UNIVERSITÀ DI PISA

Gruppo Ricerca Nucleare S. Piero a Grado

Recent Applications of RELAP5-3D at GRNSPG

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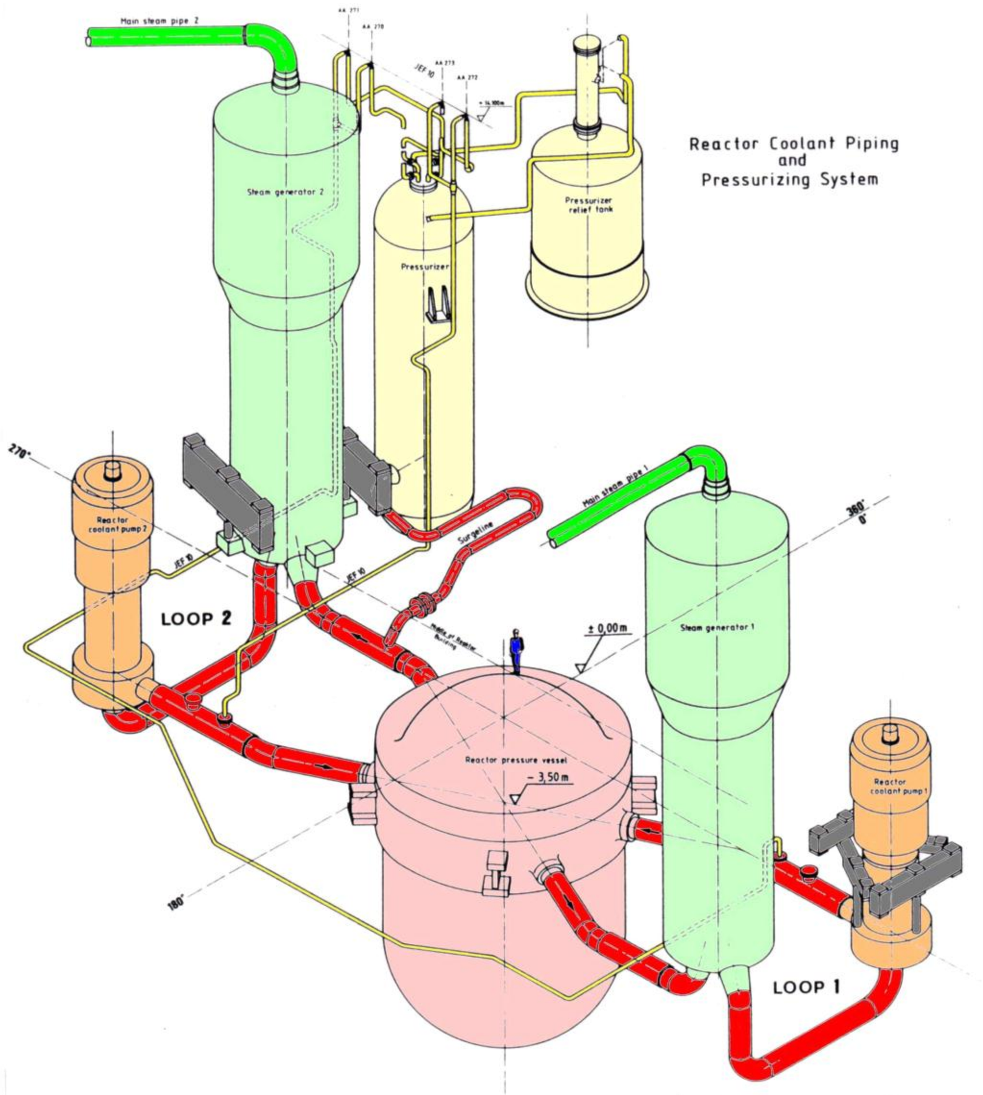
CONTENTS

- CNA2 : FSAR activities
- Standard Consolidated Reference Experimental Database
- MASLWR benchmark
- OECD benchmarks
- CHF calculation in low mass flux condition
- Turbulence effects in Relap5-3D

The Atucha-2 NPP

- **CNA2 – Chapter 15 FSAR – one of the main projects of GRNSPG 2007-2012**
  - BEPU approach
- **Relap5-3D main tool for analysis**
- **Applications (main)**
  - Three different nodalizations for RCS
  - 3D Neutron Kinetic
  - Coupling to code modeling I&C
- **LOCA recalculation and qualification activities in 2011-2012**

