KIT activities using CTF within NURESAFE project

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Outline

- **Remarks about NURESAFE CTF version**
- **D13.22: *Description of the CTF input deck for BWR ATWS analysis* (KIT & GRS)**
- **D14.22b: *Full core CTF input model for VVER MSLB analysis* (KIT & INRNE)**
- **D11 22: *Report on COBRA-TF UQ results for BWR ATWS analysis* (KIT & CEA)**
- **Conclusion & Outlook**

Remarks about NURESAFE CTF version

- Within NURESAFE, COBRA-TF is being delivered by GRS to the partners

- Code license agreement need to be signed between PSU and each interested partner

- The same source as for the CASL program

- Email communication with ORNL, GRS and PSU to solve bugs and problems

1. COBRA-TF input deck for BWR ATWS

- **D13.22: *Description of the CTF input deck for BWR ATWS analysis***

  (KIT & GRS)

EUROPEAN COMMISSION

Community Research

EURATOM

NURESAFE

NUclear REactor SAFEty Simulation Platform

Collaborative Project (Large – scale Integrating Project)

Seventh Framework Programme EURATOM

Contract Number: 323263

Start date: 01/01/2013 Duration: 36 Months

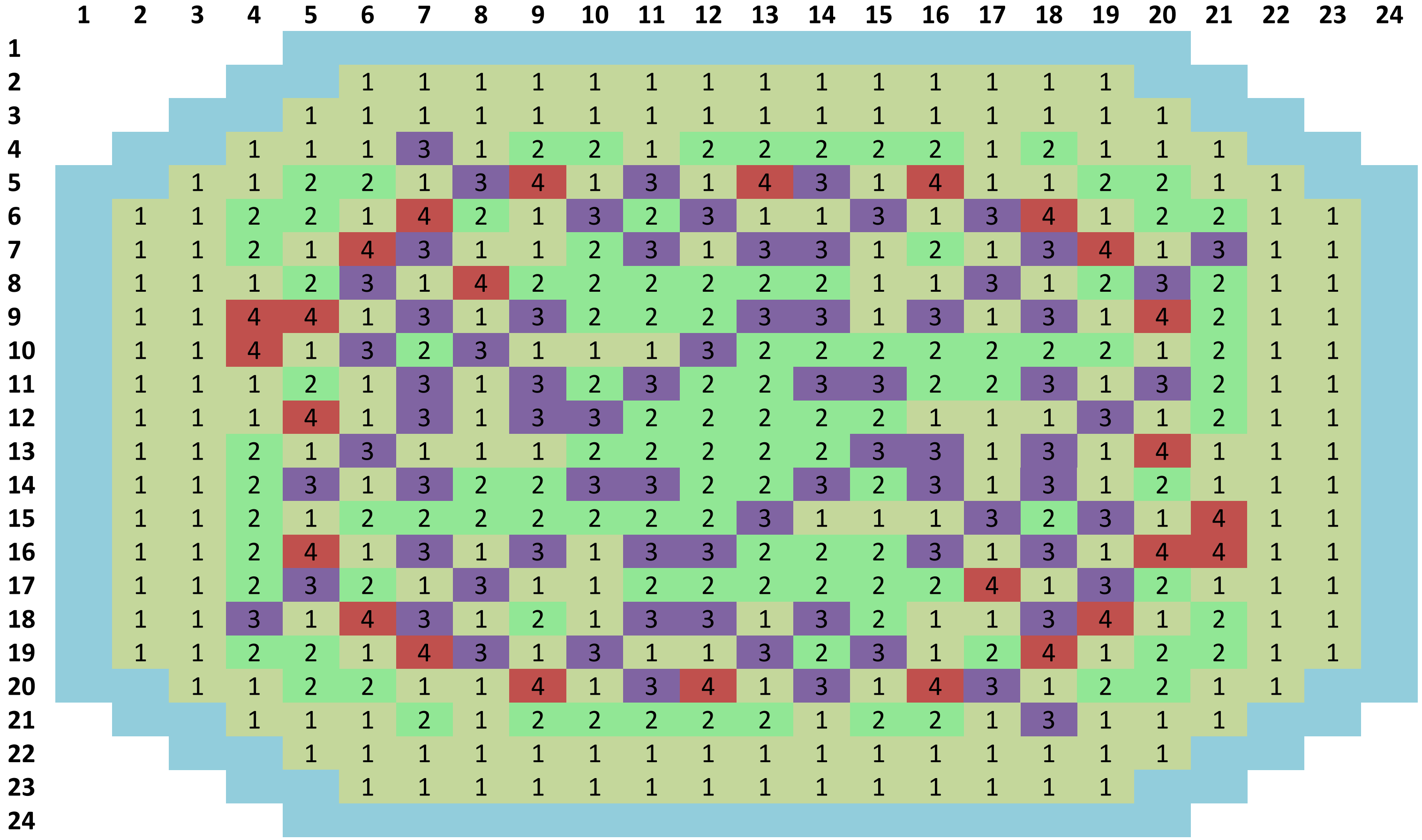
D13.22 – Description of the CTF input for BWR ATWS analysis

Authors: Javier, Jimenez Escalante (KIT) and Yann, Périn (GRS)

NURESAFE – D13.22 – version 0 – Issued on 17/12/2013

1.1 O2 Core modeling with CTF

- **444 channels: Every channel represents a FA**
- **There are 4 types of different fuel assemblies**



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23						1	1	1	1	1	1	1	1	1	1	1	1	1	1					
24																								

1.2 Current model limitations

- **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. For the coupling with a neutronic core model, a bottom and top reflector part will be needed.
  - The axial power distribution is the same in all assemblies.
  - The 444 fuel assemblies are modelled in parallel (no flow between channels).
  - The flow area, wetted perimeter and pressure loss coefficients are taken from the specifications.
- **The input deck has around 3900 lines**

1.3 CTF INPUT DECK STRUCTURE

- **MAIN PROBLEM CONTROL DATA**
  - CARD GROUP 1: Selection of the Physical Models, Global Boundary Conditions, and Initial Conditions
  - CARD GROUP 2: Channel Description
  - CARD GROUP 3: Transverse Channel Connection Data (Gap definition)
  - CARD GROUP 4: Vertical Channel Connection Data
  - CARD GROUP 7: Local Pressure Loss Coefficient and Grid Spacer Data
  - CARD GROUP 8: Rod and Unheated Conductor Data

1.4 CTF INPUT DECK STRUCTURE

- **MAIN PROBLEM CONTROL DATA**
  - CARD GROUP 9: Conductor Geometry Description
  - CARD GROUP 10: Material Properties Tables
  - CARD GROUP 11: Axial Power Distribution Tables, Radial Power Distribution, and Transient Forcing Functions
  - CARD GROUP 12: Turbulent Mixing and Void Drift Data
  - CARD GROUP 13: Boundary Condition Data
  - CARD GROUP 14: Output Options
  - CARD GROUP 15: Time Domain Data

1.5 CARD GROUP 1, 2 and 3

- **The input deck developed is in SI units**
- **The solver choice for the system pressure matrix is Bi-CGSTAB**
- **Global boundary conditions taken from the specifications**
- **Regarding the mixing:**
  - Single-phase mixing coefficient according to Rogers and Rosehart (1972)
  - Two-phase multiplier according to Beus (1970)
- **The flow area and wetted parameter for each channel are provided. The data are taken directly from the distributed data**
- **There is no CARD GROUP 3, BWR fuel bundles are wrapped**

1.6 CARD GROUP 4, 5 and 6

- Only one section was specified for the whole axial length of the active core (3.712 m)
- 50 equidistant axial nodes are used
- Only the active part of the core is modelled
- Fuel bundle type 4 contains partial fuel rods. Card group 5 and 6 allow for the modification of the flow area in selected channels (bundle type 4)

1.7 INPUT CARD GROUP 7, 8, 9 and 10

- **Local Pressure Loss Coefficient and Grid Spacer Data**
  - The data is taken directly from the distributed data
- **There are 444 nuclear fuel rods representing each FA (*nucl* component CARD 9)**
  - For the fuel rod modeling, a constant gap conductance of 9500 W/cm² is assumed
- **There are 444 unheated structures representing the canister walls (*wall* component CARD 9)**
- **In CARD 10, default material properties for UO2 fuel and Zircalloy are used**

1.8 CARD GROUP 11, 12 and 13

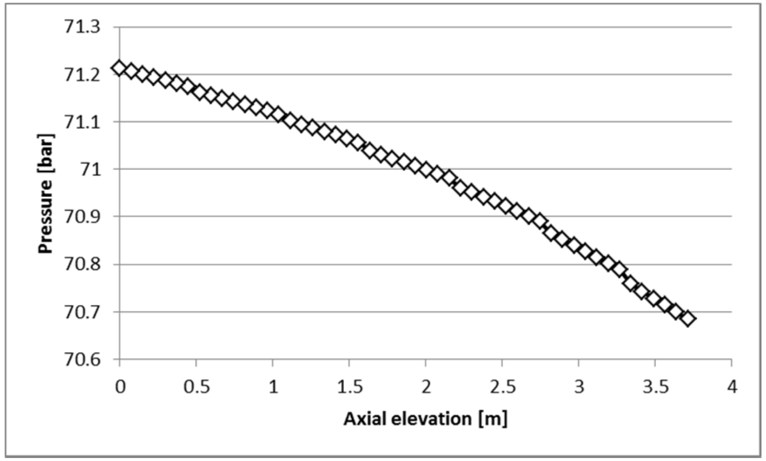
- **The radial power distribution is taken from a steady-state coupled calculation performed with TRACE/PARCS**
- **The axial power distribution is the core averaged axial power distribution extracted from the same coupled calculation and thus is the same in all assemblies**
- **Turbulent mixing and void drift data is specified in this input card.**
  - single-phase mixing coefficient is taken according to Rogers and Rosehart
  - two-phase multiplier is taken according to Beus
  - A value for THETM of 5.0 is suggested according to Sato (1992) for the ratio between maximum two-phase turbulent mixing coefficient (near the transition between slug and annular flow) and single-phase turbulent mixing coefficient (in single phase liquid)
- **In total there are 888 (444*2) boundary conditions specified**

1.9 General model assumptions

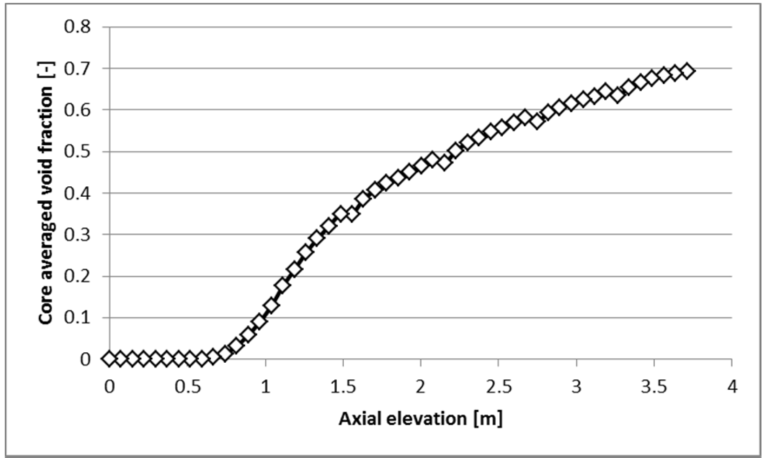
Model option	Where	Choice
Rod friction factor correlation (IRFC)	CARD GROUP 1	2 ($\lambda = 0.204\ Re^{-0.2}$)
Entrainment and deposition model (EDMOD)	CARD GROUP 1	0
Mixing and void drift model (IMIX)	CARD GROUP 1	2
Iterative Solver for pressure equation (ISOL)	CARD GROUP 1	3 (Bi-CGSTAB)
Number of simultaneous solution groups (NSIM)	CARD GROUP 4	1
Rebalancing option for iterative control (IREBAL)	CARD GROUP 4	0
Conduction in solid structures (NC)	CARD GROUP 8	1 (radial only)
Flag for steady state calculation of rod temp. (NSTATE)	CARD GROUP 8	2
Renoding flag for heat transfer solution for rod N (NRENODE)	CARD GROUP 8	0
Fuel relocation flag (IRELF)	CARD GROUP 9	0
Fuel degradation flag (ICONF)	CARD GROUP 9	0
Flag for metal-water reaction, ZrO_2 only (IMWR)	CARD GROUP 9	0

1.10 CTF Results at HFP

- **CTF converge to steady state without major problems in a 3 seconds void transient**



Core pressure versus height



Radial average void fraction versus height

- **Good agreement between O2 reference values and predictions although bypass flow is not modeled.**

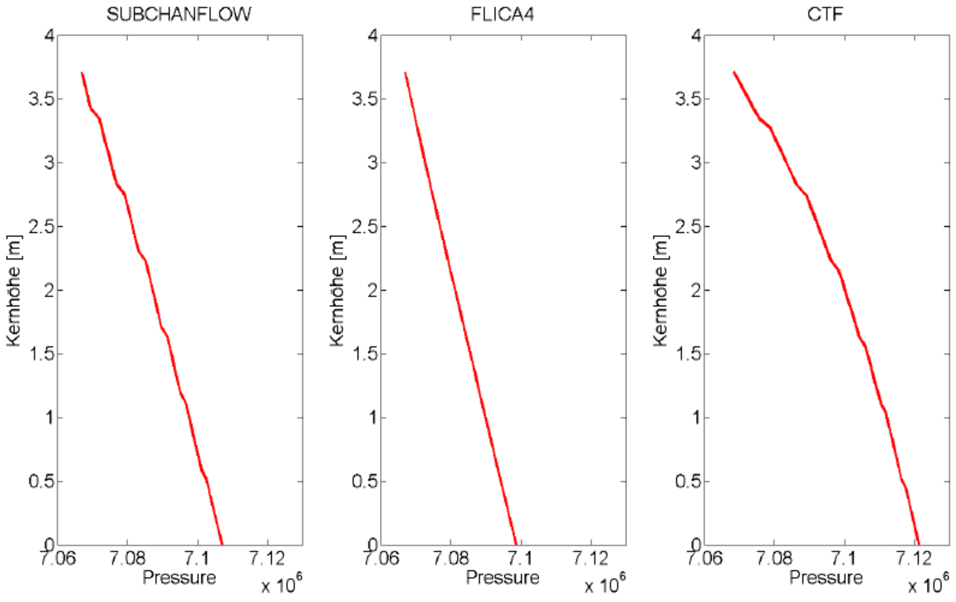
1.11 O2 Modeling with subchannel codes

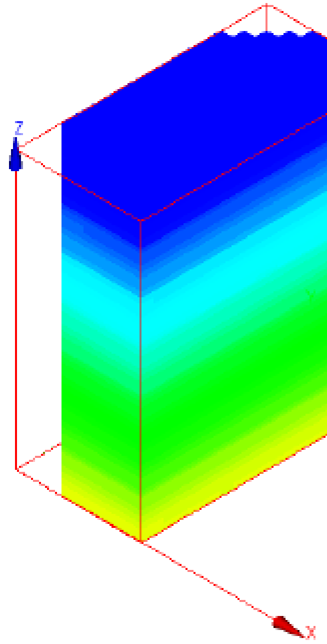
- **Oskarshamn-2 Core has being modeled with COBRA-TF, SUBCHANFLOW and FLICA4**
- **Code versus measured data comparison**

