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SCCRED: a Supporting Tool for V&V and Uncertainty Evaluation of Best-Estimate System Codes for Licensing Applications

A. Petruzzi (UNIPI-NINE), F. D'Auria (UNIPI)

Presented by M.Lanfredini (UNIPI-NINE)

Contents

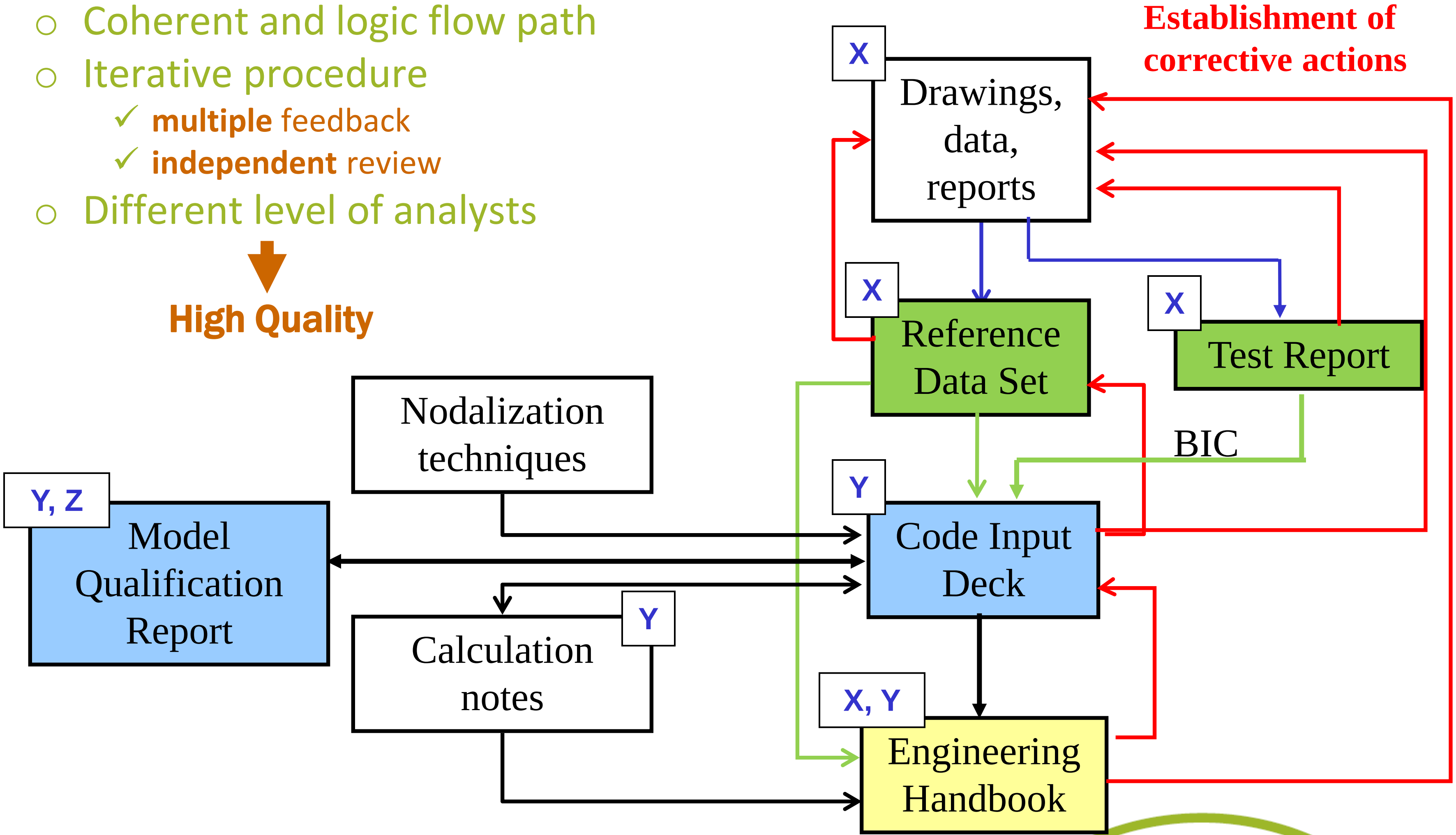
Introduction

- Availability of Experimental Data might not be enough:
  - Information spread on several reports
  - Different quality level and format of the documentation
  - Need to explain and clarify the information
  - Contradictions exist
- Preserving the Experimental Data shall be a MUST
- Qualified experimental database is envisaged by IAEA (SRS 23)
- Need for a **STANDARD** for fully exploit the experimental data and generate a **CONSOLIDATED Calculated and Reference Experimental Database (SCCRED)**
- Use of SCCRED for V&V of:
  - Computational tools
  - Uncertainty Evaluation

The SCCRED methodology

- SCCRED bases:
  - Coherent and logic flow path
  - Iterative procedure
    - ✓ **multiple** feedback
    - ✓ **independent** review
  - Different level of analysts

High Quality



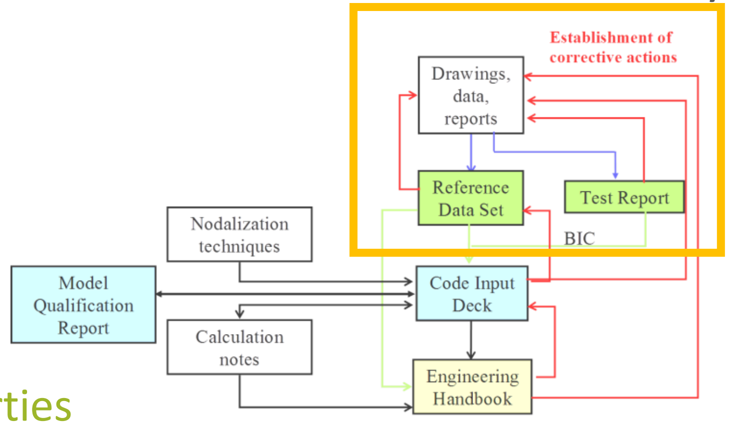
X<Y<Z: indicate three levels of analysts group

Achievements

- Development of a methodology for collecting, organizing, using and preserving an exhaustive set of geometrical data and experimental results
    - Exhaustive consolidated information is a standardized format
    - Traceability
    - Documentation of the decisions taken in case of lack of data or in presence of contradictory information
    - Creation of databases (experimental data & associated calculations) for BE code assessment and validation of UM
- Development of **Reference Data Set** documents for developing input decks
- Setting up standard procedures for using the collected data and qualify the code calculations (**Qualification Report**)
- Development of a standard report (**Engineering Handbook**) containing a full description of how the database has been converted into an input data deck for a specific computer code (support to verification)

Reference Data Set

- **Consistent**, **consolidated** and **standardized** set of relevant data of the facility and the tests
  - Check the quality of the data
  - Resolve possible contradiction review
    - ✓ dispersed and not exhaustive information
    - ✓ Duration of experimental campaign
  - Explain information on geometry and TH properties
  - Perform and independent review
  - Application of quality assurance procedures



- The RDS are **Code-independent** → suitable for input development and qualification and for UM development and validation
- Two different types of RDS
  - RDS-Facility: one RDS for each facility in a "reference status"
  - RDS-test: one for each experiment performed in the facility

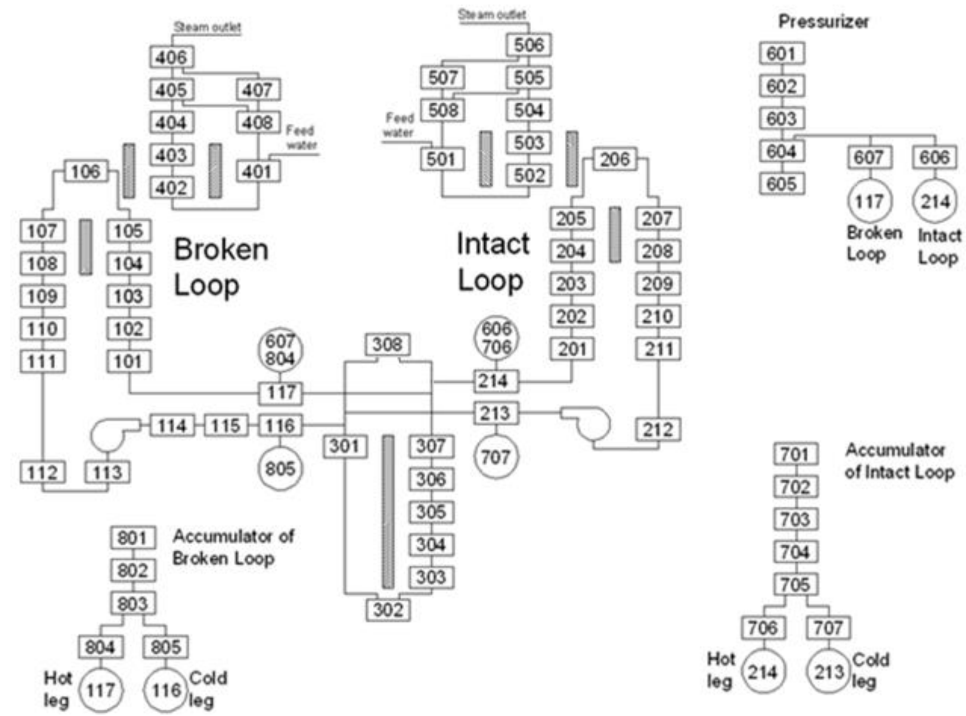
RDS-Facility structure

- The RDS-Facility is related with the design in a **“reference status”** of a facility and consists of the following **standard** sections
  - Layout of the facility
  - Collection of geometrical data (length, volumes, areas, elevations) for each subsystem and component of the facility
  - Collection of specific data for complex component (pumps, valves, heaters, etc...)
  - Identification of geometrical discontinuities and evaluation of pressure loss coefficients (normal operation)
  - Material properties
  - Measurement system
  - Nominal heat losses
  - Nuclear data (if available)
- **“Reference status”** corresponds to a geometrical and hardware configuration of the facility at a certain time