The Atucha-2 NPP



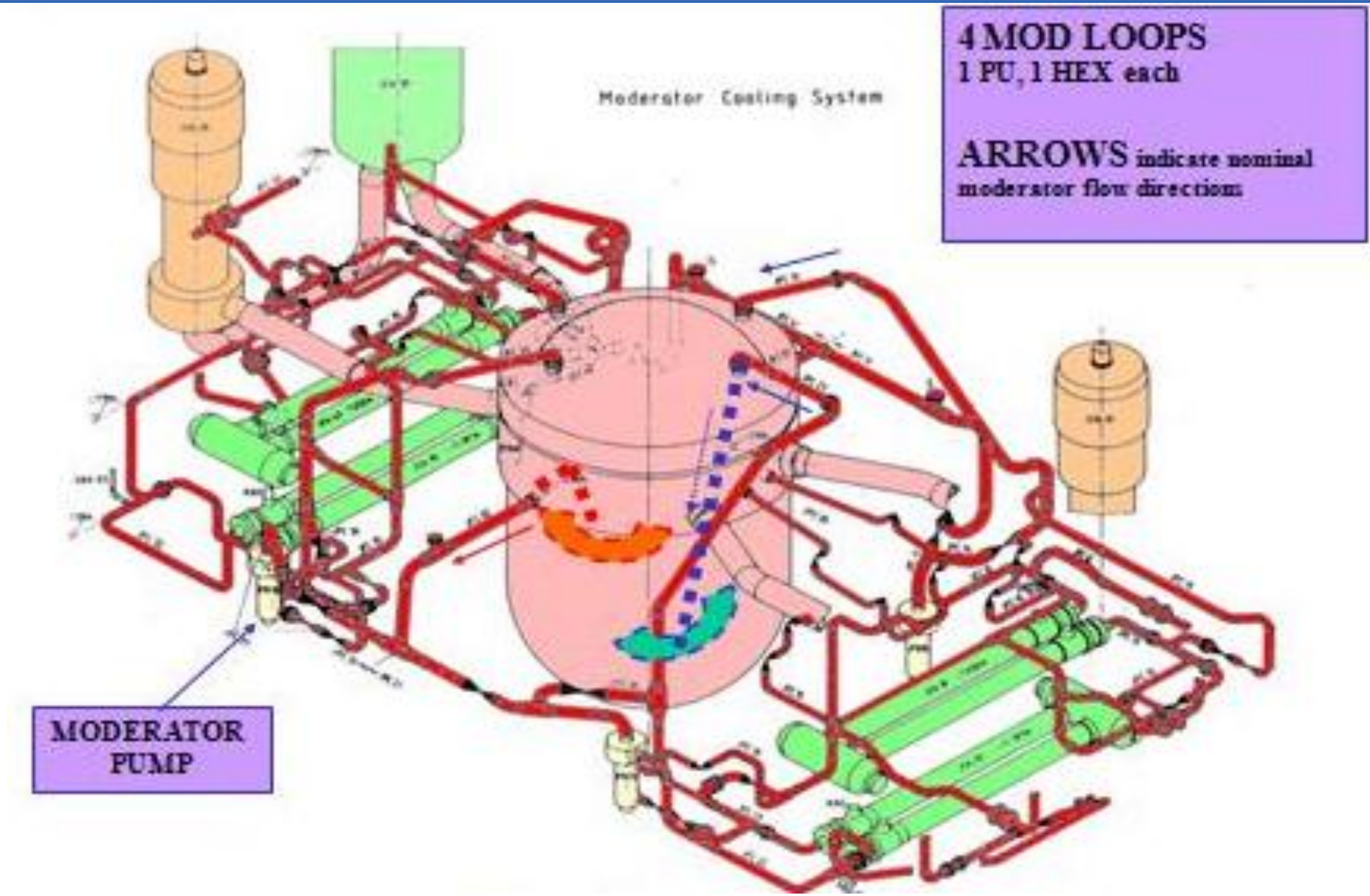
2 LOOPS
1 MCP, 1 UT SG each

1 PRZ

2160 MWth
1958 + 203 (nom. mod. T), or
2001 + 160 (max mod T)
+
14 from MCP

451 separated FC

The Atucha-2 NPP



The Atucha-2 NPP

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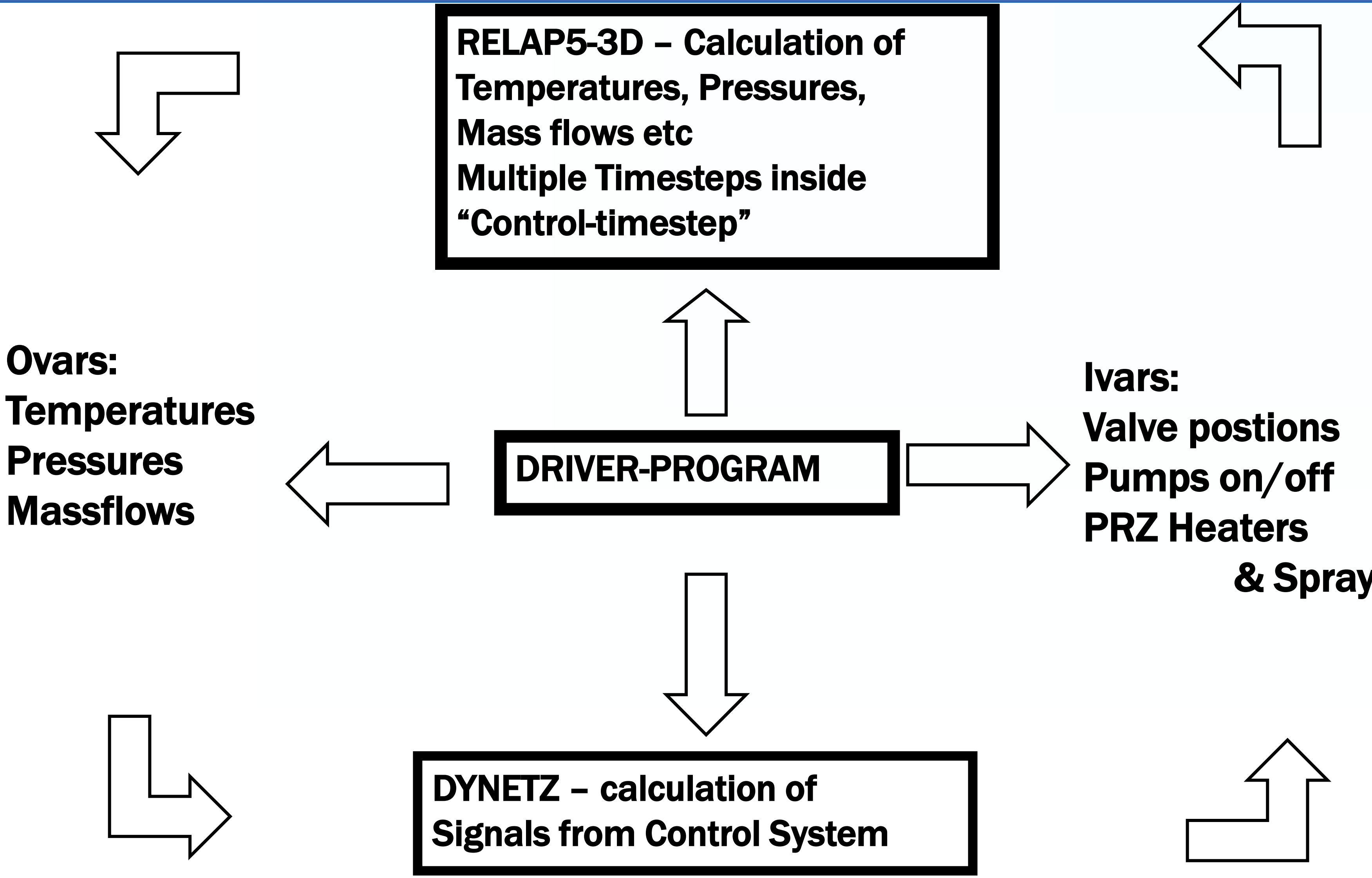
No	Transient	Section FSAR	Adopted Evaluation Model	Class of Accident
	Decrease in Reactor Coolant System Inventory (part 2 of 2)	**15.6**		
	Spectrum of LOCA	15.6.5	-	
	Primary Coolant System LOCA	15.6.5.1	-	
	Small Break LOCA	15.6.5.1.1	-	
50	30 cm2 LOCA cold	15.6.5.1.1.1	CSA	DBA
51	100 cm2 LOCA cold	15.6.5.1.1.2	CSA	DBA
52	Break of the Refueling Nipple	15.6.5.1.1.3	CSA	DBA
	Intermediate Break LOCA	15.6.5.1.2	-	
53	200 cm2 LOCA cold	15.6.5.1.2.1	CSA/CBA	DBA
54	LOCA in PRZ Surge-Line	15.6.5.1.2.2	CSA	DBA
55	0.1A LOCA cold	15.6.5.1.2.3	CSA/RCA/CBA	DBA
56	0.1A LOCA cold with Sump Swell Operation	15.6.5.1.2.4	QA	DBA
	Large Break LOCA	15.6.5.1.3	-	
57	2A LOCA cold (*DEGB. Different Break Sizes and Positions are investigated*)	15.6.5.1.3.1	CSA/RCA/CBA	SBDBA
58	2A LOCA hot	15.6.5.1.3.2	CSA/CBA	SBDBA
	Moderator LOCA	15.6.5.2	-	
59	50 cm2 Small Leak in Moderator Suction Line	15.6.5.2.1	CSA	DBA

83 NPP Scenarios

The Atucha-2 NPP



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2011-2012 Activities

- LOCA recalculation
- Use of internal coupling solution for I&C (developed by NA-SA)
- Qualification
- Consolidate data bases (QA related)
- Visualization