Parameter at HFP	**Benchmark**	**SCF**	**FLICA4**	**CTF**
Thermal Power (MW)	NON-DISCLOSURE AGREEMENT			
Core inlet Temperature (K)				
Core Inlet Mass Flow (kg/s)				
Core outlet Temperature (K)				
Average void fraction (-)				
Void fraction at core outlet (-)				
Presure drop in the core (kPa)				
Average flow velocity in the core (m/s)				

1.12 Results: Pressure drop

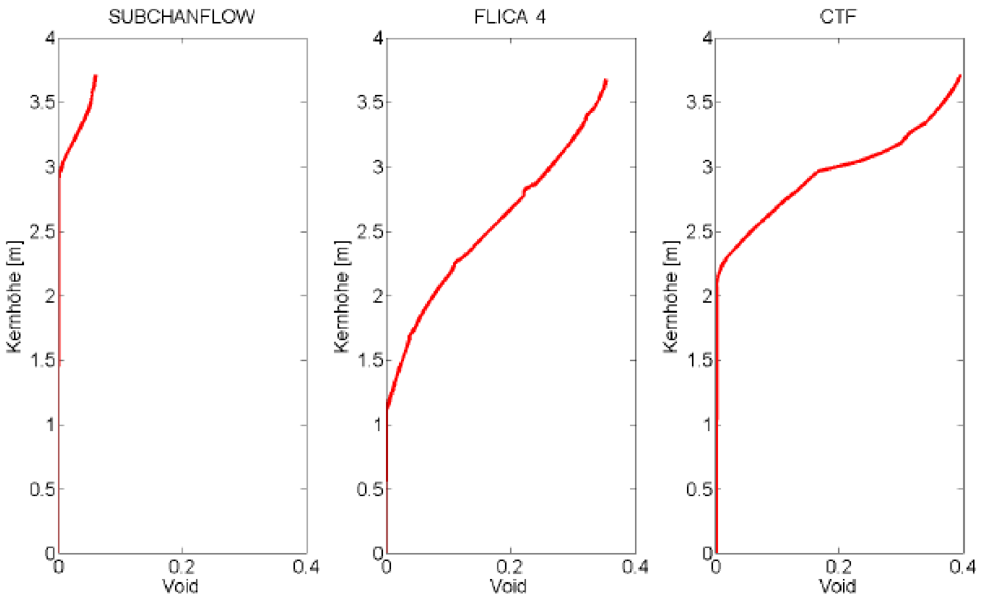
- **3D Power distribution take from converge steady state TRACE/PARCS**



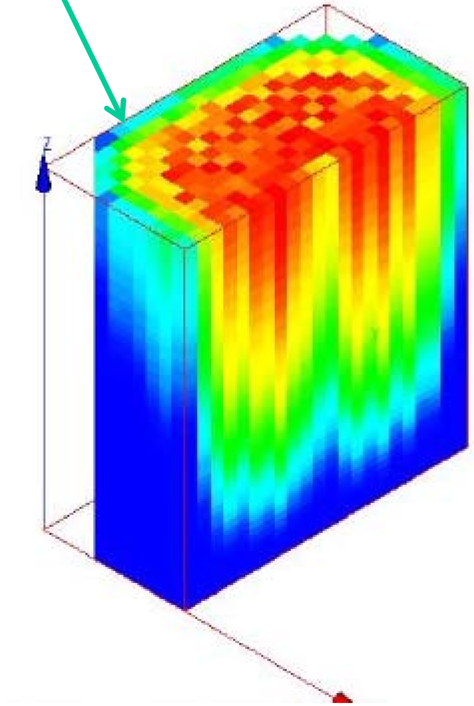


	Benchmark	SUBCHANFLOW	FLICA4	CTF
Average Pressure drop in the core (kPa)	Ref.	-1.9%	-12.8%	+16.3%

1.13 Results: Void fraction in channel 5

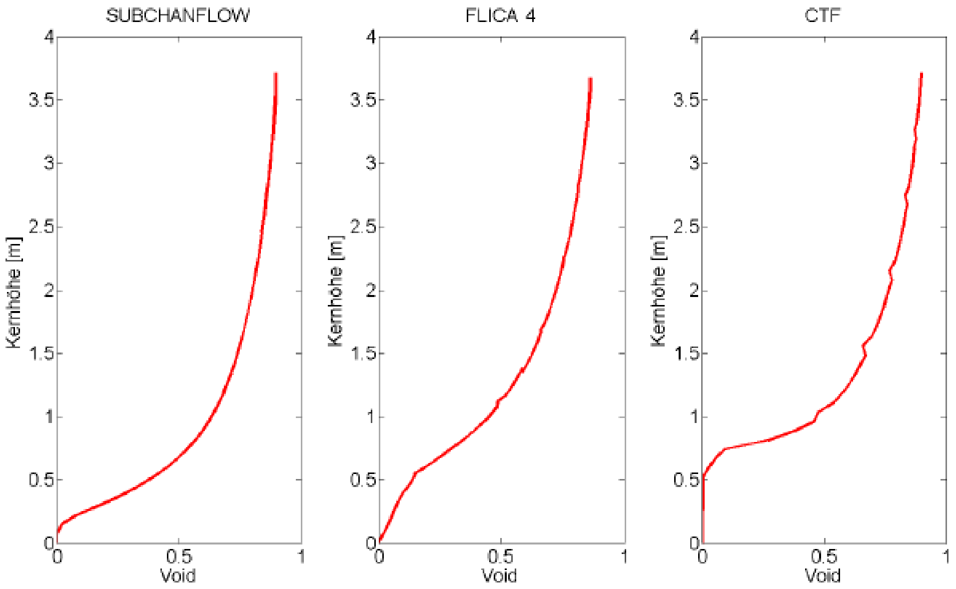


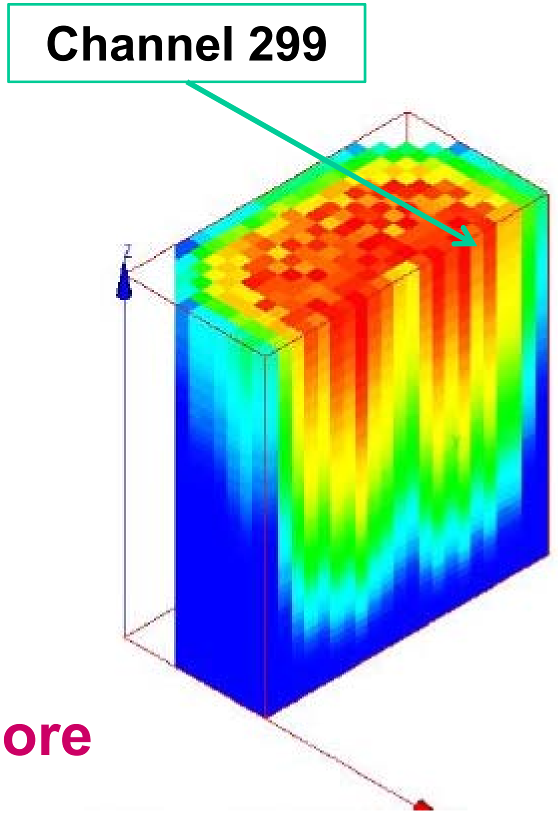
Channel 5



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

1.14 Results: Void fraction in channel 299

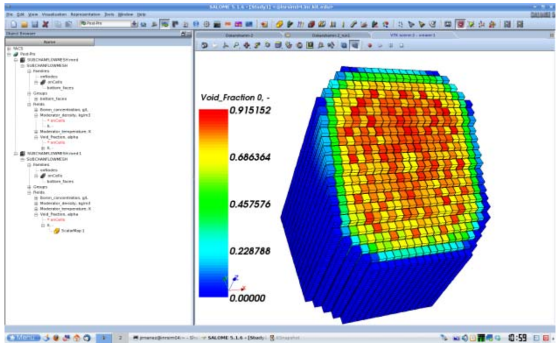


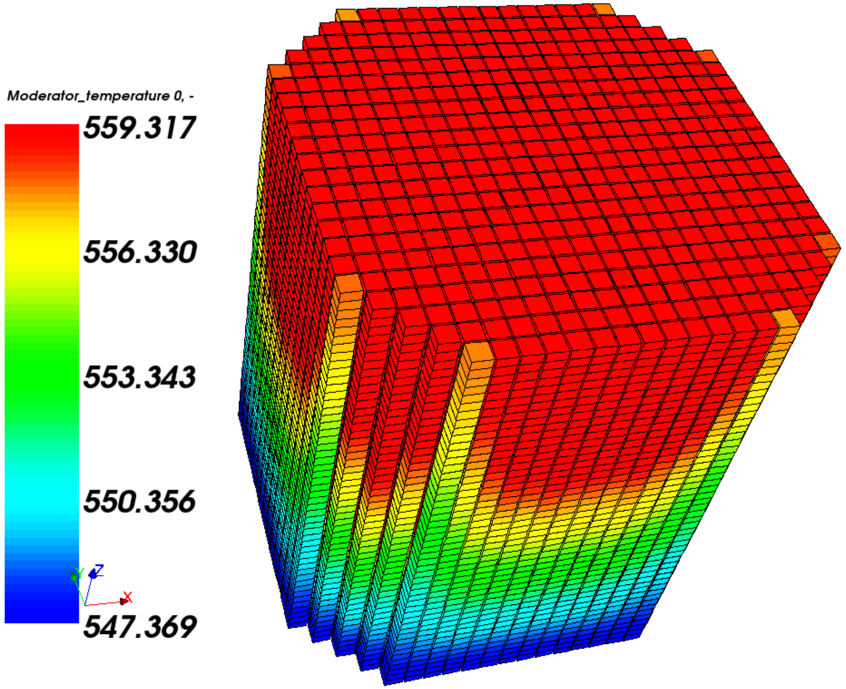


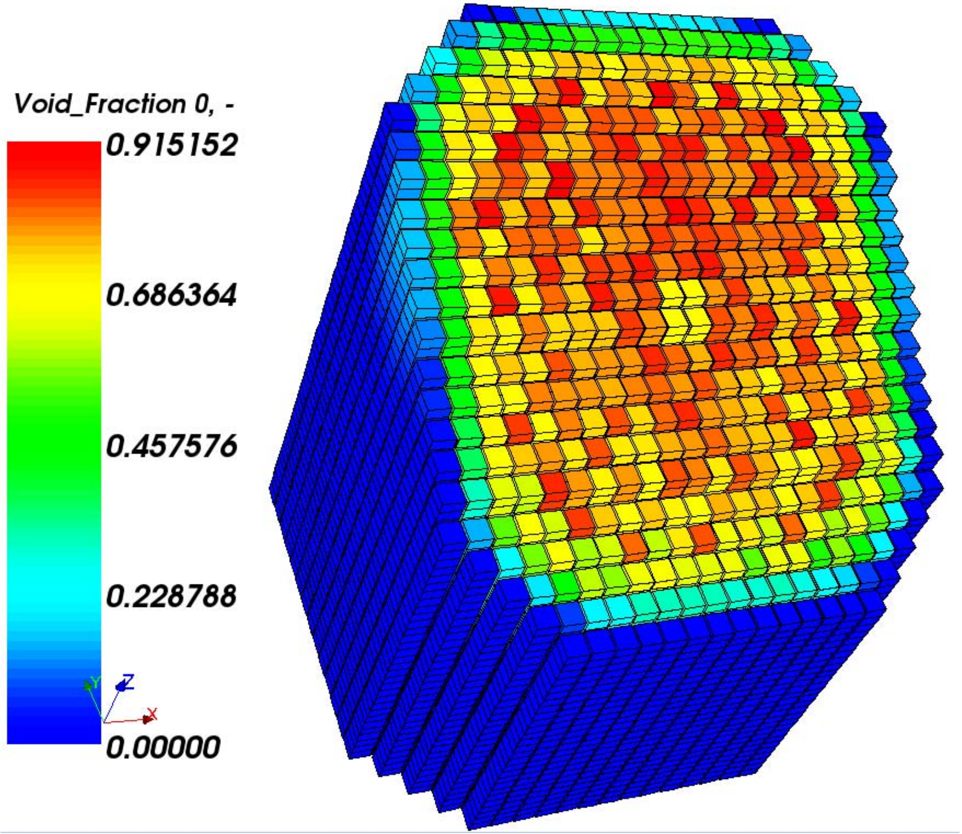
- **Similar vapor volume fraction at the core outlet**
- **The position of the spacers grids in FLICA and COBRA-TF can be seen clearly**

1.15 SUBCHANFLOW Simulation (3)

Post-processing of 3D output within SALOME (MED)