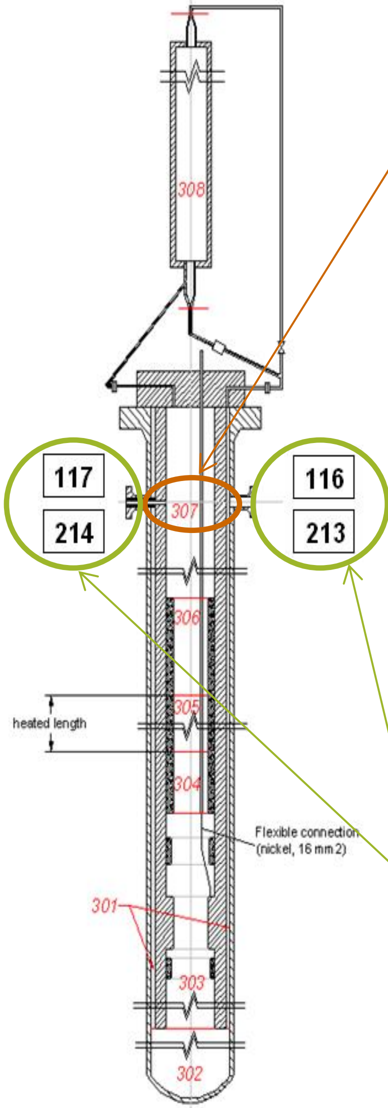
RDS-Facility sample

- Subdivision in **code-independent** modules

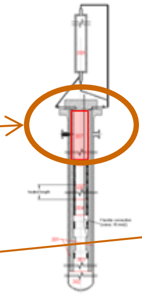
  - 100 – Primary circuit: broken loop
  - 200 – Primary circuit: intact loop
  - 300 – Pressure vessel and upper head
  - 400 – Steam generator: part of the secondary circuit of the broken loop
  - 500 – Steam generator: part of the secondary circuit of the intact loop
  - 600 – Pressurizer and its piping
  - 700 – Accumulator of the intact loop and its piping
  - 800 – Accumulator of the broken loop and its piping



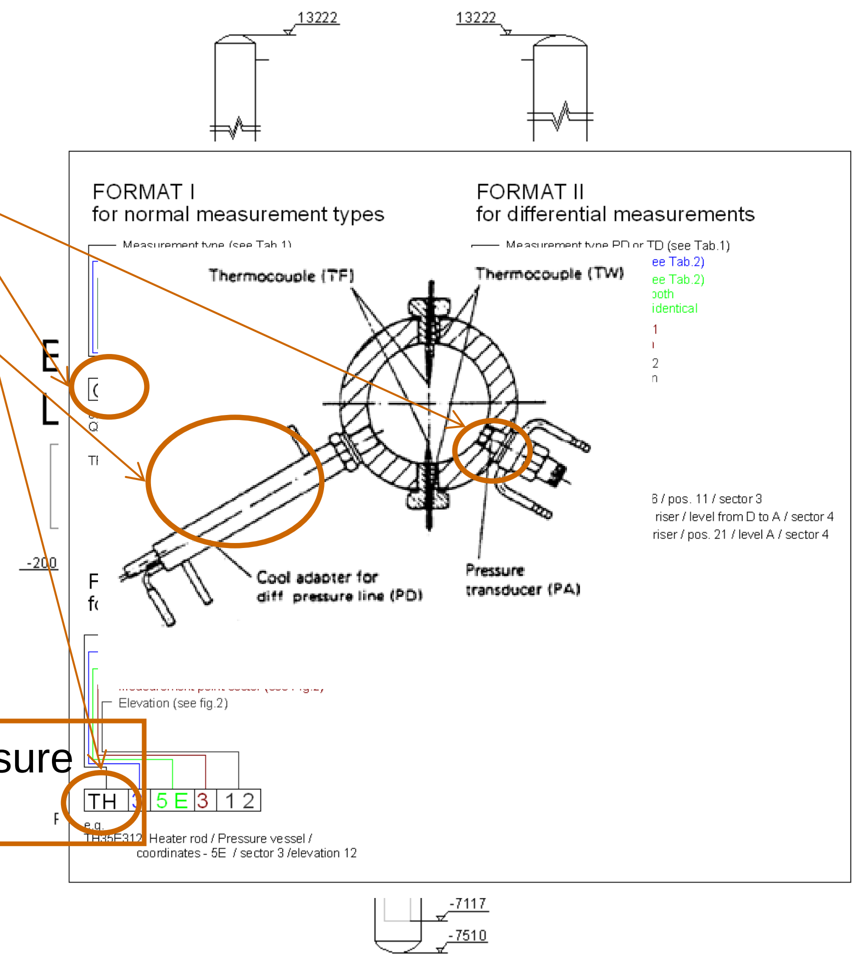
RDS-Facility sample



- Module number
- Module location
- Module description
- Geometrical description
- Lengths
- Areas
- Volumes
- Pressure losses
- Connection to other modules

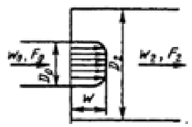
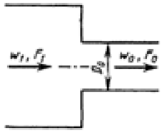
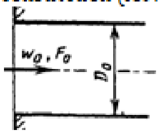
Pressure vessel				
Module number	307			
Description	Upper plenum part 2			Vertical parallelepiped
Parameters	**Evaluation**	**Value**		**Remarks**
Outer rod bundle diameter	D_{bundle}=10.75 mm	$1.075 \cdot 10^{-2}$	m	Draw. 13
Barrel inside diameter	D_{barrel}=198 mm	$1.98 \cdot 10^{-1}$	m	
Barrel outside pipe diameter	D_{out}=288 mm	$2.88 \cdot 10^{-1}$	m	Draw. 13
Number of rod bundle	64			Draw. 13
Length	L=2015+328=2343 mm	2.343	m	Draw. 13
Elevation change	2015 mm	2.015	m	
Flow area	S=S1-S2 $S1=\pi \cdot D_{barrel}^2/4=\pi \cdot 198^2/4$ =30790.7 mm² $S2=64 \cdot \pi \cdot D_{bundle}^2/4=64 \cdot \pi \cdot ^2$ =5808.8 mm² S=24981.9 mm²	$2.4982 \cdot 10^{-2}$	m²	Draw. 13
Inside surface area	**Heat exchange with downcomer** $S_{cylinder} = 2\pi \cdot R \cdot H$ $SA=\pi \cdot D_{barrel} L=\pi \cdot 198 \cdot 2343$ =1457428 mm²	1.457428	m²	Draw. 13
Outside surface area	**Outer surface of barrel** (part of module 301) $S_{cylinder} = 2\pi \cdot R \cdot H$ $SA=\pi \cdot D_{out} \cdot L=\pi \cdot 288 \cdot 2343$ =2119896 mm²	2.119896	m²	
Volume	24981.9·2343=58532592 mm³	**$5.8532592 \cdot 10^{-2}$**	m³	
Pressure loss coefficient	Expansion 307→308 k_{forw}=0.5 k_{rev}=1			Tab. 4.2

- Accurate description of the measurement system
  - Identify measured parameters
  - Identify measurement locations
  - Classify measurement insert types



To be considered in the pressure loses evaluation

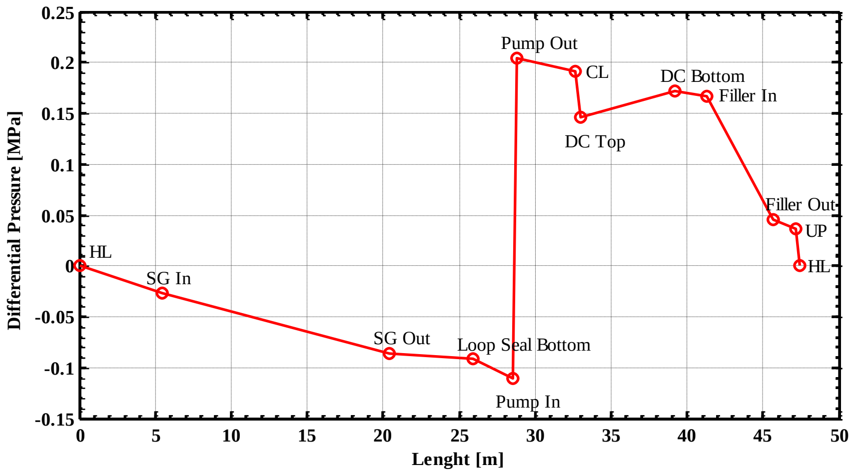
- Pressure losses evaluation in the "reference status"
  - Modules number
  - Geometrical configuration
  - Parameters values and adopted formulas
  - K-loss coefficient
  - References

N°	Element of system	Parameters	G_i kg/s	t °C	$\nu_i \cdot 10^{-7}$ m^2/s	ρ kg/m^3	w_i m/s	$Re \cdot 10^6$	Evaluation	k_{loc}	Remarks
306-307	Expansion (forward) 	$\frac{F_0}{F_2} = \frac{8115}{24982} = 0.325$	28	326	1.26	654	5.29	4.26	$k_{loc} = \left(1 - \frac{F_0}{F_2}\right)^2$	0.452	Ref. [2] Sec. 4-1 (p. 146, 158)
	Expansion (reverse) 	$\frac{F_0}{F_1} = \frac{8115}{24982} = 0.325$	28	326	1.26	654	5.29	4.26	$k_{loc} = 0.5\left(1 - \frac{F_0}{F_1}\right)^{\frac{3}{4}}$	0.371	Ref. [2] Sec. 4-9 (p. 151, 165)
307-308	Outlet from upper plenum: constriction (forward) 	$\frac{B}{D_r} = 0$ $\frac{\delta_1}{D_r} = 0$	0.4	294	1.26	740	0.6	0.16		0.5	Ref. [2] Sec. 3-1 (p. 122)
	Outlet from upper plenum: constriction (reverse)		0.4	294	1.26	740	0.6	0.16		1	Ref. [2] Sec. 11-1 p. 510

RDS-Test structure

- The RDS-Test is related with the specific test performed in the facility and consists of the following **standard** sections
  - Test objective
  - Facility Description
    - ✓ Test configuration
    - ✓ Difference between facility "reference status" and test configuration
  - Test description
    - ✓ Boundary condition
    - ✓ Initial condition
  - Thermal-hydraulic system behavior
    - ✓ Main events and major captured phenomena
    - ✓ Thermal-hydraulic parameter trends (more than 40 time trends)