The Atucha-2 NPP

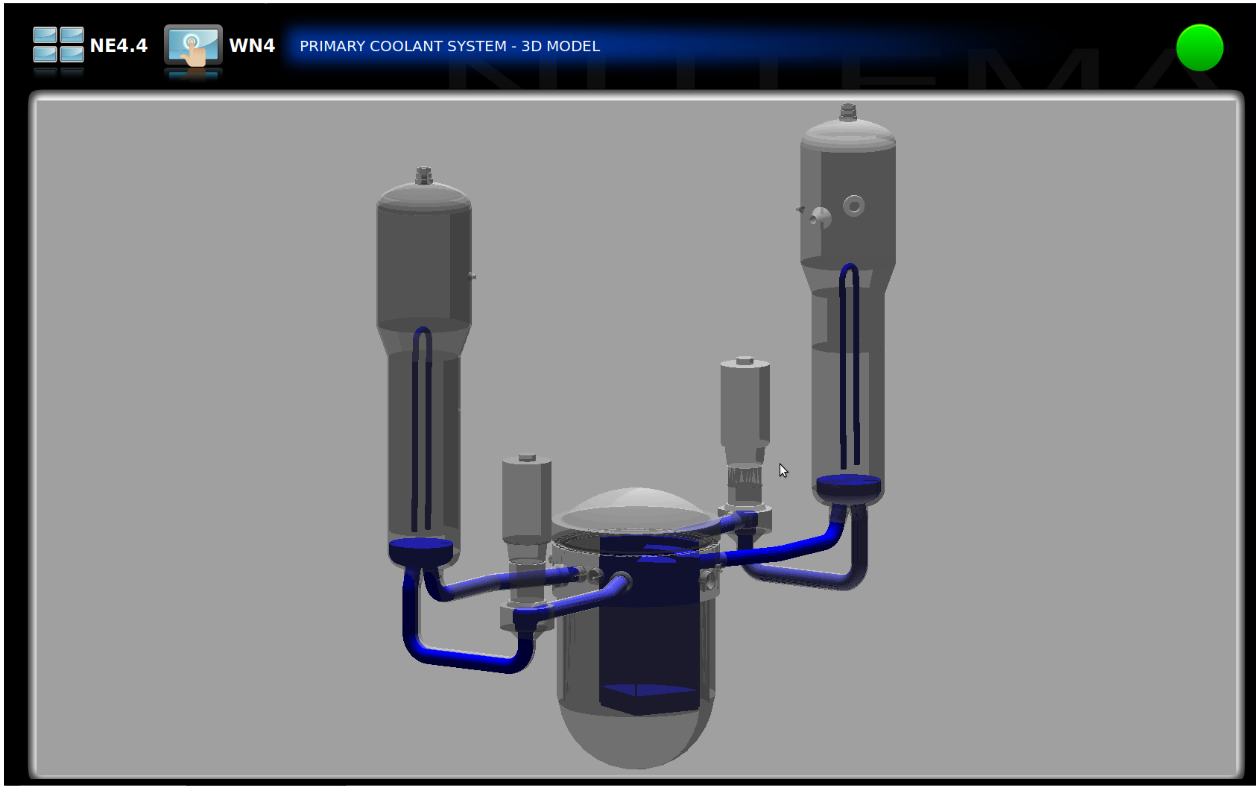
- Facility and experiments used in qualification activity related to CNA2 project:

Experimental Test	Transient Type
PSB-VVER T#3	Stuck open PRZ safety valve
PSB-VVER T#5	Main Steam Line Break + SGTR
LOBI A2-81	100 cm^2 CL LOCA (0.7%)
SPES SP-SB-04	200 cm^2 CL LOCA (4.2%)
LOBI A1-83	0.1 A CL LOCA
LOBI BT-15	Loss of one MFW pump without starting of the reserve pump
LOFT L2-5	2A CL LOCA
LOBI A1-06	2A CL LOCA
UPTF 05	2A CL LOCA

Correspondence with FSAR scenarios

The Atucha-2 NPP

- In the framework if NUTEMA project one of the most interesting feature related to Relap5 is the 3D visualizer.
  - read 3ds data file (Pro Engineer and other)
  - Relap5-3D results can be mapper onto the CAD model
  - Fast and fluently displayed with OpenGL libraries



Voidf distribution in PS during the early phase of a SBLOCA

SCRED: Standard Consolidated Reference Experimental Database

- 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 Reference Experimental Database (SCRED)
- Use of SCRED for:
  - Code Assessment
  - Uncertainty Evaluation

SCRED: Development of the Methodology

- Development of a methodology for collecting, organizing, using and preserving an exhaustive set of geometrical data and experimental results
  - Exhaustive consolidated information,
  - Traceability
  - Use of a Standard Format
  - Documentation of the decisions taken in case of lack of data or in presence of contradictory information
- Development of a Reference Data Set (RDS) document for developing input nodalization
- Setting up standard procedures for using the collected data and qualify the code calculations (Qualification Report, QR)
- Development of a standard report (Engineering Handbook, EH) containing a full description of how the database has been converted into an input data deck for a specific computer code (support to verification)

SCRED main steps: RDS-Facility

Structure and sample, RDS-Facility

- 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

SCRED main steps: RDS-Facility

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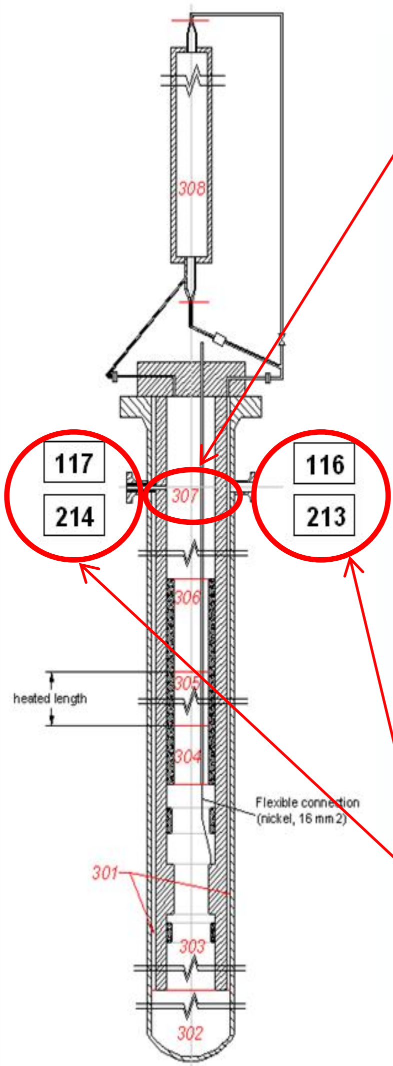
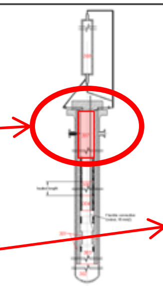
Structure and Sample, RDS-Facility



- **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_{bandle}=10.75 mm	$1.075\cdot10^{-2}$	m	Draw. 13
Barrel inside diameter	D_{barrel}=198 mm	$1.98\cdot10^{-1}$	m	
Barrel outside pipe diameter	D_{out}=288 mm	$2.88\cdot10^{-1}$	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 $S1=\pi\cdot D^2_{barrel}/4=\pi\cdot198^2/4$ =30790.7 mm² $S2=64\cdot\pi\cdot D^2_{bundle}/4=64\cdot\pi\cdot^{2}$ =5808.8 mm² S=24981.9 mm²	$2.4982\cdot10^{-2}$	m²	Draw. 13
Inside surface area	**Heat exchange with downcomer** $S_{cylinder}=2\pi\cdot R\cdot H$ $SA=\pi\cdot D_{barrel}L=\pi\cdot198\cdot2343$ =1457428 mm²	1.457428	m²	Draw. 13
Outside surface area	**Outer surface of barrel** (part of module 301) $S_{cylinder}=2\pi\cdot R\cdot H$ $SA=\pi\cdot D_{out}\cdot L=\pi\cdot288\cdot2343$ =2119896 mm²	2.119896	m²	
Volume	24981.9·2343=58532592 mm³	**$5.8532592\cdot10^{-2}$**	m³	
Pressure loss coefficient	Expansion 307→308 k_{forw}=0.5 k_{rev}=1			Tab. 4.2

