NURESAFE WP3.3
Multiscale BWR Thermal-Hydraulics

BWR TH at system and sub-channel scale

J. Jimenez, V. Di Marcello, V. Sanchez

Presented by V. Sanchez

javier.jimenez@kit.edu
or
victor.sanchez@kit.edu

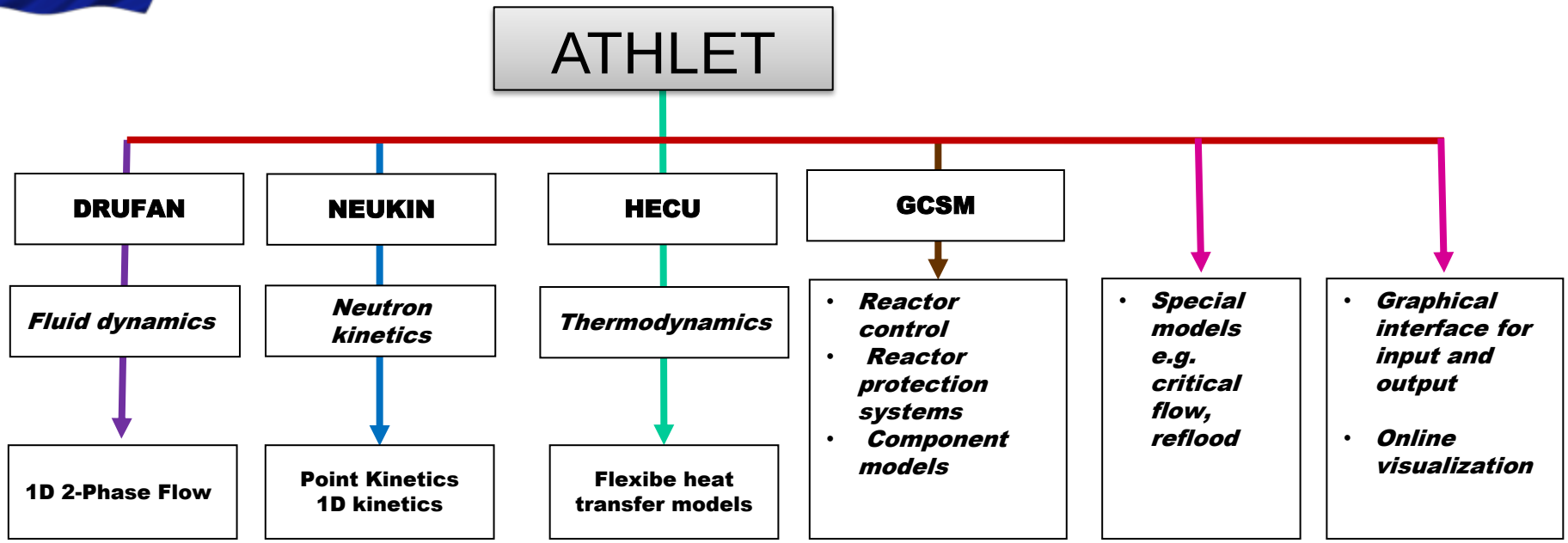
Outline

- **Status of code validation using BFBT Data**
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power.
- **Modeling of the Oskarshamn-2 core with ATHLET**
  - Development of an integral plant model of the Oskarshamn-2 plant for the analysis of an ATWS transient (consistent with ATHLET input in WP1.3 - D13.21).
- **Modeling of the Oskarshamn-2 core with subchannel codes**
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested.
- **Conclusion & Outlook**

Outline

- **Status of code validation using BFBT Data**
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power.
- **Modeling of the Oskarshamn-2 core with ATHLET**
  - Development of an integral plant model of the Oskarshamn-2 plant for the analysis of an ATWS transient (consistent with ATHLET input in WP1.3 - D13.21).
- **Modeling of the Oskarshamn-2 core with subchannel codes**
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested.
- **Conclusion & Outlook**

ATHLET: Main Features



ATHLET: Analysis of Transients as well as LOCAs of Light Water Reactors (PWR, BWR, VVER, RBMK)

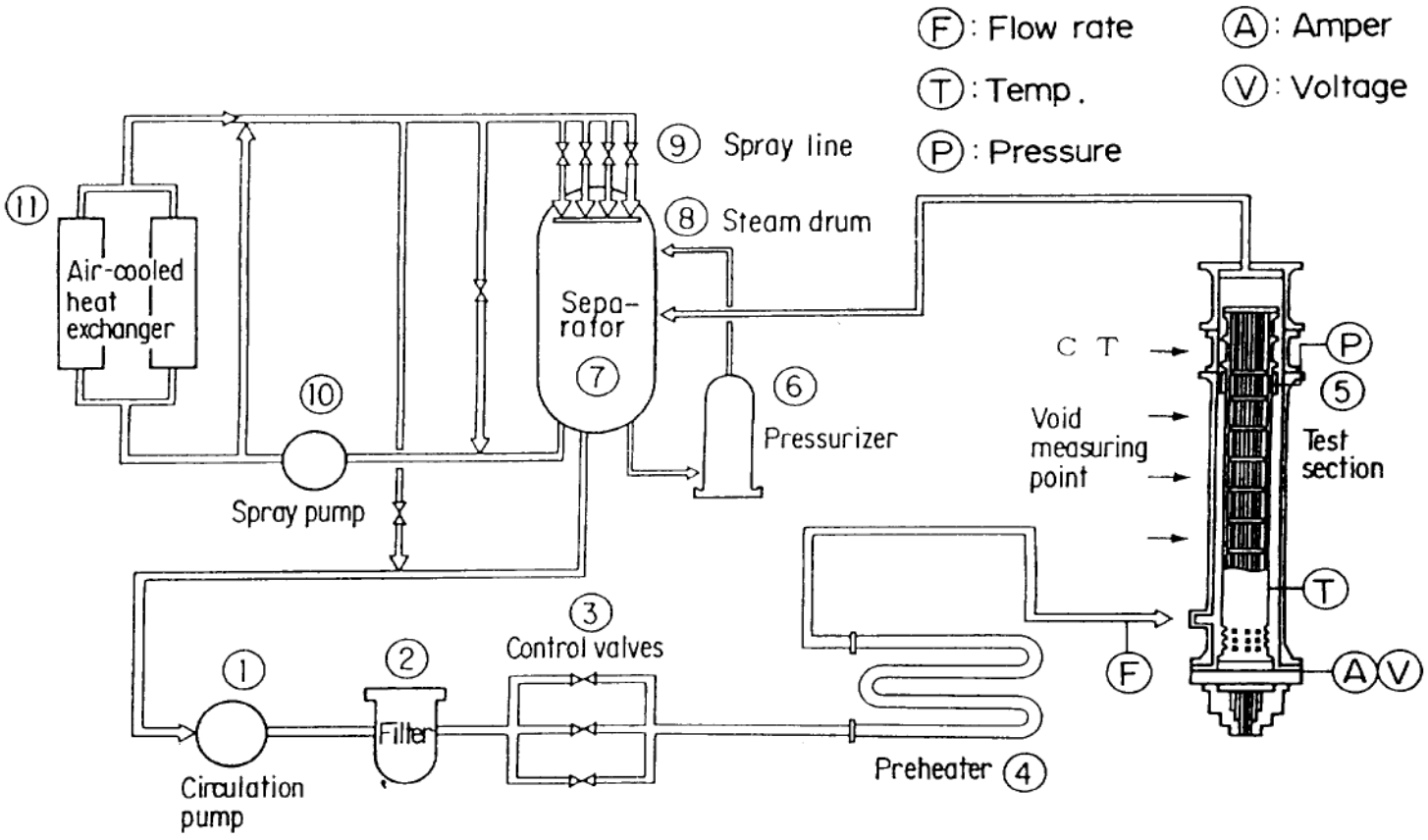
ATHLET (Analyse der Thermohydraulik für LEcks und Transienten)

ATHLET validation using the BFBT data

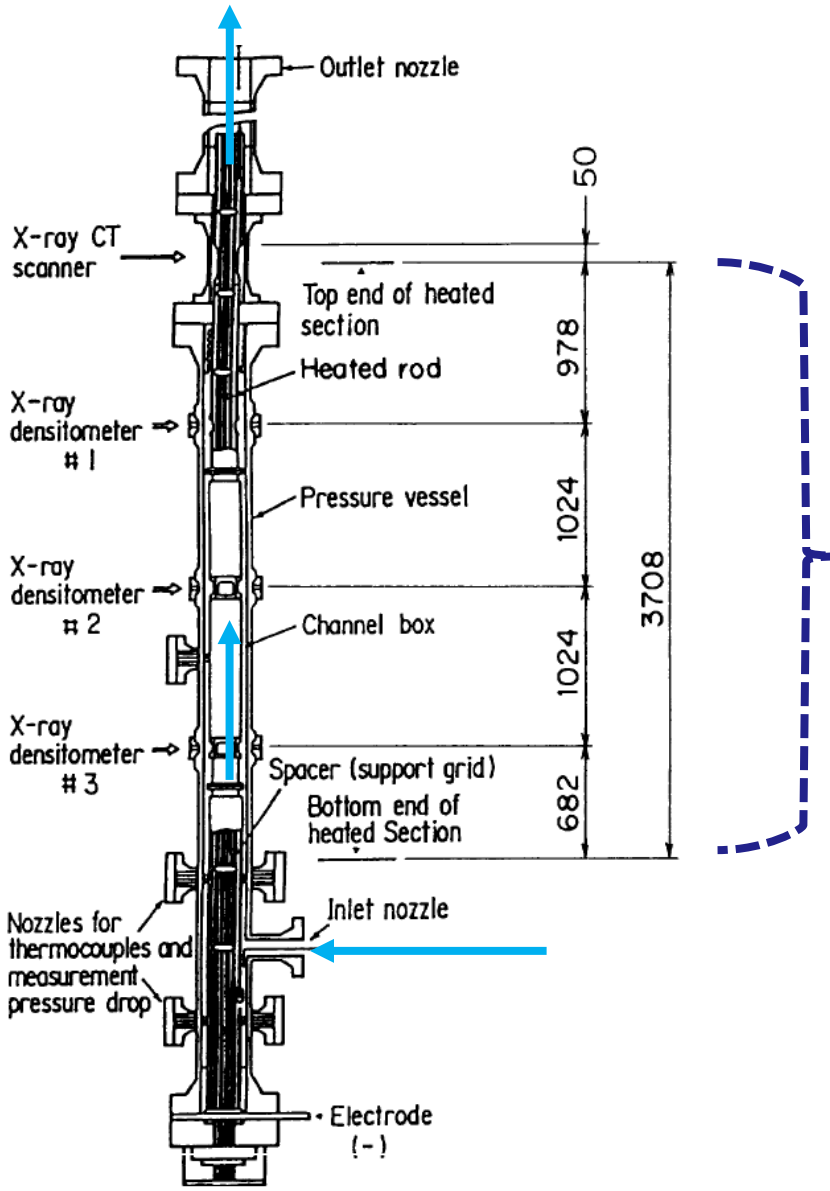
- **The validation of ATHLET using the experimental BFBT NUPEC data base has been conducted for void distribution and pressure drop.**
- **From the OECD/NEA BFBT benchmark, several exercises have been modeled.**
- **Phase I – Void distribution benchmark.**
  - Exercise 1: Steady-state sub-channel grade benchmark
  - Exercise 3: Transient macroscopic grade benchmark
    - Turbine trip and pump trip
- **Phase II – Critical power benchmark.**
  - Exercise 0: Steady-state pressure drop benchmark
    - Single phase and two phase