PD Vs length

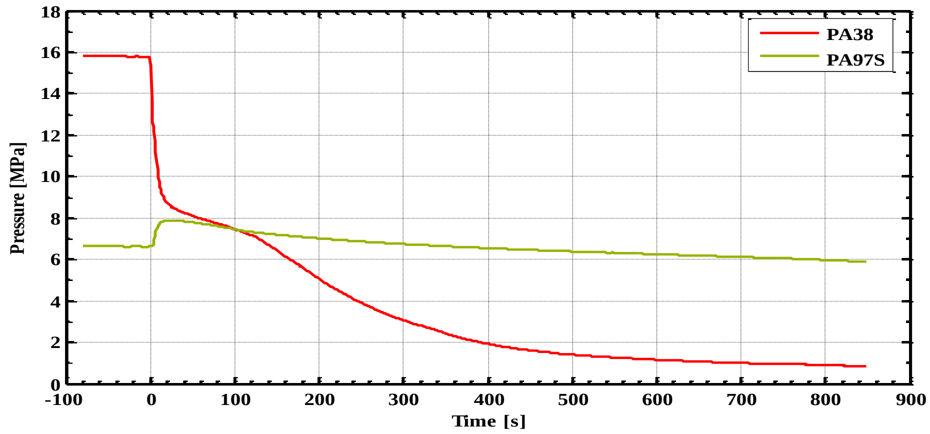


Sequence of Events

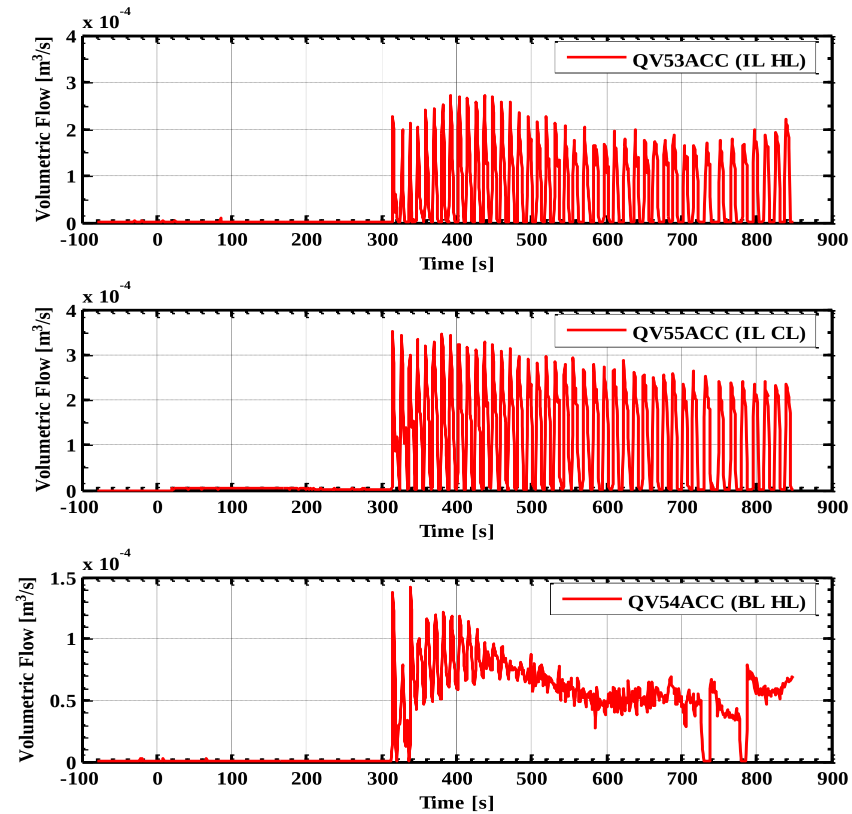
Events	Time (s)
Break valve starts to open, blowdown initiated	0
Primary system pressure equal 132 bar (core heating power and secondary system isolation and cooldown trip signals enabled)	1.8
Feedwater valves and steam valve at condenser inlet start to close Cooldown of secondary system initiated	2.0
Saturation in hot legs	2.5
Break valve fully open Core heating power decay starts	3.0
Feedwater valves and steam valve condenser inlet fully closed	3.5
Primary system pressure equal 117 bar (HPIS trip signal enabled)	5.4
Primary system pressure equal 110 bar (MCPs trip signal enabled)	6.7
Main coolant pumps coastdown initiated	8.0
Saturation in cold legs	15.8
PRZ surge line uncovers	21.0
Saturation in lower plenum	31.0
HPIS water injection initiated	41.0

Relevant ICs

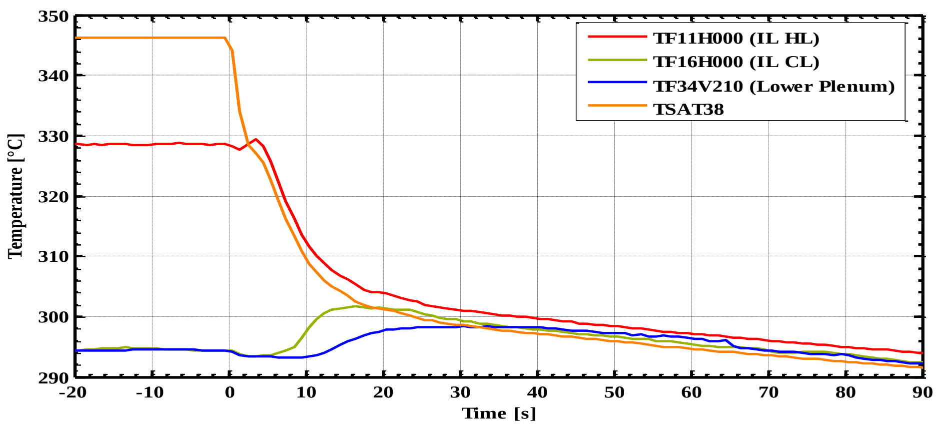
Parameters	Location	Value
Primary System:		
Mass Flow	Intact loop Broken loop	20.8 kg/s 6.7 kg/s
Pressure	Upper plenum	15.8 MPa
Fluid Temperature	Vessel outlet • Intact loop • Broken loop Vessel inlet • Intact loop • Broken loop	 327.9 °C 327.8 °C 296.2 °C 295.4 °C
Water Level	Pressurizer	c. 5.2 m
Temperature	Pressurizer	346 °C
Power	Core	5.20 MW
Water Volume	Accumulator • Intact loop • Broken loop	 246 l 76 l
Gas Volume	Accumulator • Intact loop • Broken loop	 34 l 18 l
Temperature	Accumulator • Intact loop • Broken loop	 c. 30 °C c. 30 °C
Mass Flow	MCP seal water injection Intact loop Broken loop	 0.01 kg/s 0.0087 kg/s
Temperature	MCP seal water injection	c. 30 °C
Water Temperature	HPIS	28 °C
Secondary System:		
Mass Flow	Steam generator Intact loop Broken loop	 2.0 kg/s 0.66 kg/s
Pressure	Steam dome Intact Loop Broken Loop	 6.62 MPa 6.62 MPa



Accumulators volumetric flows



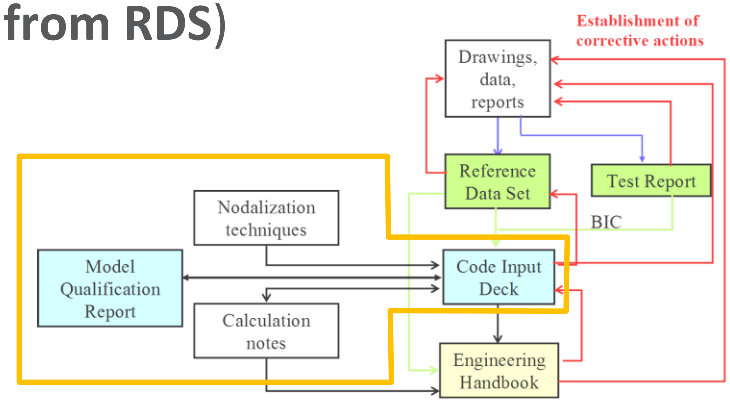
Feedwater volumetric flow (short time)



Core power (short time)

Input decks & Qualification Report

- Nodalization preparation: main choices of the model characteristics and preliminary code resources distribution (**data from RDS**)

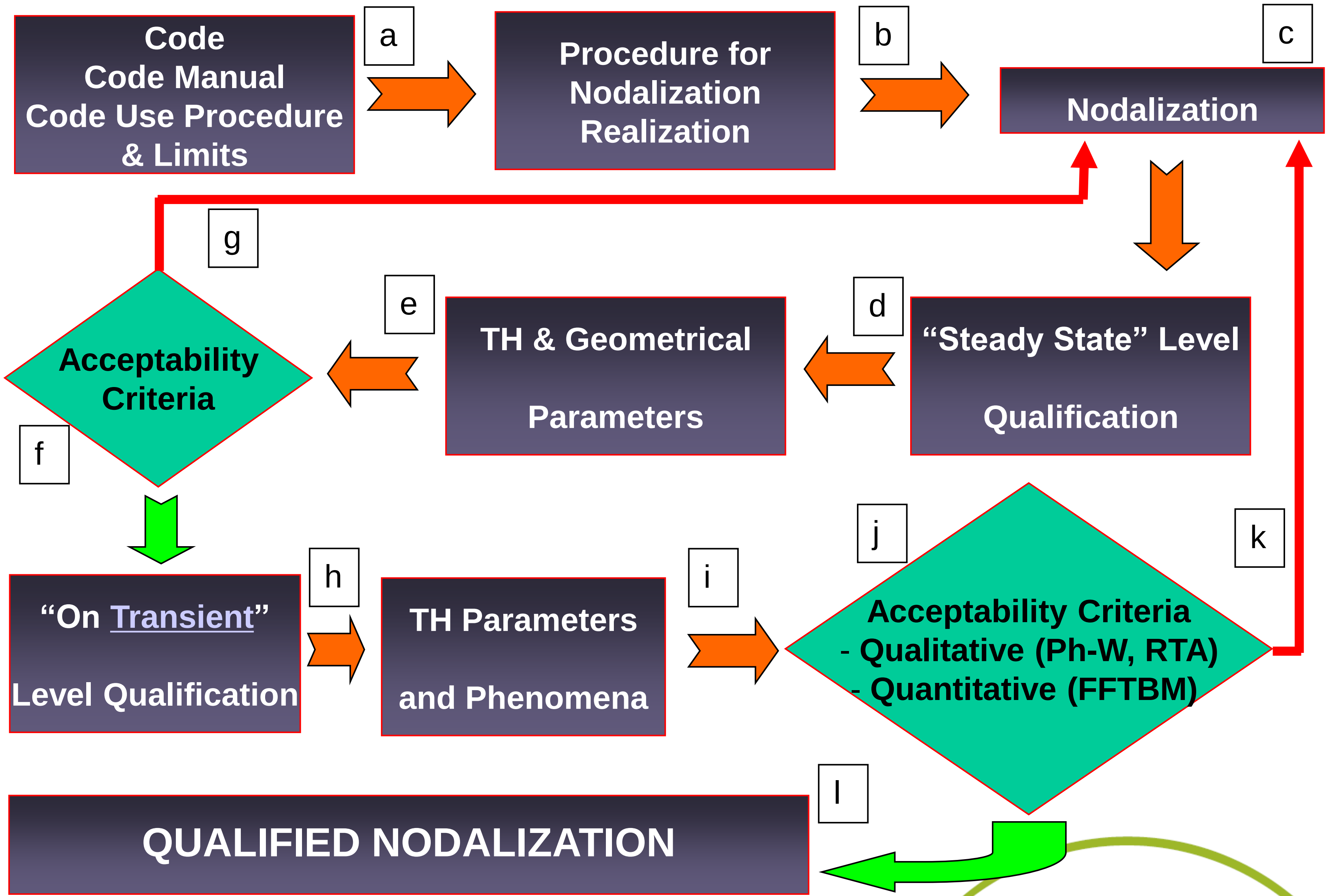


- Nodalization schematization according to the **pre-set nodalization strategies**