SCRED main steps: RDS-Test

Structure and Sample, RDS-Test

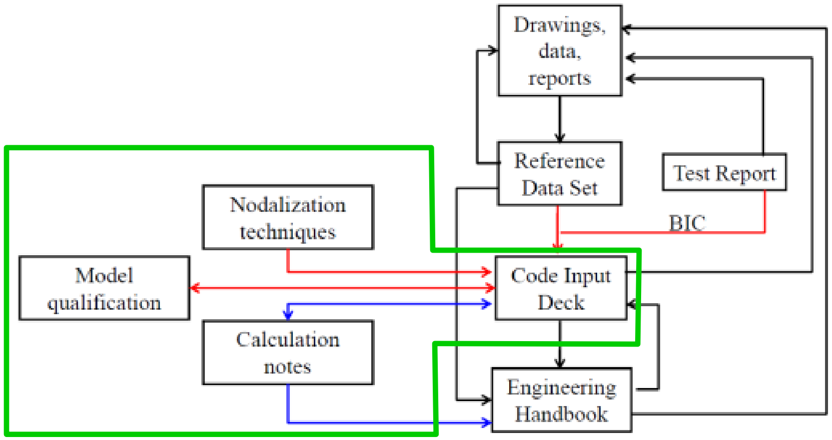
Standard structure of the RDS-Test:

- Test objective
- Facility description
  - Test configuration
  - Difference between facility "reference status" and test configuration
- Test description
  - Initial condition
  - Boundary condition
- Thermal-hydraulic system behaviour
  - Main events and major phenomena
  - Thermal-hydraulic parameter trends (more than 40 time trends)

SCRED main steps: Input Files and Qualification Reports (QR)

Purpose

- 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

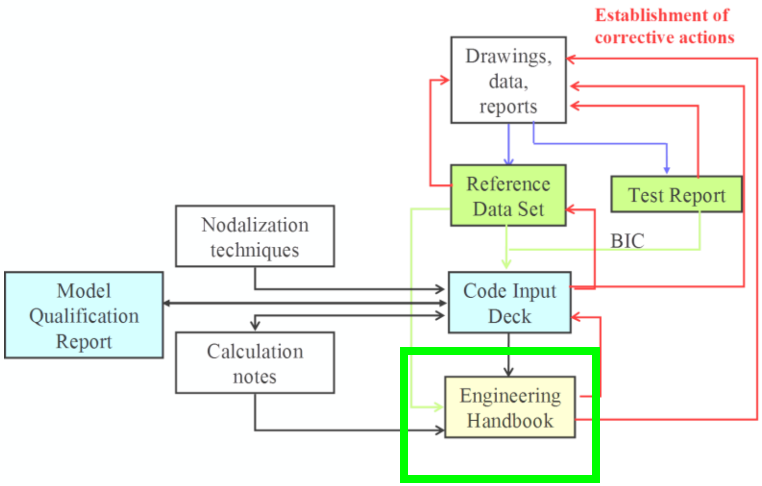


- The Qualification Report (QR) collects the results of the qualification procedures of the code input and it is reviewed by the higher level analyst in the group

SCRED main steps: ENGINEERING HANDBOOK (EH)

Purpose

- 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



SCRED main steps: ENGINEERING HANDBOOK (EH)

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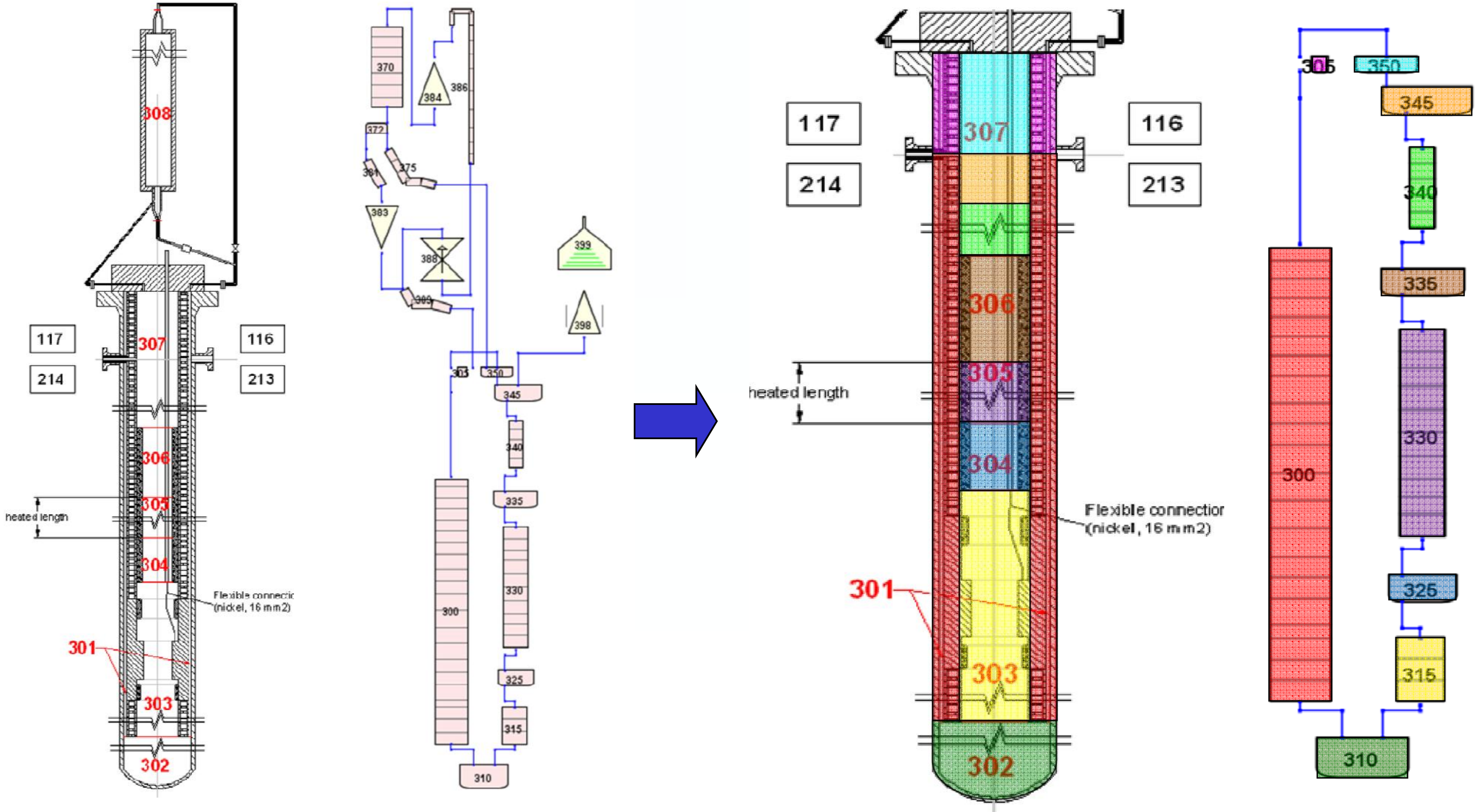
Structure and Sample, EH