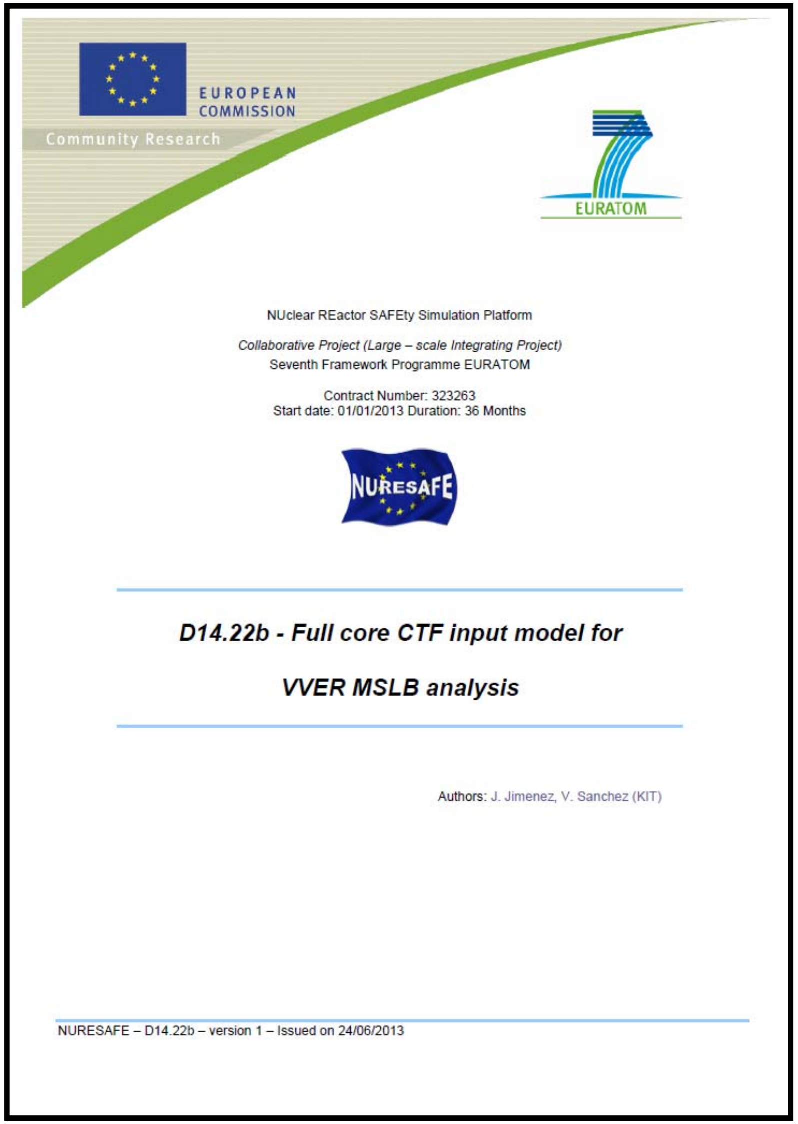






2. VVER-1000 COBRA-TF input model

- ***D14.22b Released: Full core CTF input model for VVER MSLB analysis* (KIT & INRNE)**
  - CTF input deck
  - SUBCHANFLOW input deck
  - Comparison of results at HZP and HFP



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Collaborative Project (Large – scale Integrating Project)
Seventh Framework Programme EURATOM

Contract Number: 323263
Start date: 01/01/2013 Duration: 36 Months

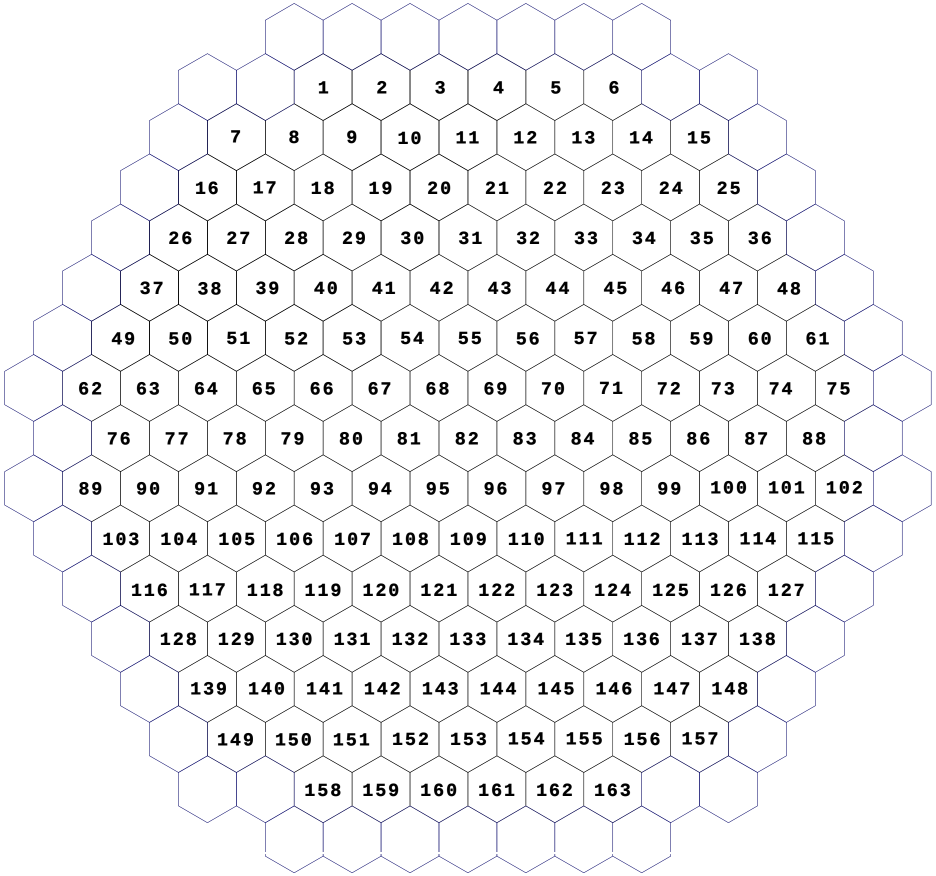
D14.22b - Full core CTF input model for VVER MSLB analysis

Authors: J. Jimenez, V. Sanchez (KIT)

NURESAFE – D14.22b – version 1 – Issued on 24/06/2013

2.1 Core modeling VVER 1000

- **163 channels: Every channel represents a FA composed by 312 fuel pins, 18 guide tubes and 1 instrumentation rod resulting in a total of 331 rods**



Basic geometrical dimensions	Value
Fuel rod external diameter, m	0.0091
Guide tube diameter, m	0.0126
Instrumentation rod diameter, m	0.0112
Clad wall thickness, m	0.00069
Fuel pellet outer diameter, m	0.00756
Fuel pellet inner diameter, m	0.00235
Fuel assembly pitch, m	0.236

2.2 CTF INPUT DECK STRUCTURE

- **MAIN PROBLEM CONTROL DATA**
  - CARD GROUP 1: Selection of the Physical Models, Global Boundary Conditions, and Initial Conditions
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2.3 CTF INPUT DECK STRUCTURE

- **MAIN PROBLEM CONTROL DATA**
  - CARD GROUP 9: Conductor Geometry Description
  - CARD GROUP 10: Material Properties Tables
  - CARD GROUP 11: Axial Power Distribution Tables, Radial Power Distribution, and Transient Forcing Functions
  - CARD GROUP 12: Turbulent Mixing and Void Drift Data
  - CARD GROUP 13: Boundary Condition Data
  - CARD GROUP 14: Output Options
  - CARD GROUP 15: Time Domain Data

2.4 CARD GROUP 1, 2, 3, 4

- **Global boundary conditions:**

Global boundary conditions	Value
Total inlet mass flow rater, kg/s	17217.31
Average linear heat rate per rod, kW/m	16.6169
Initial pressure in the fluid domain, bar	158.4
Initial enthalpy in the fluid domain, kJ/kg	1273.64
Enthalpy of non-condensable gas mixture, kJ/kg	288.39

$$\text{Channel area} = \frac{\sqrt{3}}{2}\text{pitch}^2 - \left(312\frac{\pi D_{rod}^2}{4} + 18\frac{\pi D_{guide\ tube}^2}{4} + \frac{\pi D_{instr.\,rod}^2}{4}\right) = 0.025599\ \text{m}^2$$

$$\text{Wetted Perimeter} = 312\pi D_{rod} + 18\pi D_{guide\ tube} + \pi D_{instr.rod} = 9.667310\ \text{m}$$

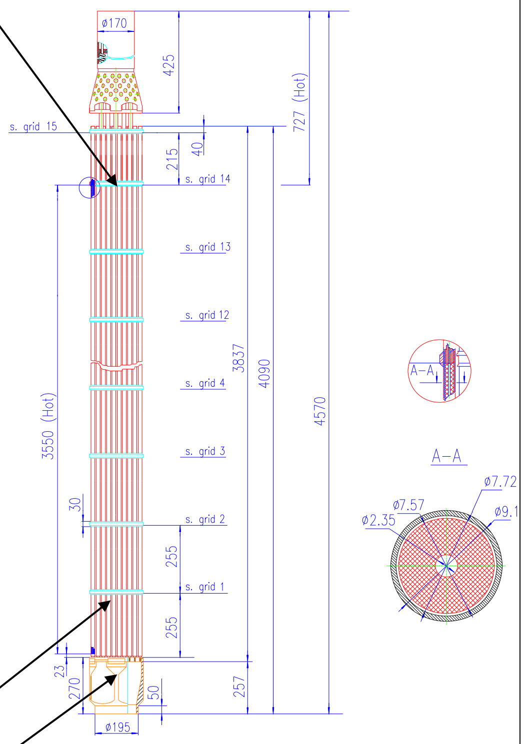
$$\text{Nominal gap width} = \text{pitch}/\sqrt{3} = 0.13625\ \text{m} \qquad \text{Nominal gap lenght} = \text{pitch} = 0.236\ \text{m}$$

- **444 gap connectivities between channels**
- **30 equidistant axial layers were chosen (3.55 m)**

$$\text{DXS} = \frac{\text{total length}}{\text{number of axial nodes}} = \frac{3.55}{30} = 0.11833\ \text{m}$$

2.5 INPUT CARD GROUP 7

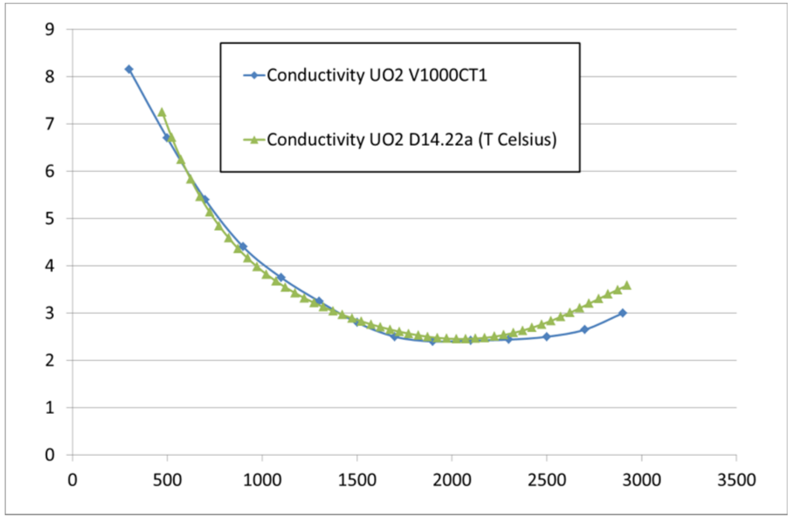
Local Pressure Loss Coefficient and Grid Spacer Data

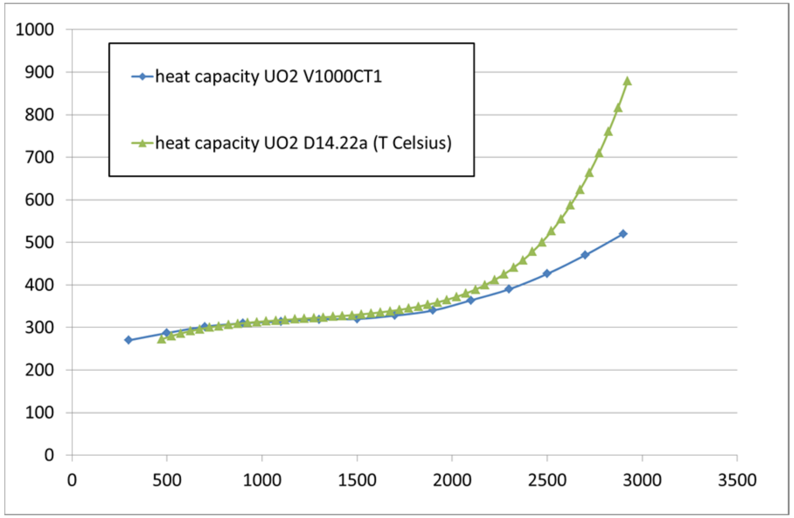
node number	axial location (top of the node), m	grid location, m	Representation of the fuel assembly
30	3.5500		
29	3.4317	3.3150	
28	3.3133		
27	3.1950		
26	3.0767	3.0600	
25	2.9583		
24	2.8400	2.8050	
23	2.7217		
22	2.6033	2.5500	
21	2.4850		
20	2.3667	2.2950	
19	2.2483		
18	2.1300	2.0400	
17	2.0117		
16	1.8933	1.7850	
15	1.7750		
14	1.6567		
13	1.5383	1.5300	
12	1.4200		
11	1.3017	1.2750	
10	1.1833		
9	1.0650	1.0200	
8	0.9467		
7	0.8283	0.7650	
6	0.7100		
5	0.5917	0.5100	
4	0.4733		
3	0.3550	0.2550	
2	0.2367		
1	0.1183		

- No values provided in the spefications for the spacer grid pressure loss coeff.
- They are modeled now with 0.0 coefficient waiting for a better value.