- Writing input following a **pre-set structure**
    - Specific care on avoiding typing error

- The Qualification Report (QR) collects the results of the qualification procedures of the code input and it is reviewed by the higher level analyst in the group

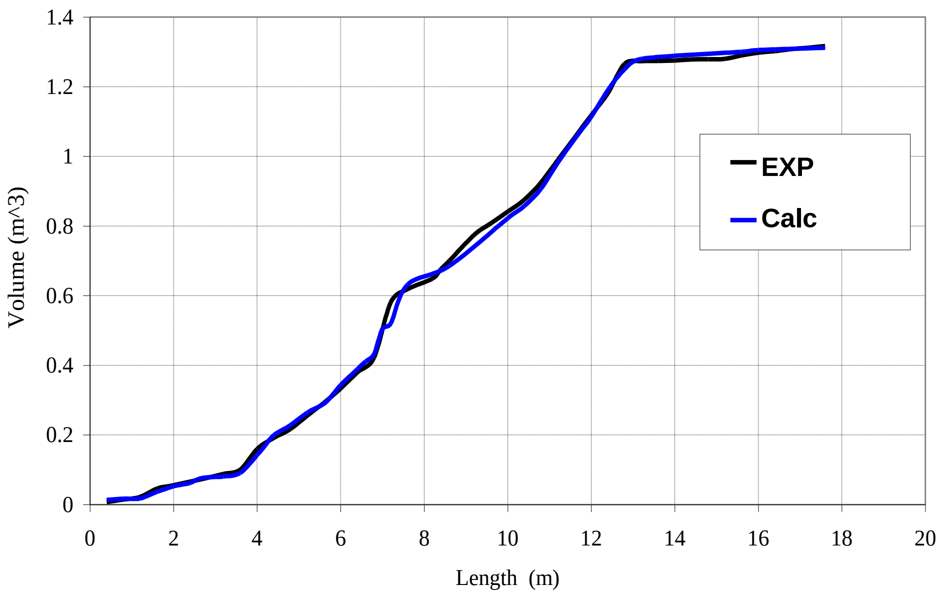
Qualification process



Geometrical Fidelity

	QUANTITY	ACCEPTABLE ERROR (°)
1	Primary circuit volume	1 %
2	Secondary circuit volume	2 %
3	Non-active structures heat transfer area (overall)	10 %
4	Active structures heat transfer area (overall)	0.1 %
5	Non-active structures heat transfer volume (overall)	14 %
6	Active structures heat transfer volume (overall)	0.2 %
7	Volume vs. height curve (i.e. "local" primary and secondary circuit volume)	10 %
8	Component relative elevation	0.01 m
9	Axial and radial power distribution (°°)	1 %
10	Flow area of components like valves, pumps orifices	1 %
11	Generic flow area	10 %

Acceptable errors
-Geometrical Values-



Example of
"Volumes vs Elevation" curve

Steady State Achievement

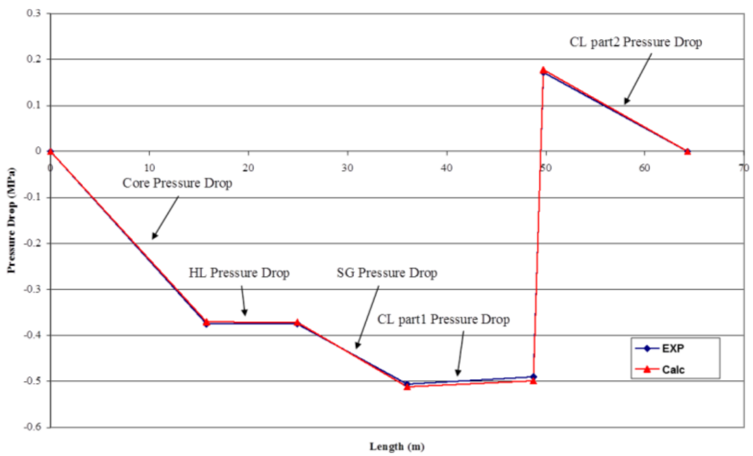
	QUANTITY	ACCEPTABLE ERROR (°)
12	Primary circuit power balance	2 %
13	Secondary circuit power balance	2 %
14	Absolute pressure (PRZ, SG, ACC)	0.1 %
15	Fluid temperature	0.5 % (**)
16	Rod surface temperature	10 K
17	Pump velocity	1 %
18	Heat losses	10 %
19	Local pressure drops	10 % (^)
20	Mass inventory in primary circuit	2 % (^^)
21	Mass inventory in secondary circuit	5 % (^^)
22	Flow rates (primary and secondary circuit)	2 %
23	Bypass mass flow rates	10 %
24	Pressurizer level (collapsed)	0.05 m
25	Secondary side or downcomer level	0.1 m (^^)

(°) The % error is defined as the ratio

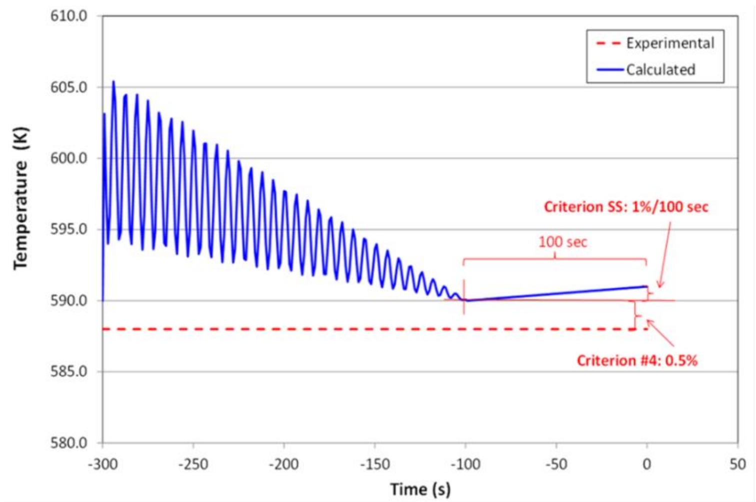
$$\frac{|\text{reference or measured value} - \text{calculated value}|}{|\text{reference or measured value}|}$$

The "dimensional error" is the numerator of the above expression

Acceptable errors – TH quantities



Example of "pressure drop vs length" curve



Inherent drift criterion check

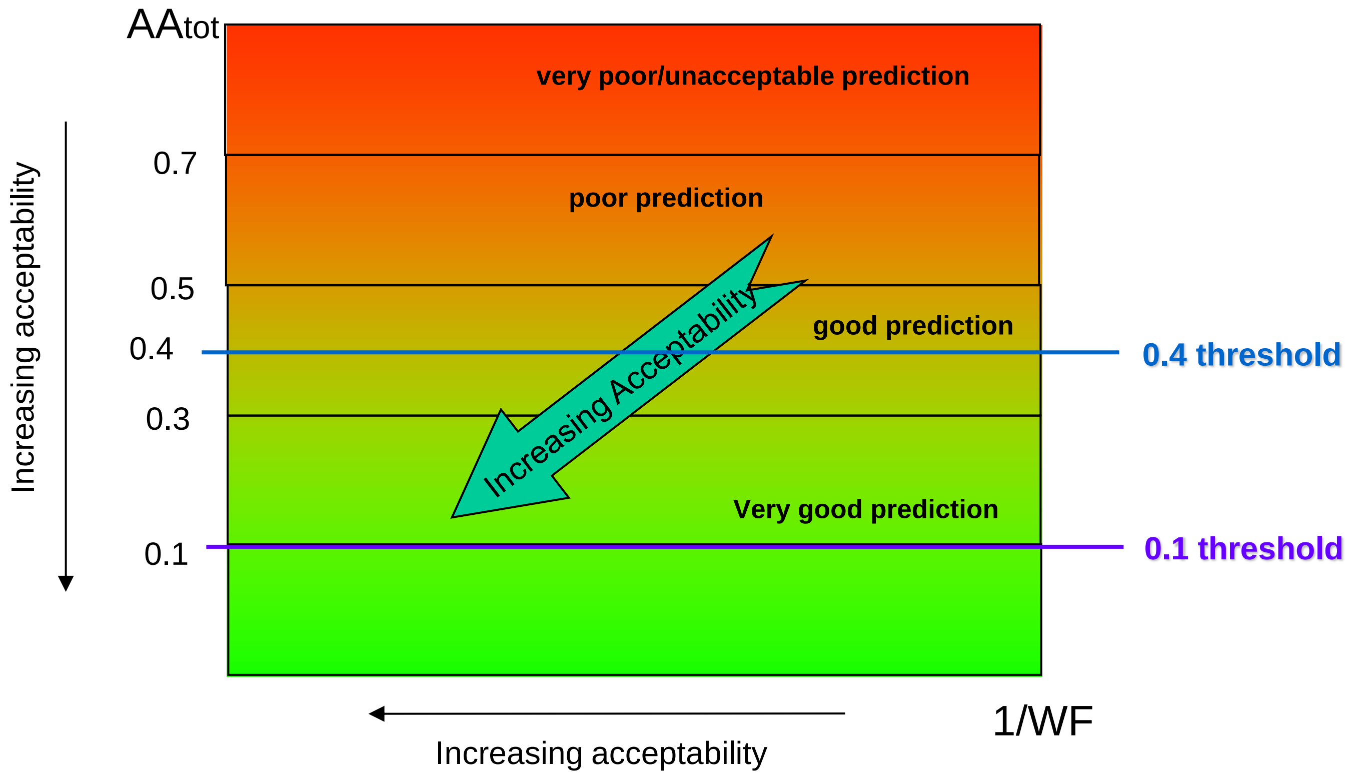
Qualitative Evaluation

- Use of CSNI phenomena
  - To evaluate the facility design, the experimental quality and the calculation performance
- Visual observation
  - Comparison between experimental and calculated time trends.
- Resulting time sequence of events
  - Calculated significant events and the timing of the events are compared with the experimental events
- Phenomenological Windows (Ph.W.)
  - PH.Ws should be distinguished
- Relevant Thermal-hydraulic Aspects (RTAs)
  - Inside each Ph.W., RTAs must be identified and characterized by numerical values of significant parameters