- Cross links between (RDS) Drawings and Nodalizations



SCRED achievements

- A methodology to develop a Standard Consolidated Reference Experimental Database (SCRED) has been set-up
- Recommendations from IAEA guidelines have been considered
- The methodology ensures the fulfillment of QA through:
  - The application of a standard format
  - Strict observance of each step of the methodology
  - The development of RDS to consolidate in a standard way the experimental information
  - The application of a rigorous qualification process discussed in the QR
  - The verification of each value of the input file by the EH
- SCRED allows for an easier transfer in time and to different group of the experimental information and acquainted knowledge
- SCRED can be used for code assessment and uncertainty quantification

BENCHMARKING

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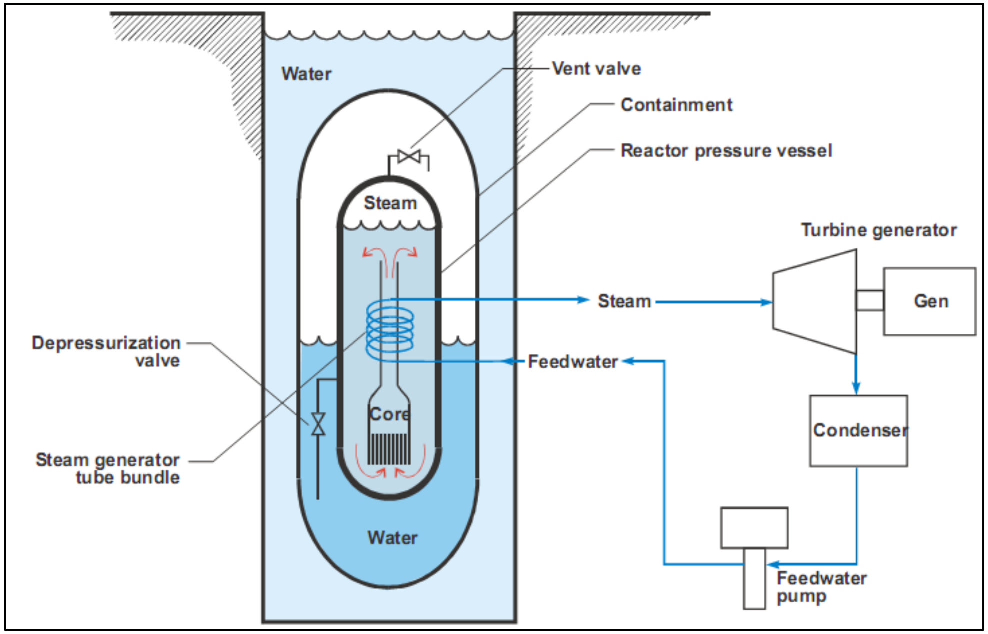
- The Multi-Application Small Light Water Reactor (MASLWR) project was conducted under the auspices of the Nuclear Energy Research Initiative (NERI) of the U.S. Department of Energy (DOE)
- The primary project objectives were to develop the conceptual design for a safe and economic small, natural circulation light water reactor
- Installed and operated at Oregon State University

#	QUANTITY	Unit	Value
1	Tot. No. of HYDR volumes	--	319
2	Tot. No. of HYDR juctions	--	378
3	Tot. No. of HYDR subvolumes in the core	--	6
4	Tot. No. of heat structures	--	314
5	Tot. No. of mesh points in the heat structures	--	3310
6	Tot. No. of core active structures (radial x axial meshes)		17 x 6



MASLWR: validation activities

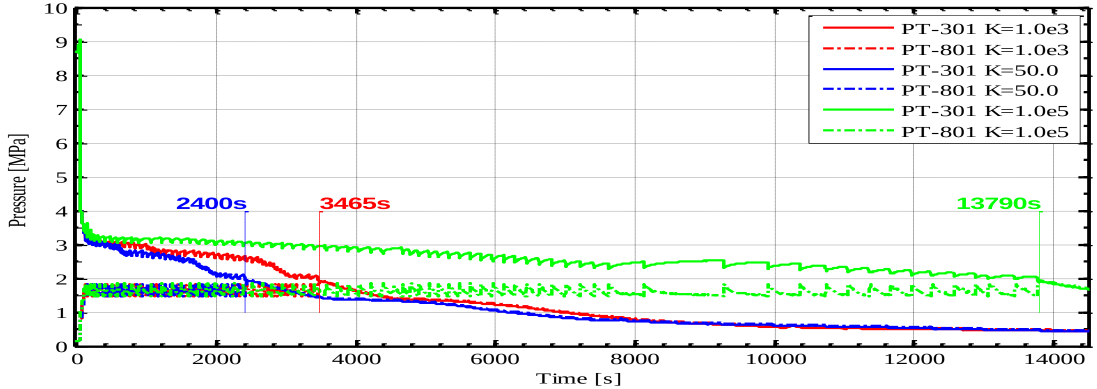
RELAP5-3D MASLWR blind calculations

- Pretest calculation of two scenarios
  - SP-2: *Loss of Feedwater Transient with Subsequent ADS Operation and Long Term Cooling*
    - *Thermal stratification, natural convection, circulation and steam condensation in large pools of liquid*
    - *Single phase, two-phase and intermittent natural circulation*
  - SP-3: *Normal Operating Conditions at Different Power Levels*
    - *Natural circulation*
    - *Heat transfer in helical tubes*

MASLWR: validation activities

RELAP5-3D SP-2 blind calculation

- Primary vessel and Containment vessel are modeled as two parallel vertical stacks of volumes
  - In order to simulate internal circulation and mixing;
  - Containment vessel parallel volumes are interconnected with cross-flow junctions
- Primary side depressurization time sensible on K-loss at the cross-jun in containment model
  - different mixing degree