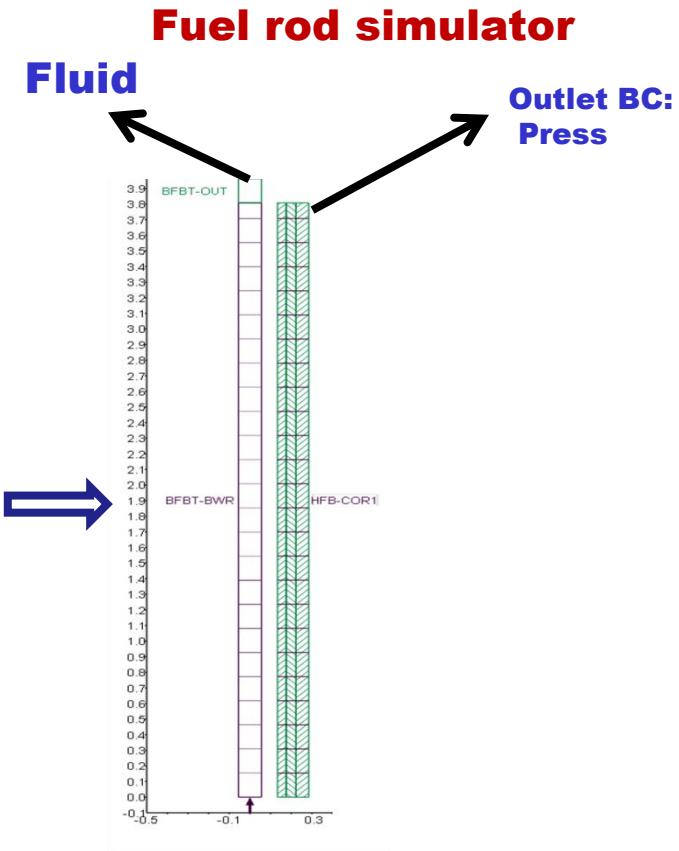
BFBT : BWR Full-Size Fine-Mesh Bundle Test

- **NUPEC BFBT experimental facility.**



BFBT Model with ATHLET (1)





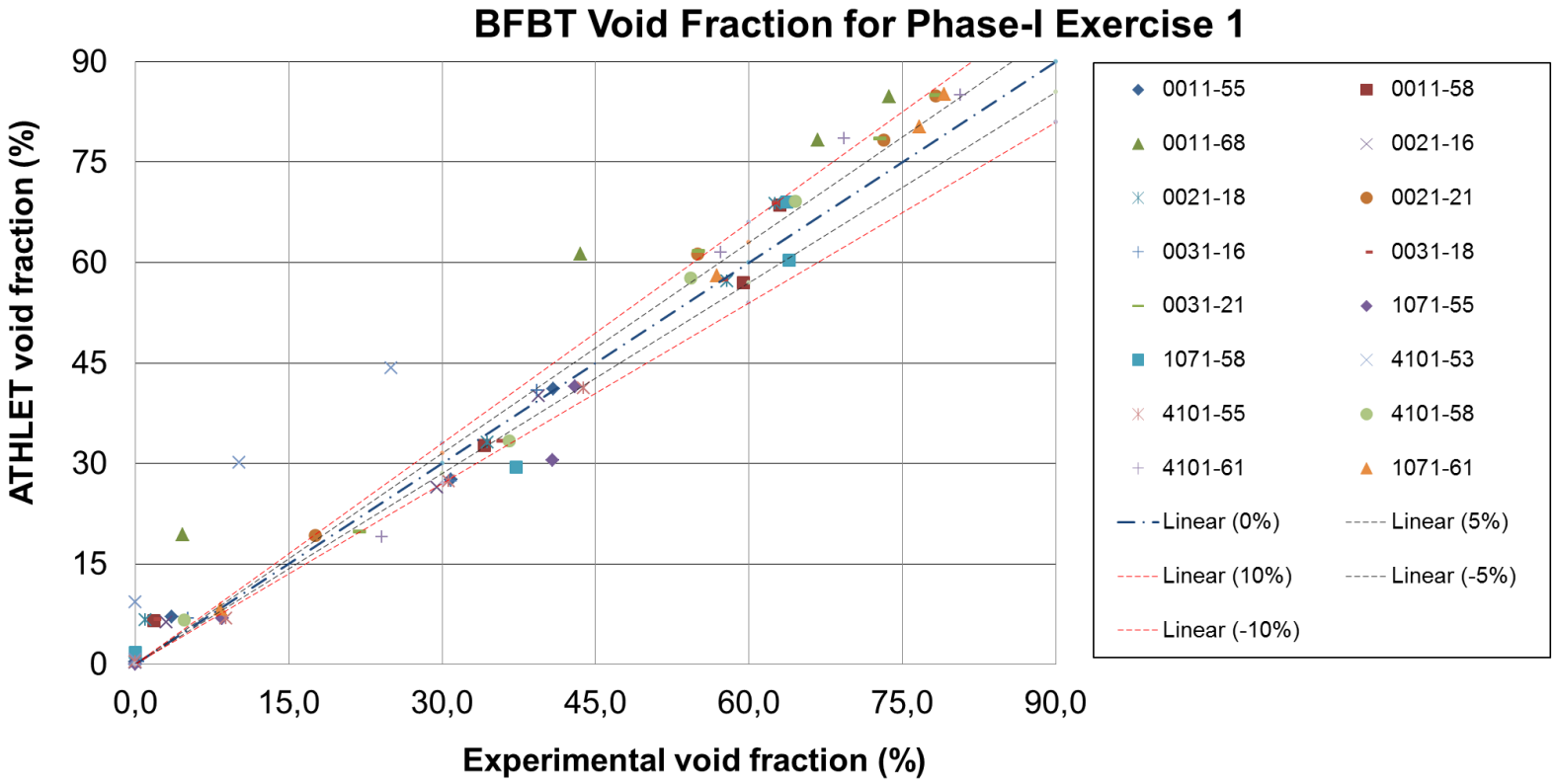
ATHLET Nodalization

ATHLET validation using the BFBT data

- BFBT Phase I Steady State experiments.

Test no.	Pressure [MPa]	Flow rate [t/h]	Inlet sub-cooling [kJ/kg]	Power [MW]	Exit quality [%]
0011-55	7.18	54.0	52.6	1.9	5.0
0011-58	7.17	54.9	51.0	3.51	12.0
0011-61	7.21	54.8	50.9	6.44	24.9
0021-16	7.19	54.9	54.0	1.91	4.8
0021-18	7.17	54.9	49.8	3.51	12.1
0021-21	7.18	54.9	51.4	6.45	24.9
0031-16	7.18	55.0	52.4	1.92	4.9
0031-18	7.18	54.8	50.0	3.52	12.1
0031-21	7.17	54.9	49.4	6.45	25.0
1071-55	7.19	54.6	52.8	1.92	4.9
1071-58	7.16	55.1	50.3	3.52	11.9
1071-61	7.20	54.7	51.8	6.48	25.1
4101-53	7.16	55.0	50.2	2.0	1.24
4101-55	7.20	54.6	52.9	1.92	5.0
4101-58	7.15	54.6	50.6	3.52	12.1
4101-61	7.18	54.7	52.5	6.48	25.1