2.6 CARD GROUP 10

- **Material properties taken from given correlations**





$$\lambda_{UO2}(T) = 10.1139 - A_1T + A_2T^2 - A_3T^3 + A_4T^4 - A_5T^5 \; \frac{W}{m \cdot K}$$

$$c_{P,UO2}(T) = C_1 + C_2T - C_3T^2 + C_4T^3 - C_5T^4 + C_6T^5 \; \frac{J}{kg \cdot K}$$

$A_1 = 0.01783$ $\quad A_2 = 1.98486.10^{-5}$ $\quad A_3 = 1.23717.10^{-8}$

$A_4 = 3.93580.10^{-12}$ $\quad A_5 = 4.78491.10^{-16}$

$C_1 = 229.61$ $\quad C_2 = 0.28346$ $\quad C_3 = 4.0.10^{-4}$

$C_4 = 3.17462.10^{-7}$ $\quad C_5 = 1.34368.10^{-10}$ $\quad C_6 = 2.6214.10^{-14}$

2.7 General model assumptions

Model option	Where	Choice
Rod friction factor correlation (IRFC)	CARD GROUP 1	**2 ($\lambda = 0.204\, Re^{-0.2}$)**
Entrainment and deposition model (EDMOD)	CARD GROUP 1	**0**
Mixing and void drift model (IMIX)	CARD GROUP 1	**2**
Iterative Solver for pressure equation (ISOL)	CARD GROUP 1	**3 (Bi-CGSTAB)**
Number of simultaneous solution groups (NSIM)	CARD GROUP 4	**1**
Rebalancing option for iterative control (IREBAL)	CARD GROUP 4	**0**
Conduction in solid structures (NC)	CARD GROUP 8	**1 (radial only)**
Flag for steady state calculation of rod temp. (NSTATE)	CARD GROUP 8	**2**
Renoding flag for heat transfer solution for rod N (NRENODE)	CARD GROUP 8	**0**
Fuel relocation flag (IRELF)	CARD GROUP 9	**0**
Fuel degradation flag (ICONF)	CARD GROUP 9	**0**
Flag for metal-water reaction, ZrO_2 only (IMWR)	CARD GROUP 9	**0**

2.10 VVER Core Model Benchmarking for MSLB Analysis

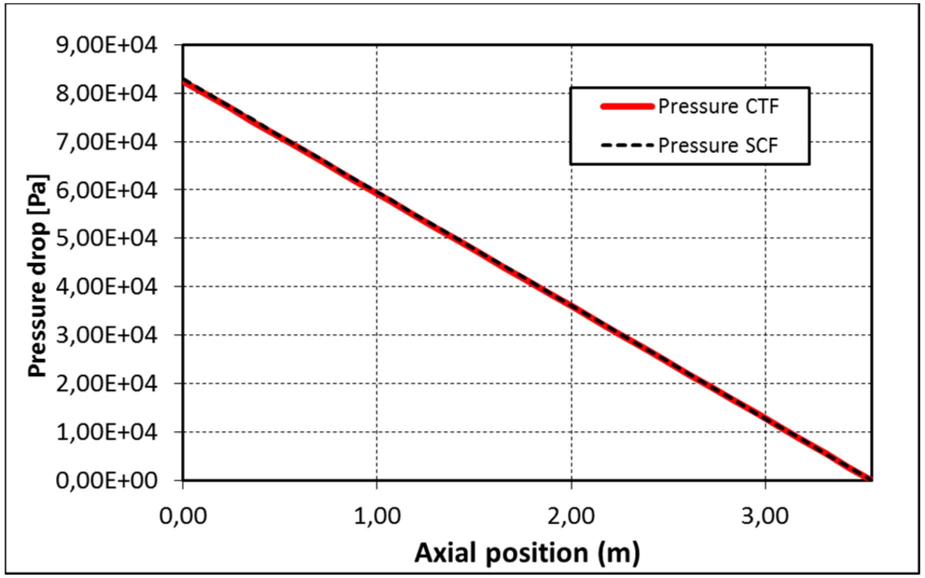
- **Representative boundary conditions of realistic HZP and HFP**
- **Assumption of flat radial and axial power profiles.**

Inlet boundary conditions	HZP	HFP
Thermal power (W)	$0.3 * 10^6$	$3000 * 10^6$
Inlet coolant temperature (C)	279.0	287.7
Inlet Outlet pressure (bar)	158.4	158.4
Inlet Enthalpy (kJ/kg)	1227.4	1272.0

- **Comparison of pure TH results between CTF and SUBCHANFLOW**

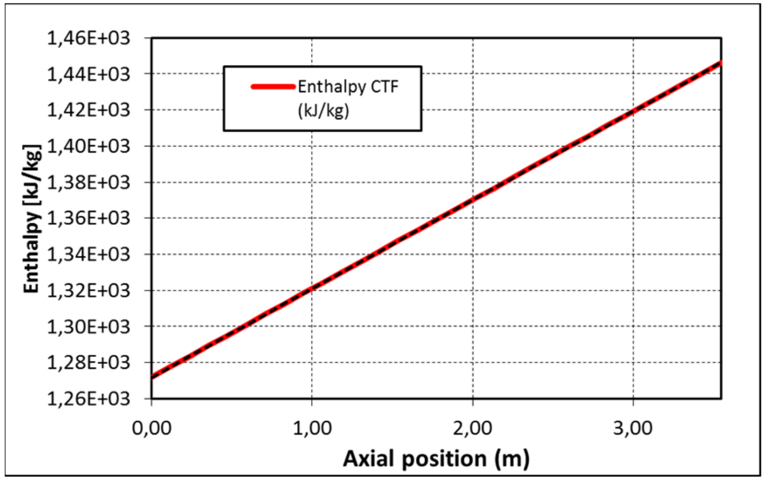
2.11 Analysis of HZP results

Results at HZP	CTF	SUBCHANFLOW
Total axial height pressure loss (bar) **(geodetic +frictional + single head losses)**	0.82455	0.82882 (+0.51%)
Total no gravity pressure loss (bar) **(frictional and single head losses)**	0.55721	0.56195 (+0.84%)
Inlet Reynolds number	464526	450410 (-3.13%)

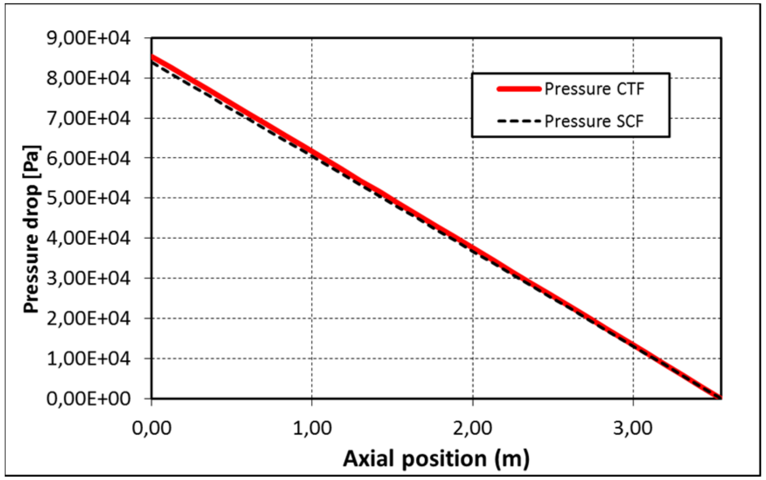


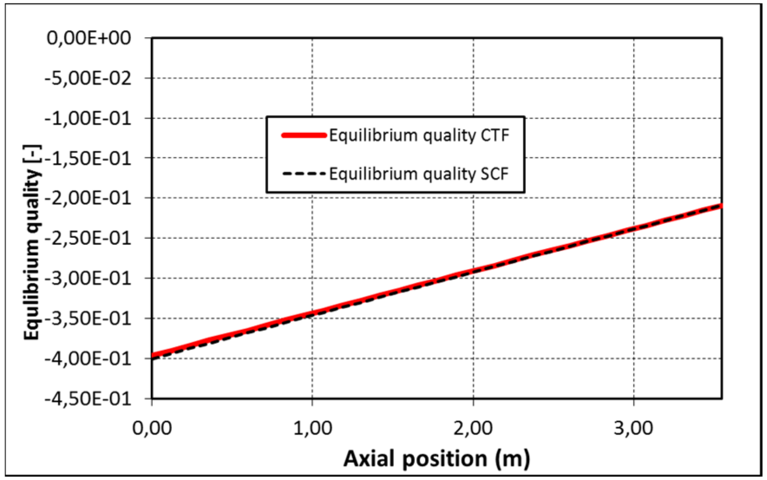
- **Very good agreement in the all the parameters**

2.12 Analysis of HFP results



Results at HFP	CTF	SCF
Total axial height pressure loss (bar) **(geodetic +frictional + single head losses)**	0.85486	0.83844 (-1.96%)
Total no gravity pressure loss (bar) **(frictional and single head losses)**	0.58219	0.58871 (+1.11%)
Inlet Reynolds number	481170	467240 (-2.98%)

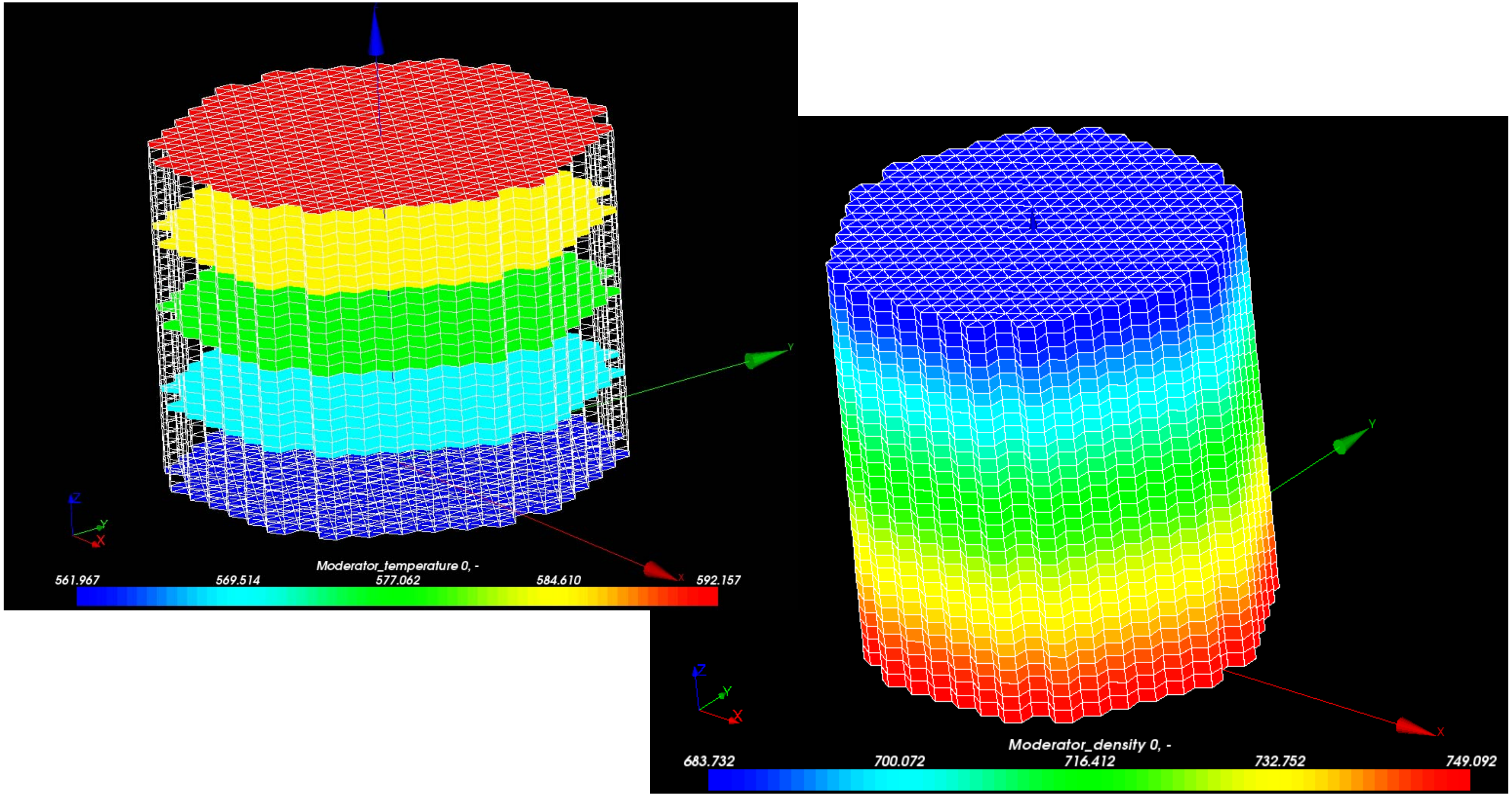




- **Very good agreement in the all the parameters**

2.13 SUBCHANFLOW Results: HFP moderator density

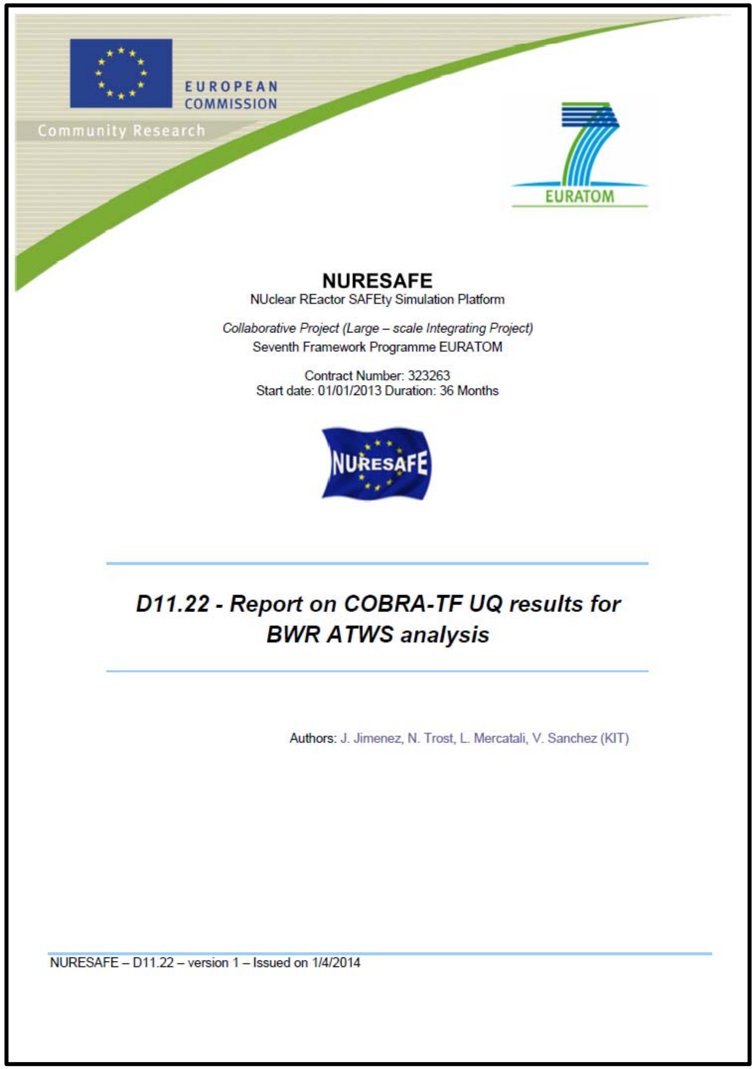
- **Post-processing of SCF results within SALOME**



