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ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis of the O2 event within the NURESAFE project

J. Jiménez, V. Di Marcello, V. Sánchez (KIT)
Y. Perin (GRS)

Institute for Neutron Physics and Reactor Technology (INR)
Reactor Physics and Dynamic Group (RPD)

KIT – Die Forschungsuniversität in der Helmholtz-Gemeinschaft

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- The NURESAFE project
- ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis of the O2 event
- Sensitivity and uncertainty analysis of the Oskarshamn-2 stability event with COBRA-TF *(updated results since O2-3 meeting)*
- Summary

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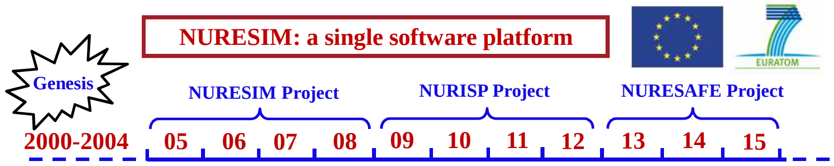
The NURESIM Simulation Platform

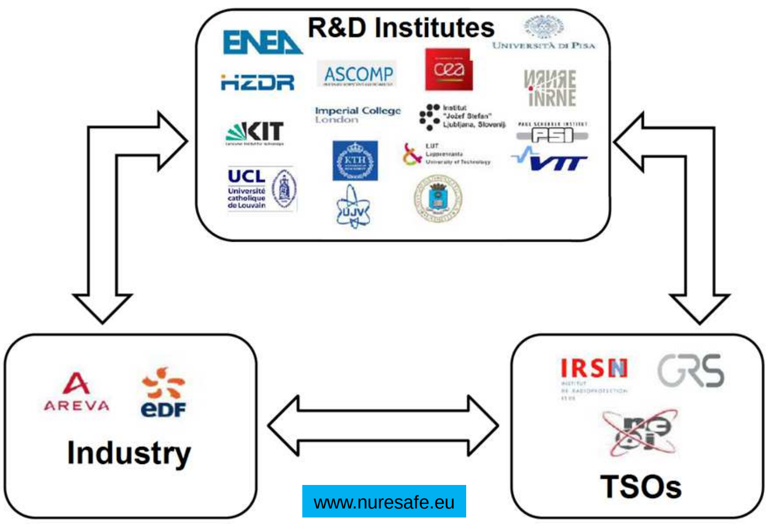
- NURESIM project established the basic architecture of the NURESIM platform and resulted in a first prototype of a truly integrated multi-physics simulation environment.
- The NURISP project was conceived as a consolidation of the platform plus an extension towards higher-resolution both in space and time.
- The NURESAFE project will show the extended capabilities of the platform and demonstrate the readiness of the tool for Industrial safety applications.



The NURESAFE Objectives

- Develop and apply for reactor applications a novel Simulation Environment: the NURESIM Software Integrated Platform
  - Includes core-physics, thermal-hydraulics, fuel thermo-mechanics
- In order to address safety and operational issues for LWRs (normal operation and design basis accidents)
  - PWR incl. VVER and BWR
- A reference platform
  - Includes state-of-the art codes, well validated
- Create a community that brings together the European key-players and engage them in advanced simulation for LWRs
  - 23 partners contributing (Research centers, Universities, industry)

The NURESAFE Consortium



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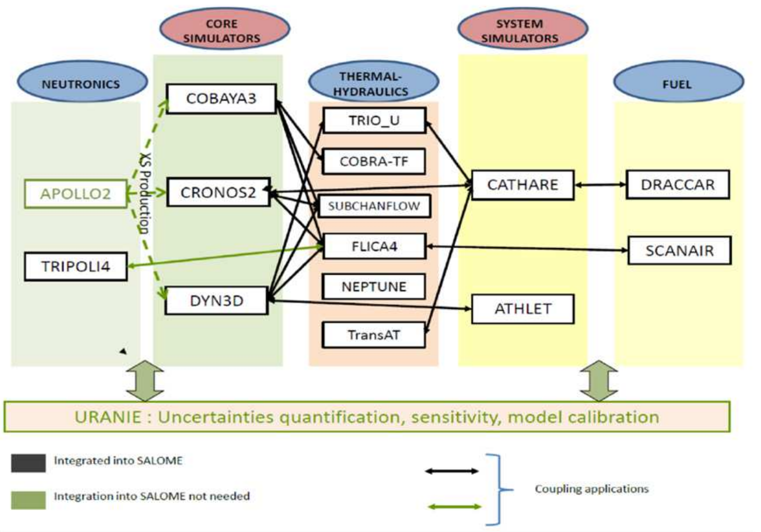
nationales Forschungszentrum in der Helmholtz-Gemeinschaft

NURESAFE Project

- The project was organized in 5 big sub-projects
  - SP1: **Multiphysics applications involving core physics (Coordinator: UPM)** KIT-CN
  - SP2: **Multiscale analysis of core thermo-hydraulics (Coordinator: ASCOMP)**
  - SP3: **Multiscale and multi-physics applications of Thermal-hydraulics (HZDR)** KIT-CN
  - SP4: **Software platform (Coordinator: CEA)**
  - SP5: **Dissemination and Training (coordinator: KIT)** KIT-CN

The final seminar took place in Brussels, November 2015.

Tools of the NURESIM Simulation Platform (at the end of NURESAFE)



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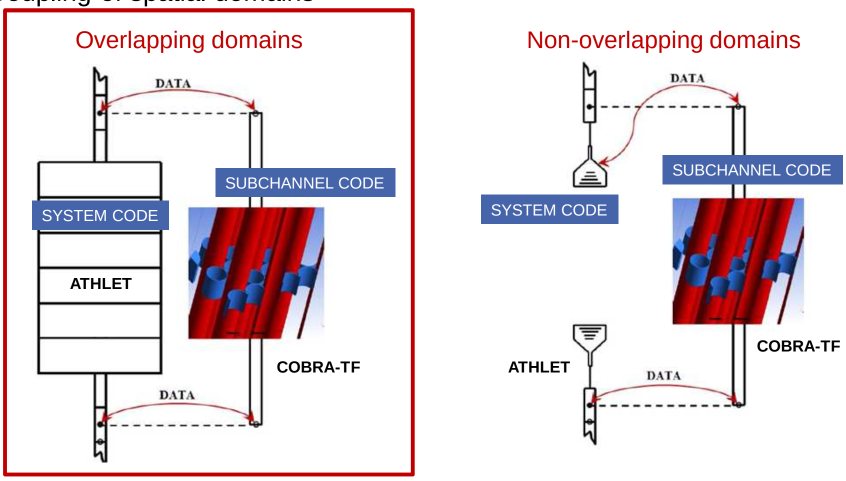
Description of ATHLET/COBRA-TF (1)

- Coupling of spatial domains



Domains are spatially superimposed to some extent

Domain is split into separate regions with well defined interfaces

Description of ATHLET/COBRA-TF (2)

- Synchronization

Off-line Coupling

Codes run separately and sequentially. Results from one code are used as boundary or initial conditions for the other.

- **Simple** to implement and **no modifications** of the codes is requested;
- The information transfer is only "**one-way coupling**", **no feedback** is possible.

Case of ATHLET/COBRA-TF using MEDCoupling

In-line Coupling

Codes run **concurrently** with a **continuous exchange** of information in both ways ("**two-way coupling"**)

Case of CATHARE/TRIO_U using ICOCO

- Code Integration
  - Internal coupling: Ad hoc solver to simultaneously solve the coupled system; Transfer internal memory
  - External coupling: Independent solvers are employed (coupling interface is needed).