MASLWR: validation activities

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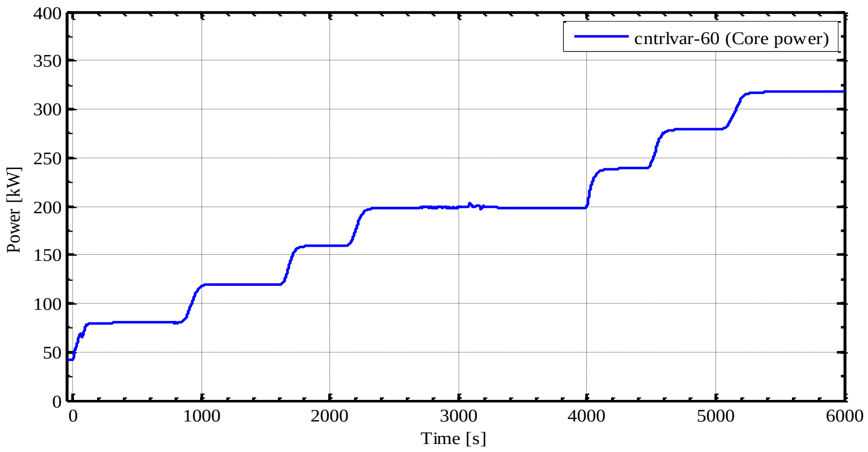
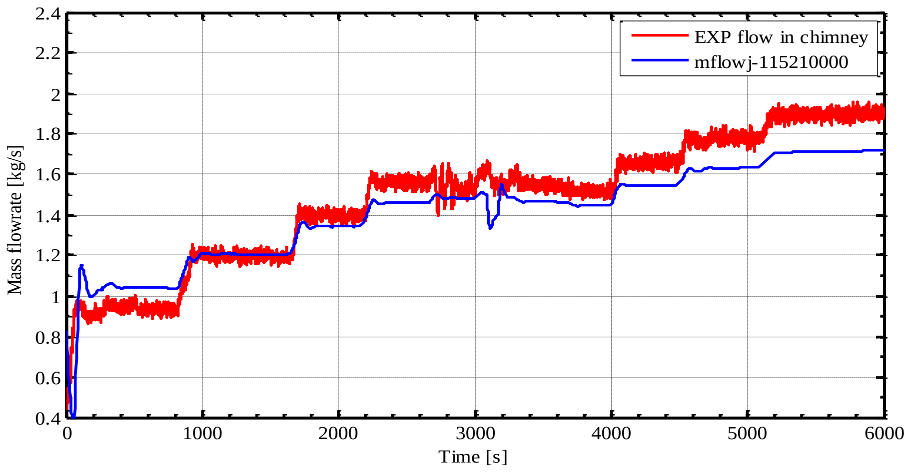
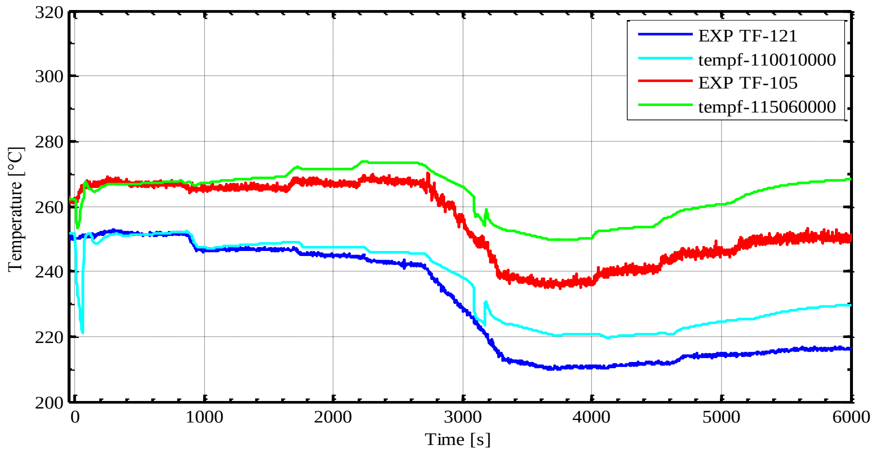
RELAP5-3D SP-3 blind calculation



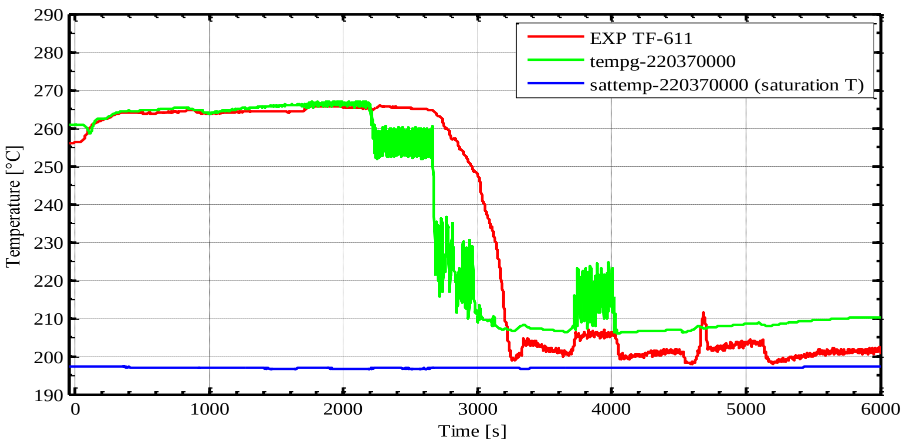
Core power



Primary side mass flow



Core inlet/outlet temperature



Sec.side steam outlet temperature

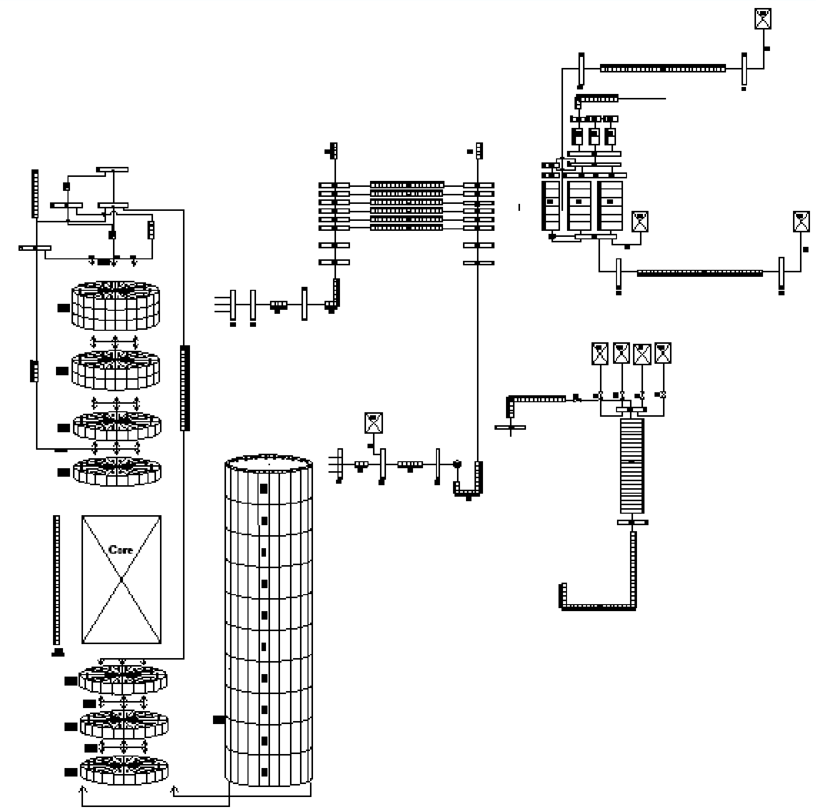
OECD benchmarks

- GRNSPG is involved in many OECD projects

- Recent (on-going) activities with Relap5-3D
  - Oskarshamn benchmark
  - Kalinin 3 benchmark

Kalinin 3 BENCHMARK : MODELS

- **VVER 1000 NPP**
- **RELAP5-3D TH model developed by GRNSPG**
- **RELAP5-3D/Point kinetics SS and transient calculation. SUBMITTED**
- **RELAP5-3D/NESTLE for 3D-NK model:** Best estimate coupled code plant transient modeling. **ONGOING**