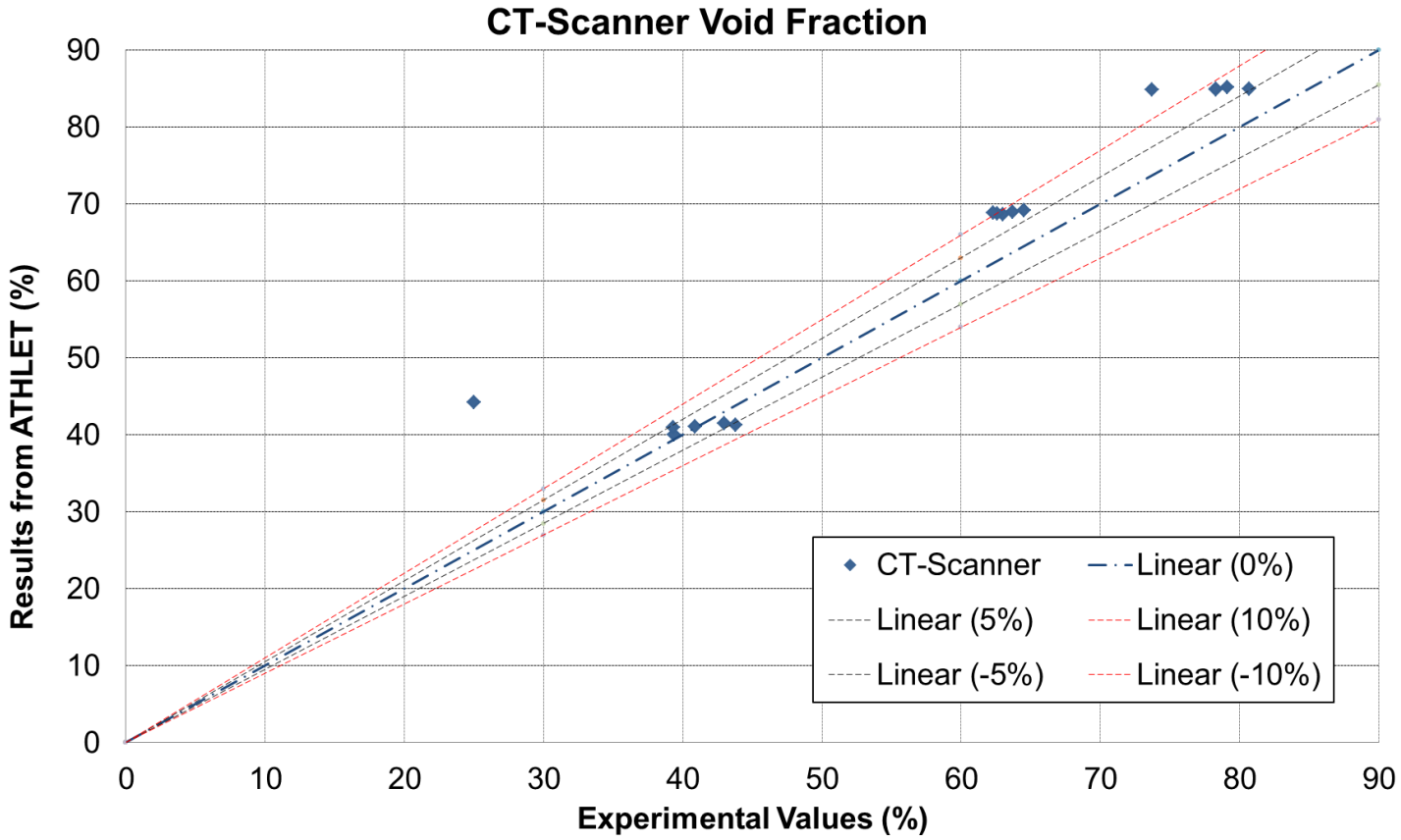
ATHLET Validation based on BFBT Data



- **Except for a few cases where the predictions are quite off from the measurements, in general ATHLET is able to predict the void fraction within ±10% for all the cases.**

ATHLET Validation based on BFBT Data

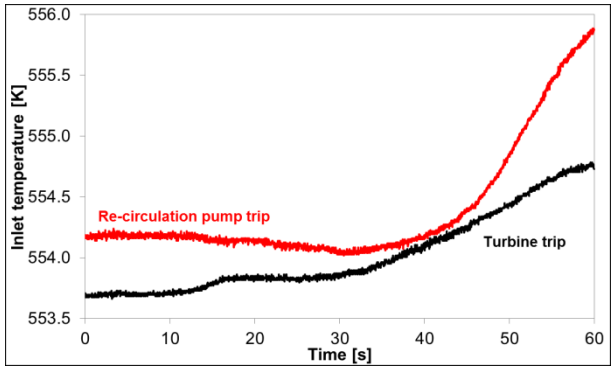
- ATHLET results versus the measured void fraction by the CT-Scanner at the outlet of the bundle.

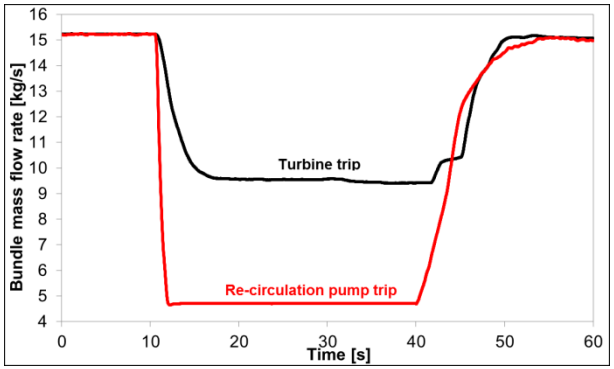


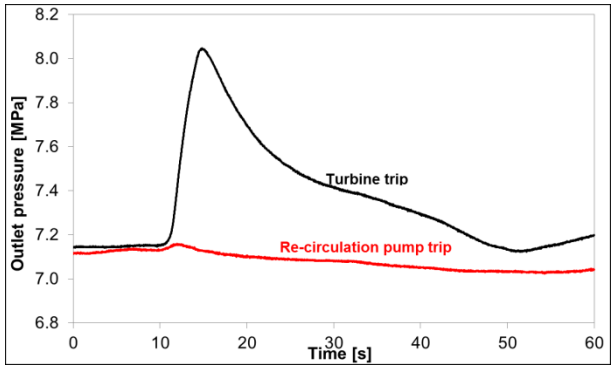
ATHLET Validation based on BFBT Data

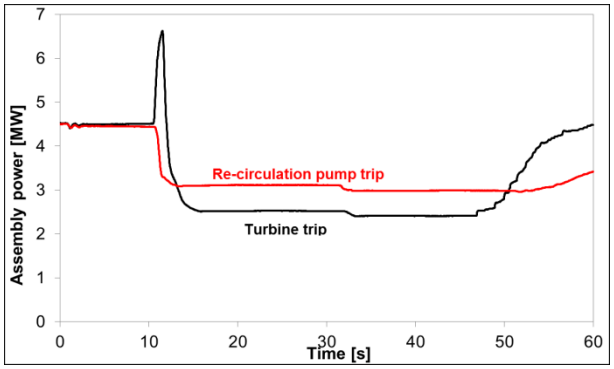
- **BFBT Phase I – Transient experiments.**

Test no.	Pressure [MPa]	Power [MW]	Flow rate [t/h]	Inlet temperature [Celsius]	Outlet quality [%]	Transients
4102-001~009	7.16	4.5	55	279	18	Turbine trip w/o bypass
4102-019~027	7.2	4.5	55	279	18	Re-circulation pump trip