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Description of ATHLET/COBRA-TF (3)

- Numerical schemes (in-line coupling)

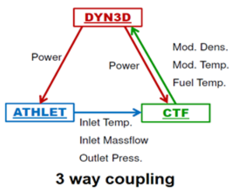
Explicit coupling scheme

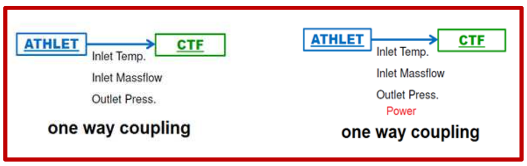
Time iteration is pure explicit, the codes take the minimum allowed time step for numerical stability and courant limit.

Implicit Coupling scheme

On each time step there is an inner iteration loop, convergence is achieved, allows for much bigger time step sizes.

- A one-way coupling with domain overlapping and explicit time scheme between ATHLET/COBRA-TF was developed.
- The coupling is implemented in a python script.





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NURESAFE SP3 – KIT contribution
WP3.3: BWR thermal-hydraulics ATWS

- ATHLET code validation using BFBT Data
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power (D33.11.5).
  - *"**Validation of the Thermal-hydraulic System Code ATHLET based on Selected Pressure Drop and Void Fraction BFBT Tests**"*, V. Di Marcello, J. Jiménez, V. Sanchez, NED-D-14-00862R1, 2015, http://dx.doi.org/10.1016/j.nucengdes.2015.04.003
- Modeling of the Oskarshamn-2 core with subchannel codes
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested.
- Multi-scale simulation of BWR transients with ATHLET-CTF (D33.12.5).
  - ***"Application of the ATHLET/COBRA-TF multi-scale thermal-hydraulics coupled code to the analysis of BWR ATWS"***, J. Jimenez, V. Di Marcello, V. Sanchez, Y. Perin, submitted to NED, 2016

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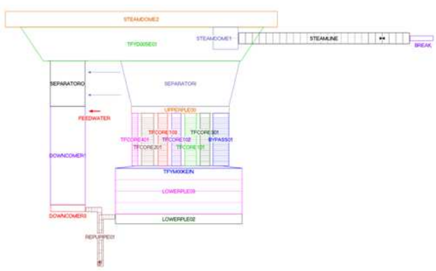
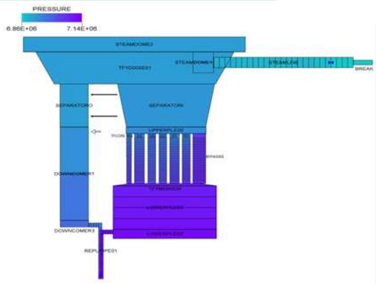
ATHLET Oskarshamn-2 model (GRS-KIT)

- ATHLET HFP steady state results

Parameter	Deviation of ATHLET Mod 3.0 cycle B versus the benchmark data
Steam dome pressure	-0.37%
Feedwater Temperature	-0.05%
Core Inlet Temperature	-0.76%
Total Core Flow Rate	1.23%
Steam Flow Rate	0.60%





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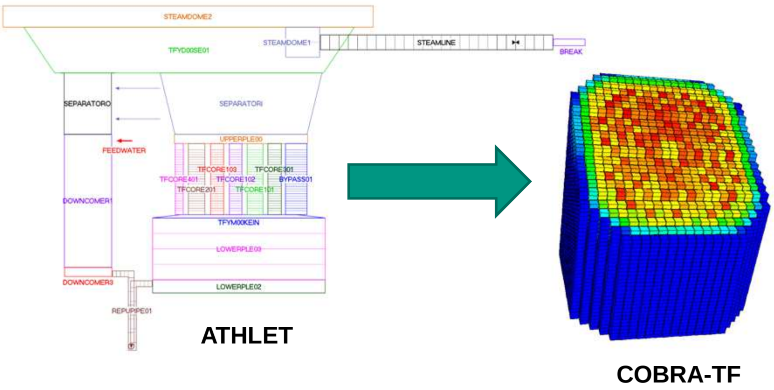
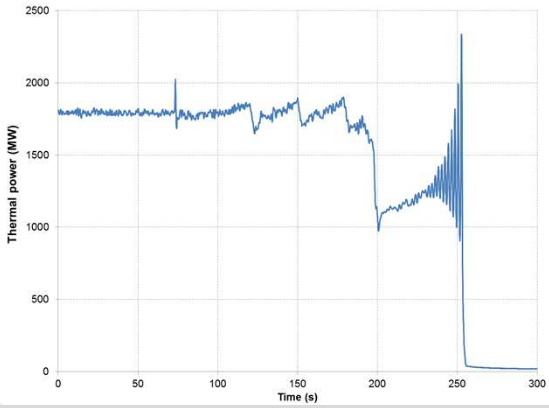
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (1)

- Multi-scale simulation of the Oskarshamn-2 feedwater event (1999).
  - ATHLET with a coarse core model and COBRA-TF full core assembly-wise
    - ATHLET using 6 channel model of the O2 core
    - COBRA-TF using 444 channel model of the O2 core



ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (2)

- The Oskarshamn-2 feedwater transient has been computed using the most accurate 3D power distribution available.
  - A 3D power distribution coming from a coupled TRACE/PARCS using 444 parallel channels (1 per FA).



ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (3)

