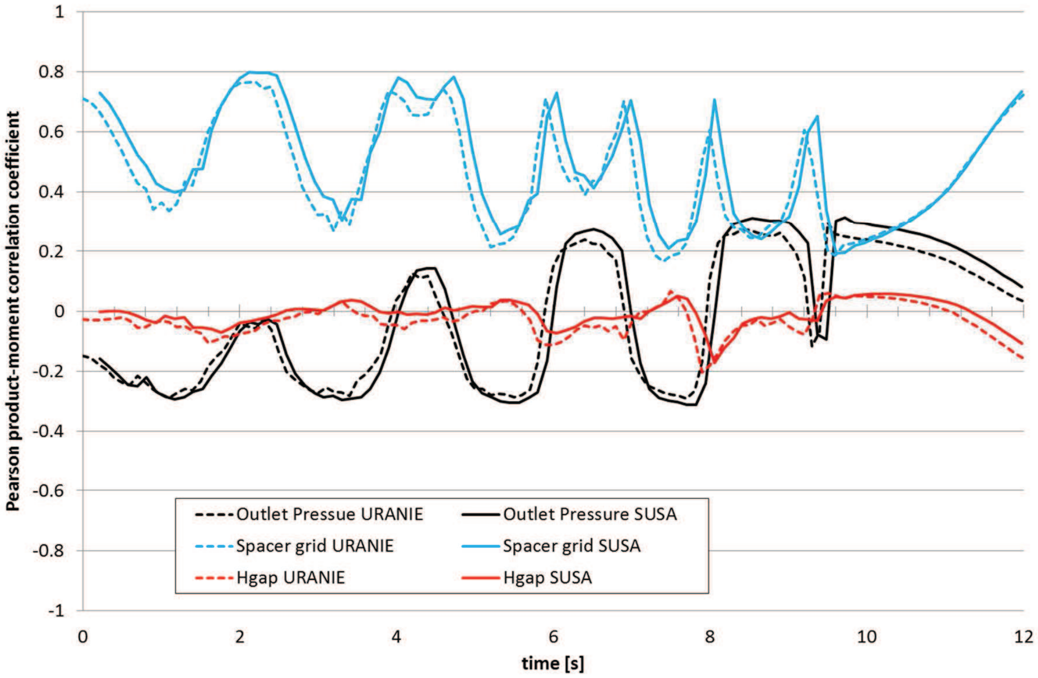
Comparison of URANIE against SUSA (2)

Pearson sensitivity coefficients of the **axial pressure drop**



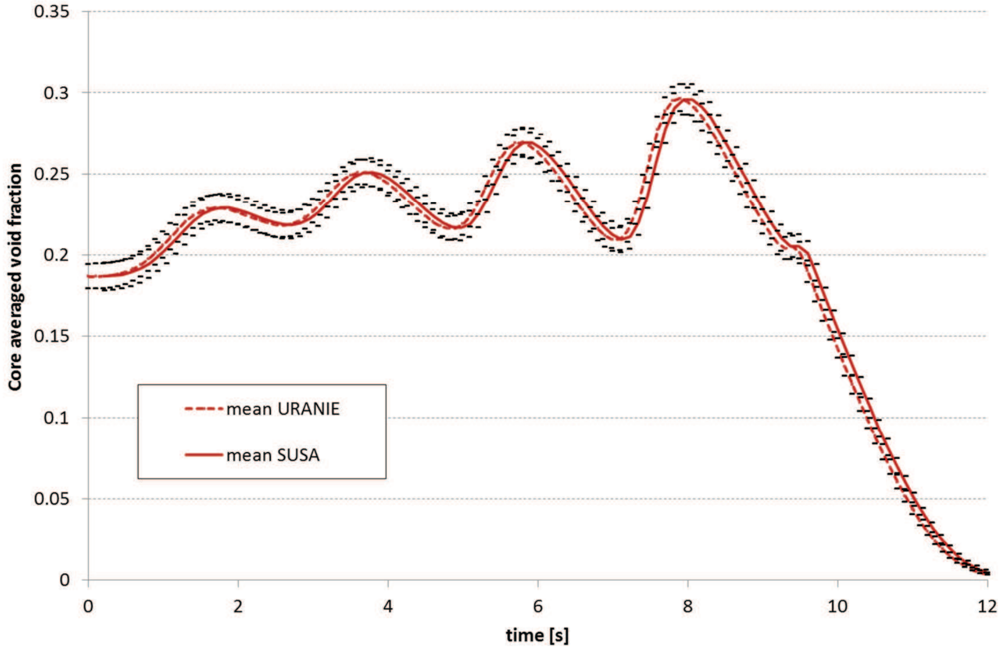
Comparison of URANIE against SUSA (3)

Pearson sensitivity coefficients of the **axial pressure drop**



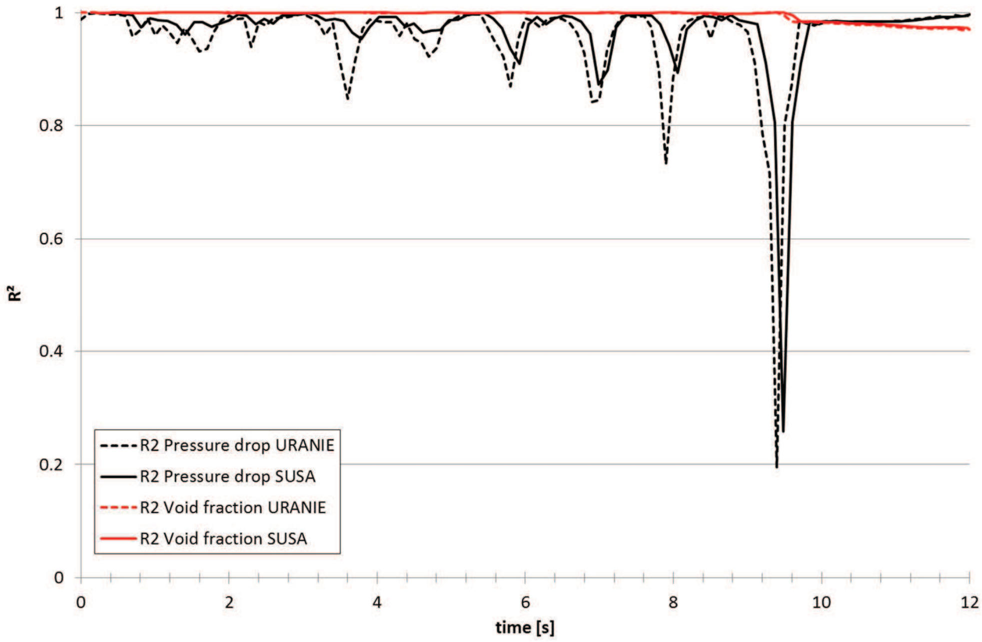
Comparison of URANIE against SUSA (4)

Core averaged void fraction



Comparison of URANIE against SUSA (5)

The experiment is well covered, $R^2 \approx 1.0$



Conclusions and Outlook

- Studies using the **COBRA-TF** code on steady state and transient simulations were carried out.
- Satisfactory results for the SS and transient analysis.
- High degree of flexibility in the URANIE scripts.
- URANIE provides similar results to SUSA.

FUTURE WORK

- Application to coupled simulations is foreseen in the next months.
- KIT will participate in several exercises of the O2 benchmark.
- Uncertainty in model parameters could be considered as soon as its parameters are included in the input deck. Otherwise the source code of COBRA-TF needs to be modified to allow that.

THANKS FOR YOUR ATTENTION

Questions?