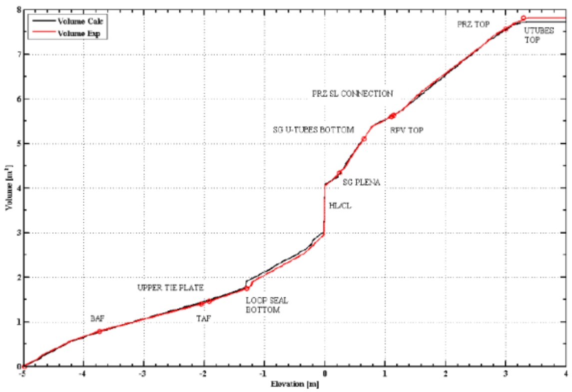
Quantitative Evaluation

$$AA = \frac{\sum_{n=0}^{2^m} \left|\tilde{\Delta} F(f_n)\right|}{\sum_{n=0}^{2^m} \left|\tilde{F}_{exp}(f_n)\right|}$$

$$WF = \frac{\sum_{n=0}^{2^m} \left|\tilde{\Delta} F(f_n)\right| \cdot f_n}{\sum_{n=0}^{2^m} \left|\tilde{F}_{exp}(f_n)\right|}$$



Geometrical fidelity and Steady-State achievement



"Volume vs Elevation" curve

	N°	QUANTITY	UNIT	ACCEPT ERROR	EXP DATA		CALC DATA	ERR.
					Y_r	ERROR		
(A) Nodalization Development	1	Primary circuit volume	m^3	1%	7.81	0.00	7.750	0.77%
	2	Secondary circuit volume		2%	6.65	0.00	6.624	0.39%
	3	Non Active structures heat transfer area (overall)	m^2	10%	NA	NA	---	---
	4	Core heat structure transfer surface area		0.10%	73.259	0.02	73.250	0.00%
	5	SG U-tubes heat structure external surface area (without tube sheet)			335	2.00	336.944	0.00%
	6	Maximum of the axial power distribution for the average rod in average channel (zone2)	KW/m	1.0%	26.95	2.05	25.165	0.00%
	7	Maximum of the axial power distribution for the hot rod in hot channel (zone4)		2.0%	40.10	3.05	40.689	0.00%

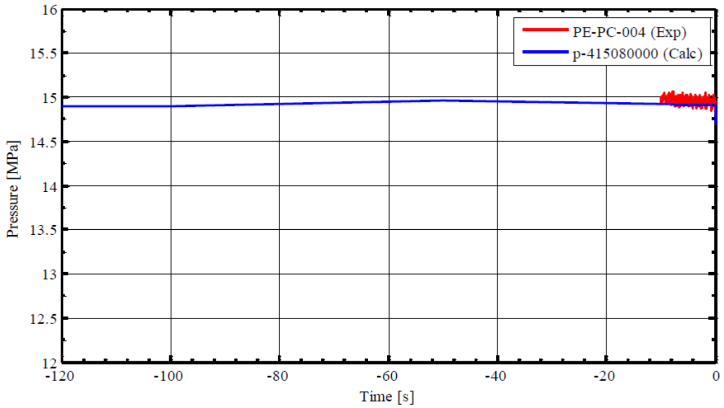
Geometrical fidelity check

POSITION ALONG THE LOOP		R5 COMP.	R5 [MPa]	EXP [MPa]
Hot leg inlet	HL IN	100010000	14.928	14.940
Hot leg outlet	HL OUT	107030000	14.922	14.937
Steam generator inlet plenum	SG IN	110010000	14.922	Na
U-tube top	UT TOP	112070000	14.901	Na
Steam generator outlet plenum	SG OUT	114010000	14.913	Na
Bottom of loop seal	LOOP SEAL	116050000	14.920	14.899
Pump inlet	PUMP IN	118(9)020000	14.917	NA
Pump outlet	PUMP OUT	124(5)020000	14.988	NA
Cold leg in	CL IN	126010000	14.973	14.972
Cold leg out	CL OUT	136010000	14.967	14.966
Lower plenum (0.15m from vessel bottom)	LP	220010000	15.002	NA
Core inlet	CORE IN	232010000	14.980	NA
Core outlet	CORE OUT	245010000	14.967	NA

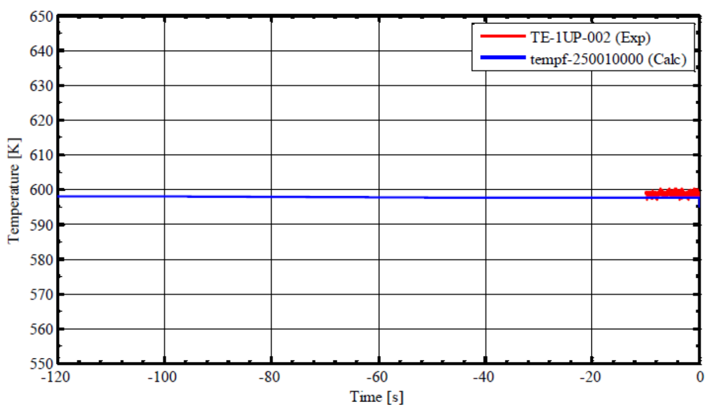
Pressure drops distribution

Geometrical fidelity and Steady-State achievement

Inherent drift criterion check



PS pressure

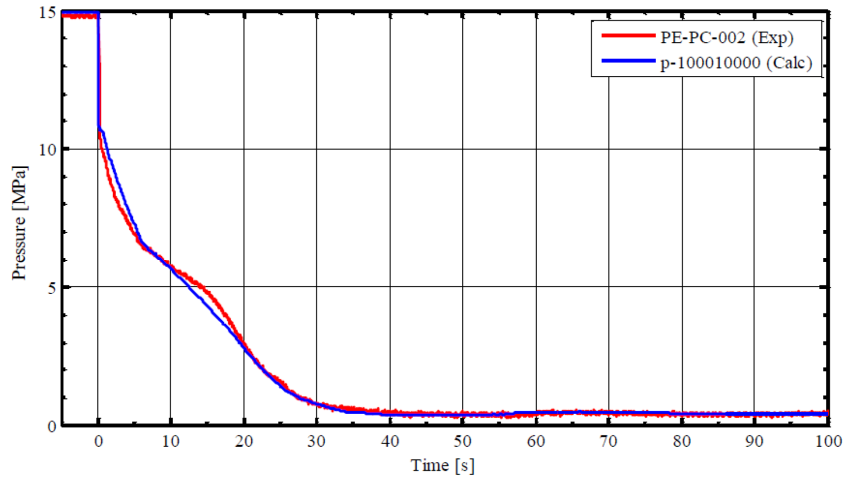


Core Outlet temperature

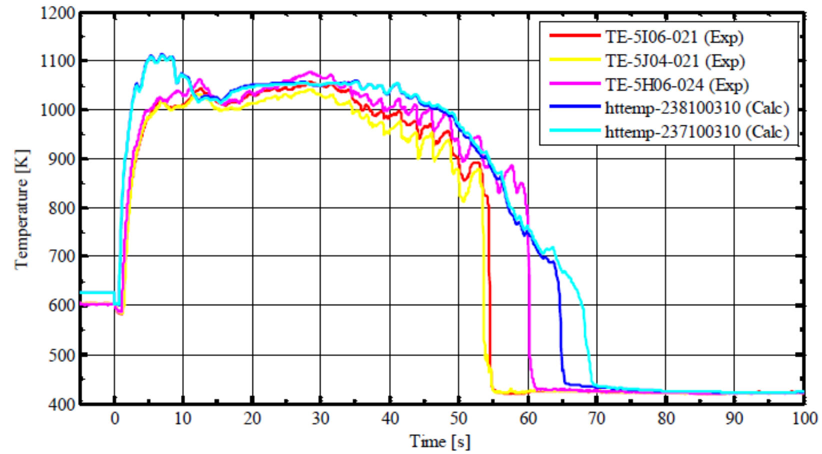
SS values achievement check

	Nº	QUANTITY	UNIT	ACCEPT ERROR	EXP DATA		CALC DATA	ERR.
					Y_r	ERROR		
(B) Nodalization qualification at Steady State	1	Primary circuit power balance	MW	2.0%	36.00	1.20	36.00	0.00%
	2	Secondary circuit power balance			NA	NA	---	---
	3	Primary system hot leg pressure	MPa	0.10%	14.94	0.10	14.928	0.00%
	4	PRZ pressure			14.95	0.10	14.911	0.00%
	5	SG exit pressure			5.85	0.06	5.838	0.00%
	6	Accumulator A pressure			4.29	0.06	4.290	0.00%
	7	Intact loop HL temperature (near vessel)	K	0.50%	589.50	4.20	592.00	0.00%
	8	Intact loop CL temperature (near vessel)			556.40	4.30	557.10	0.00%
	9	Reactor vessel downcomer temperature			555.00	4.00	557.50	0.00%
	10	Broken loop HL temperature (near vessel)			561.90	4.30	561.50	0.00%
	11	Broken loop CL temperature (near vessel)			554.30	4.20	557.00	0.00%
	12	Intact loop pressurizer temperature			615.60	0.70	614.90	0.00%
	13	Pump velocity	rpm	1.0%	1250.00	70.00	1262.70	0.00%
	14	Heat losses	-	NA	NA	NA	---	---
	15	RPV pressure loss		10.0%	26.00	1.90	28.00	0.36%
	16	Core pressure loss			NA	NA	---	---
	17	PS total loop pressure loss			75.00	20.30	52.00	4.94%
	18	Total mass inventory in PS	Kg	2.0%	NA	NA	5900.0	-
	20	Total mass inventory in SG		5.0%	NA	NA	---	---
	21	PS total loop coolant mass flow	Kg/s	2.0%	192.40	7.80	191.90	0.00%
	22	SG feedwater mass flow			19.10	0.40	19.51	0.05%
	23	Core coolant mass flow rate			NA	NA	---	---
	24	Core bypass mass flow (LP-UP)		10%	NA	19.5	---	---
	25	Pressurizer level (collapsed level)		0.05	1.14	0.03	1.14	0.0000
	26	Secondary side or downcomer level		0.1	NA	NA	---	---