- Radial power distribution imposed in COBRA-TF.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1					0.1966	0.2342	0.2744	0.2937	0.3162	0.3068	0.3101	0.3129	0.3146	0.3052	0.3038	0.2819	0.2426	0.1983				
2				0.2766	0.3866	0.4672	0.5023	0.5447	0.5685	0.5548	0.5629	0.5713	0.5729	0.5742	0.5740	0.5224	0.4802	0.3849	0.2761			
3			0.3186	0.4621	0.7549	0.8995	0.8139	1.0392	1.0334	0.8767	1.0546	1.0131	1.0044	1.0715	1.0572	0.9302	0.9274	0.7474	0.4612	0.3302		
4		0.2825	0.4709	0.8128	1.0333	0.9651	1.2122	1.3493	1.0188	1.2375	1.0989	1.4017	1.2738	1.0024	1.3436	1.0100	0.9662	1.0469	0.8238	0.4769	0.2905	
5	0.2062	0.4024	0.7694	1.0383	0.9540	1.4205	1.3249	1.1210	1.3502	1.2950	1.3777	1.1287	1.2535	1.3477	1.1410	1.3310	1.4342	0.9813	1.0632	0.7853	0.4080	0.2072
6	0.2563	0.4845	0.9386	0.9249	1.4205	1.3694	1.1397	1.1708	1.3125	1.6084	1.2345	1.4669	1.6069	1.1548	1.3954	1.1959	1.4082	1.4571	0.9462	0.9428	0.5018	0.2529
7	0.2904	0.5434	0.9337	1.1648	1.3382	1.1374	1.5362	1.2264	1.2469	1.2983	1.5338	1.3520	1.2986	1.2357	1.2443	1.5853	1.2296	1.3714	1.2572	0.9658	0.5334	0.2894
8	0.3102	0.5908	1.0717	1.3786	1.1533	1.4036	1.1663	1.5737	1.2485	1.2856	1.3187	1.7341	1.5286	1.2497	1.6086	1.2297	1.4201	1.0704	1.3804	1.0842	0.5428	0.3001
9	0.3125	0.5766	1.0813	1.0352	1.3653	1.3045	1.4371	1.0890	1.2859	1.3439	1.5079	1.3409	1.4614	1.3981	1.2904	1.3146	1.3336	1.3715	1.0431	0.9865	0.5718	0.3096
10	0.3144	0.5604	0.9751	1.2879	1.1747	1.5745	1.2183	1.4737	1.4295	1.6429	1.2674	1.4640	1.6613	1.3000	1.2799	1.2557	1.5478	1.1484	1.2265	0.9940	0.5712	0.3042
11	0.3198	0.5918	0.9822	1.3696	1.0583	1.3998	1.2292	1.6385	1.3420	1.4593	0.9599	0.9270	1.2694	1.5029	1.2433	1.2095	1.1660	1.3185	1.0811	1.0648	0.5903	0.3188
12	0.3172	0.5889	1.0639	1.0798	1.3180	1.1653	1.2090	1.2405	1.5041	1.2729	0.9277	0.9598	1.4582	1.3252	1.6387	1.2297	1.4003	1.0590	1.3696	0.9825	0.5928	0.3216
13	0.3022	0.5695	0.9932	1.2259	1.1478	1.5470	1.2553	1.2790	1.3001	1.6626	1.4657	1.2706	1.6450	1.4305	1.4760	1.2199	1.5763	1.1763	1.2867	0.9743	0.5609	0.3158
14	0.3073	0.5682	0.9856	1.0422	1.3711	1.3336	1.3137	1.2863	1.3977	1.4622	1.3420	1.5109	1.3474	1.3058	1.0929	1.4407	1.3084	1.3663	1.0232	1.0804	0.5775	0.3137
15	0.2976	0.5408	1.0826	1.3789	1.0701	1.4193	1.2281	1.6065	1.2481	1.5289	1.7355	1.3230	1.2914	1.2534	1.5804	1.1709	1.4067	1.1542	1.3791	1.0716	0.5900	0.3118
16	0.2862	0.5305	0.9637	1.2553	1.3703	1.2258	1.5825	1.2420	1.2333	1.2976	1.3515	1.5362	1.3021	1.2528	1.2347	1.5406	1.1406	1.3415	1.1666	0.9352	0.5445	0.2917
17	0.2484	0.4911	0.9395	0.9443	1.4546	1.4055	1.1938	1.3932	1.1542	1.6028	1.4653	1.2372	1.6106	1.3147	1.1734	1.1414	1.3720	1.4234	0.9384	0.9414	0.4862	0.2575
18	0.2027	0.4050	0.7824	1.0613	0.9794	1.4315	1.3290	1.1383	1.3434	1.2360	1.1239	1.3769	1.2948	1.3513	1.1221	1.3266	1.4221	0.9547	1.0406	0.7712	0.4059	0.2072
19		0.2879	0.4723	0.8218	1.0454	0.9643	1.0078	1.3397	0.9971	1.2692	1.3974	1.0985	1.2369	1.0188	1.3496	1.2117	0.9653	1.0336	0.8128	0.4740	0.2875	
20			0.3276	0.4603	0.7461	0.9266	0.9288	1.0548	1.0680	1.0008	1.0097	1.0525	0.8763	1.0325	1.0387	0.8136	0.8987	0.7541	0.4646	0.3198		
21				0.2751	0.3885	0.4788	0.5208	0.5714	0.5715	0.5703	0.5688	0.5613	0.5536	0.5671	0.5439	0.5016	0.4670	0.3887	0.2820			
22					0.1992	0.2416	0.2801	0.3013	0.3026	0.3120	0.3104	0.3087	0.3047	0.3104	0.2922	0.2734	0.2333	0.1972				

ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (4)

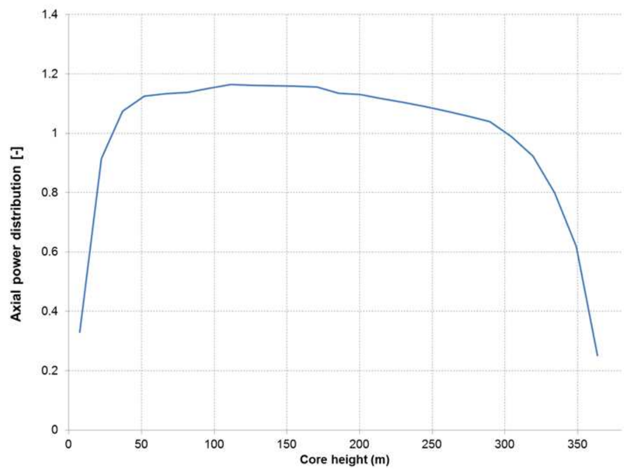
- Radial power distribution imposed in ATHLET.

				6	6	6	6	6	6	6	6	6	6	6	6	6	6				
			6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6			
		6	5	1	3	1	2	2	1	2	2	2	2	2	1	2	1	5	6		
	6	5	2	2	1	3	4	1	3	1	4	3	1	4	1	1	2	2	5	6	
6	5	2	2	1	4	2	1	3	2	3	1	1	3	1	3	4	1	2	2	5	6
6	5	2	1	4	3	1	1	2	3	1	3	3	1	2	1	3	4	1	3	5	6
6	5	1	2	3	1	4	2	2	2	2	2	2	1	1	3	1	2	3	2	5	6
6	5	4	4	1	3	1	3	2	2	2	3	3	1	3	1	3	1	4	2	5	6
6	5	4	1	3	2	3	1	1	1	3	2	2	2	2	2	2	2	1	2	5	6
6	5	1	2	1	3	1	3	2	3	2	2	3	3	2	2	3	1	3	2	5	6
6	5	1	4	1	3	1	3	3	2	2	2	2	2	1	1	1	3	1	2	5	6
6	5	2	1	3	1	1	1	2	2	2	2	2	3	3	1	3	1	4	1	5	6
6	5	2	3	1	3	2	2	3	3	2	2	3	2	3	1	3	1	2	1	5	6
6	5	2	1	2	2	2	2	2	2	2	3	1	1	1	3	2	3	1	4	5	6
6	5	2	4	1	3	1	3	1	3	3	2	2	2	3	1	3	1	4	4	5	6
6	5	2	3	2	1	3	1	1	2	2	2	2	2	2	4	1	3	2	1	5	6
6	5	3	1	4	3	1	2	1	3	3	1	3	2	1	1	3	4	1	2	5	6
6	5	2	2	1	4	3	1	3	1	1	3	2	3	1	2	4	1	2	2	5	6
	6	5	2	2	1	1	4	1	3	4	1	3	1	4	3	1	2	2	5	6	
		6	5	1	2	1	2	2	2	2	2	1	2	2	1	3	1	5	6		
			6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6			
				6	6	6	6	6	6	6	6	6	6	6	6	6	6				

Channel TFCORE	101	201	301	401	102	103
# of channels	100	64	68	112	74	26
Position	1	5	6	2	3	4
Type of FA (Figure 29)	1	1	1	2	3	4
Radial power	1.1150	0.5308	0.2904	1.2103	1.4474	1.3890
# of pins per FA	64	64	64	72	72	91