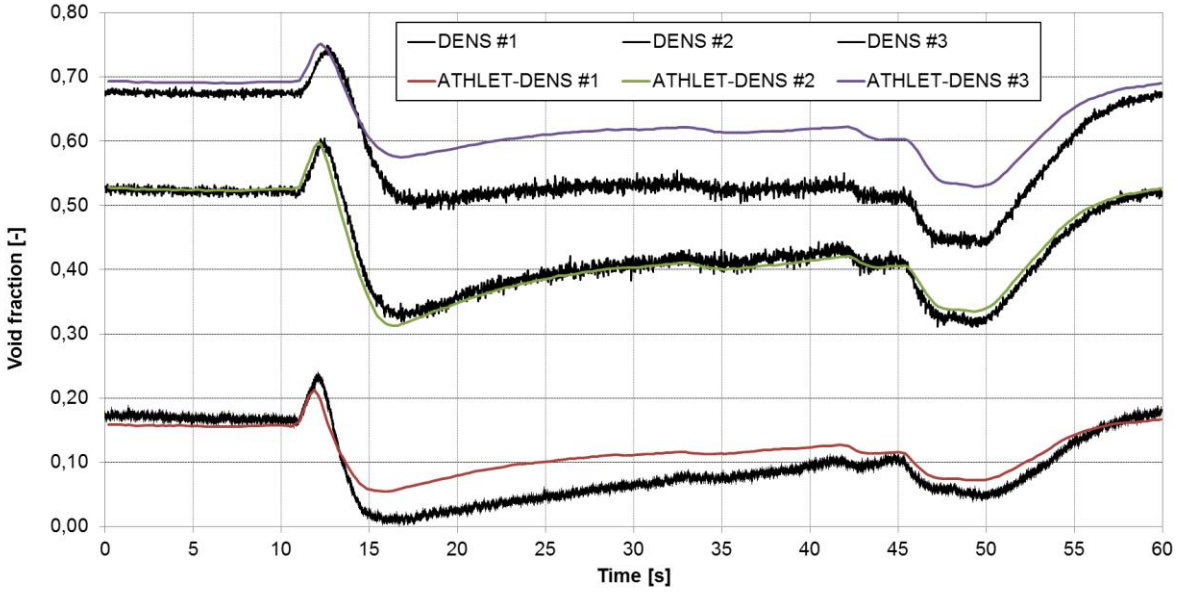




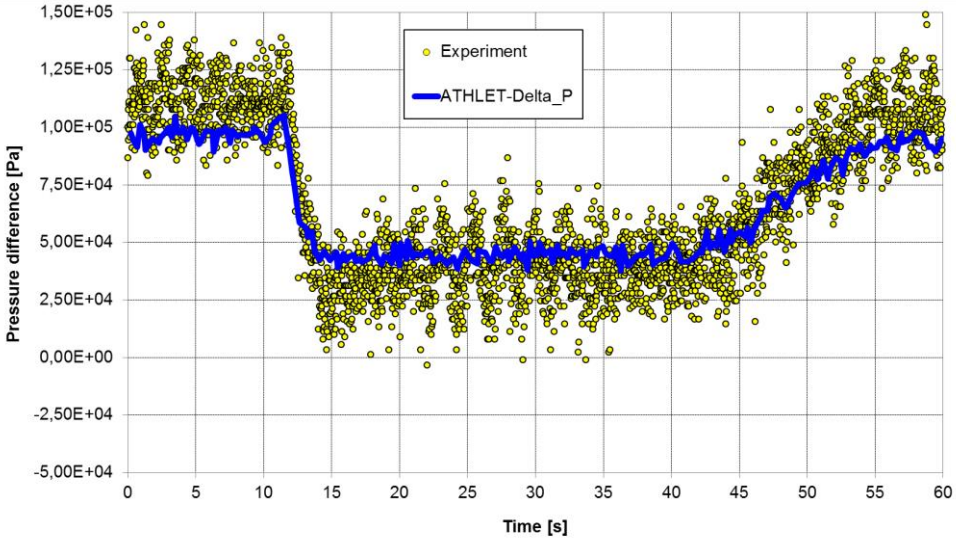




ATHLET Results for the turbine trip

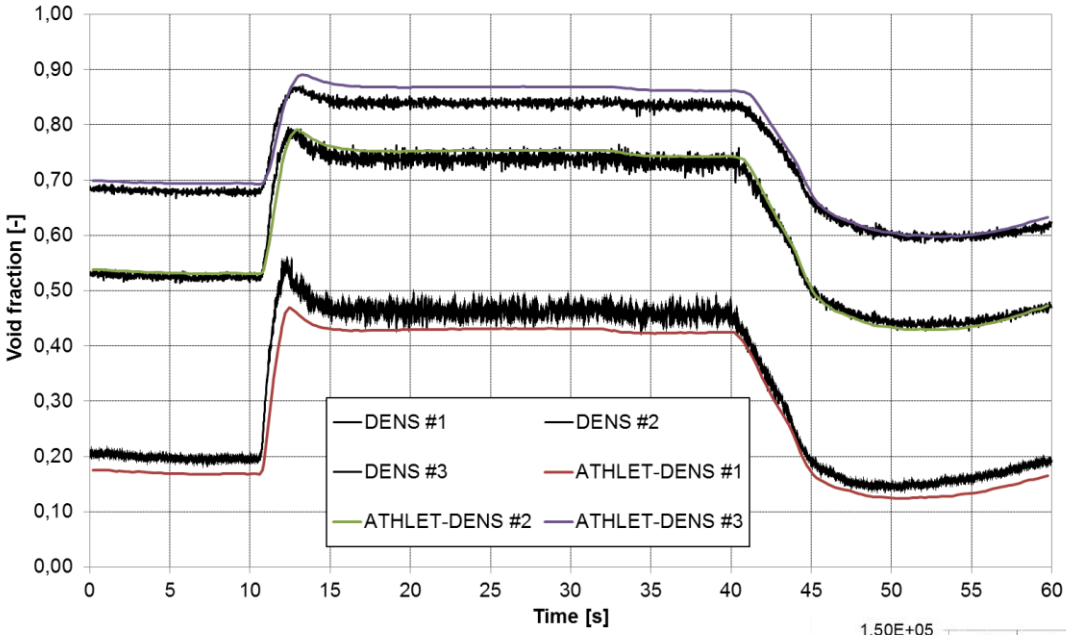


- ATHLET turbine trip void fraction versus experimental values.

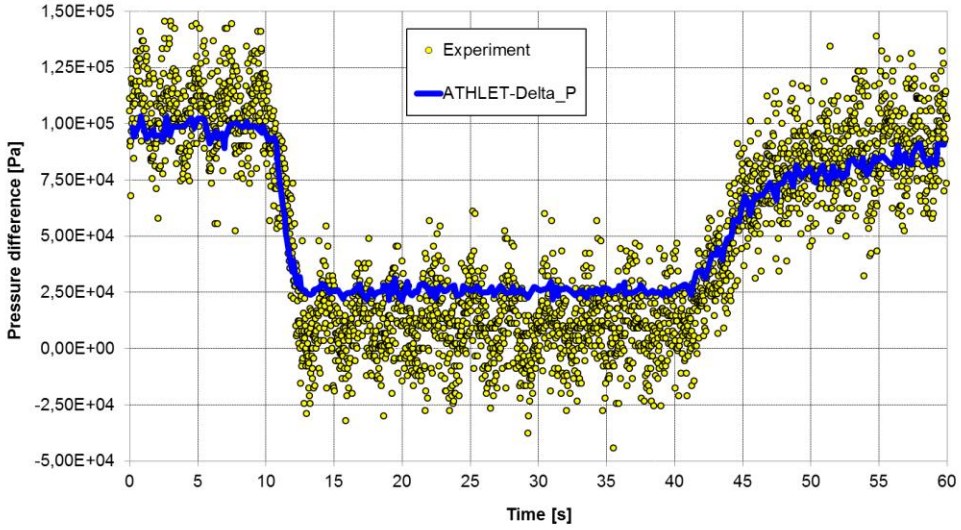


- ATHLET turbine trip total bundle pressure drop versus experimental values.

ATHLET Results for the pump trip



- ATHLET pump trip void fraction versus experimental values.



- ATHLET pump trip total bundle pressure drop versus experimental values.

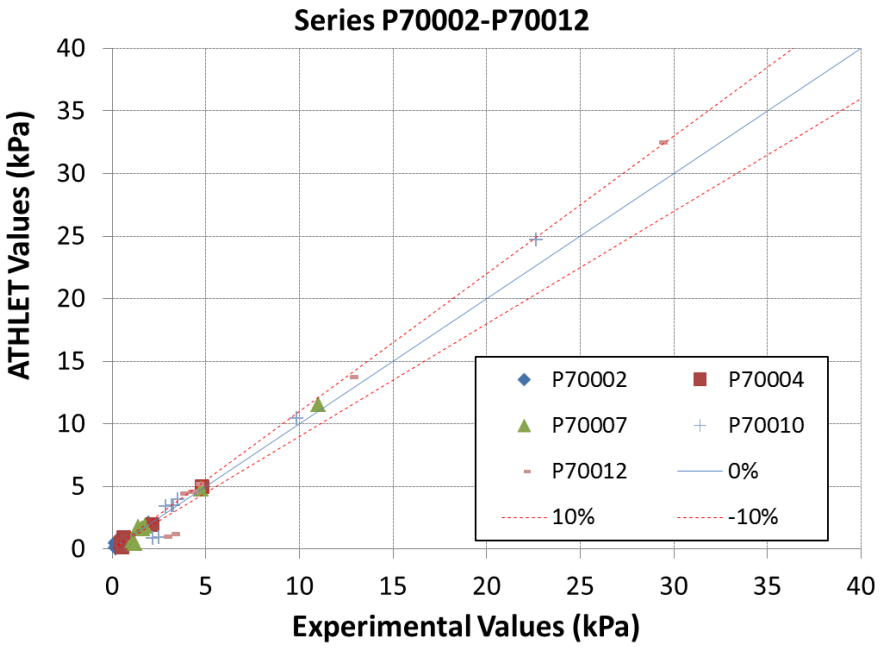
ATHLET validation using the BFBT data

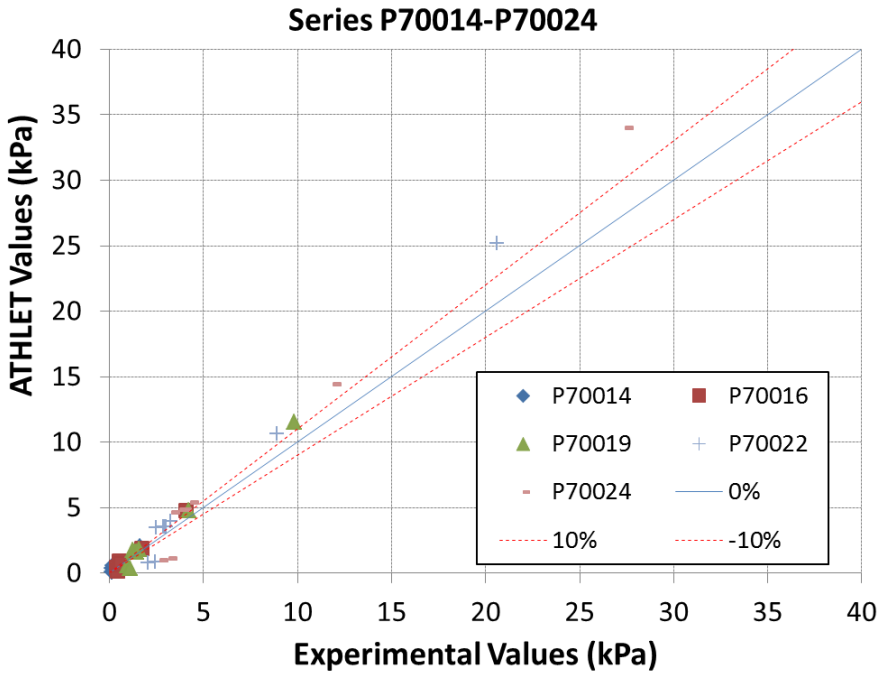
- BFBT Phase II Single-Phase pressure drop.
- From the 36 available experiments in the benchmark data base, 15 cases have been selected.

Experiment Number	Outlet Pressure [MPa]	Inlet Temp. [deg-C]	Flow Rate [ton/h]	Re x10^4
P70002	0,2	38,5	14,5	0,8
P70004	0,2	38,4	24,9	1,38
P70007	0,2	36,2	39,7	2,11
P70010	0,2	41,4	59,8	3,5
P70012	0,2	44,4	69,2	4,28
P70014	0,99	176,5	14,9	3,7
P70016	0,98	176,2	24,8	6,15
P70019	0,99	176	39,8	9,86
P70022	0,98	175,3	59,8	14,75
P70024	0,98	175,1	69,8	17,2
P70026	7,15	285,5	15,4	6,13
P70028	7,16	285,1	24,9	9,91
P70031	7,16	285,6	39,7	15,81
P70034	7,15	284,8	59,7	23,74
P70036	7,15	284,8	69,9	27,79

ATHLET Results for the single-phase

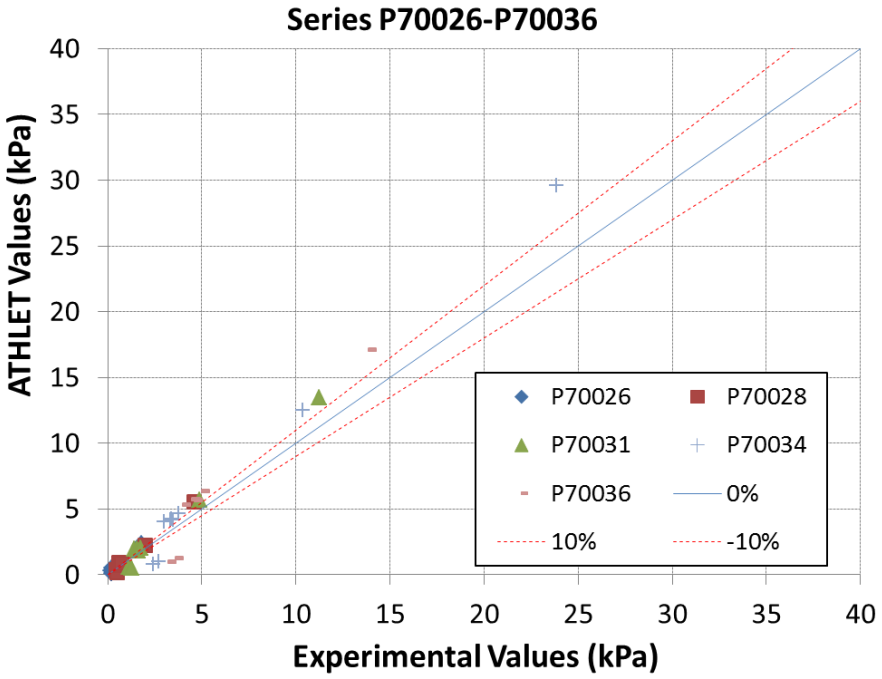
- The test data have been grouped into three different groups.
- Each of them sharing the same pressure boundary conditions and showing an increasing mass flow rate within the series.