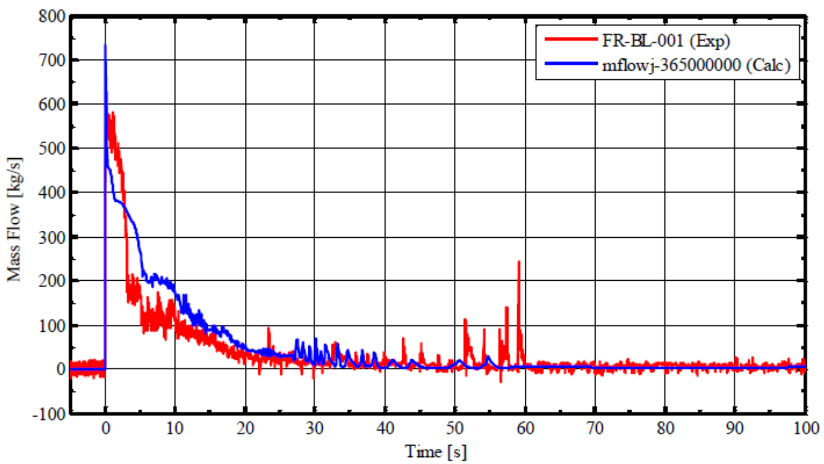
Qualitative Evaluation



Intact HL pressure



PCT



Break mass flow rate

EVENT	Time (s)		
	EXP	ERR	CALC
Experiment L2-5 initiated	0.0	-	0.0
Subcooled blowdown ended	0.043	±0.01	0.032
Reactor scrammed	0.24	±0.01	0.24
Cladding temperature initially deviated from saturation	0.91	±0.2	0.3
Primary coolant pumps tripped	0.94	±0.01	0.94
Subcooled break flow ended (cold leg)	3.4	±0.5	0.1
Partial rewet initiated	12.1	±1.0	8.2
Pressurizer emptied	15.4	±1.0	15.3
Accumulator A injection initiated	16.8	±0.1	15.1
Partial rewet ended	22.7	±1.0	15.1
HPIS injection initiated	23.9	±0.02	23.9
Maximum cladding temperature reached	28.47	±0.02	5.2
LPIS injection initiated	37.32	±0.02	37.32
Accumulator emptied	49.6	±0.1	52.0
Core cladding quenched	65.0	±2	65.5
BST maximum pressure reached	72.5	±1.0	-
LPIS injection terminated	107.1[III]	±0.4	-

Time sequence of events

Qualitative Evaluation

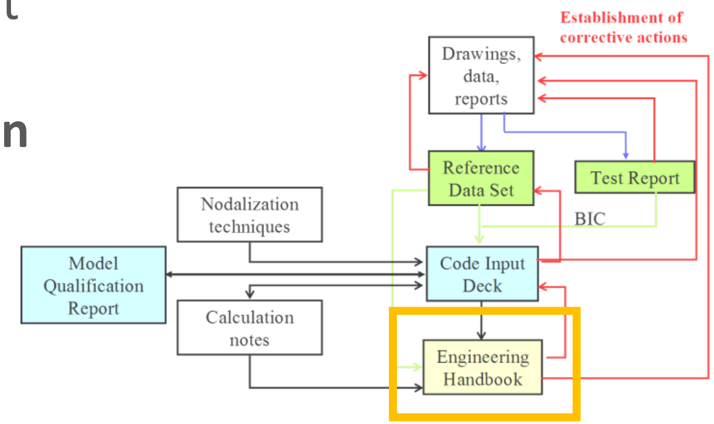
RTA	RTA Parameter	UNIT	EXP	R5	Judg. R5
	RTA: Critical Flow				
TSE	Time of maximum break mass flow rate	s	0.1	0.1	E
	Time of two-phase flow at the break	s	0.043	0.032	R
SVP	Maximum break mass flow rate	kg/s	869	1073	R
IPA	Integral break mass flow at:				
	- two-phase flow at the break occurrence	kg	243	53	R
	- dryout occurrence	kg	595	435	R
	- PRZ emptying time	kg	3638	4719	R
	- ACC injection time	kg	3790	4693	R
	- minimum PS mass inventory occurrence	kg	4003	5332	R
	- HPIS injection time	kg	4114	5332	R
	- PCT time	kg	4238	2658	M
	- LPIS injection time	kg	4408	5684	R
	- core quenching occurrence	kg	4804	5927	R
	- end of calculation (t=100 s.)	kg	5280	6134	R
	RTA: Pressurizer behavior				
TSE	Time of emptying	s	15.4	15.3	E
	Time of PRZ pressure equal to PS pressure	s	38.0	40.0	E
SVP	PRZ pressure at:				
	- two-phase flow at the break occurrence	MPa	14.77	14.87	E
	- dryout occurrence	MPa	14.55	14.4	E
	- PRZ emptying time	MPa	8.85	7.78	R
	- ACC injection time	MPa	7.17	7.96	R
	- HPIS injection time	MPa	2.88	2.79	E
	- PCT time	MPa	1.62	12.8	M
	- LPIS injection time	MPa	0.73	0.56	R
	- core quenching occurrence	MPa	0.67	0.48	R
	RTA: Primary System behaviour				
TSE	Time of UP in saturation condition	s	0.18	0.2	E
	Time of PS pressure equal to SS pressure	s	10.1	9.9	E
SVP	PS pressure at:				
	- two-phase flow at the break occurrence	MPa	10.15	10.2	E
	- dryout occurrence	MPa	9.69	10.6	M[3]
	- PS equal to SS pressure occurrence	MPa	5.71	5.73	E
	- PRZ emptying time	MPa	4.73	4.24	R
	- ACC injection time	MPa	4.25	4.3	E
	- minimum PS mass inventory occurrence	MPa	2.56	1.77	R
	- HPIS injection time	MPa	1.76	1.77	E
	- PCT time	MPa	0.91	7.2	M
	- LPIS injection time	MPa	0.5	0.45	E
	- core quenching occurrence	MPa	0.47	0.47	E
	RTA: Core power behaviour				
TSE	Time of dryout	s	0.91	0.6	R
	Time of peak cladding temperature (PCT)	s	28.47	5.2	R
	Time of core quenching	s	65.1	65.5	E
SVP	Peak cladding temperature	°C	1078	1114	E

RTA	RTA Parameter	UNIT	EXP	R5	Judg. R5
	RTA: Accumulator Behaviour				
TSE	ACC injection time	s	16.8	15.1	R
	Time of ACC emptied	s	49.6	52.0	E
SVP	ACC pressure at core quenching occurrence	MPa	0.98	0.63	R
IPA	Integral ACC mass flow at:				
	- minimum PS mass inventory occurrence	kg	123.9	312.0	R
	- PCT time	kg	516.6	0.0	M
	- core quenching occurrence	kg	1504	1570	E
	- end of calculation (t=100 s.)	kg	1506	1584	E
	RTA: HPIS Behaviour				
TSE	HPIS injection time	s	23.9	23.7	-
SVP	HPIS mass flow rate at:				
	- core quenching occurrence	kg/s	0.74	0.79	E
	- end of calculation (t=100 s.)	kg/s	0.75	0.79	E
IPA	Integral HPIS mass flow at:				
	- core quenching occurrence	kg	33.3	30.24	E
	- end of calculation (t=100 s.)	kg	59.5	60.36	E
	RTA: LPIS Behaviour				
TSE	LPIS injection time	s	37.32	37.1	-
SVP	LPIS mass flow rate at:				
	- core quenching occurrence	kg/s	5.67	5.71	E
	- end of calculation (t=100 s.)	kg/s	7.21	6.1	R
IPA	Integral HPIS mass flow at:				
	- core quenching occurrence	kg	146.8	173.0	R
	- end of calculation (t=100 s.)	kg	376.66	310.0	R
	RTA: Secondary System behavior				
SVP	SS pressure at:				
	- two-phase flow at the break occurrence	MPa	5.84	5.84	E
	- dryout occurrence	MPa	5.84	5.85	E
	- ACC injection time	MPa	5.68	5.69	E
	- HPIS injection time	MPa	5.68	5.67	E
	- PCT time	MPa	5.69	5.81	R
	- LPIS injection time	MPa	5.64	5.65	E
	- core quenching occurrence	MPa	5.59	5.60	E
	RTA: Mass Distribution in Primary System (*)				
TSE	Time of minimum PS mass inventory	s	21	23.7	E
SVP	Minimum PS mass inventory	kg	2020.8	928.6	R
	PS mass inventory at:				
	- two-phase flow at the break occurrence	kg	5656.3	5926.4	R
	- dryout occurrence	kg	5326.5	5522.5	R
	- ACC injection time	kg	2143.3	1258.6	R
	- HPIS injection time	kg	2056.1	928.6	R
	- PCT time	kg	2183.2	3294.4	M
	- LPIS injection time	kg	2480.7	1200.0	R
	- core quenching occurrence	kg	2780.4	1784.6	R

Quantitative Evaluation

	PARAMETER	AA	WF
1	Intact loop hot leg pressure	0.076	0.203
2	Pressurizer pressure	0.051	0.108
3	Accumulator pressure	0.103	0.093
4	Secondary side steam dome pressure	0.013	0.379
5	Fluid temperature at fuel bundle bottom	0.039	0.269
6	Fluid temperature at fluid bundle top	0.135	0.207
7	Fluid temperature at core inlet	0.063	0.271
8	Fluid temperature at core outlet	0.082	0.288
9	Fluid temperature at BL CL nozzle	0.069	0.275
10	Fluid temperature at HL IL nozzle	0.239	0.180
11	Fluid temperature at SG IL in	0.122	0.192
12	Fluid temperature at SG IL out	0.109	0.244
13	Fluid Temperature at BL HL nozzle	0.256	0.179
14	Pressurizer level	0.040	0.214
15	Accumulator level	0.599	0.083
16	Cladding temperature, zone 1, bottom level	0.234	0.306
17	Cladding temperature, zone 4, 2/3 level (PCT)	0.315	0.223
18	Cladding temperature, zone 1, 2/3 level	0.635	0.217
19	Cladding temperature, zone 2, top level	0.228	0.270
20	Cladding temperature, zone 4, top level	0.297	0.205
21	Mass flow at cold leg break	0.443	0.274
22	Mass flow at hot leg break	0.702	0.232
	TOTAL	**0.178**	**0.255**