- **Primary side and SGs**

K-3 BENCHMARK: TH & 3D-NK modeling

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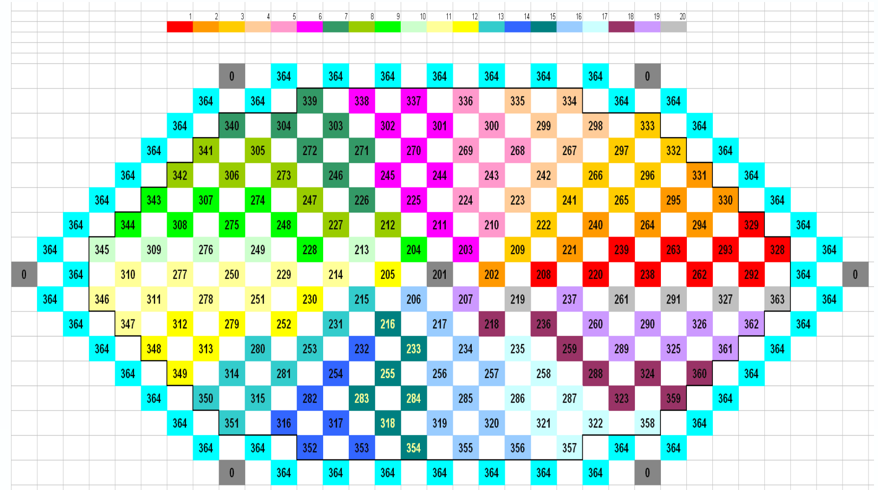
TH MODEL

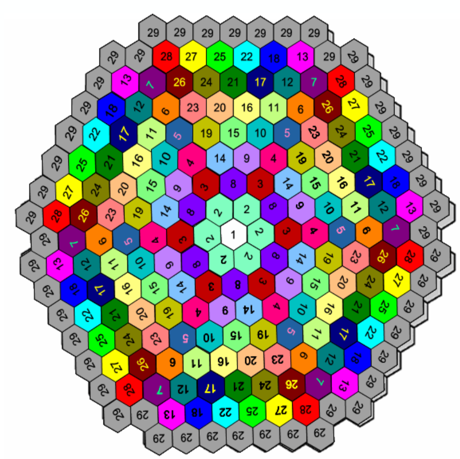
- ❑ Particular care was devoted to the RPV modeling
  - 3D modeling of Downcomer (20 azimuthal sectors = 18 deg, 10 axial levels)
  - 3D Modeling of LP, UP, Lower and Upper Core Plate (always 20 azimuthal sectors)
  - 1D modeling for the UH
  - Radial, Upper and Bottom Reflector modeled
  - **32** axial layers (2 for top/bottom reflector, **30 for the core**)

3D-NK MODEL

- ❑ 6752 NK nodes
- ❑ Radial, Upper and Bottom Reflector modeled
- ❑ 32 axial layers (2 for top/bottom reflector, 30 for the core)
- ❑ Up to 840 unrodded + 330 rodded compositions

❑ **FA versus azimuthal sectors (1-20)**





K-3 BENCHMARK: Exercise 1 (MCP-1 trip)

- **Exercise 1 has been executed.**
  - Steady state: Null-transient option for achieving SS
    - Checking main parameters for verifying consistency between experimental and calculation data
  - Transient: MCP-1 off, CR #10 & #9 moving, according to the Benchmark specifications

Parameter	SS			Transient		
	Experiment	Calculation	Deviation (%)	Experiment	Calculation	Deviation (%)
Power, MW	2970.00	2970.00	0.00	1996.00	2017.00	1.05
PRZ level,m	8.60	8.69	1.03	7.99	7.82	-
Average heating in the reactor core °C	29.03	28.77	0.87	22.38	22.55	0.75
SG #1 pressure, MPa	6.26	6.29	0.47	6.02	5.98	-0.66
SG #2 pressure, MPa	6.29	6.30	0.15	6.27	6.20	-1.11
SG #3 pressure, MPa	6.25	6.28	0.48	6.23	6.22	-0.16
SG #4 pressure, MPa	6.24	6.31	1.12	6.16	6.14	-0.32
Coolant flow rate in loop #1, kg/s	4635.00	4635.00	0.00	-1530.00	-1883.00	23.07
Coolant flow rate in loop #2, kg/s	4639.00	4635.00	-0.09	5145.00	5288.96	2.72
Coolant flow rate in loop #3, kg/s	4550.00	4552.00	-0.04	5083.00	5120.80	0.72
Coolant flow rate in loop #4, kg/s	4550.00	4557.00	0.15	5200.00	5270.36	1.35
Total coolant flow rate, kg/s	18340.00	18379.00	0.21	13900.00	13794.10	-0.08
CL coolant temp in loop #1	288.00	287.90	0.03	284.90	284,48	-0.14
CL coolant temp in loop #2	287.80	288.00	0.07	287.40	287,18	-0.08
CL coolant temp in loop #3	287.60	289.80	0.76	288.00	289.84	0.66
CL coolant temp in loop #4	287.50	287.90	0.14	284.90	283,85	-0.36
HL coolant temp in loop #1	317.40	316.70	-0.22	276.90	273.17	-1.36
HL coolant temp in loop #2	317.40	317.00	-0.13	311.70	311.77	0.02
HL coolant temp in loop #3	316.40	318.20	0.57	313.60	315.90	0.73
HL coolant temp in loop #4	317.20	316.80	-0.13	304.01	300.94	-1.00

K-3 BENCHMARK: Selected results

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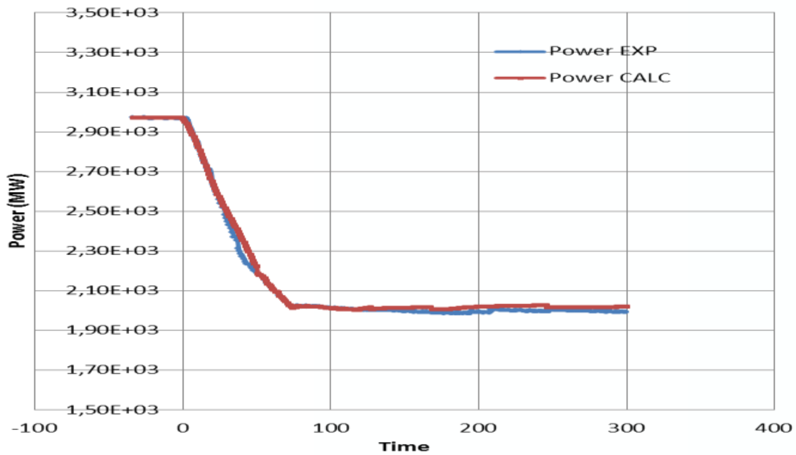
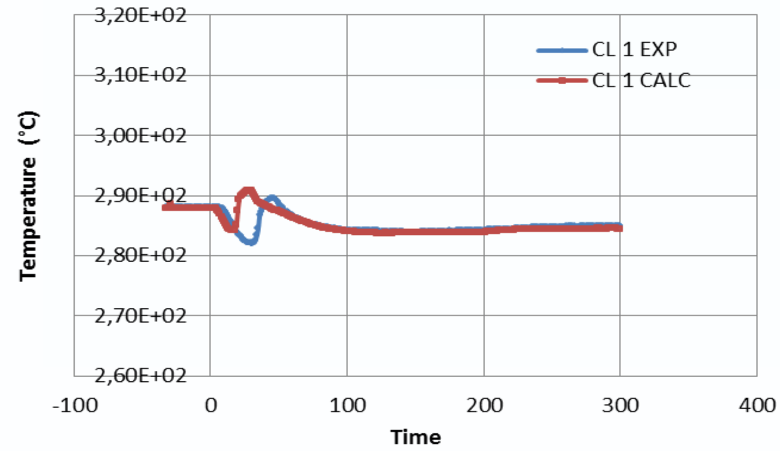
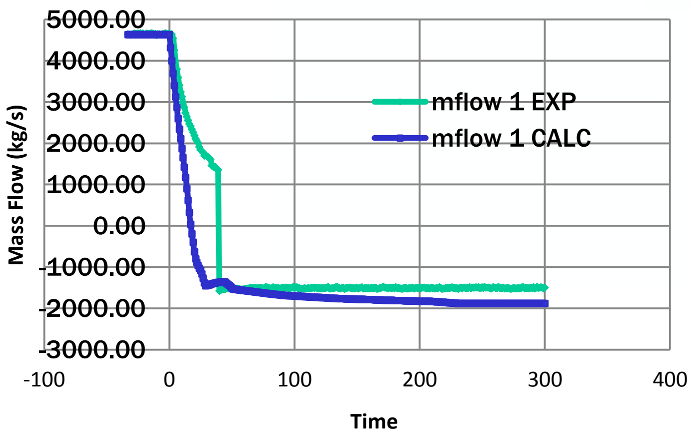