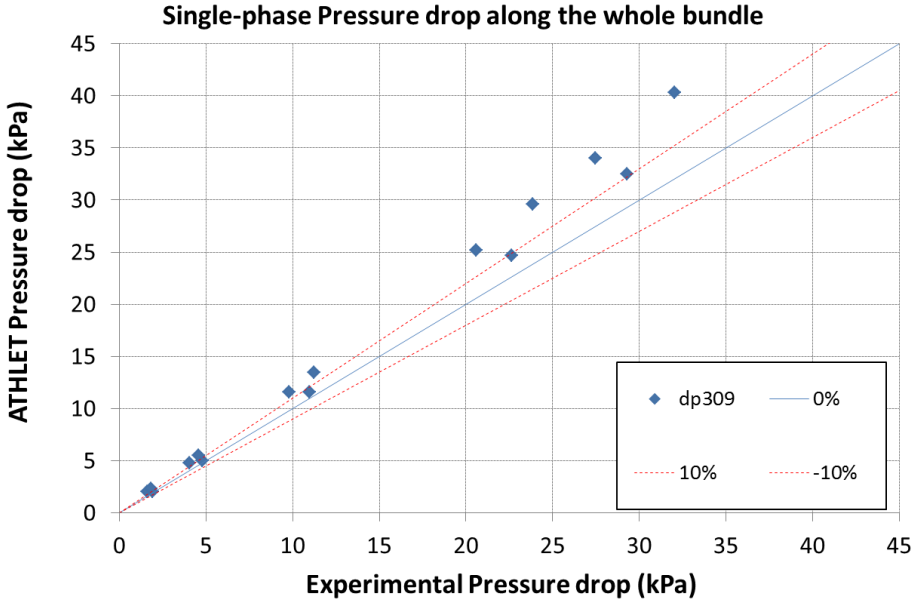




ATHLET Results for the single-phase

- ATHLET trends to over predict systematically the single-phase pressure drop with an increasing mass flow rate.
- In any case, the agreement with the measured data is very good.





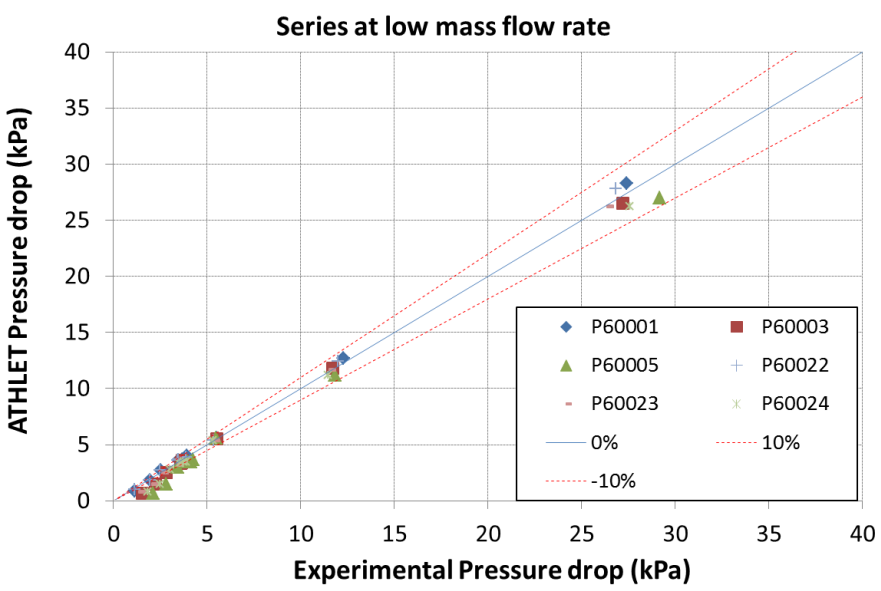
ATHLET validation using the BFBT data

- **BFBT Phase II Two-Phase pressure drop.**

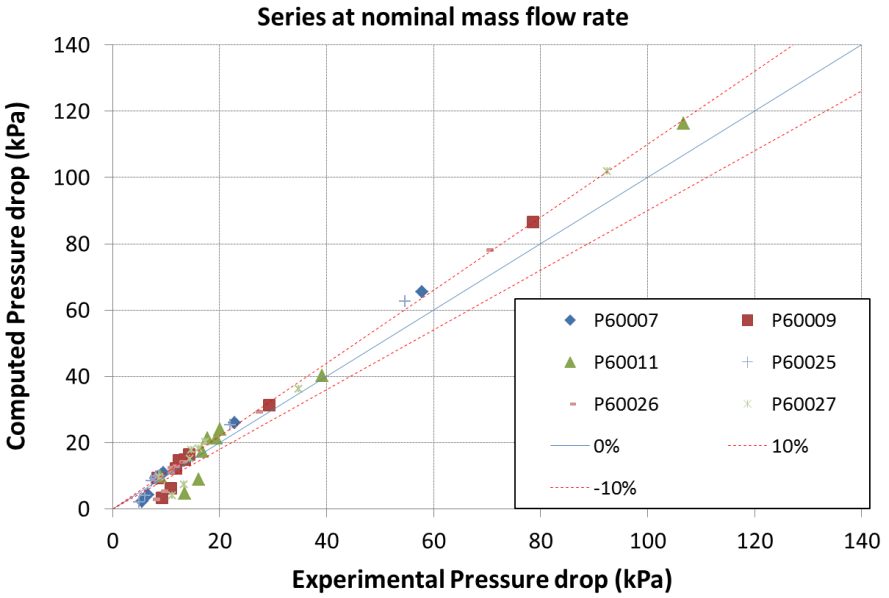
Experiment Number	Outlet Pressure [MPa]	Inlet Temp. [deg-C]	Inlet Subcooling [kJ/kg]	Flow Rate [ton/h]	Power [MW]
P60001	7,16	277,3	53,3	20,2	0,863
P60003	7,16	277,8	50,8	20,1	1,521
P60005	7,16	277,7	51,1	20	2,357
P60007	7,17	277,8	51,1	55	2,375
P60009	7,17	277,8	51,1	55	4,197
P60011	7,17	278	50,6	54,9	6,478
P60013	7,16	278,4	47,2	69,9	3,022
P60015	7,17	278,2	49,5	70	5,34
P60017	7,16	277,8	51	45,1	1,919
P60019	7,17	278,2	49,4	45	3,437
P60021	7,16	277,8	50,8	45,1	5,312
P60022	8,64	291,3	50,7	20,2	0,837
P60023	8,63	291	52,3	20,2	1,464
P60024	8,63	290,9	52,9	20,2	2,252
P60025	8,64	291,3	51,3	55	2,271
P60026	8,64	291	53	55,1	3,975
P60027	8,64	291,2	51,5	55,1	6,137
P60029	8,64	291,3	51,5	70,1	2,888
P60030	8,64	291,2	51,4	70,2	5,076
P60031	8,64	290,9	53	45,1	1,869
P60032	8,63	291,2	51,3	45,2	3,262
P60033	8,63	291,2	51,6	45,1	5,021

ATHLET Results for the two-phase

- **The test data have been grouped into four different groups with regards to the mass flow rate. It ranges between 20, 45, 55 and 70 ton/h.**



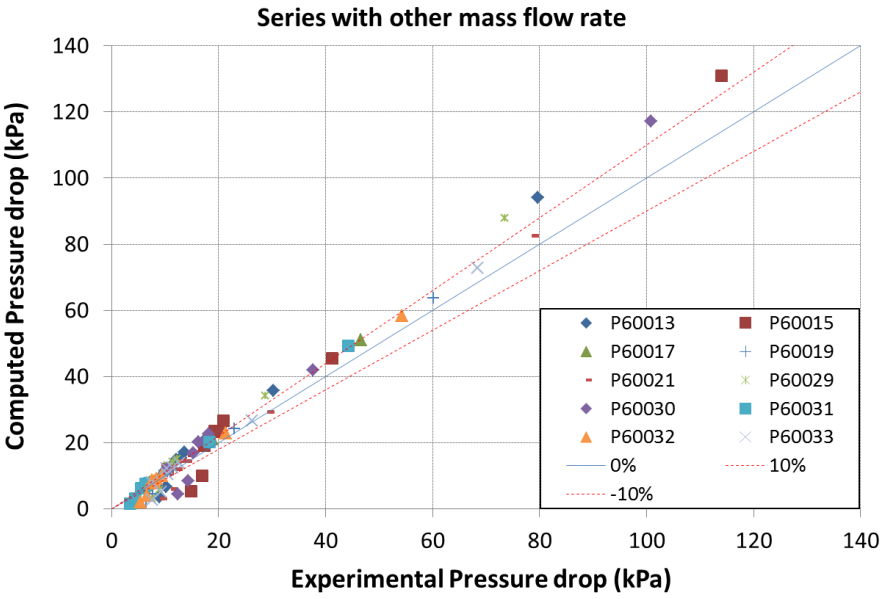
Pressure drop for cases with low mass flow rate (20 ton/h)