3. COBRA-TF URANIE scripts

- **The same scripts can be used for:**
  - **Steady state**
  - **Transient analyses**
- **Dedicated general script for post-processing.**
- **Around 500 lines of URANIE code.**
- **Documentation reported under D11.22 deliverable (WP1.1).**

  (KIT & CEA)



EUROPEAN COMMISSION

Community Research

EURATOM

NURESAFE
NUclear REactor SAFEty Simulation Platform

Collaborative Project (Large – scale Integrating Project)
Seventh Framework Programme EURATOM

Contract Number: 323263
Start date: 01/01/2013 Duration: 36 Months

NURESAFE

D11.22 - Report on COBRA-TF UQ results for BWR ATWS analysis

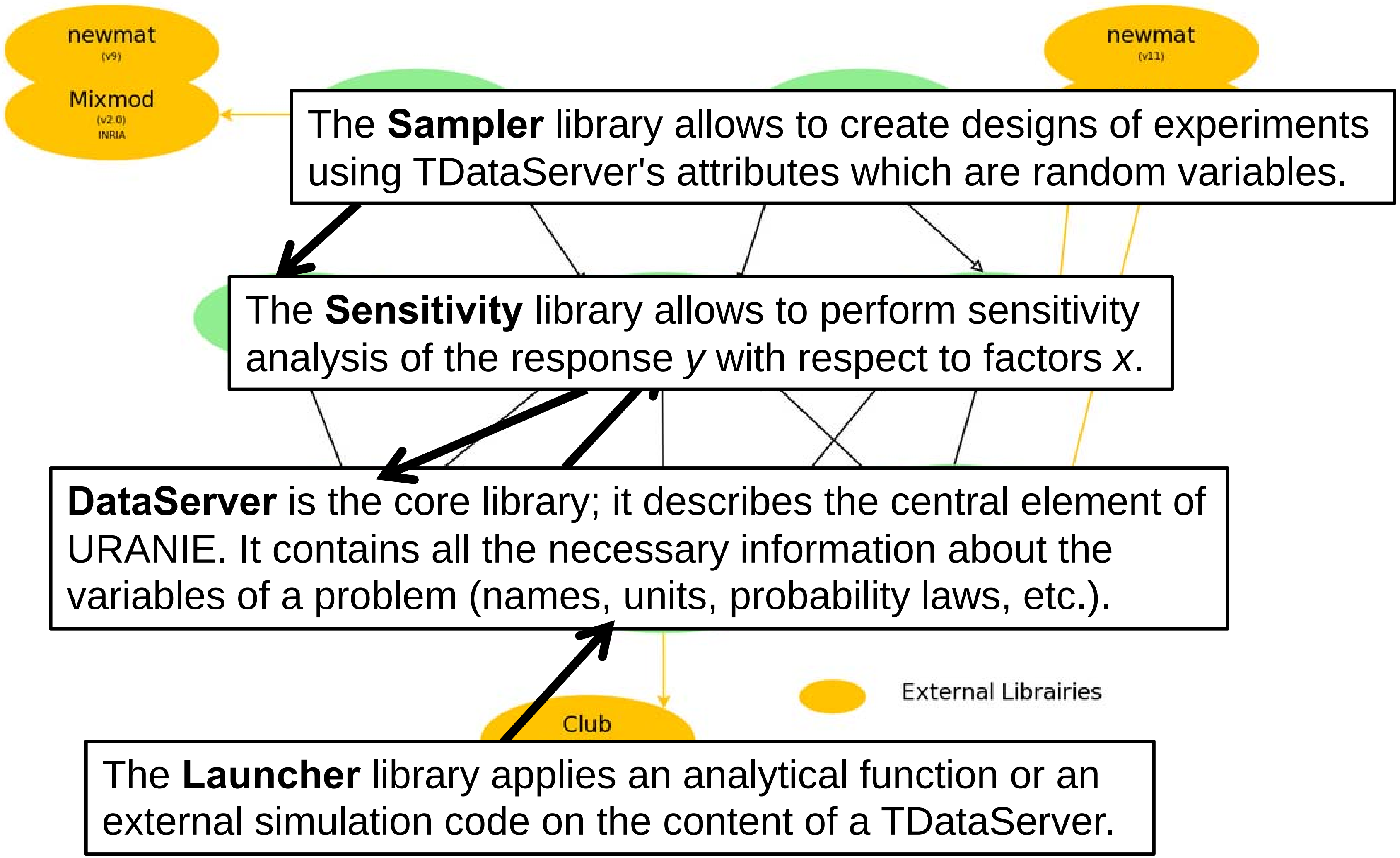
Authors: J. Jimenez, N. Trost, L. Mercatali, V. Sanchez (KIT)

NURESAFE – D11.22 – version 1 – Issued on 1/4/2014

3.1 URANIE Software

- **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.**
- **Based on ROOT, a software developed at CERN for particle physics data analysis. As a result, 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
- **URANIE training course attended 2-4th April 2013 in Saclay.**

3.2 URANIE Software Functional Diagram



The **Sampler** library allows to create designs of experiments using TDataServer's attributes which are random variables.

The **Sensitivity** library allows to perform sensitivity analysis of the response *y* with respect to factors *x*.

DataServer is the core library; it describes the central element of URANIE. It contains all the necessary information about the variables of a problem (names, units, probability laws, etc.).

The **Launcher** library applies an analytical function or an external simulation code on the content of a TDataServer.

3.3 Script for COBRA-TF run

```
void BFBT_P6x(Int_t nS = 100) {

  TDataServer *tds = new TDataServer("tdsCTF", "BFBT_P6x");

  TNormalDistribution *tnp = new TNormalDistribution("OutletPressure", 7.16e6, 71600.0);  // +-1%
  TNormalDistribution *tnf = new TNormalDistribution("MassFlowRate", 5.61, 0.0561);       // +-1%
  TUniformDistribution *tut = new TUniformDistribution("InletTemperature", 276.3, 279.3); // +-1.5K
  TNormalDistribution *tnl = new TNormalDistribution("Power", 1.951e6, 29265.0);          // +-1.5%

  tnp->setBounds(7.0884e6, 7.2316e6);
  tnf->setBounds(5.5539, 5.6661);
  tnl->setBounds(1.921735e6, 1.980265e6);

  tds->addAttribute(tnp);
  tds->addAttribute(tnf);
  tds->addAttribute(tut);
  tds->addAttribute(tnl);

  TString sFileName = TString("deck.inp");
...
```

Specify the number of simulation runs

Create DataServer to hold all informations

Specify the distribution for each parameter

Set upper and lower bound to avoid non-physical values

Fill up the DataServer

Specify the input file of COBRA-TF to be parsed by URANIE and replaced by the sampled random data

3.4 Script for COBRA-TF run

```
...
  tds->getAttribute("pref")->setFileFlag(sFileName, "@Pref@");
  tds->getAttribute("massf")->setFileFlag(sFileName, "@Massf@");
  tds->getAttribute("hin")->setFileFlag(sFileName, "@Hin@");
  tds->getAttribute("aflux")->setFileFlag(sFileName, "@Aflux@");

  TSampling *sampling = new TSampling(tds, "lhs", nS);
  sampling->generateSample();

  TOutputFileKey *fout = new TOutputFileKey("result_channels.out");

  TAttribute *avgpres = new TAttribute("total_ax_pres_loss_uranie");
  avgpres->setDefaultValue(-200.0);
  fout->addAttribute(avgpres);

  TCode *mycode = new TCode(tds, "COBRA-TF");
  mycode->addOutputFile(fout);

  TLauncher *tlch = new TLauncher(tds, mycode);
  tlch->setSave();
  tlch->setClean();
  tlch->setWorkingDirectory(gSystem->Getenv("PWD") + TString("/tmpUranie/cobratf"));
  tlch->setVarDraw("MassFlowRate:total_ax_pres_loss_uranie","","");
...
```

Give URANIE the strings of COBRA-TF input to be changed

Generate the random data

Specify the output file to extract the data for post-processing

Tell URANIE which value has to be extracted from CTF output and initialize it with a non-physical value for easier error detection

Initiate a COBRA-TF simulation run

3.5 Script for COBRA-TF post-processing

```
  TCanvas *Canvas = new TCanvas("c1", "Graph",5,64,1270,667);
   c1->Divide(2, 2);
   c1->cd(1);
   tlch->run();
   c1->cd(3);
   tds->draw("OutletPressure:total_ax_pres_loss_uranie");
   c1->cd(2);
   tds->draw("InletTemperature:total_ax_pres_loss_uranie","","");
   c1->cd(4);
   tds->draw("Power:total_ax_pres_loss_uranie","","");

   TCanvas *Canvas2 = new TCanvas("c2", "Graph",5,64,1270,667);
   tds->draw("total_ax_pres_loss_uranie");

   tds->exportData("BFBT_P6x_Sampling.dat");

}
```

Visualize the output of URANIE

Plot a histogram of the output data

Export the output as well as the sampled random numbers into a file for post-processing.

3.6 Script for COBRA-TF statistics

```
{
  using namespace URANIE::DataServer;
  using namespace URANIE::Sampler;

  TDataServer *tds = new TDataServer();

  tds->fileDataRead("COBRA-TF_O2.dat");

  tds->addAttribute("OutletPressure", "OutletPressure");
  tds->addAttribute("MassFlowRate", "MassFlowRate");
  tds->addAttribute("InletTemperature", "InletTemperature");
  tds->addAttribute("Power", "Power");
  tds->addAttribute("AxialPressureLoss", "total_ax_pres_loss_uranie");

  tds->computeStatistic();
  tds->computeCorrelationMatrix()->Print();

  std::cout << "mean: " << tds->getAttribute("AxialPressureLoss")->getMean()    << std::endl;
  std::cout << "min:  "  << tds->getAttribute("AxialPressureLoss")->getMinimum() << std::endl;
  std::cout << "max:  "  << tds->getAttribute("AxialPressureLoss")->getMaximum() << std::endl;
  std::cout << "std:  "  << tds->getAttribute("AxialPressureLoss")->getStd()     << std::endl;
}
```

Read in an URANIE file that contains sampled random data

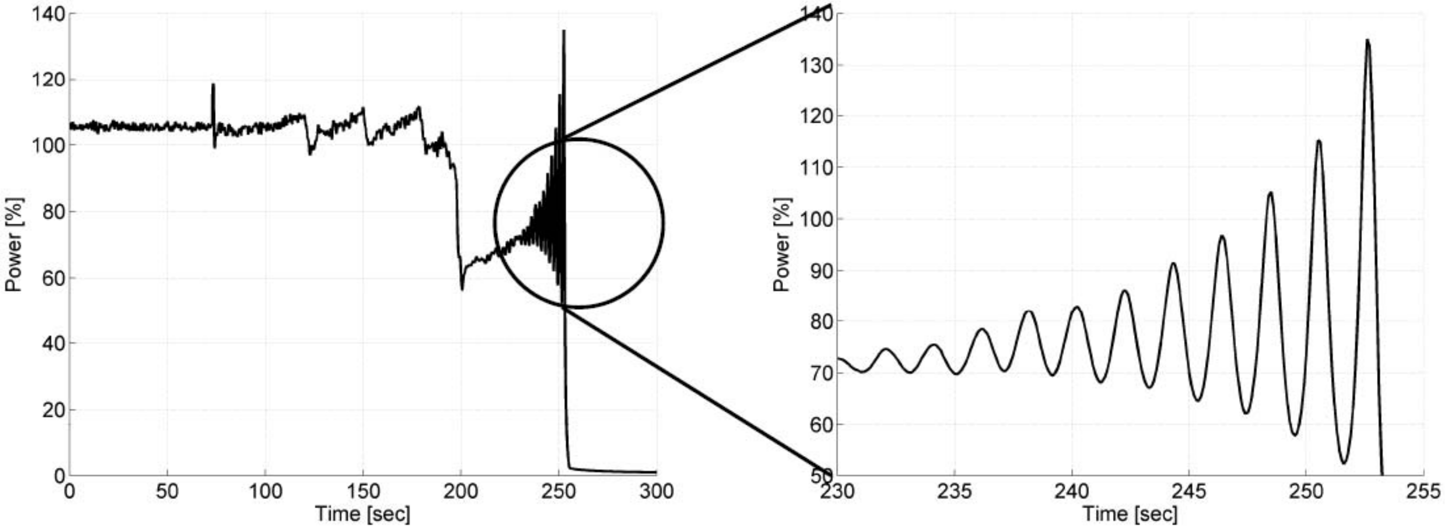
Fill up the DataServer structure

Compute the statistics and print the correlation matrix

Print mean, min, max, and standard deviation

3.7 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 (WP1.3)**

3.8 Sensitivity study

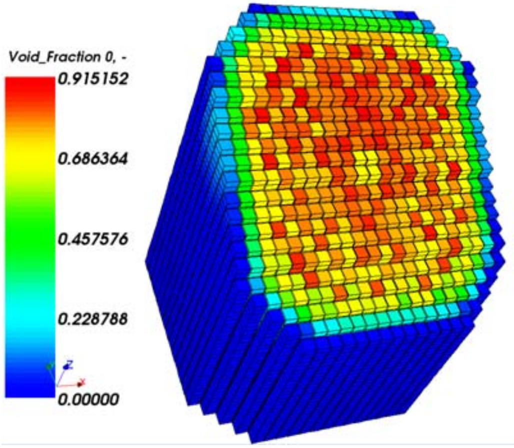
- **Sensitivity analysis with parameters taken from the NURESAFE benchmark specifications (D13.11)**