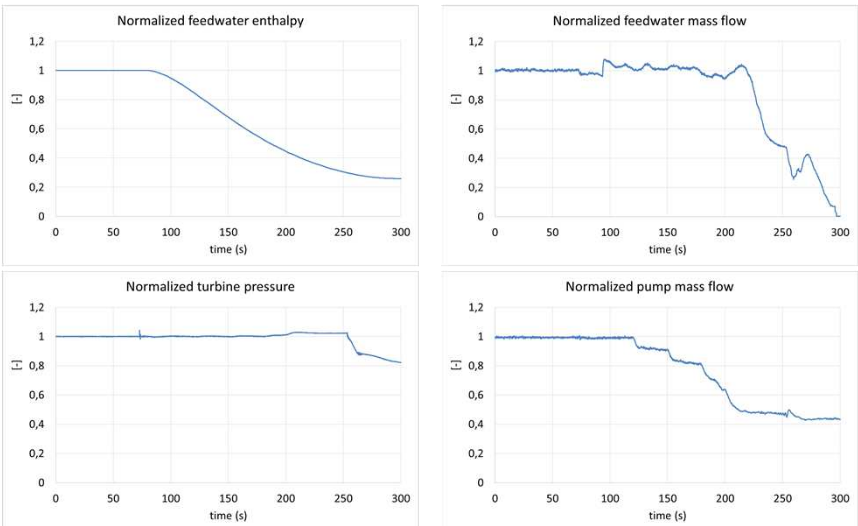
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (5)

- Axial power distribution imposed in COBRA-TF and ATHLET



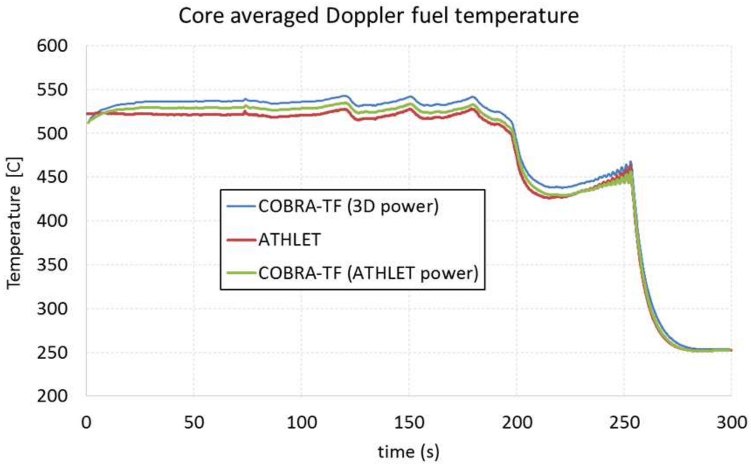
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (6)

- Transient boundary conditions imposed in ATHLET



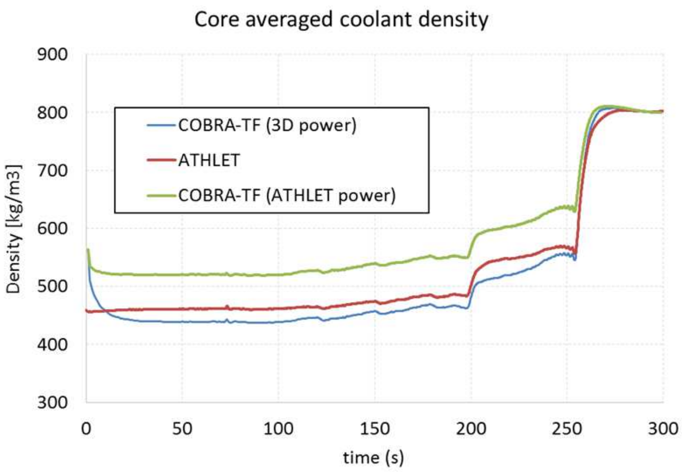
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (7)

- COBRA-TF core average results:



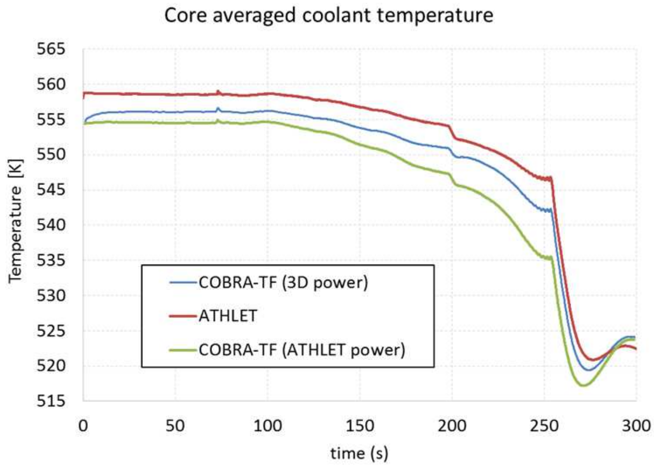
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (8)

- COBRA-TF core average results:



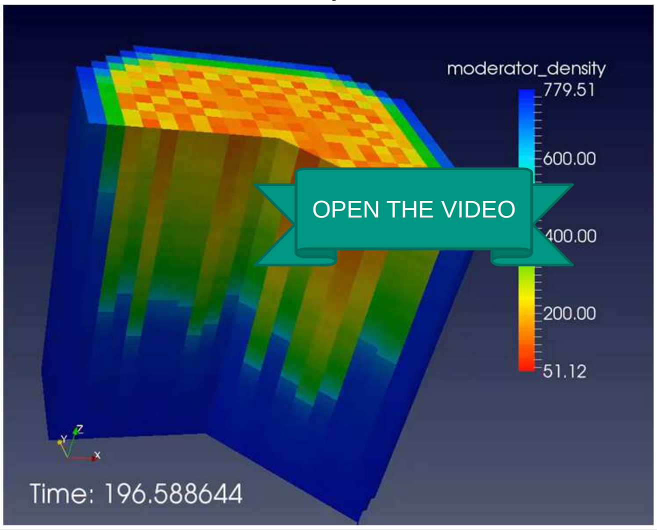
ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (9)

- COBRA-TF core average results:

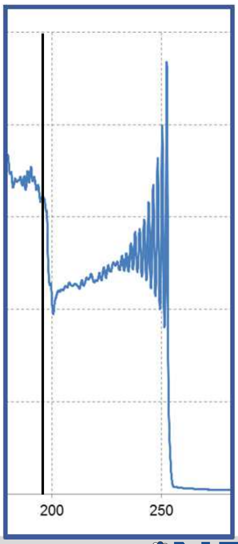


ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (10)

- COBRA-TF coolant density

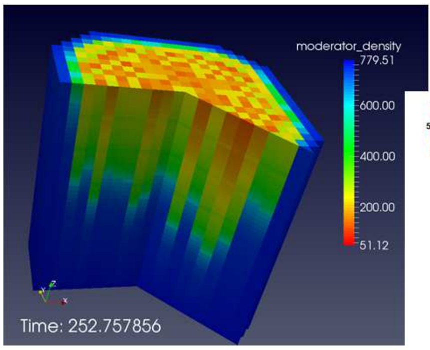


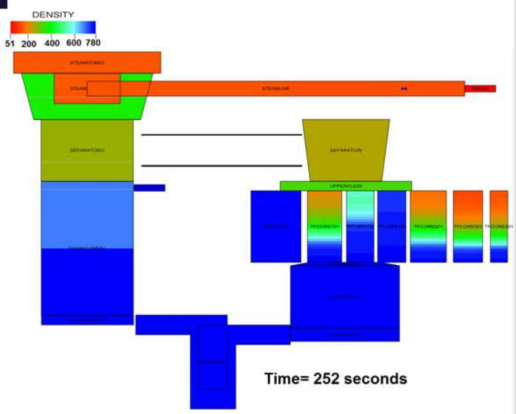
Power vs. time



ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (11)