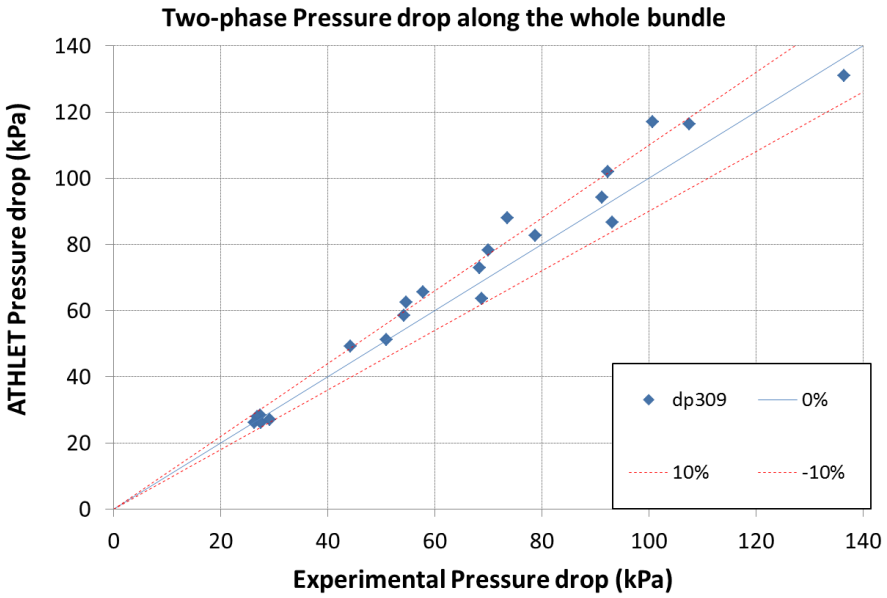
Pressure drop for cases with nominal mass flow rate (55 ton/h)

ATHLET Results for the two-phase

- As it can be seen, a very good agreement is found for the two-phase pressure drop.
- Almost all the points are within ±10% error bands.



Pressure drop for cases with 45 and 70 ton/h mass flow rate



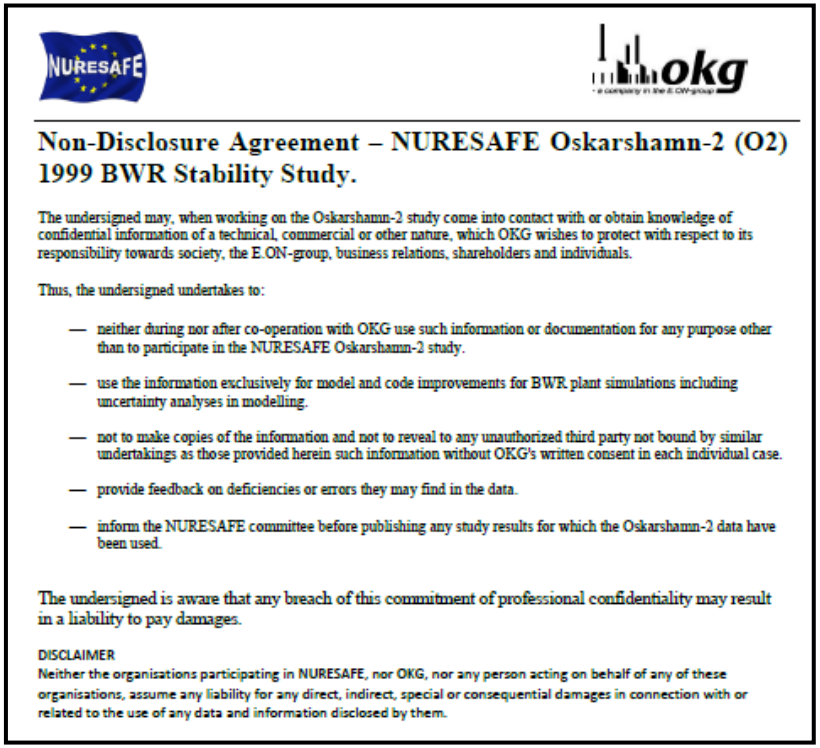
Total pressure drop along the fuel bundle

Outline

- **Status of code validation using BFBT Data**
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power
- **Modeling of the Oskarshamn-2 core with ATHLET**
  - Development of an integral plant model of the Oskarshamn-2 plant for the analysis of an ATWS transient (consistent with ATHLET input in WP1.3 - D13.21)
- **Modeling of the Oskarshamn-2 core with subchannel codes**
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested
- **Conclusion & Outlook**

Modeling of Oskarshamn-2 NPP with ATHLET

- Using ATHLET Mod3.0 Cycle A for the WP1.3 and WP3.3 task.
- COBRA-TF NURESAFE version distributed by GRS.
- Non-Disclosure Agreement signed with OKG



Non-Disclosure Agreement – NURESAFE Oskarshamn-2 (O2) 1999 BWR Stability Study.

The undersigned may, when working on the Oskarshamn-2 study come into contact with or obtain knowledge of confidential information of a technical, commercial or other nature, which OKG wishes to protect with respect to its responsibility towards society, the E.ON-group, business relations, shareholders and individuals.

Thus, the undersigned undertakes to:

— neither during nor after co-operation with OKG use such information or documentation for any purpose other than to participate in the NURESAFE Oskarshamn-2 study.

— use the information exclusively for model and code improvements for BWR plant simulations including uncertainty analyses in modelling.

— not to make copies of the information and not to reveal to any unauthorized third party not bound by similar undertakings as those provided herein such information without OKG's written consent in each individual case.

— provide feedback on deficiencies or errors they may find in the data.

— inform the NURESAFE committee before publishing any study results for which the Oskarshamn-2 data have been used.

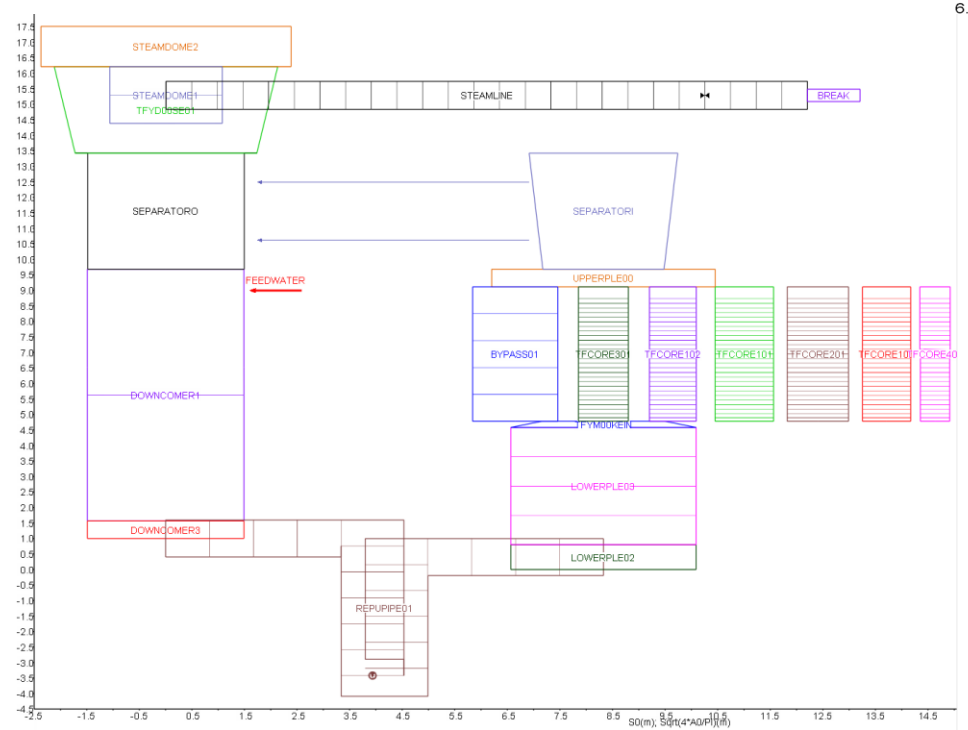
The undersigned is aware that any breach of this commitment of professional confidentiality may result in a liability to pay damages.

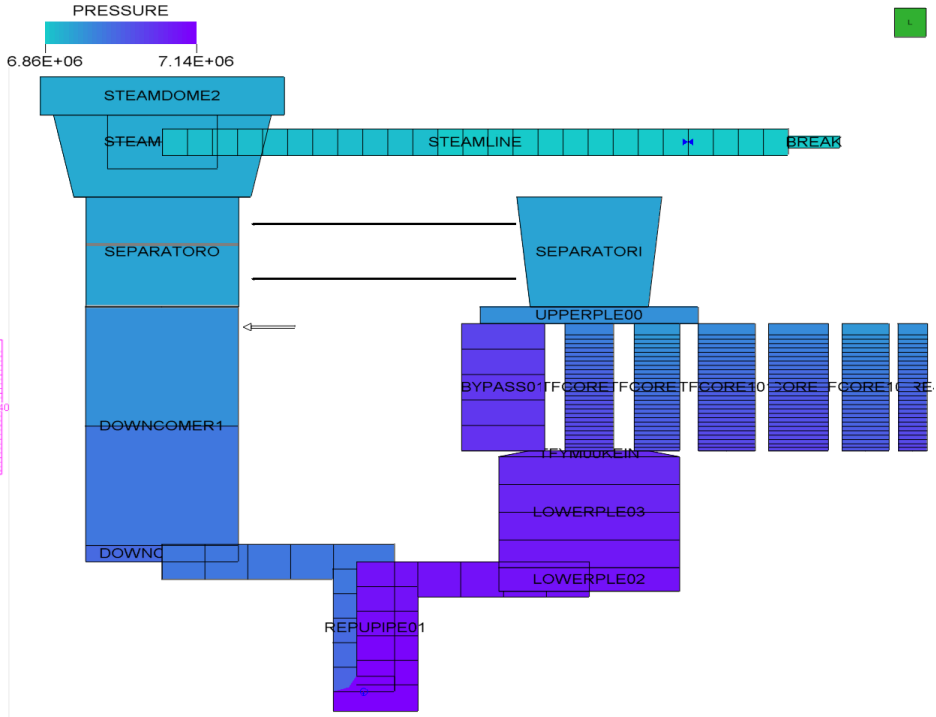
DISCLAIMER
Neither the organisations participating in NURESAFE, nor OKG, nor any person acting on behalf of any of these organisations, assume any liability for any direct, indirect, special or consequential damages in connection with or related to the use of any data and information disclosed by them.