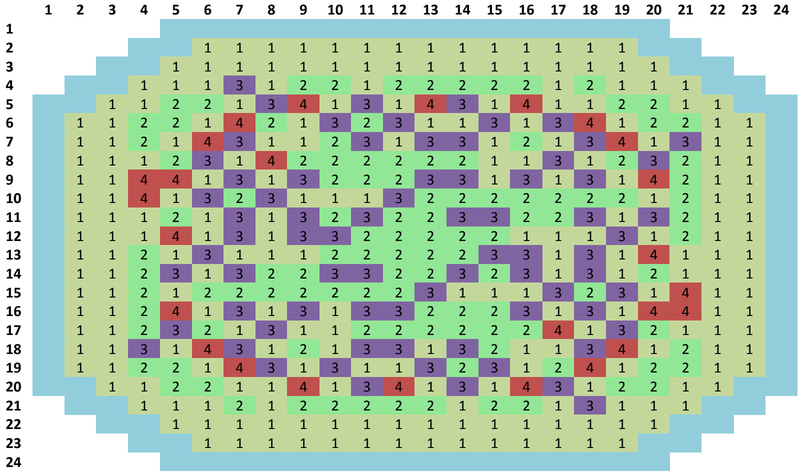
No.	Parameter	Range	Distribution
1	Outlet pressure	**± 0.5 %**	**Uniform**
2	Mass flow rate	**± 0.5 %**	**Uniform**
3	Inlet temperature	**± 2.0 %**	**Normal**
4	Power	**± 2.0 %**	**Normal**
5	Cladding Wall Roughness	**± 30.0 %**	**Normal**
6	Spacer grid pressure drop coefficient	**± 5.0 %**	**Uniform**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

3.9 O2 nominal steady state results

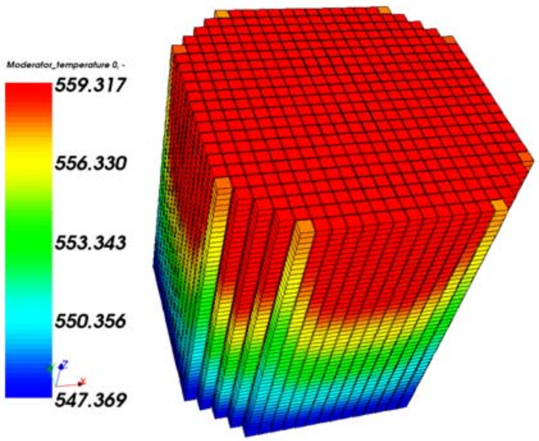
- ***Axial pressure drop*** **and** ***Outlet void fraction*** **are the output parameters studied (500 runs were used).**
- **The computed sensitivity coefficients by URANIE corresponding to a steady state at nominal operating conditions using COBRA-TF.**

	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

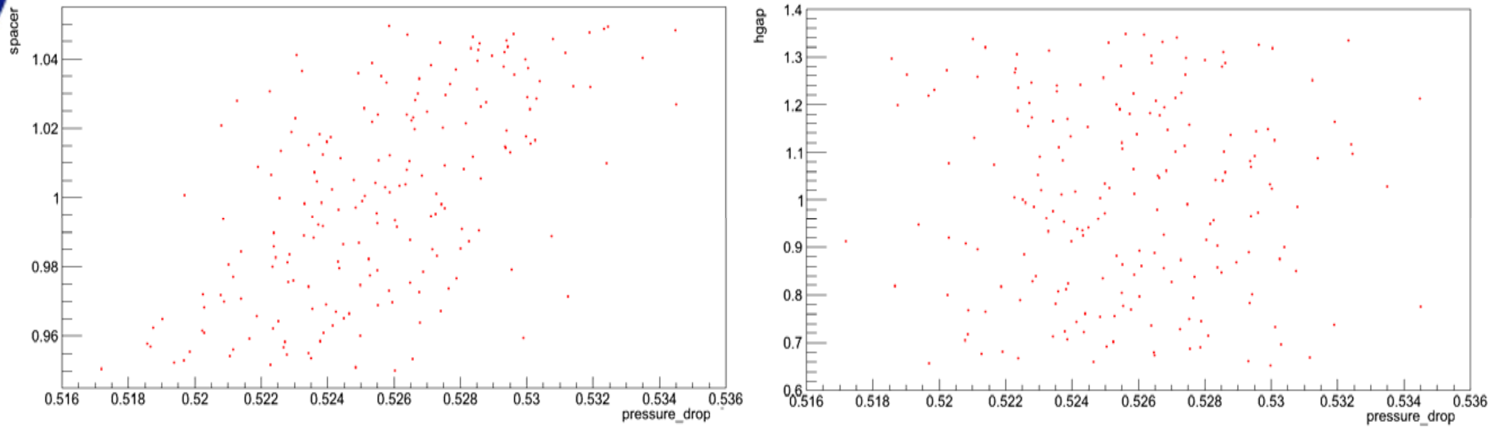




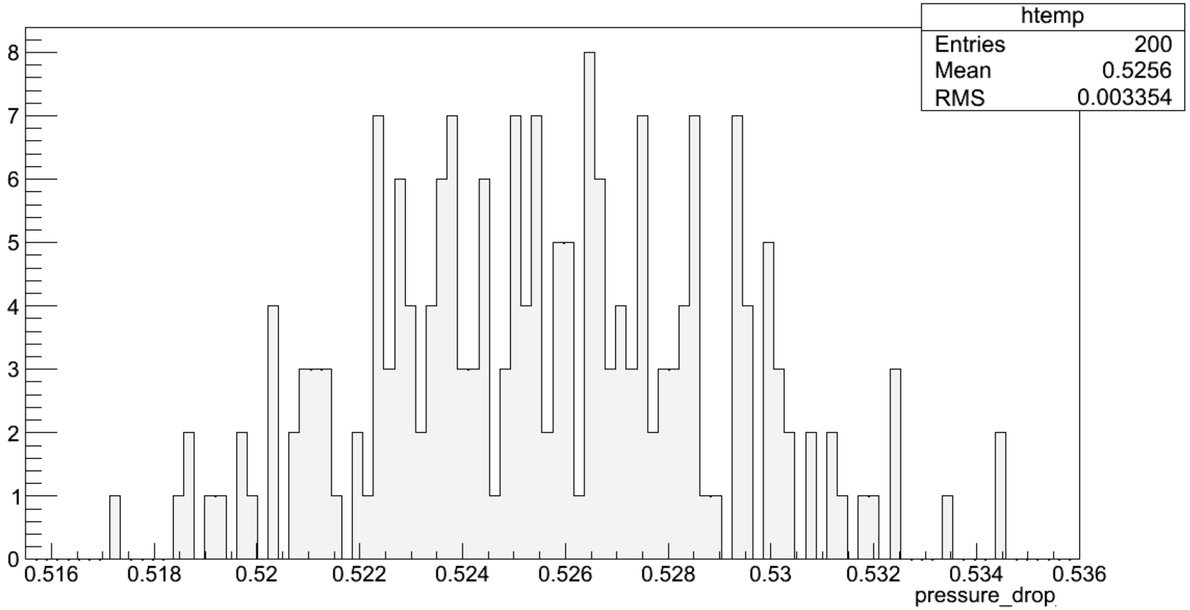
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2						1	1	1	1	1	1	1	1	1	1	1	1	1	1					
3					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
4				1	1	1	3	1	2	2	1	2	2	2	2	2	1	2	1	1	1			
5			1	1	2	2	1	3	4	1	3	1	4	3	1	4	1	1	2	2	1	1		
6		1	1	2	2	1	4	2	1	3	2	3	1	1	3	1	3	4	1	2	2	1	1	
7		1	1	2	1	4	3	1	1	2	3	1	3	3	1	2	1	3	4	1	3	1	1	
8		1	1	1	2	3	1	4	2	2	2	2	2	2	1	1	3	1	2	3	2	1	1	
9		1	1	4	4	1	3	1	3	2	2	2	3	3	1	3	1	3	1	4	2	1	1	
10		1	1	4	1	3	2	3	1	1	1	3	2	2	2	2	2	2	2	1	2	1	1	
11		1	1	1	2	1	3	1	3	2	3	2	2	3	3	2	2	3	1	3	2	1	1	
12		1	1	1	4	1	3	1	3	3	2	2	2	2	2	1	1	1	3	1	2	1	1	
13		1	1	2	1	3	1	1	1	2	2	2	2	2	3	3	1	3	1	4	1	1	1	
14		1	1	2	3	1	3	2	2	3	3	2	2	3	2	3	1	3	1	2	1	1	1	
15		1	1	2	1	2	2	2	2	2	2	2	3	1	1	1	3	2	3	1	4	1	1	
16		1	1	2	4	1	3	1	3	1	3	3	2	2	2	3	1	3	1	4	4	1	1	
17		1	1	2	3	2	1	3	1	1	2	2	2	2	2	2	4	1	3	2	1	1	1	
18		1	1	3	1	4	3	1	2	1	3	3	1	3	2	1	1	3	4	1	2	1	1	
19		1	1	2	2	1	4	3	1	3	1	1	3	2	3	1	2	4	1	2	2	1	1	
20			1	1	2	2	1	1	4	1	3	4	1	3	1	4	3	1	2	2	1	1		
21				1	1	1	2	1	2	2	2	2	2	1	2	2	1	3	1	1	1			
22					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
23						1	1	1	1	1	1	1	1	1	1	1	1	1	1					
24																								



3.10 O2 nominal steady state results



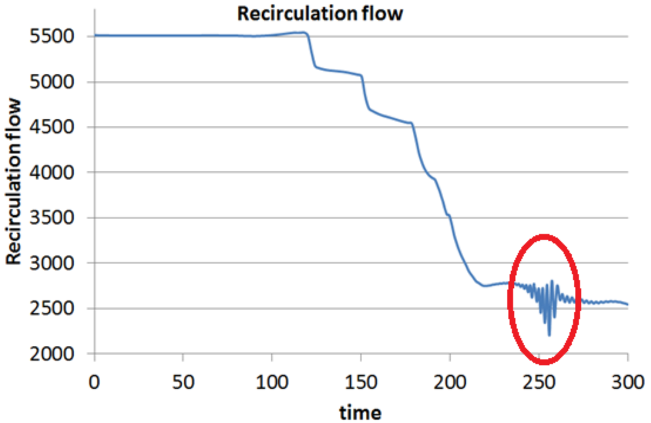
Axial pressure drop for different spacer coefficient and gap boundary conditions

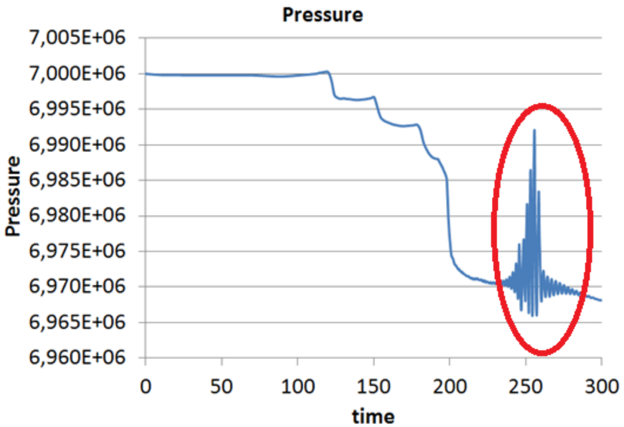


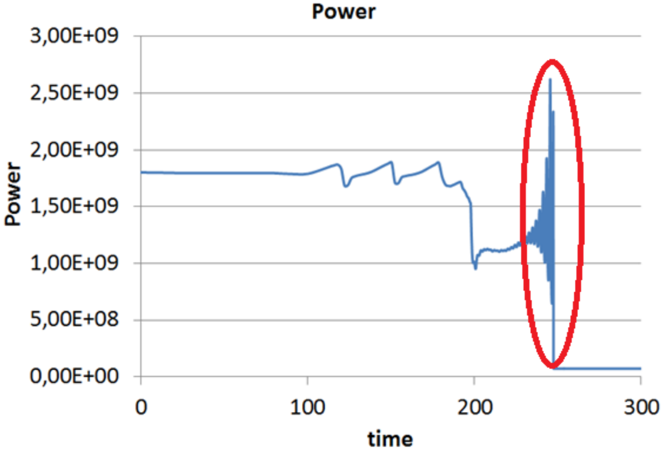
Pressure drop distribution over all COBRA-TF runs

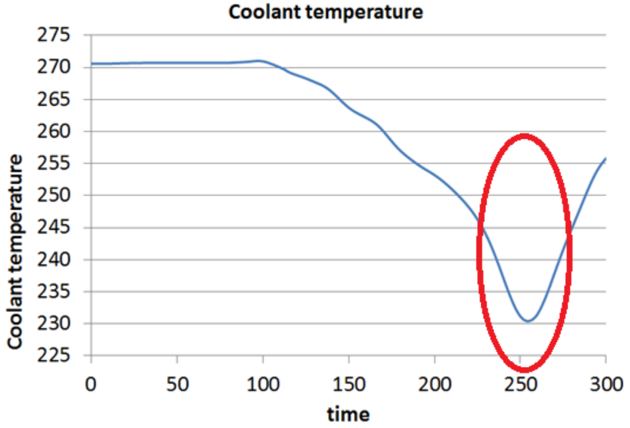
3.11 Transient Boundary Conditions applied

- **The next boundary conditions were introduced into CTF for the simulation of the oscillations (only 12s are analyzed).**
- **They have been extracted from a TRACE5p3/PARCS results**
  - Power, inlet temperature, pressure, mass flow rate.