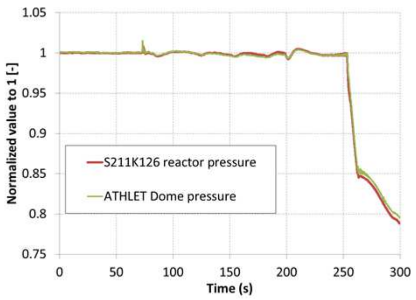
- Coolant density in the time where the power peak occurs (252.7 s)



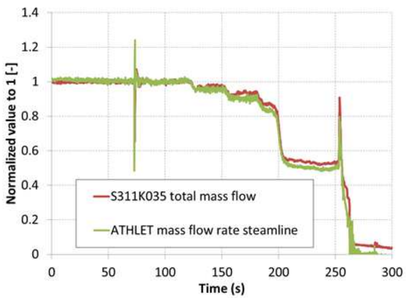


ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (12)

- Multi-scale simulation of the BWR Oskarshamn-2 reactor
  - The coupled ATHLET/COBRA-TF code predicts the key thermal-hydraulic phenomena of BWR with fairly good accuracy for the selected ATWS transient, thus confirming the validity of the selected coupling approach



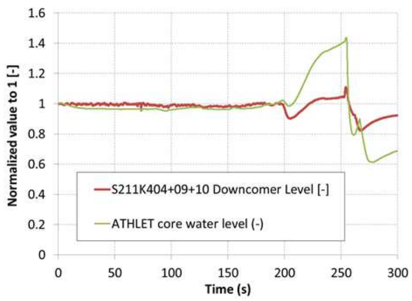
Comparison of the reactor pressure



Comparison of total mass flow rate in the steamline

ATHLET/COBRA-TF multi-scale thermal-hydraulics analysis (13)

- Multi-scale simulation of the BWR Oskarshamn-2 reactor
  - The coupled ATHLET/COBRA-TF code predicts the key thermal-hydraulic phenomena of BWR with fairly good accuracy for the selected ATWS transient, thus confirming the validity of the selected coupling approach



Comparison of the core water level

Conclusions from the multi-scale TH simulations

- Multiscale TH simulations could be performed using the system ATHLET/COBRA-TF developed by GRS.
- Application to the Oskarshamn-2 feedwater transient event has been succesfully conducted
- During the coupling only the inlet and outlet boundary conditions are exchange from ATHLET to COBRA-TF, one-way coupling.
- The effect on COBRA-TF of using a 3D power distribution coming from a 444 channel model or from a 6 lumped channel model is relevant.
  - This points out the need of having a coupled neutronic code.
  - ATHLET/COBRA-TF/DYN3D could not be used due to the lack of a XS library in nemtab format.

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Sensitivity and uncertainty analysis of the Oskarshamn-2 stability event with COBRA-TF

- KIT contribution within NURESAFE WP1.1
- Using URANIE and SUSA
  - *"**Sensitivity Analysis of the Oskarshamn-2 Stability Event Using the URANIE Software**",* J. Jiménez, N. Trost, W. Jaeger, V. Sanchez; NUTHOS10-1319. Okinawa, Japan, December 14-18, 2014

KIT – Universität des Landes Baden-Württemberg und
nationales Forschungszentrum in der Helmholtz-Gemeinschaft

URANIE

- URANIE is a software dedicated to uncertainty and optimization.
- It allows to perform studies on uncertainty propagation, sensitivity analysis or model calibration in an integrated 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 (1)

- 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 (2)

- **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.

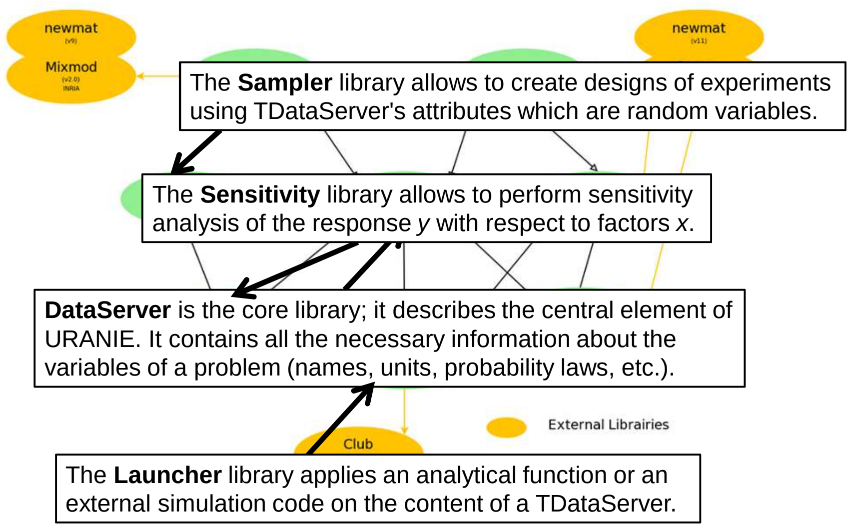
Input Sample of Size N — Random Sampling — Output Sample of Size N

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

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.

URANIE Software Functional Diagram



SUSA Software system for Uncertainty and Sensitivity Analysis

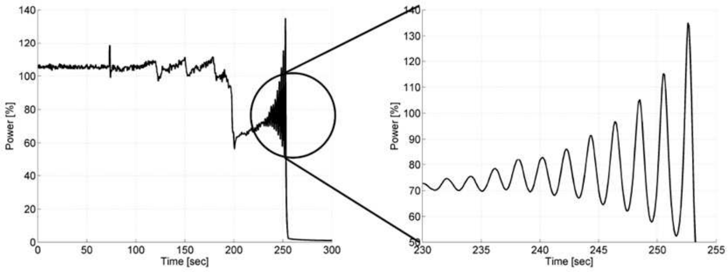
- Under development at GRS (Germany).
- Probabilistic approach with input error propagation to the output.
- Minimal number of code runs defined by Wilk's formula.
- Monte Carlo simple random and Latin Hypercube sampling (LHS).
- Widely used in nuclear community. Well validated.
- Used in this work as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

- Power oscillation during the event (feedwater transient)



Oskarshamn-2 February 25, 1999 feedwater transient

- Boundary conditions taken from TRACE/PARCS calculation (KIT model with 444 channels)
- Modeling the O2 core with COBRA-TF using 444 channels

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 Modeling with subchannel codes

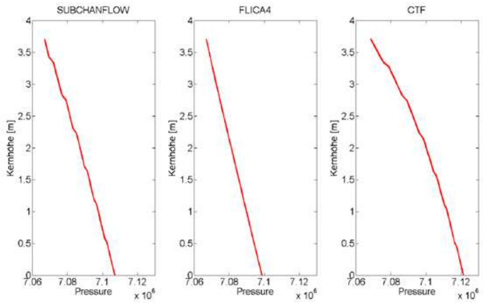
- Oskarshamn-2 Core has being modeled with COBRA-TF, SUBCHANFLOW and FLICA4
- Code versus measured data comparison