ATHLET model for O-2

- **ATHLET input deck from D13.21 (GRS)**
  - Modifications performed to use the point kinetic model.

Model contains: Downcomer, Recirculation Loop and Pump, Lower Plenum, Steam Separator, Steam Dome, Core Model, Core Bypass, Steam Line.

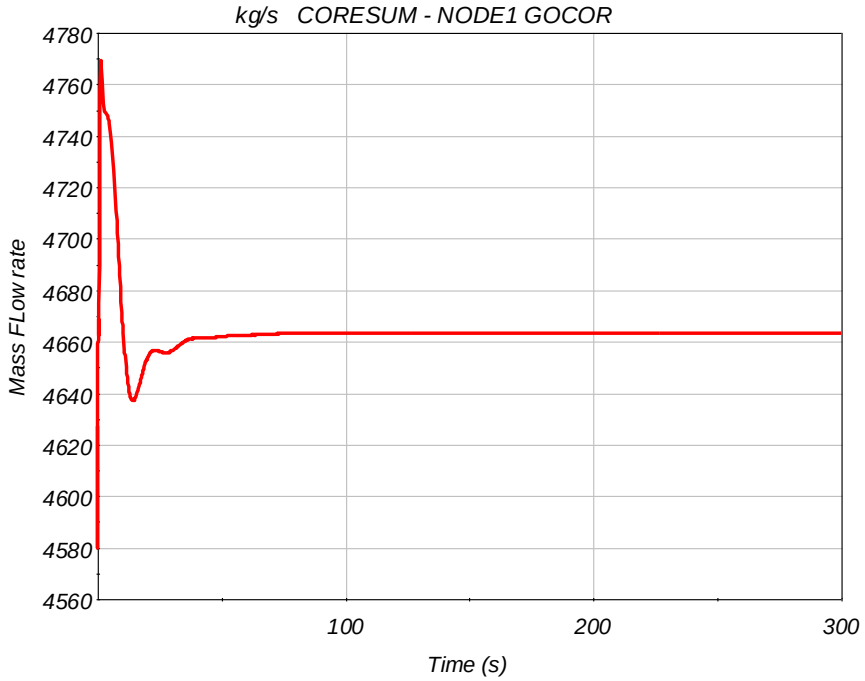


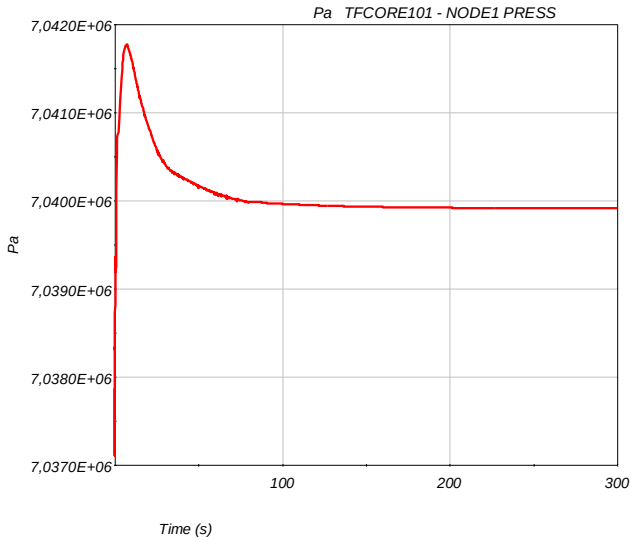


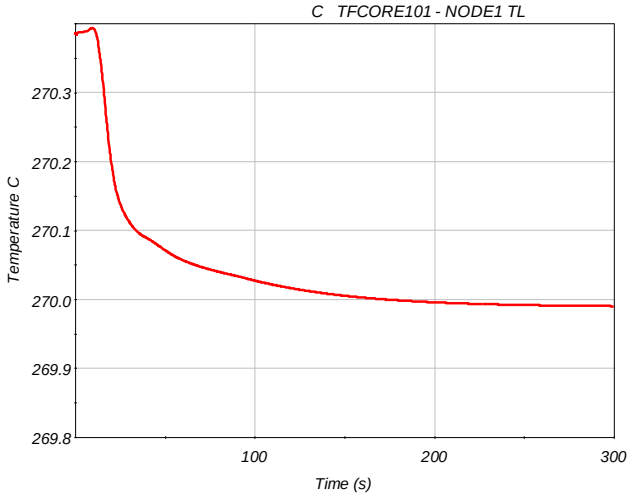
Preliminary results for the SS at HFP

- **Results from ATLAS**

Steady State convergence achieved after 300s







Preliminary results for the SS at HFP

- **Comparison of values against measured data.**
  - Using a simple point kinetics model imposing the nominal power and no reactivity insertion.

Parameter	Benchmark	ATHLET 3.0 deviations with regards to the measured data
Steam dome pressure	Ref.	-0.375%
Feedwater Temperature	Ref.	-0.049%
Core Inlet Temperature	Ref.	-0.760%
Total Core Flow Rate	Ref.	1.234%
Steam Flow Rate	Ref.	0.597%

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

Outline

- Status of code validation using BFBT Data
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power
- Modeling of the Oskarshamn-2 core with ATHLET
  - Development of an integral plant model of the Oskarshamn-2 plant for the analysis of an ATWS transient (consistent with ATHLET input in WP1.3 - D13.21)
- **Modeling of the Oskarshamn-2 core with subchannel codes**
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested
- Conclusion & Outlook

O2 Modeling with subchannel codes

- **Oskarshamn-2 Core has being modeled with COBRA-TF, SUBCHANFLOW and FLICA4 (444 Channels)**

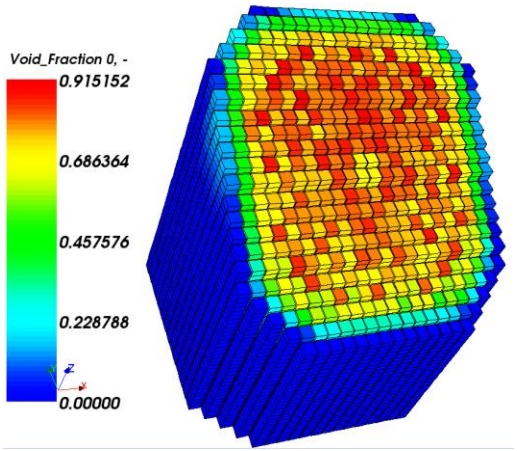
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2						1	1	1	1	1	1	1	1	1	1	1	1	1	1					
3					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
4				1	1	1	3	1	2	2	1	2	2	2	2	2	1	2	1	1	1			
5			1	1	2	2	1	3	4	1	3	1	4	3	1	4	1	1	2	2	1	1		
6		1	1	2	2	1	4	2	1	3	2	3	1	1	3	1	3	4	1	2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

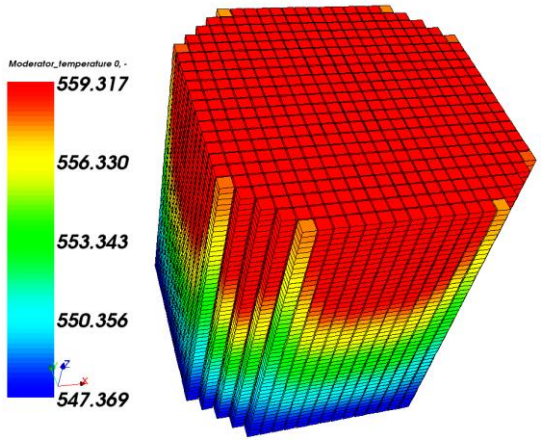
				1	2	3	4	5	6	7	8	9	10	11	12	13	14							
			15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						
		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48				
	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68				
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90			
91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112			
113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134			
135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156			
157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178			
179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200			
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222			
223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244			
245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266			
267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288			
289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310			
311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332			
333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354			
355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376			
	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396				
		397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414					
			415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430						
				431	432	433	434	435	436	437	438	439	440	441	442	443	444							

O2 Modeling with subchannel codes

- **Code versus measured data comparison**

Parameter at HFP	Benchmark	SCF	FLICA4	CTF
Core outlet Temperature (K)	Ref.	+0.206%	-0.05%	+0.138%
Average void fraction (-)	Ref.	-2.38%	-7.14%	-11.9%
Void fraction at core outlet (-)	-	0.7124	0.6698	0.7080
Presure drop in the core (kPa)	Ref.	-1.95%	-12.8%	16.34%
Average flow velocity in the core (m/s)	-	2.99	4.59 (Vap.) 2.77 (Liq.)	3.21