- EH contains the **technical rationale** for the input provides the **engineering justifications** of the adopted assumptions and allows the **verification** of the model's input file
    - Methods and assumptions used to convert the RDS-Facility and RDS-Test information into the code input data
    - Nodalization schemes of the components
    - The calculation notes (traceability of the information)
    - Adequate description and explanation of adopted modeling assumptions



- By the EH, information and knowledge of the input files can be transferred easier in time and to different groups
- Final step of the process to set up a **qualified database**, IAEA states that a: "documents contains a full description of how the database has been converted into an input data deck for a specific computer code", (IAEA, SRS n°23) should be available

- Relap5-3D © nodalization description

TH components

General Zone	Zone	Name	Number	Type	Document Section
Primary Side					
Intact Loop	IL HL	ILHL-1	100	BRANCH	2.2.3.1
		ILHL-2	105	BRANCH	
		ILHL-3	110	PIPE	
	IL SG	ILSG-IN	115	BRANCH	2.2.3.2
		IL-UT	120	PIPE	
		ILSG-OUT	125	BRANCH	
	IL LOOP SEAL	ILLS-1	130	PIPE	2.2.3.3
	IL PUMP	IL-PUMP	140	PUMP	2.2.3.4
	IL CL	ILCL-1	150	PIPE	2.2.3.5
		ILCL-2	160	BRANCH	
		ILCL-3	170	BRANCH	
Broken Loop	BL HL	BLHL-1	200	BRANCH	2.2.5.1
		BLHL-2	205	BRANCH	
		BLHL-3	210	PIPE	
	BL SG	BLSG-IN	215	BRANCH	2.2.5.2
		BL-UT	220	PIPE	
		BLSG-OUT	225	BRANCH	
	BL LOOP SEAL	BLLS-1	230	PIPE	2.2.5.3
	BL PUMP	BL-PUMP	240	PUMP	2.2.5.4
	BL CL	BLCL-1	250	SNGLVOL	
		BL-ROTOR	251	VALVE	2.2.5.5
		BLCL-2	255	PIPE	
		BLCL2			
		BLCL-3			
		BLCL-4			
		BLCL-5			

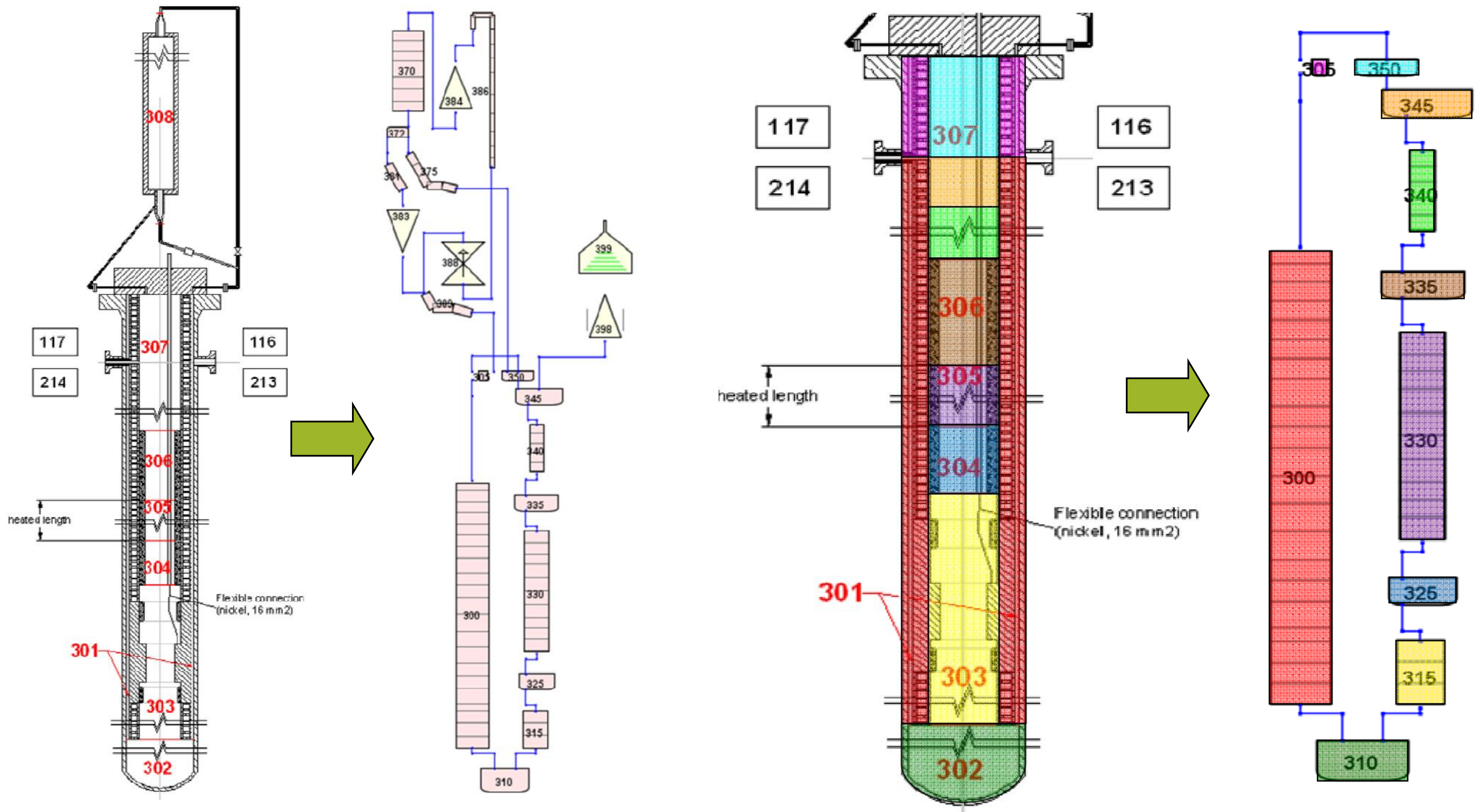
Link to the document section (component by component)

User friendly

Control system components

General Location	Location	Control Variable Number	Control variable Name	Experimental Channel Measurement Correspondence	Description	Reference
IL LEVEL	Pressurizer	4209	PRZ_L1	-		5.1.1.1
		4309	PRZ_L	-		
	IL SG inlet global	1159	ILSGIN-L	CL90AB+1.19m-0.055m		5.1.1.1
	IL U-tubes ascending side	1189	ILUTAS-L	CL90BP+2.995m		
		1199	ILUTAS-L			
	IL U-tubes descending side	1219	ILUTDS-L	-		
		1229	ILUTDS-L	CL92BP+2.955m		
	IL SG outlet Global level	1259	ILSGOT-L	-		
				CL93AB+1.19m-0.055m		
	IL Loop Seal	1299	ILLS-1	-		
		1309	ILLS-2	-		
		1319	ILLS-L	CL1792X3		
BL LEVEL	BL SG Inlet global	2159	BLSGIN-L	CL80+1.045m -0.02m		5.1.1.2
	BL U-tubes ascending side	2189	BLUTAS-L	-		
		2199	BLUTAS-L	CL80BP+2.95m		
	IL U-tubes descending side	2219	ILUTDS-L	-		
		2229	ILUTDS-L	CL82BP+2.95m		
	BL SG outlet Global	2259	BLSGOT-L	CL82AB+0.045m-0.02m		
	BL Loop Seal	2309	BLLS-1			
		2319	BLLS-L	CL2782x2		
RPV LEVEL	RPV Core Level	3295	RPVCOR-1	-		5.1.1.3
		3309	RPVCOR-L	-		
	RPV Riser Level	3159	RPVRSR-1	-		
		3409	RPVRSR-3	-		
		3459	RPVRSR-L	CL3RYA	Approximately	
	RPV Downcomer Level	3009	RPVDC-1	-		
		3019	RPVDC-2	-		
		3029	RPVDC-3	-		
		3059	RPVDC-L	CL3DYB+0.17m		
IL SG	IL SG Downcomer level	6009	ILSGDC-1	-		5.1.1.4
		6359	ILSGDC-L	-		

- Cross link between (RDS) Drawings and Nodalization



- Conversion from RDS data (code-independent) to input data (code-dependent)

5 LOGIC AND CONTROL SYSTEM

5.1 Control Variables

5.1.1 Level

Table 5-1 summarized the level control variable that are present in the RELAP5 input. In the present *Table 5-1*, the control variable related to a particular part of the ITF are grouped together (the same approach has been used in the input file). For each control variable the location of the level measurement is identified (second column), the correspondence with the ITF measurement channel is given in the fifth column. For each control variable the last column of *Table 5-1* provide the reference to the section that the described the specific control variable.

5.1.1.1 Pressurizer level

The pressurizer level is calculated summing the liquid void fraction in each cells multiplied by the elevation change of each cell for which the variable *"voidf"* is calculated (*Equation 2-1* and *Equation 2-2*). Two control variable are used to calculated the actual collapsed level of the pressurizer: 4209 and 4309.

Control variable 4209:

$$PRZ\_L1 = 0.395 \cdot voidf\ 420\_01 + 0.395 \cdot voidf\ 425\_01 + 0.585 \cdot voidf\ 430\_01 + 0.5 \cdot voidf\ 430\_02 + 0.5 \cdot voidf\ 430\_03 + 0.5 \cdot voidf\ 430\_04 + 0.5 \cdot voidf\ 430\_05 + 0.345 \cdot voidf\ 430\_06 \quad \text{Equation 5-1}$$

Control variable 4309:

$$PRZ\_L = 0.336 \cdot voidf\ 430\_07 + 0.5 \cdot voidf\ 430\_08 + 0.5 \cdot voidf\ 430\_09 + 0.6 \cdot voidf\ 430\_10 + 0.6 \cdot voidf\ 430\_11 + 0.705 \cdot voidf\ 430\_12 + 0.705\ voidf\ 440\_01 + 1.0 \cdot cntrlvar\ 4209 \quad \text{Equation 5-2}$$

5.1.1.1 Intact Loop Level

Intact Loop Steam Generator Inlet Global Level (CNTRLVAR 1159)

Control variable 1159 calculates the collapsed liquid level in the inlet pipe of the intact loop steam generator, it corresponds to measurement channel "CL90AB" +1.19 m – 0.055 m. The collapsed liquid level is calculated summing the liquid void fraction in each cells multiplied by the elevation change of each cell for which the variable *"voidf"* is calculated (*Equation 5-3*). The initial value for the variable is 2.9 m.