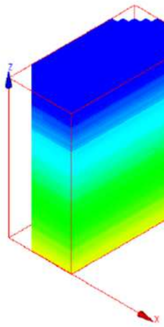
Parameter at HFP	Benchmark	SCF	FLICA4	CTF
Thermal Power (MW)	1798.6	1798.6	1798.6	1798.6
Core inlet Temperature (K)	547.30	547.30	547.30	547.30
Core Inlet Mass Flow (kg/s)	4793.50	4793.50	4793.50	4793.50
Core outlet Temperature (K)	558.48	559.63	558.2	558.43
Average void fraction (-)	0.42	0.41	0.39	0.37
Void fraction at core outlet (-)	-	0.7124	0.6698	0.687
Presure drop in the core (kPa)	46.0	45.1	40.1	47.91
Average flow velocity in the core (m/s)		2.99	4.59 (Vap.) 2.77 (Liq.)	3.21

NEW CTF RESULTS

Results: Pressure drop

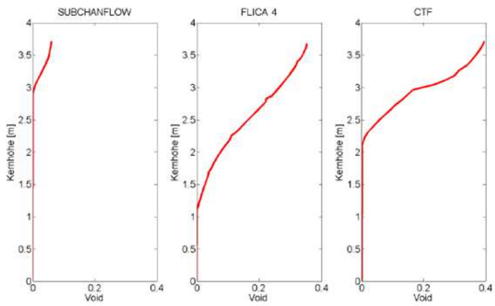
- **3D Power distribution take from converge steady state TRACE/PARCS**

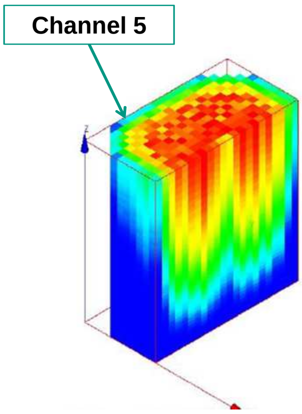




	Benchmark	SUBCHANFLOW	FLICA4	CTF
Average Pressure drop in the core (kPa)	Ref.	-1.9%	-12.8%	+4.1%

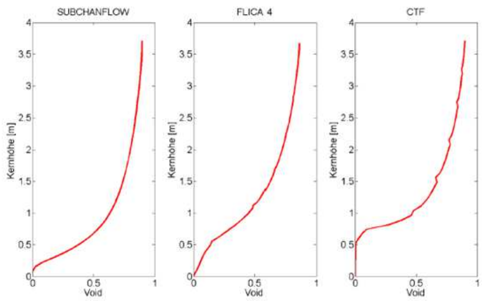
Results: Void fraction in channel 5

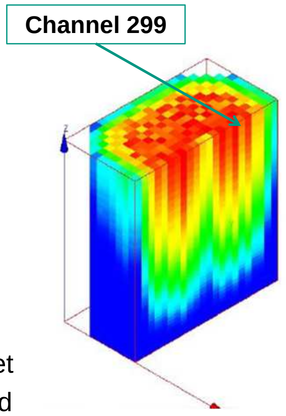




- Very different onset of boiling
- Effects of subcooled boiling are modeled differently

Results: Void fraction in channel 299





- Similar vapor volume fraction at the core outlet
- The position of the spacers grids in FLICA and COBRA-TF can be seen clearly

Sensitivity study, PDFs determination

- Sensitivity analysis with parameters taken from the NURESAFE benchmark specifications (D13.11)
  - Power range was increased from ± 0.75% to ± 2.0%

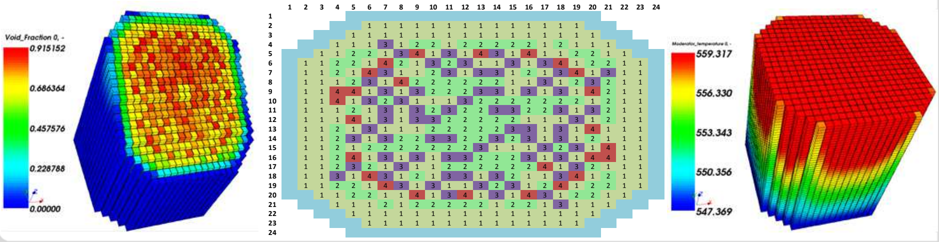
No.	Parameter	Range	Distribution
1	Outlet pressure	± 0.5 %	Uniform
2	Mass flow rate	± 0.5 %	Uniform
3	Inlet temperature	± 2.0 %	Normal
4	Power	± 2.0 %	Normal
5	Cladding Wall Roughness	± 30.0 %	Normal
6	Spacer grid pressure drop coefficient	± 5.0 %	Uniform
7	Gap Conductance	± 35.0 %	Uniform
8	Fuel Conductivity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

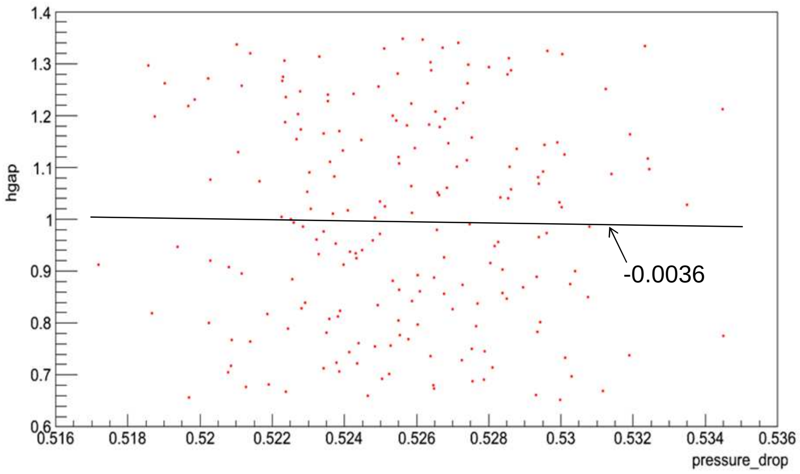
COBRA-TF O2 nominal steady state results

- **Axial pressure drop** and **Outlet void fraction** are the output parameters studied (200 runs were used **-** 97.3% confidence level).
- The computed 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

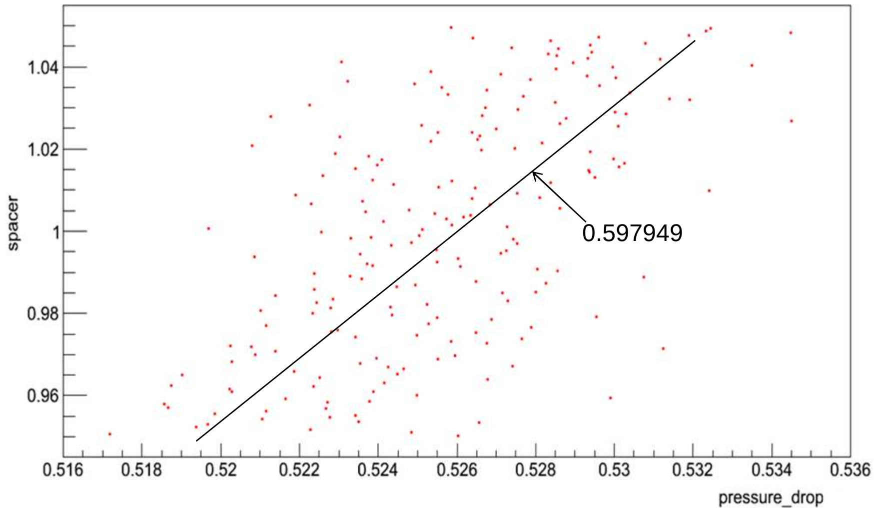


COBRA-TF O2 nominal steady state results (1)



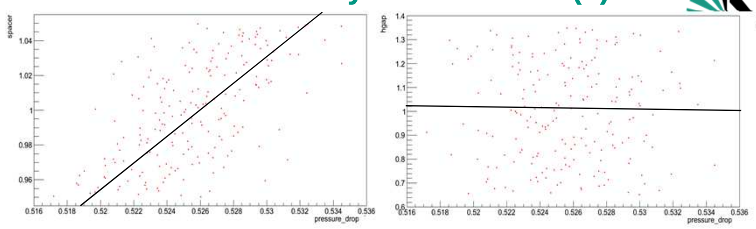
Axial pressure drop sensitivity with regards to fuel gap conductivity.