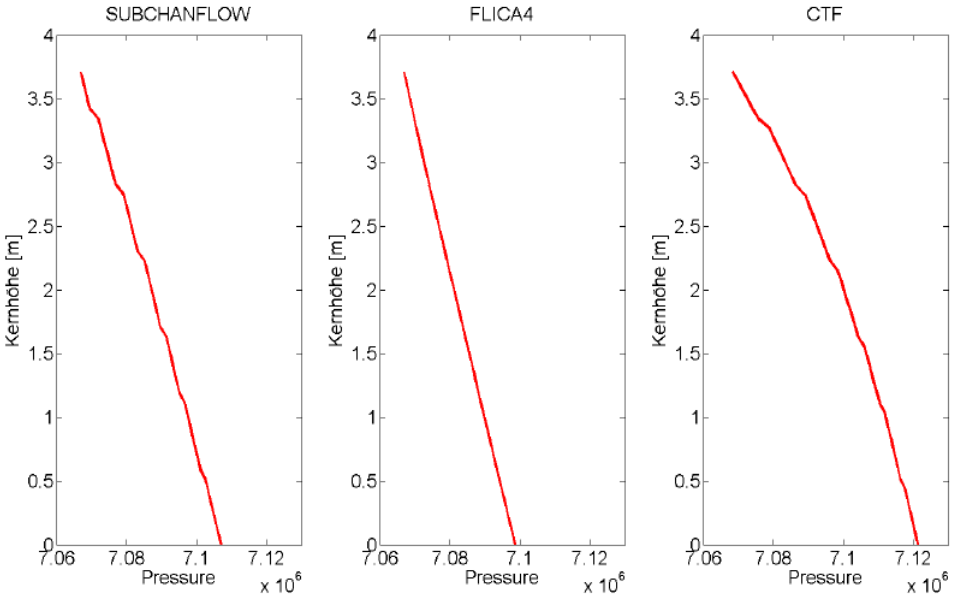


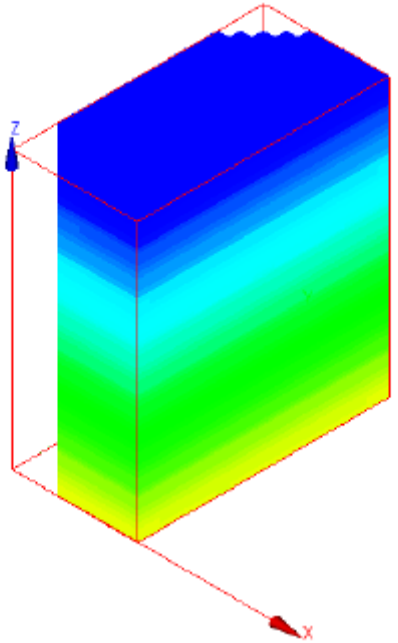


$$\text{Deviation} = \frac{Messured - CODE}{Messured} * 100$$

Results: Pressure drop

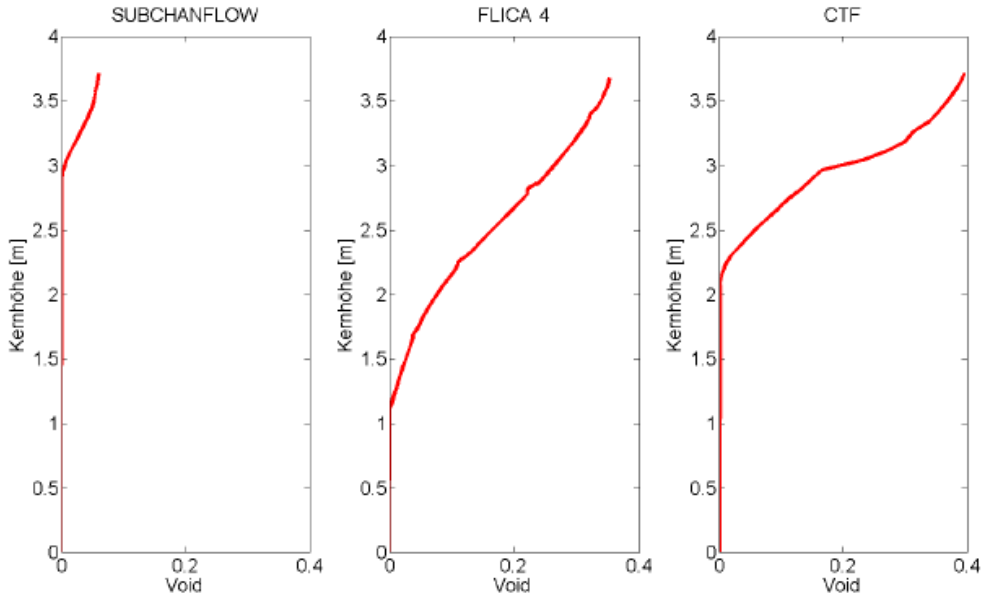
- 3D Power distribution taken from converged steady state TRACE/PARCS

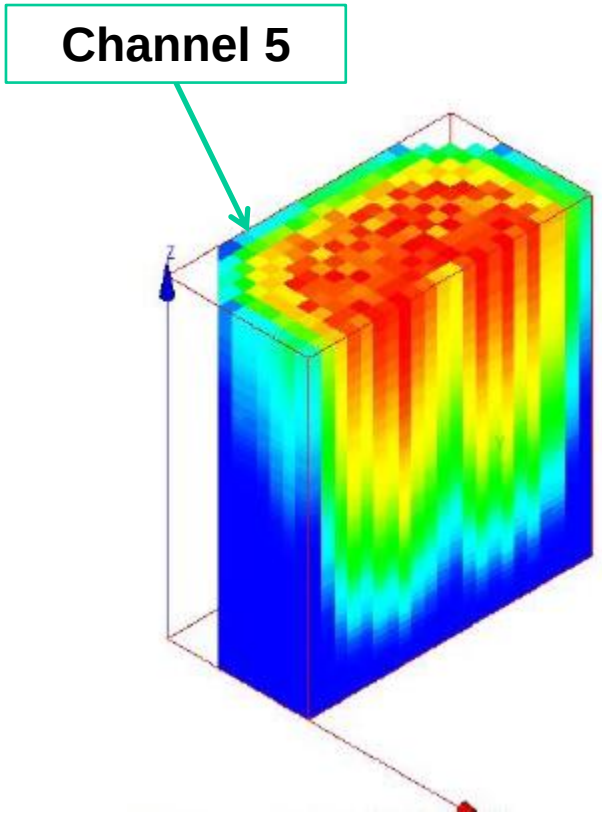




	Benchmark	SUBCHANFLOW	FLICA4	CTF
Average Pressure drop in the core (kPa)	Ref.	-1.9%	-12.8%	+16.3%

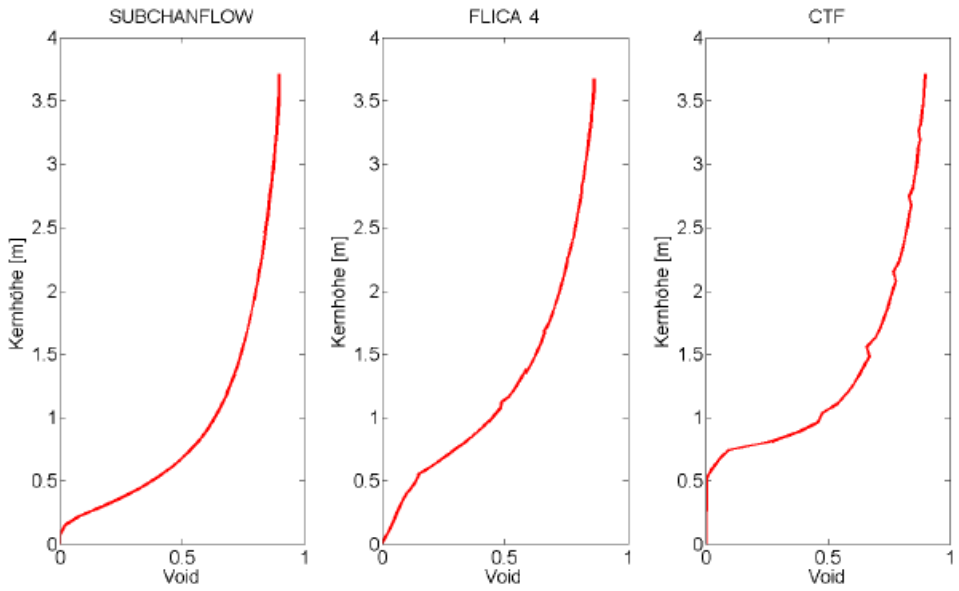
Results: Void fraction in channel 5

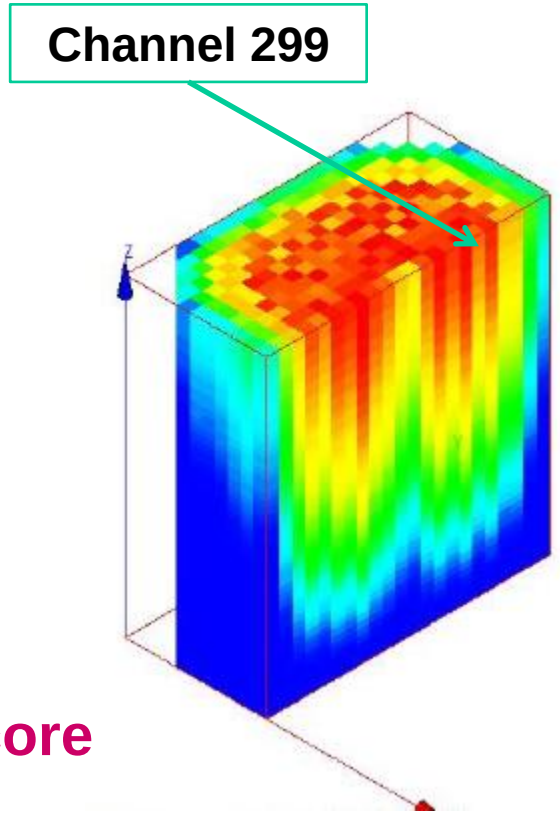




- Very different onset of boiling
- Effects of subcooled boiling are modeled differently

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

Outline

- **Status of code validation using BFBT Data**
  - Validation of ATHLET using the BWR NUPEC BFBT tests for void fraction and critical power
- **Modeling of the Oskarshamn-2 core with ATHLET**
  - Development of an integral plant model of the Oskarshamn-2 plant for the analysis of an ATWS transient (consistent with ATHLET input in WP1.3 - D13.21)
- **Modeling of the Oskarshamn-2 core with subchannel codes**
  - Input decks for COBRA-TF, SUBCHANFLOW, FLICA4 developed and successfully tested
- **Conclusion & Outlook**

Conclusions and Outlook

- **AHTLET validation using the BFBT data completed.**
  - In overall, very good agreement with the measurements.
- **Verification of ATHLET model completed.**
  - Good agreement between the ATHLET model and the measured data.
  - Extensions of the model to ATWS will be needed, add more components.
- **SUBCHANFLOW, COBRA-TF and FLICA4 model for O2 core completed.**
  - Good agreement between O2 reference values and predictions.
  - FLICA4 and SUBCHANFLOW models developed as a backup solution for O2.

Conclusions and Outlook

- Integration and coupling of ATHLET and COBRA-TF in the SALOME platform are in a good progress (GRS).
- Multi-scale TH simulation using ATHLET/CTF inside SALOME.
- In the next months the coupling via ICOCO interface will be tested.
- Application of the developed, and standalone tested, inputs decks to ATWS will follow within WP1.3 and WP3.3.

THANKS FOR YOUR ATTENTION