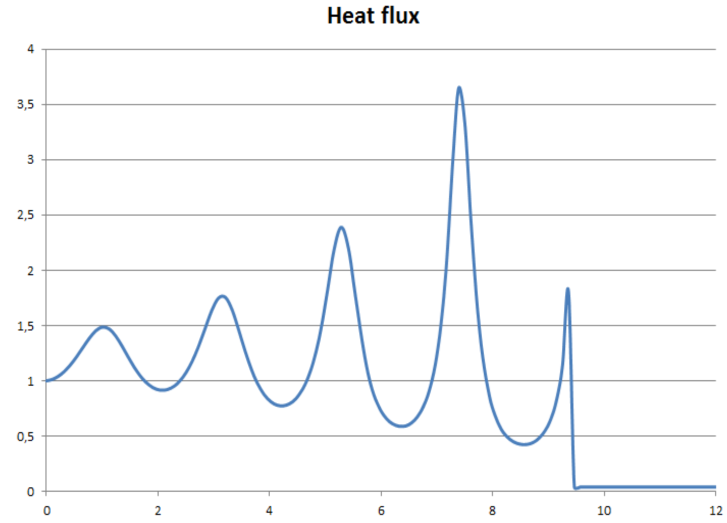


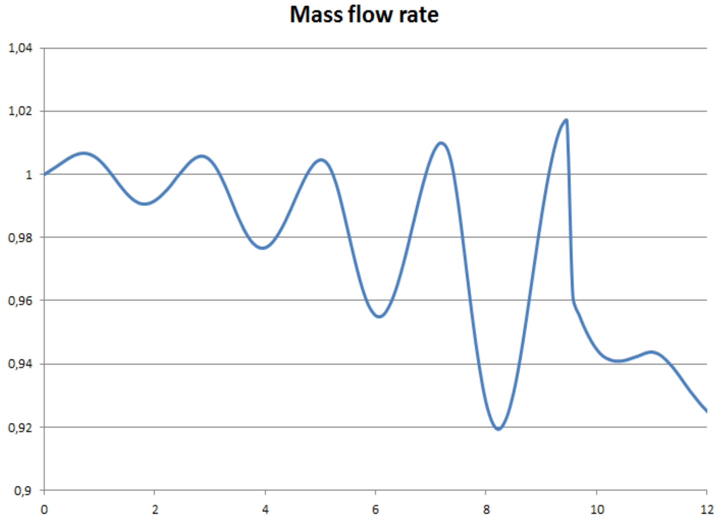


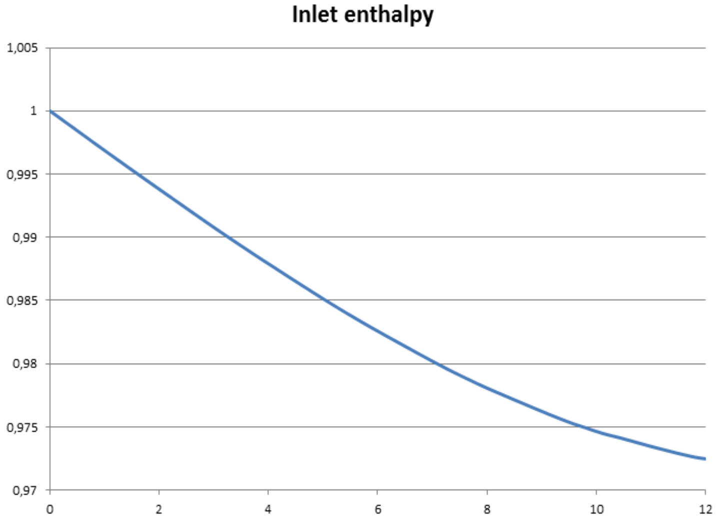


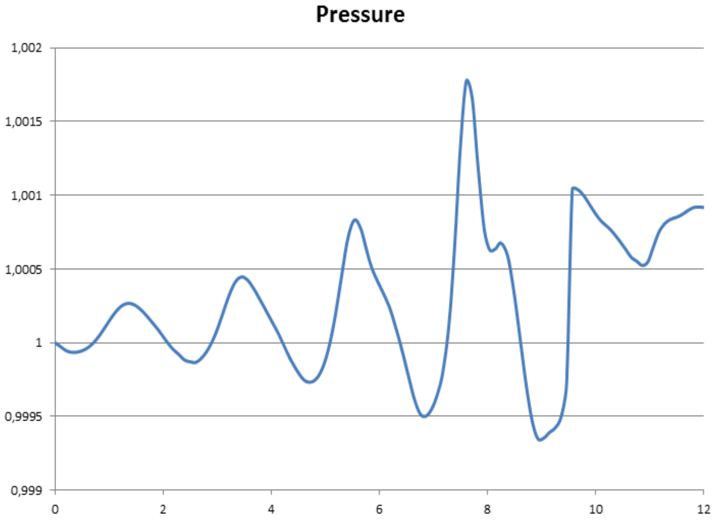
3.12 Transient Boundary Conditions applied