COBRA-TF O2 nominal steady state results (2)

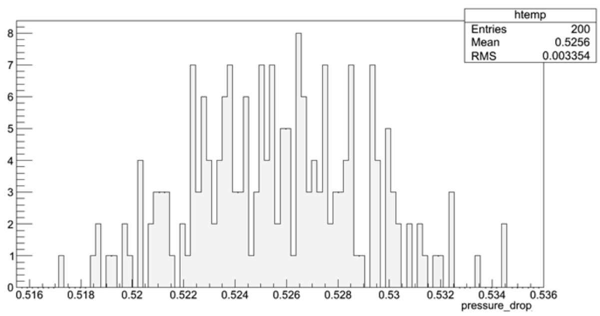


Axial pressure drop sensitivity with regards to spacer grids pressure loss coeff.

COBRA-TF O2 nominal steady state results (3)



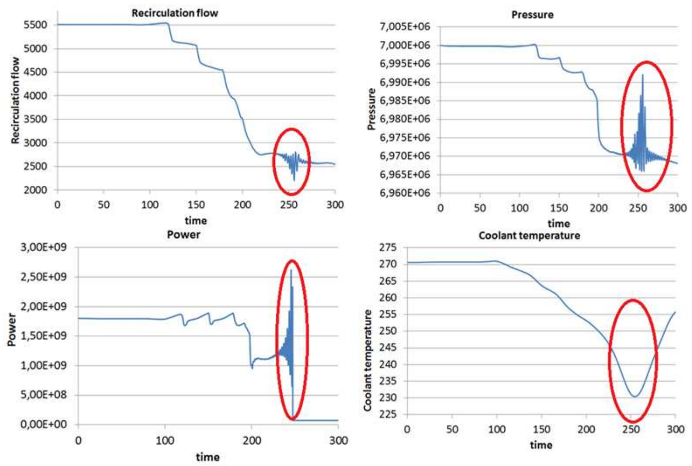
Axial pressure drop for different spacer coefficient and gap boundary conditions



Pressure drop distribution over all COBRA-TF runs

Transient Boundary Conditions applied

- The next boundary conditions were introduced into CTF for the simulation of the oscillations (only 12s are analyzed).
  - Power, inlet temperature, pressure, mass flow rate.



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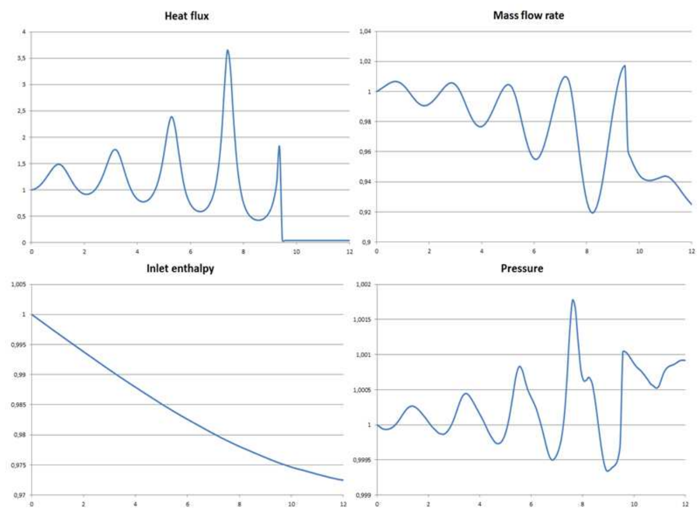
Transient Boundary Conditions applied

- Those BC are representative of a stability event.
- 500 COBRA-TF runs were used - 98.7% confidence level



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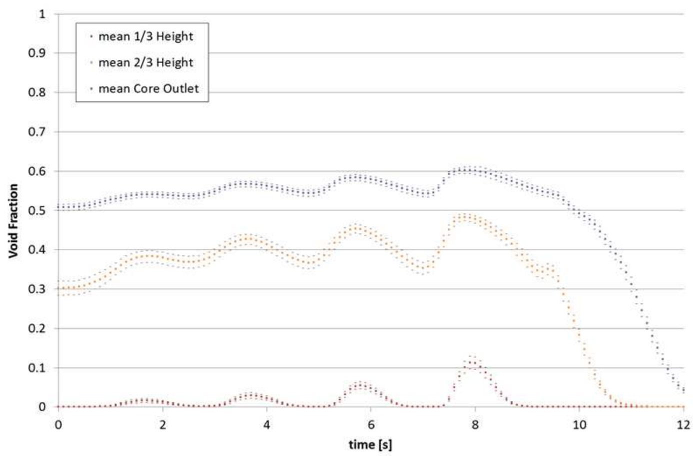
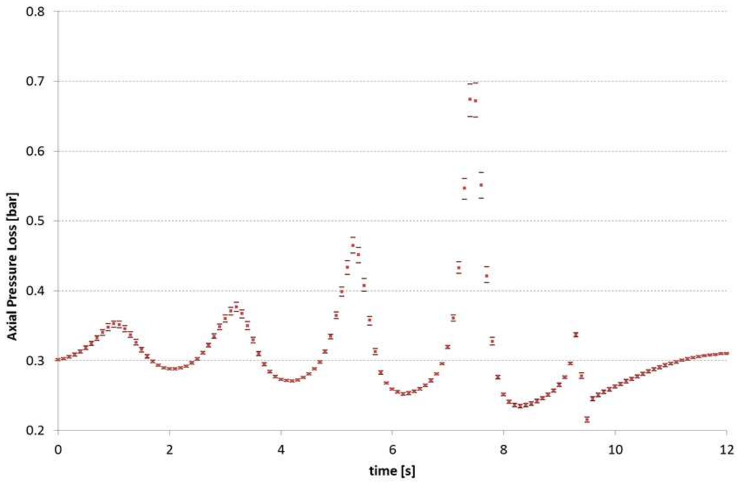
URANIE Results in the zooming area

- **Mean, min and max** value of the **void fraction** at three different elevations: 1/3, 2/3 and exit



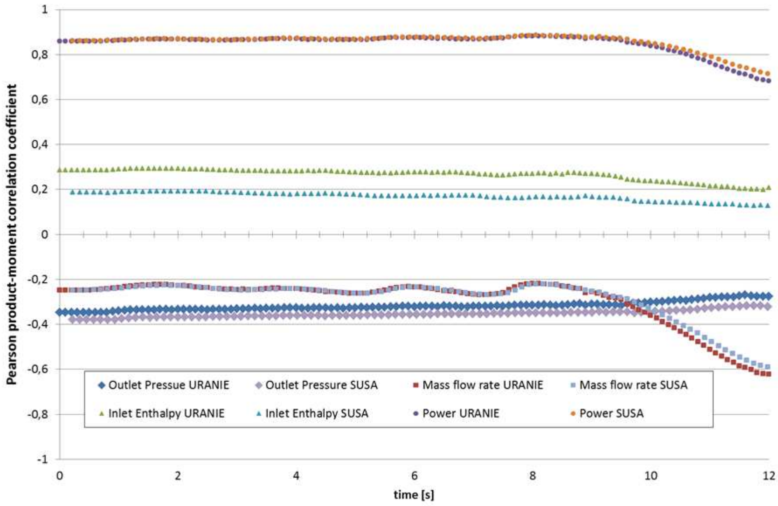
URANIE Results in the zooming area

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



Comparison of URANIE against SUSA (1)