Control variable 1159:

$$ILSGIN\_L = 0.83 + 0.458 \cdot voidf\ 110\_08 + 0.4 \cdot voidf\ 110\_09 + 0.4 \cdot voidf\ 110\_10 + 0.3 \cdot voidf\ 110\_11 + 0.2 \cdot voidf\ 110\_12 + 0.312 \cdot voidf\ 115\_01 \quad \text{Equation 5-3}$$

2.2.1.2 Lower Plenum

HYDRO COMPONENTS

- **Rationale**
- **User choices**
- **Models (flag)**
  - BRANCH 310 (HEMISPHERICAL HEAD)

    Default
  - PIPE 315 (CORE INLET)

    Default
- **Geometry Data**
  - BRANCH 310 (HEMISPHERICAL HEAD)

Component 310 models the bottom of the reactor pressure vessel, it consists of the cylindrical part and the hemispherical bottom. The internal diameter of the core vessel is 0.312 m, the internal radius of the hemispherical bottom is 0.373 m and the average flow area of the component is $7.0954 \cdot 10^{-2}$ m^2 (*Equation 2-7*). See *Table 2-2* for detailed geometry summary.

$$A_{310} = V_{M302} / L_{M302} = 0.026465 / 0.373 = 7.0954 \cdot 10^{-2}\ m^2 \quad \text{Equation 2-4}$$

- PIPE 315 (CORE INLET)

Component 315 models the entrance region to the core barrel. It is subdivided in 3 cells, the total length is 1.006 m and the average flow area is $2.5651 \cdot 10^{-2}$ m^2 (*Equation 2-5*). The component PIPE 315 corresponds to module 303. See *Table 2-2* for detailed geometry summary.

$$A_{315} = V_{M303} / L_{M303} = 0.025805 / 1.006 = 2.5651 \cdot 10^{-2}\ m^2 \quad \text{Equation 2-5}$$

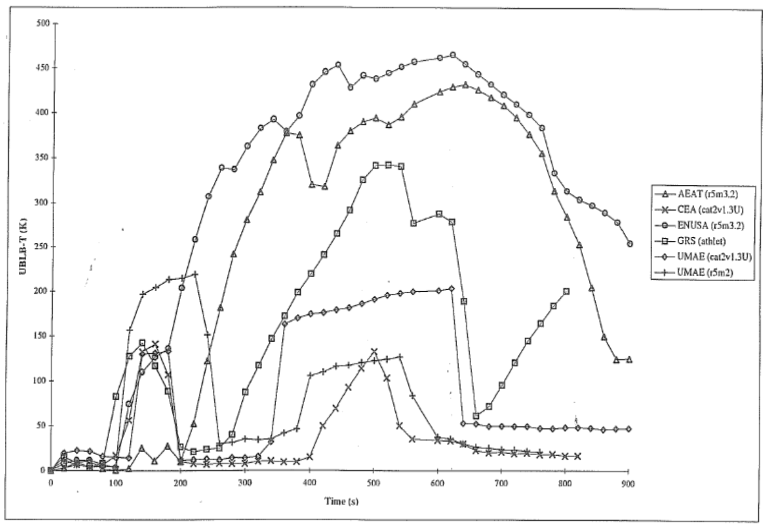
- Computational tools in BEPU analyses includes:
  - BE Computer codes
  - Nodalization
    - ✓ Procedure for development and qualification
    - ✓ Procedure to address the “code-user-effect”
  - Uncertainty methodology
    - ✓ Procedure for the validation of the methodology
    - ✓ Procedure to address the “uncertainty-method-user-effect”
  - Platform for coupling and interfacing different codes

- The SCCRED is applicable in the V&V of all the BEPU computational tools

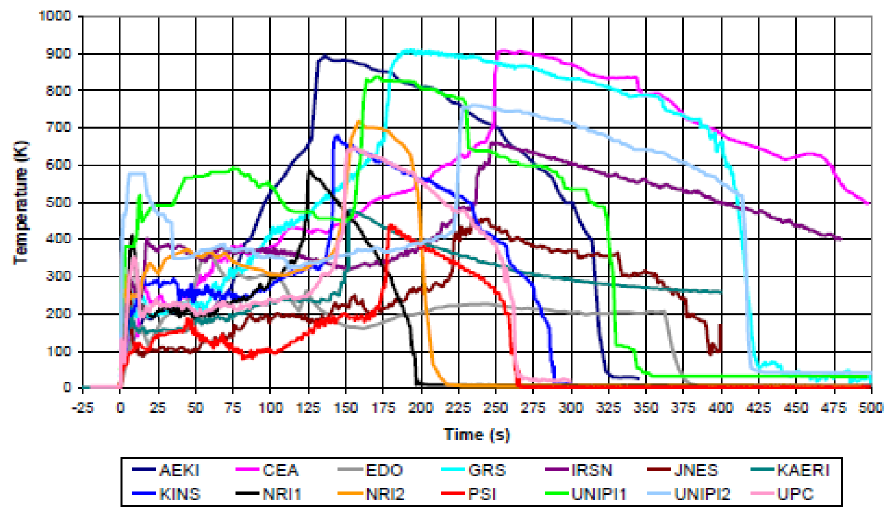
Relevant experimental data ⟺ **Qualified computational tool**

- A key feature of BEPU methodologies is to adopt a **validated UM**
  - Improvements and validation of the present UM are necessary
    - ✓ UMS, BEMUSE → PREMIUM project focused on the “uncertainty-method-user-effect”

- Spread of uncertainty Bands for cladding temperature
  - Similar uncertainty methods (propagation of input uncertainty parameters) and in some cases the same thermal-hydraulic code

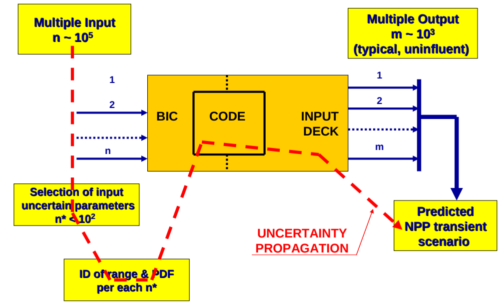


UMS (1995)

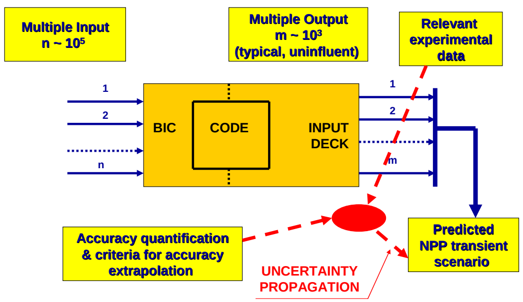


BEMUSE (2009)

- The Propagation of Code Input Errors
  - Need to Implement V&V Concepts to characterize:
    - ✓ Input Uncertainty Parameters
    - ✓ Ranges of variation of Input Uncertainty parameters
    - ✓ Probability Distribution Functions



- The Propagation of Code Output Errors
  - V&V concepts are (inherently) part of the approach

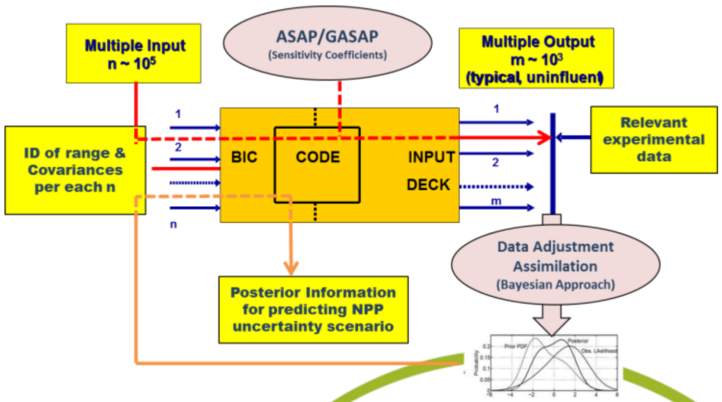


Relevant experimental data ⟺ Qualified code calculation

Accuracy Database ⟹ Uncertainty Database
(applicable to qualified calculations)

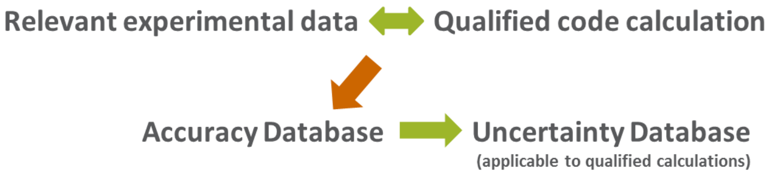
- Predictive Modeling Methodology
  - V&V concepts are (inherently) part of the approach

Relevant experimental data ⟺ Qualfied compuational tool



- SCCRED methodology: needed to the V&V process of UM based on the “propagation of output errors”

- CIAU and CIAU-TN bases:
  - Use of systematic **qualification** process
  - The ‘NPP status approach’ to identify ‘phase spaces’ to which associate single uncertainty values for each of the selected – output – quantities
  - The ‘separation and recombination of time and quantity ‘error’
  - ‘error filling process’ and ‘error extraction process’
    - ✓ accuracy database →uncertainty database for the uncertainty evaluation of the **qualified** NPP code calculation.



- Should be a mandatory requirement also for
  - predictive modeling methodology
  - “propagation of input uncertainties” methods to validate the selection of
    - ✓ Input uncertainty parameters
    - ✓ Associated ranges of variations and the PDFs

Reduce the uncertainty-method-user effect

Conclusions

- Main outcomes deriving from the application of the SCCRED methodology:
  - Demonstration of the code qualification level
  - Reduction of code-user-effect
    - ✓ Code user guidelines
    - ✓ User discipline & QA procedure in development of the nodalization, analysis of the results and documentation
  - Traceability of user choice and derivation of input data
  - Database of experimental data and associated code calculations
  - derivation and availability of an accuracy database
  - Demonstration of the qualification level of the accuracy database;
  - Reduction of the uncertainty-method-user effect
  - Application of the desired level of quality assurance when a BEPU approach is applied in licensing framework
  - Possibility to perform a V&V of BEPU applications(BE computational codes and associated uncertainty methodologies)