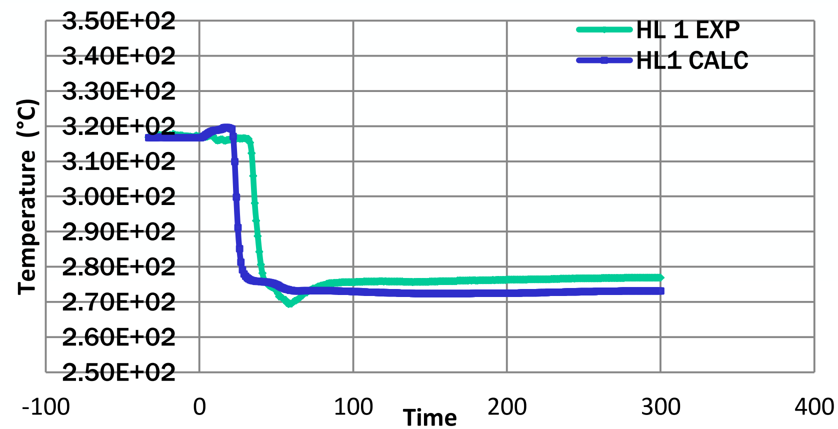
Power



CL coolant temperature Loop #1



Coolant Flow Rate Loop #1



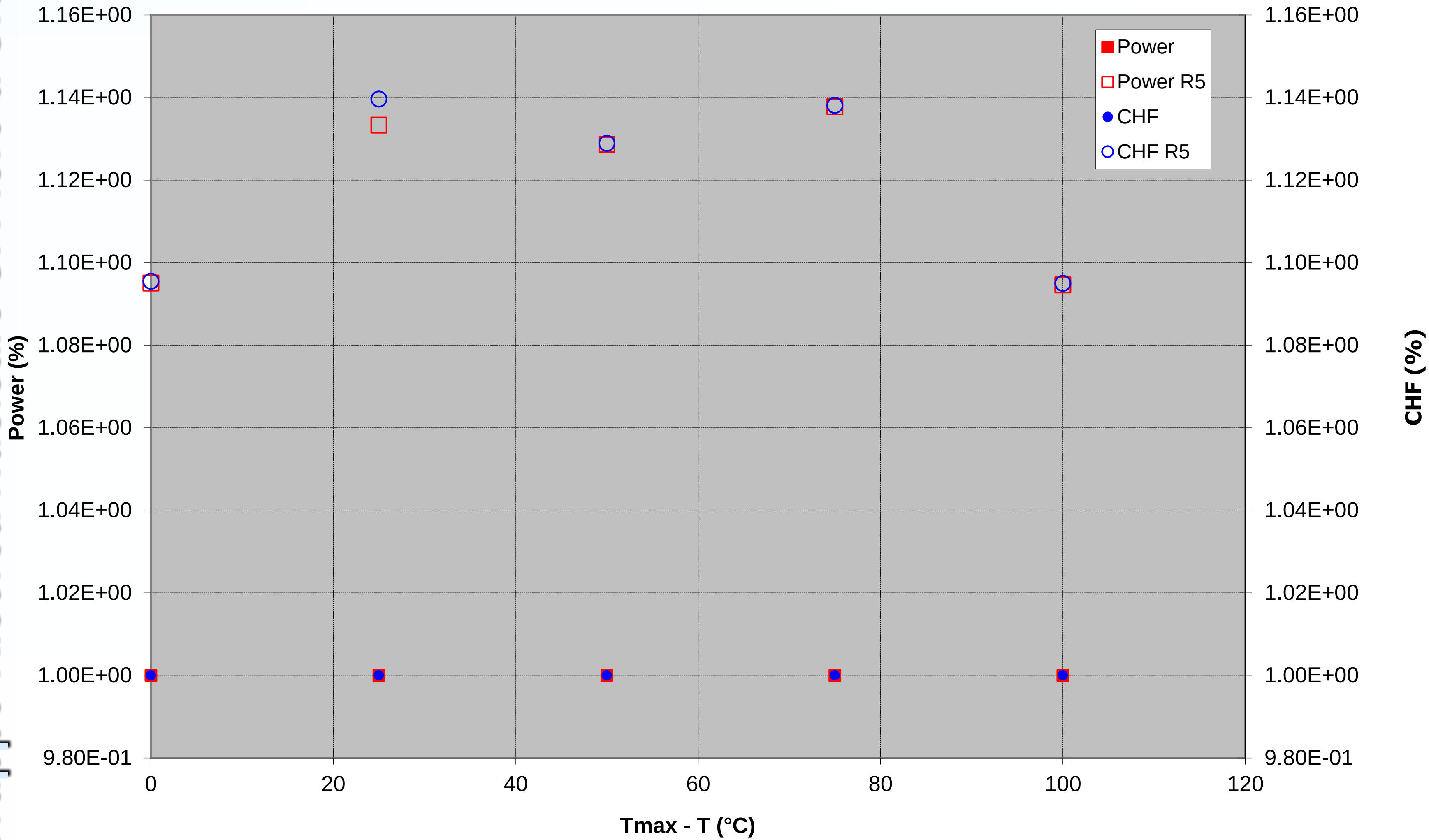
HL coolant temperature Loop #1

CHF in low mass flux condition

- Pre-test activity
- Support to the design of an experimental facility (flat profile)
- Benchmark between Relap5-3D 2.4.2 and COBRA-EN (EPRI corr.)
- 30 calculations performed
  - Different pressure, mass flux, inlet temperature
- Discrepancy on CHF prediction: 10% to 30%
- Future activities:
  - 100 calculations
  - Use of Relap5-3D 4.0.3 (due to fixies in Groenevald look up tables)

CHF in low mass flux condition

- Power and CHF discrepancy between Relap5-3D and COBRA-EN (1 case)



Turbulence in Relap5-3D

- Relap5-3D 4.0.3: capability to describe turbulent effect in MULTID components (option 31)
- Boron dilution test in ROCOM facility
- Main scopes of the (future) activity:
  - Comparison with TRACE and CATHARE codes capability in describing mixing phenomena
  - Comparison with experimental data
  - Accuracy evaluation by FFTBM
  - Paper submitted to NURETH 15

CONCLUSION

- GRNSPG activities related with Relap5-3D applications presented
- Activities attain to applied (FSAR) and validation (benchmarking) research
- Activities conducted following developed methodologies (e.g. SCRAD)
- Internal code validation benefits of:
    - Availability of huge experimental databases
    - Participation to international projects

Thank you

… and don't miss

May 12-17, 2013 Pisa (Italy)

NURETH-15

15th International Topical Meeting on Nuclear Reactor Thermalhydraulics