- Pearson sensitivity coefficients of the **void fraction**



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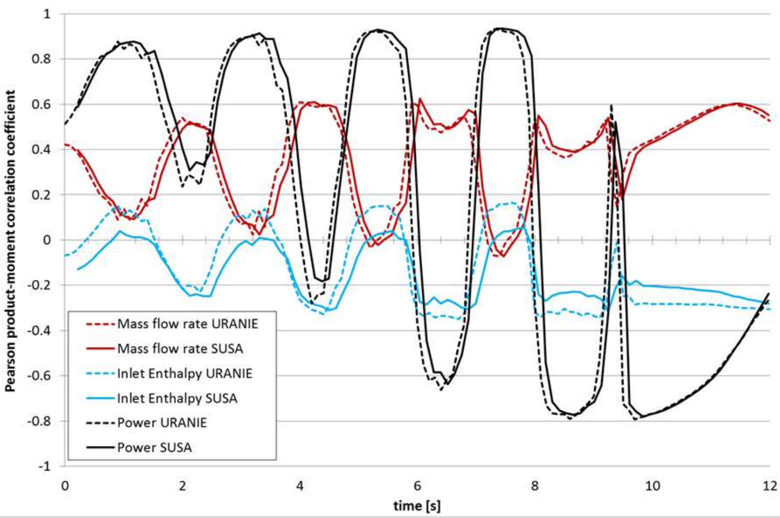
Comparison of URANIE against SUSA (2)

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



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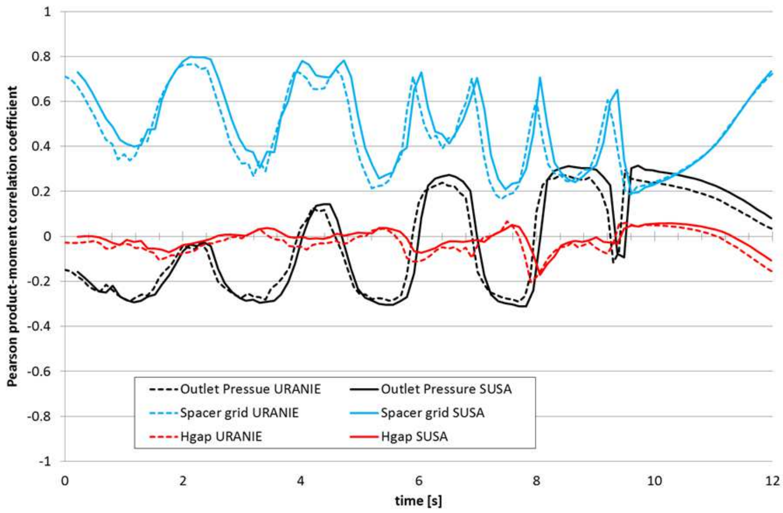
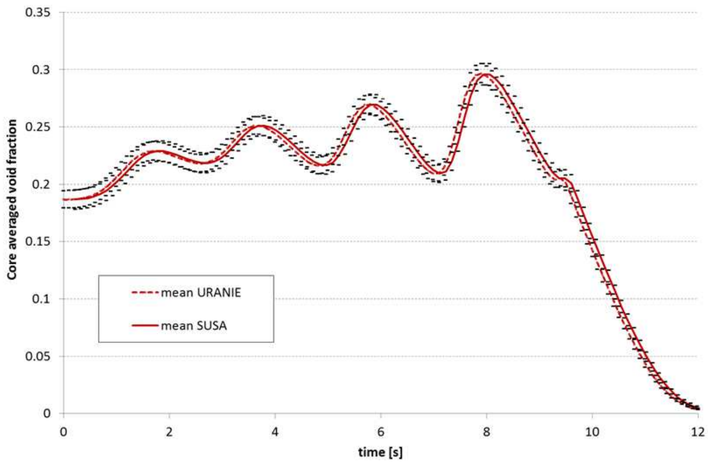
Comparison of URANIE against SUSA (3)

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



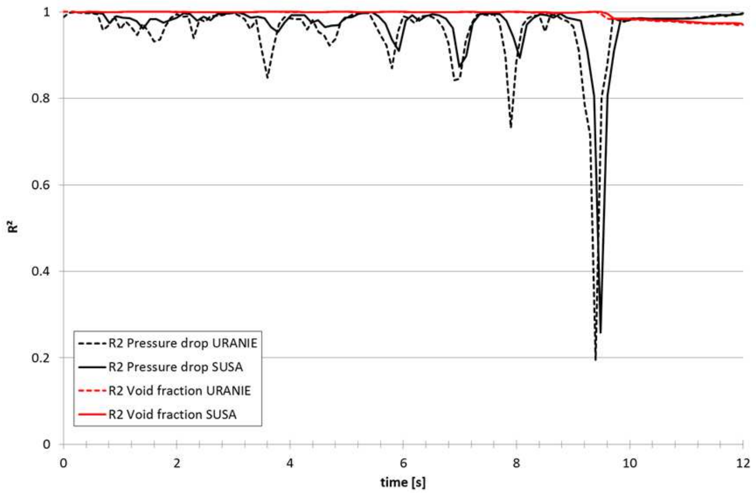
Comparison of URANIE against SUSA (4)

- Core averaged void fraction



Comparison of URANIE against SUSA (5)

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



Conclusions

- Investigations on the use of URANIE platform for sensitivity analyses have been conducted within the framework of the NURESAFE FP7 EU project.
- COBRA-TF model for O2 core was developed
  - Good agreement between O2 reference values and predictions,
  - FLICA4 and SUBCHANFLOW models developed too.
- Studies using the COBRA-TF code on steady state and transient simulations were carried out.
- Satisfactory results, high degree of flexibility in the URANIE scripts.
- Further validation of the inputs is still needed (FLICA4 v1.11.13).
- URANIE provides similar results to SUSA.
- The developed inputs could be applied in Phase 3, exercise 2 and 3 of the O2 benchmark.

Index of content

Summary and Outlook

- KIT has computed the transient event corresponding to phase 1 with TRACEV5P3 and TRACEV5P2 using a one-to-one coupling (444 channels in TRACE/ 444 FA in PARCS).
  - Results reported in O2-3 meeting at GRS (2014).
  - Missing the steady state simulations for the Event Points 1, 4, 6, 8 and 11
  - The lack of a nemtab XS library didn´t allow to prepare a solution set using TRADYN code (PhD work at KIT).
- Within NURESAFE project, multi-scale coupling using ATHLET/COBRA-TF has been applied successfully to the stability event.
- Submit the results using the official benchmark templates.
- Now getting ready:
  - for Phase 2, the extreme scenarios need to be analysed.
  - for Phase 3, some models have been developed at channel level with COBRA-TF and SUBCHANFLOW. A sensitivity study has been conducted and presented in NUTHOS-10 conference. URANIE vs. SUSA.

Thanks for your attention