- **Those BC are representative of a stability event.**



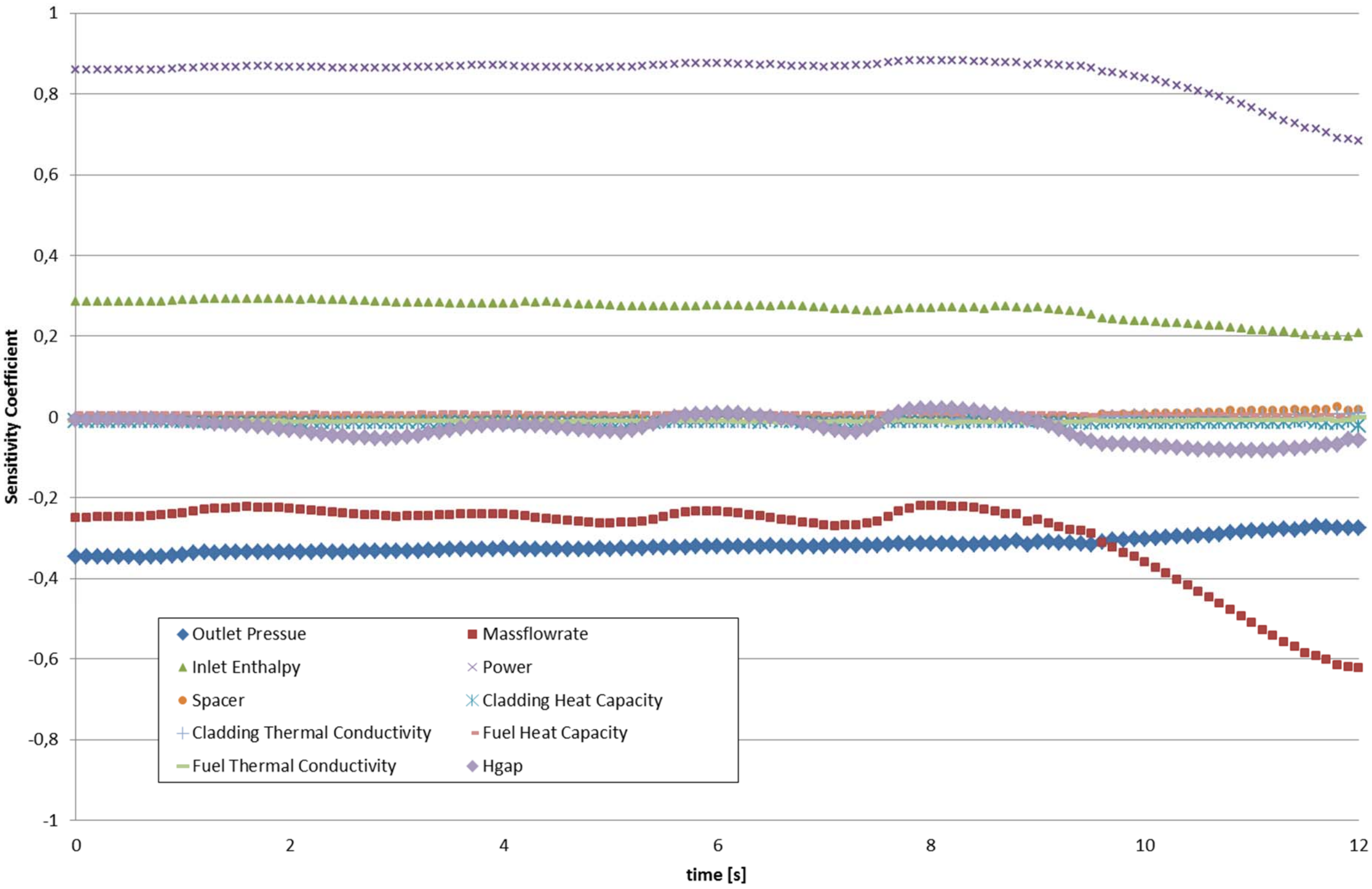






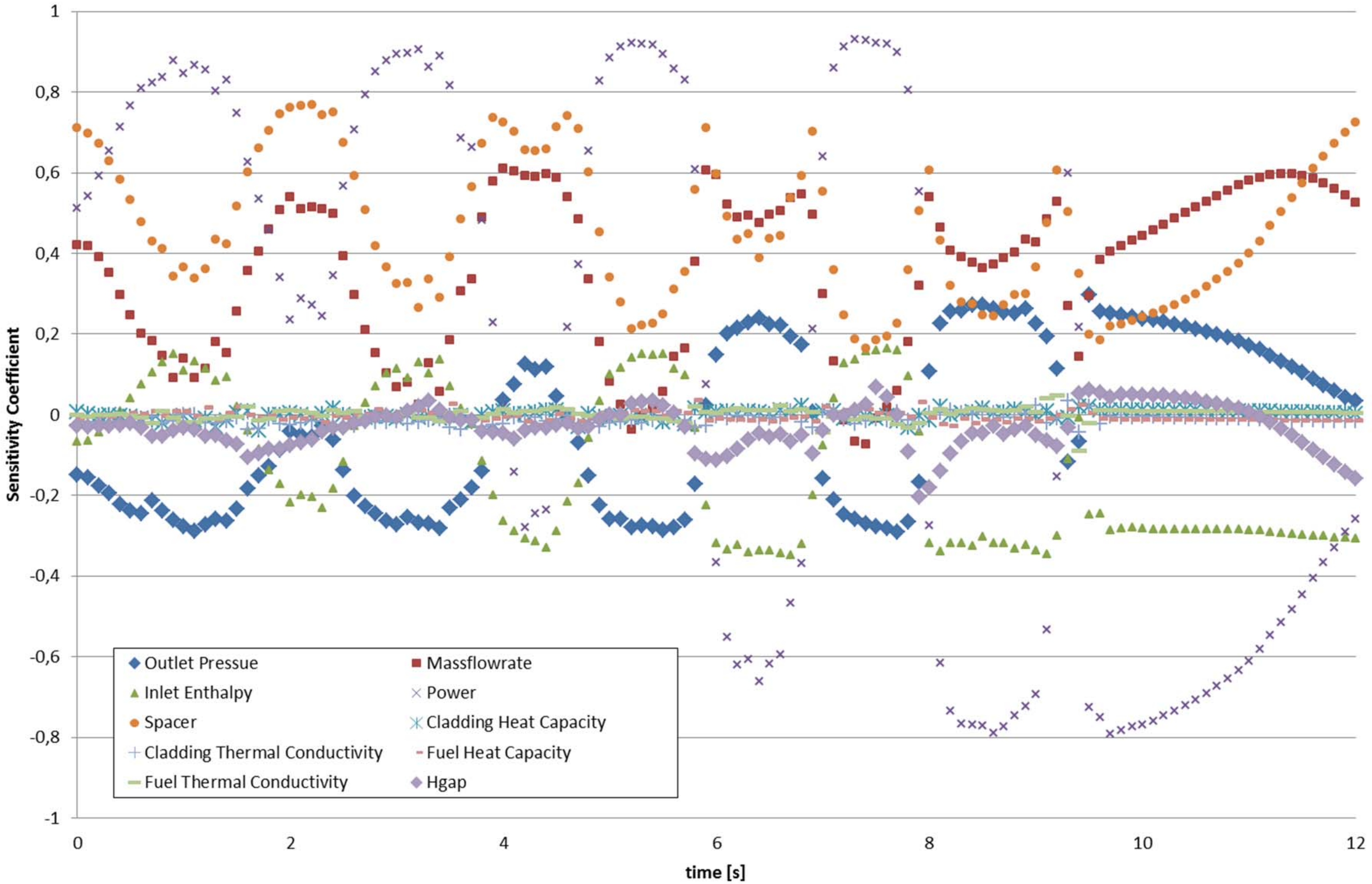
3.13 Results in the zooming area

- **Sensitivity coefficients of the void fraction**



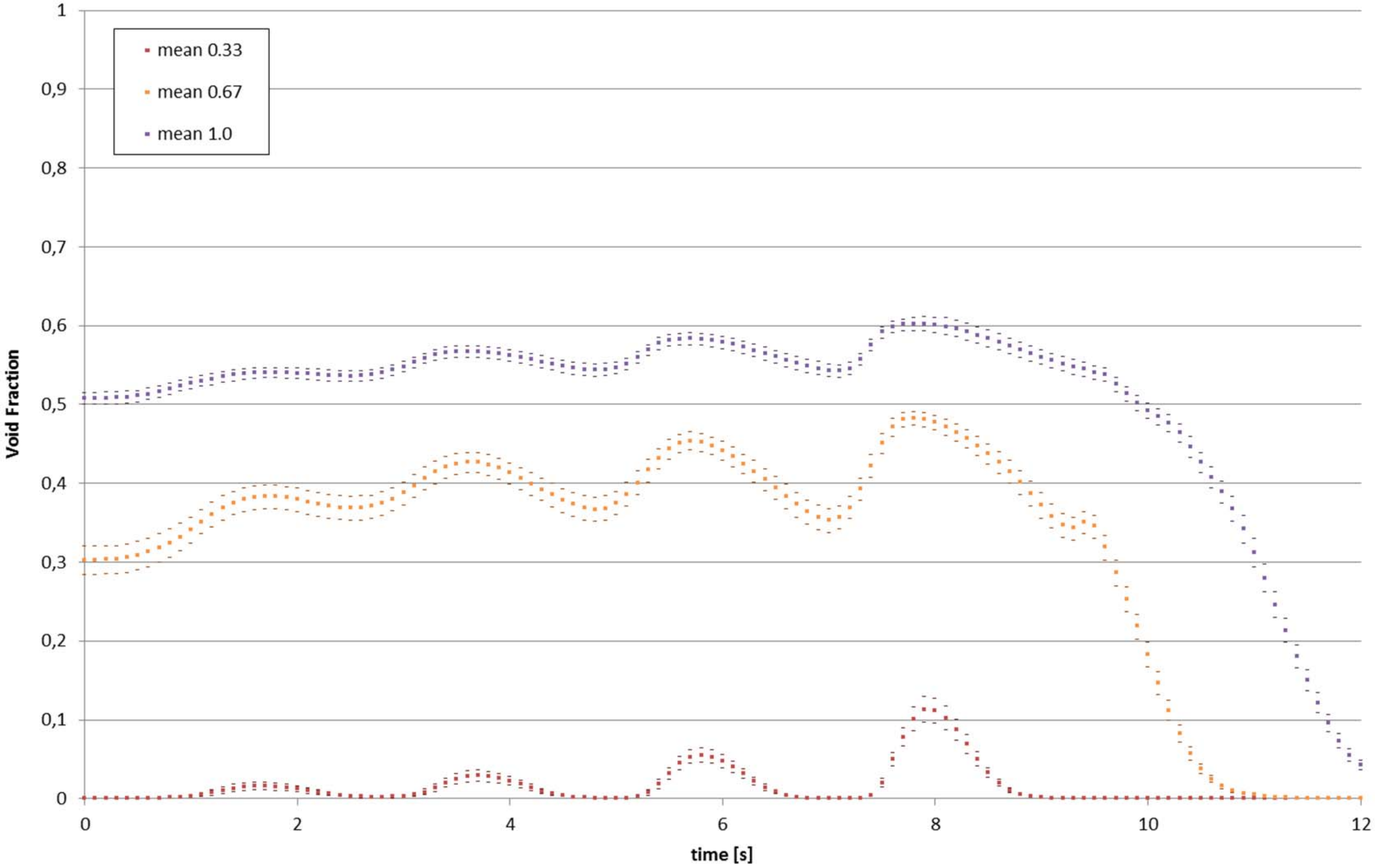
3.14 Results in the zooming area

- **Sensitivity coefficients of the axial pressure drop**



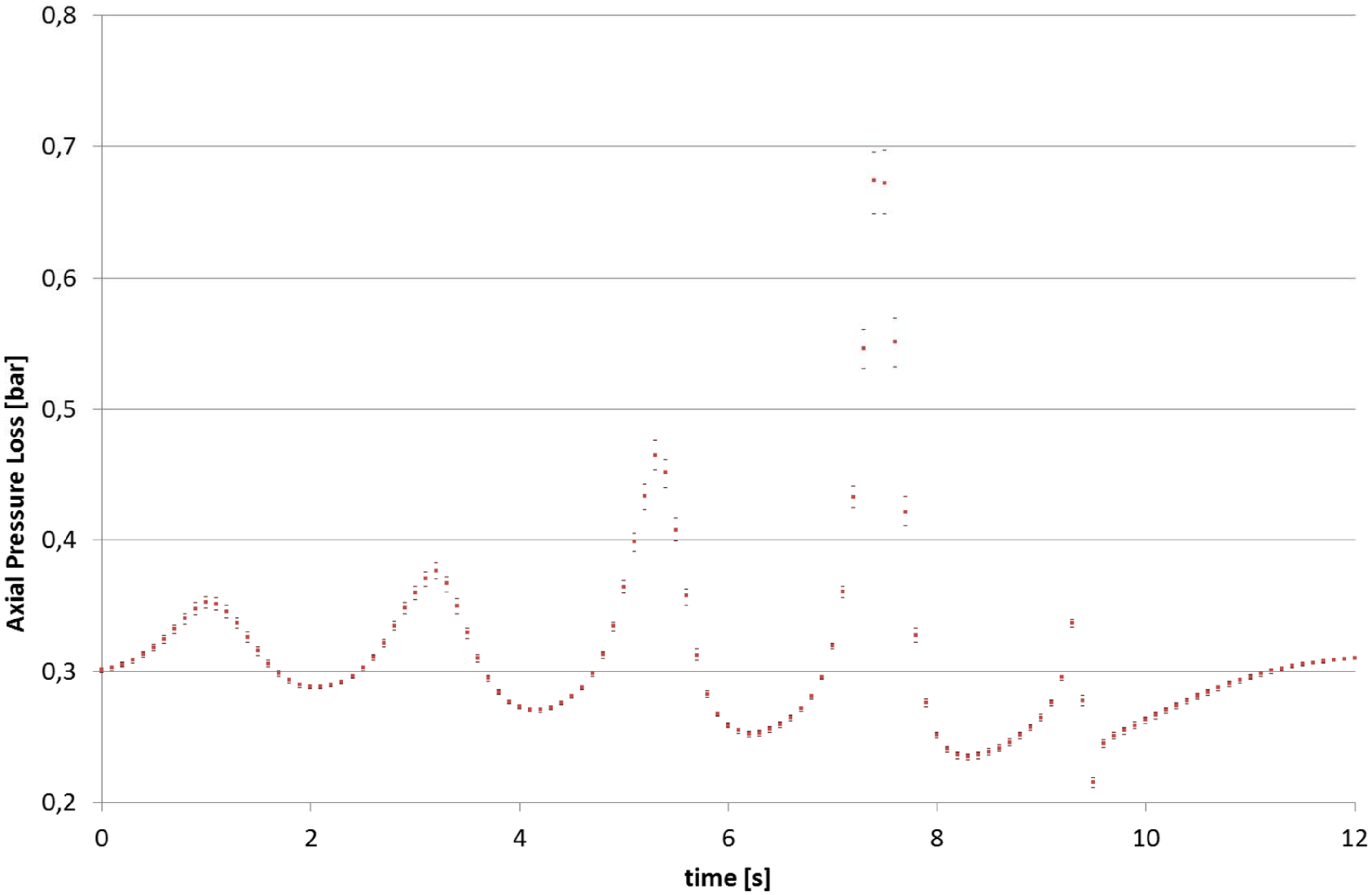
3.15 Results in the zooming area

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



3.16 Results in the zooming area

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



Conclusions and Outlook

- **COBRA-TF model for O2 core completed**
    - Good agreement between O2 reference values and predictions,
    - FLICA4 and SUBCHANFLOW models developed as a backup solution for O2
- **During the first 18 months of the project, investigations on the use of URANIE platform for sensitivity analyses have been conducted.**
- **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.**
- **The scripts can be extrapolated to any code with input text files: FLICA4, DYN3D, COBAYA3, ATHLET, etc, ...**

Conclusions and Outlook

- **The first version of a full-core CTF input model for VVER-1000 MSLB analysis has been developed and tested standalone.**
- **In overall, standalone CTF vs. SUBCHANFLOW results show a very good agreement.**
- **Main differences come from the use of different steam water properties tables (See inlet Re number). The models are very similar for single phase flow.**

FUTURE WORK

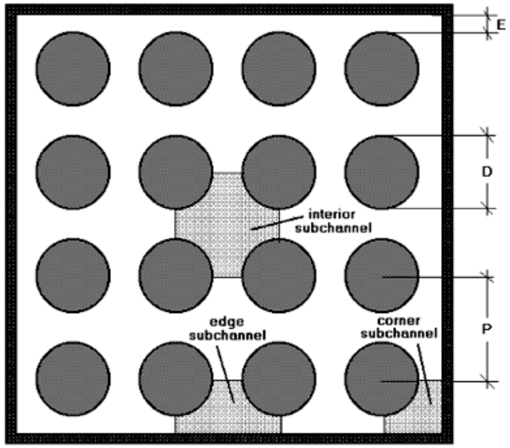
- **Application to coupled simulations is foreseen in the next months.**

THANKS FOR YOUR ATTENTION

SUBCHANFLOW Features

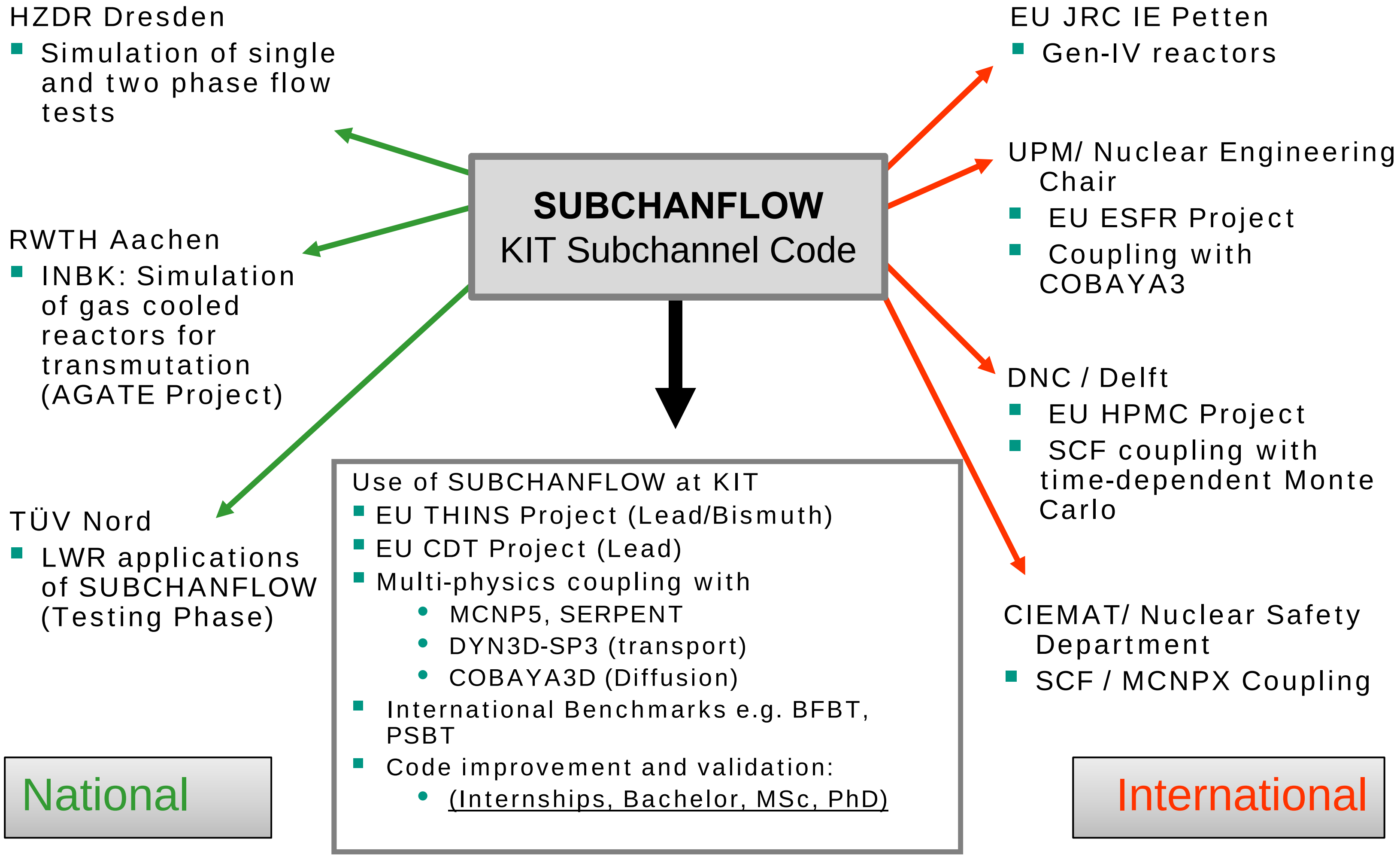
- **Description of the KIT code SUBCHANFLOW**

- ✓ **Single and two phase (mixture) subchannel code for water, sodium, lead and gas cooled reactors**
- ✓ **Mass, momentum, enthalpy (3)-equation solver for strictly upward flow**
- ✓ **Fast running implicit fix-point iteration solver with axial plane wise matrix solution**
- ✓ **Hexagonal and square bundle geometry**
- ✓ **Stationary and transient solutions**
- ✓ **Applicable to LWR & Innovative reactors (SFR)**
- ✓ **Capability for coupling with a system code**



Sub-channel analysis of SUBCHANFLOW

SUBCHANFLOW Features



SUBCHANFLOW
KIT Subchannel Code

HZDR Dresden
- Simulation of single and two phase flow tests

RWTH Aachen
- INBK: Simulation of gas cooled reactors for transmutation (AGATE Project)

TÜV Nord
- LWR applications of SUBCHANFLOW (Testing Phase)

National

Use of SUBCHANFLOW at KIT
- EU THINS Project (Lead/Bismuth)
- EU CDT Project (Lead)
- Multi-physics coupling with
  - MCNP5, SERPENT
  - DYN3D-SP3 (transport)
  - COBAYA3D (Diffusion)
- International Benchmarks e.g. BFBT, PSBT
- Code improvement and validation:
  - (Internships, Bachelor, MSc, PhD)

EU JRC IE Petten
- Gen-IV reactors

UPM/ Nuclear Engineering Chair
- EU ESFR Project
- Coupling with COBAYA3

DNC / Delft
- EU HPMC Project
- SCF coupling with time-dependent Monte Carlo

CIEMAT/ Nuclear Safety Department
- SCF / MCNPX Coupling

International